Safety and efficiency at intersections
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Tim Brown and Steve Griffith
Resolve Group, Auckland

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New Zealand 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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An important note for the reader

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- Various subject matter experts in the industry, particularly within the NZ Transport Agency, who provided key technical input/advice at various stages of the project.

Abbreviations and acronyms

AADT	average annual daily traffic
ATMU	Auckland Traffic Management Unit
CMP	Corridor Management Plan (Auckland)
CPTED	crime prevention through environmental design
CRF	crash reduction factor
DSIs	deaths and serious injuries
EEM	*Economic evaluation manual*
FHWA	Federal Highway Administration
GPS	*Government policy statement on land transport 2015/16 – 2025/26*
ILM	investment logic map
LoS	level(s) of service
MoT	Ministry of Transport
ONRC	One Network Road Classification
RARP	Regional Arterial Road Plan (Auckland)
RCA	road controlling authority
SEFT (score)	safety/efficiency framework trade-off (score)
SWIPP	safety works investment prioritisation process
Transport Agency	New Zealand Transport Agency
TRB	Transportation Research Board
vpd	vehicles per day

Contents

Executive summary

The NZ Transport Agency and other road controlling authorities now have best practice approaches for assessing levels of safety and efficiency. However, the objectives underpinning the respective approaches often clash, particularly at intersections.

The purpose of the research was to study the relationship between safety and efficiency at intersections by investigating both local and international literature, and to develop an evaluation framework that would incorporate the best practice guidelines from all sources researched. This would determine whether in principle it is possible to develop an optimum outcome from these often competing approaches.

A number of local and international jurisdictions were researched, including New Zealand, Australia, US, UK and several other European countries.

The problem identified was that despite robust design standards, plans and legislation in place (underpinning the importance of safety and efficiency as separate considerations), in practice the decision-making framework considers one aspect over the other. This is because the interdependencies between safety and efficiency at intersections are not currently well understood, and there is currently no known way of developing projects that maximises outcomes for both safety and efficiency at intersections in a coordinated manner.

While New Zealand closely follows Australian (Austroads) practice, the documentation sets are quite separate, although processes to evaluate the safety and efficiency of projects as separate considerations are relatively mature. This is also true of other jurisdictions researched (such as those under Federal Highway Administration guidelines).

Specifically, current New Zealand processes, tools and practices were reviewed. This included the following:

- road safety audit procedures
- NZ Transport Agency publications: *High-risk intersections guide, Economic evaluation manual* and the *Pedestrian planning and design guide*
- network operating frameworks
- One Network Road Classification (ONRC) system
- other relevant documentation (such as corridor management plans) and the better business case approach.

It was noted strong similarities exist between the processes to develop either safety or efficiency countermeasures, which have strong alignment with overseas practice, and also with the NZ Transport Agency's business case approach.

However, there is very little in the literature to define what is considered to be an acceptable trade-off between safety and efficiency at intersections, largely due to the existing separation of the two fields in all jurisdictions researched.

It was originally considered the most likely opportunities included taking specific elements of the various approaches to create an integrated framework that ensured an optimum 'blend' of safety and efficiency was achieved. Ideally, this would occur at a number of stages of the project development lifecycle. Examples of ideal stages to implement such a framework would have included:

1 Indicative business case stage/options development stage

This would allow the nature of the intervention to be tested, to determine whether the proposed project could realistically be expected to be major/minor in nature (eg grade separated intersection, or left turn slip lane?).

2 Pre-implementation/detailed design stage

With the form of the intersection improvement to achieve optimal safety and efficiency outcomes selected under 1 above, this stage would fine tune the nature of the selected treatment, based on a more advanced level of understanding of the intersection characteristics (eg if a left turn slip lane was selected, what additional intersection characteristics would complement the overall design?)

Note: It is envisaged the framework would not be used at the strategic business case stage, as this is for determining at a fundamental level whether in fact a physical solution is appropriate, or a 'non-build' solution (such as education or enforcement) is more appropriate.

From the outset, developing an evaluation framework for New Zealand, by combining efficiency and safety into one 'level of service' metric at intersections was not considered appropriate. For the development of an evaluation method it would be appropriate to consider the following components together:

- network operating gap
- level of service at intersections not covered by network operating plans
- differences at all intersections in the number of deaths and serious injuries, and the level of safety service, as well as changes in crash frequencies.

In response to the above, a 'proof of concept' evaluation framework/tool was developed (see appendix F, published separately at www.nzta.govt.nz/resources/research/reports/600) which provides a shortlist of available treatment options as follows:

- Safety – defining the level of service gap arbitrarily as the crash reduction percentage to be expected by implementing a specific measure. This is because traditional crash reduction factor figures do not consider existing site conditions to determine a specific percentage improvement. They only assume the site is significantly different from the one proposed through the selection criteria.
- Efficiency – defining the level of service gap as the difference between the target levels of service (from ONRC definitions) converted to a percentage, and then measured against the existing level of service for efficiency.

The framework provides a ranked list of feasible upgrade options for the intersection, with a ranking assigned for each option based on expected percentage improvements. The ranking is referred to as the safety/efficiency framework trade-off score. In addition, the framework allows an indicative budget estimate to be assigned against options in a prepopulated library. This allows the user to consider options within the budget allocated.

A number of case studies were selected in conjunction with the project's Steering Group, with the objective of testing the outputs developed by the framework. Existing traffic flows and crash data were compiled, target levels of service for the roading hierarchy were established, and a shortlist of potential interventions was generated for each site. The shortlist, together with the respective rankings were considered, and compared with what was actually constructed, or what is currently planned or designed, if known. Consideration was given to the fact that output quality was restricted for the following reasons:

- Quality/extent of input data was very coarse.

- Available treatments were based on the extent of the current 'library' of solutions, which was based on the *High-risk intersections guide*.
- Network operating gaps were based on determining existing efficiency levels of service using the saturation ratio (V/C) as an input. Due to the allocated bandings, this resulted in frequent reporting of large operating gaps.
- Efficiency improvements for specific schemes were only estimated (in reality these would need to be modelled for each improvement option for each scheme).

The case studies demonstrated that the ranking of solutions was producing the constructed (or yet to be constructed) scheme as a high priority on the list, albeit with some approximate assumptions around the anticipated efficiency improvements and type of scheme (major or minor) required. What can be concluded is that the methodology in principle appears to be relatively sound.

A way of expressing the safety and efficiency elements of an intersection in terms of a common unit was also demonstrated via the use of one of the case studies. With further development, parts of the *Economic evaluation manual* could be integrated into the model to allow the development of a direct comparison of safety/efficiency, or a trade-off compared with other schemes, rather than relying solely on arbitrary percentage improvements.

It is anticipated there will be opportunities to refine the framework following site trials, as the level of detail currently available is based on relatively 'coarse' treatment options as presented in the *High-risk intersections guide*. If the relative success of implementing an optimum mix of efficiency/safety focused objectives is tracked correctly, there will be a significant opportunity to inform change to existing standards/guidelines and achieve an outcome that is a suitable substitute to solving the efficiency/safety trade-off. This will in turn support the better business case approach in ensuring the screening process functions more effectively, while also supporting emerging 'safety in design' principles.

Abstract

This report considers evidence on safety and efficiency at intersections, using New Zealand data and international research, and outlines a systematic approach for evaluating the safety and efficiency benefits at intersections, as part of the project development process.

A review of New Zealand and international practices, analysis tools, guides and processes were considered. The authors found very little in the literature to define what is considered to be an acceptable trade-off between safety and efficiency at intersections, largely due to the existing separation of the two fields in all jurisdictions researched. A recommended solution has been presented in the form of a 'proof of concept' evaluation framework, which takes into account a range of factors and case studies. It is recommended that the transport sector considers utilising this framework as a decision support tool in ensuring the correct decisions, with respect to delivering against safety and efficiency outcomes, are made at the appropriate stage of the project development.

1 Introduction

1.1 Context

The NZ Transport Agency (the Transport Agency) and other road controlling authorities (RCAs) now have best practice approaches for safety (the *High-risk intersections guide* (HRIG) (NZ Transport Agency 2013c)) and for efficiency (the network operating framework) at intersections.

However, these dual objectives often clash at intersections, which pose complex problems when attempting to manage the movement of people and goods on the transport network, consider the needs of a range of road users and ensure that solutions minimise delays while maximising safety.

The purpose of this research was to develop an evaluation framework that would incorporate best practice guidance from the HRIG and network operating frameworks (specifically from New Zealand) as well as international best practice, in order to determine whether in principle it would be possible to develop an optimum outcome from these competing objectives. This would require the impacts of each to be measured in terms of a common value that would allow any trade-offs between the two components to be identified and assessed.

The research specifically aimed to:

- identify the impacts of the proposed changes to an intersection on a reasonably consistent basis, which could be applied to both rural and urban intersections
- put the safety and operational characteristics into a common framework to allow robust solutions to be developed.

While the research drew on the benefits and impacts of different treatments at intersections, it was not intended to provide guidance on what specific treatments should be applied at particular locations. However, selected case studies have been used to validate the accuracy of solutions proposed by the framework.

1.2 Identification of problem

Despite robust design standards, plans and legislation in place (underpinning the importance of safety and efficiency as separate considerations), in practice the decision-making framework considers one aspect over the other. There is currently no known way of developing projects that maximises outcomes for both safety and efficiency in a coordinated manner.

1.3 Research objectives

The first objective of the research was therefore to determine the feasibility of the following models and preference for evaluating the safety and efficiency of intersections:

- Standards-based approach – this identifies deficiencies in both safety and operational performance but does not necessarily produce solutions.
- Continuous approach – this develops alternatives to address the problems identified and by putting these into a common monetary framework allows efficiency and safety elements to be traded off.

- Combine the levels of service metrics – a multi-criteria analysis would simply define the problem but not explicitly consider solutions. However, the approach can be used to put safety and efficiency impacts on a common although non-monetary basis.

The second objective of the research was to ensure the process and methodology would be scalable from the smallest of rural intersections to the largest of urban interchanges so that the solutions eventually developed would evaluate the relative efficiency and safety factors alongside each other, rather than just as a component of the economic evaluation.

1.4 Report structure

The rest of this report is structured as follows:

Chapter 2 provides some background context explaining why the current processes are not entirely conducive to a combined consideration of the safety and efficiency elements.

Chapter 3 broadly explains the existing frameworks and research that may be useful to integrate the safety and efficiency considerations, as well as some of the key challenges.

Chapter 4 outlines some of the considerations that will be required to develop a meaningful way to trade safety off against efficiency.

Chapter 5 summarises what previous research (if any) can be used to develop the evaluation framework, and subsequently identifies (in broad terms) how the framework will be developed.

Chapter 6 explains how the evaluation framework was developed, where the input information comes from, how it is processed and what the outputs are.

Chapter 7 describes the case studies, where a number of sites from around New Zealand (with known safety and/or efficiency issues) were selected, and used to test/calibrate the evaluation framework in its ability to generate a shortlist of feasible solution options.

Chapter 8 looks at how the evaluation framework can be integrated with an appropriate project development model, and suggests a process through which a treatment option can be selected.

Chapters 9, 10 and 11 provide conclusions, recommendations and a bibliography.

Appendix A sets out the Transport Agency's hierarchy of classifications of all roads, including the considerations that determine these classifications.

Appendix B contains a guideline used by one of New Zealand's largest local authorities, Auckland Transport. This document provides a similar hierarchy of classifications as the Transport Agency's One Network Road Classification system from a multi-modal perspective.

Appendix C provides an example of how strategic investment decisions are made.

Appendix D gives an indication of the degree of impact on both safety and efficiency for a range of given treatment selections. This information could be used as an input into the next stage of development for the evaluation framework.

Appendix E provides an example of a (mostly) qualitative approach that is currently used for investment decision making for projects with both safety and efficiency considerations.

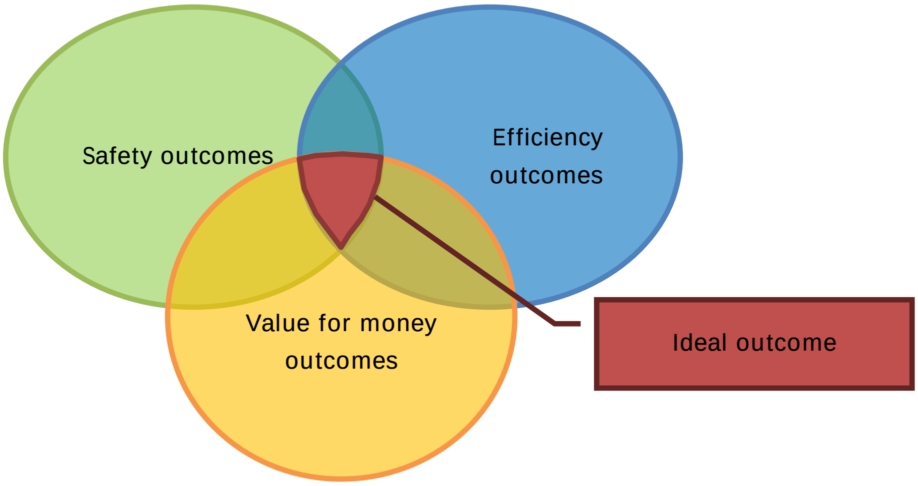
Appendix F is the Microsoft Excel based safety/efficiency framework trade-off (SEFT) evaluation tool, provided separately at www.nzta.govt.nz/resources/research/reports/600

2 Project and programme development

2.1 Overview

In developing a framework for assessing the safety and efficiency of intersection treatments, both factors should be considered even if the focus is on the development of measures to improve one of them. This is in line with the strategic direction set out in the *Government policy statement on land transport 2015/16 – 2025/26* (GPS) (MoT 2015) and the *Statement of intent (SoI) 2015–19* (NZ Transport Agency 2015), which is to have a safe system meeting the needs of all road users and delivering the outcomes for the right price, as illustrated in figure 2.1.

Figure 2.1 Overview of achieving the ideal outcome



Although the two components would ideally be considered in conjunction, in practice the decision-making framework considers one aspect of network operation (either efficiency or safety) over the other. This is evidenced in the development of individual projects and programmes of works by RCAs that are focused on one of the two, with the other assessed as a component of the economic evaluation. Sharma (2008) developed an economic evaluation approach to provide an appropriate level of safety protection that is also cost effective as it uses a range of available options. This is the type of consideration that will assist in developing a better understanding of the trade-offs, and how the often competing demands of safety and efficiency can best be managed.

The following chapters examine three components of the project development: processes, analysis methods and trade-offs present.

2.2 Processes

2.2.1 Overview

New Zealand practice closely follows Australian (Austroads) practice in developing and evaluating safety programmes (and projects) separately, with a safety audit process common to both. The context for considering both safety and efficiency at intersections is that intersections are over-represented in crashes and are the limiting factor in urban network capacity. In rural areas, the efficiency of intersections is not typically the dominant factor in the initiation of projects because of the relatively good performance due to lower levels of congestion. However, there are exceptions to this. Recent notable examples include the intersections of SH2/SH25, and SH26/SH27 in the Waikato where give-way controlled intersections have been converted to roundabouts. Similar intersections were used as case studies during stage 5 of this research (refer chapter 7).

Current practice in New Zealand is to develop and deliver safety and efficiency programmes independently. This may be in part due to:

1. The documentation and standard processes are separate, with little overlap in the treatment selection process (with the exception of the safety audit process).
2. The responsible parties consider delivering either safety outcomes or efficiency outcomes, in line with their responsibilities.
3. There is little guidance on how or when to consider efficiency in safety projects or vice versa.

The intention of the research was to provide the tools and framework to consider both safety and efficiency when developing intersection treatments. It was also anticipated that professional engineering judgement would be required in the treatment selection, although this would be within a framework within which safety and efficiency impacts could be traded off.

2.3 Assessment tools currently in use

2.3.1 Safety (projects or programmes)

Safety programmes are developed in isolation from efficiency programmes until the funding prioritisation is undertaken within an organisation. The Transport Agency uses a prioritisation tool called safety works investment prioritisation process (SWIPP) which is applied nationally. SWIPP can also include the operational efficiency benefits; however, the programme and project development processes through *A New Zealand guide to the treatment of crash locations* (NZ Transport Agency 2004) and Austroads (2006-2013) *Guide to road safety* (9 parts) do not specifically require the assessment of efficiency. There is a strong case for suggesting they should include efficiency, and effective future use of the framework may include a useful input into the project development process used under SWIPP.

2.3.2 Efficiency projects or programmes (network operating framework)

The network operating framework is simply an agreed process that enables collaborative discussions and links strategic intent with operational and planning decisions. It focuses on:

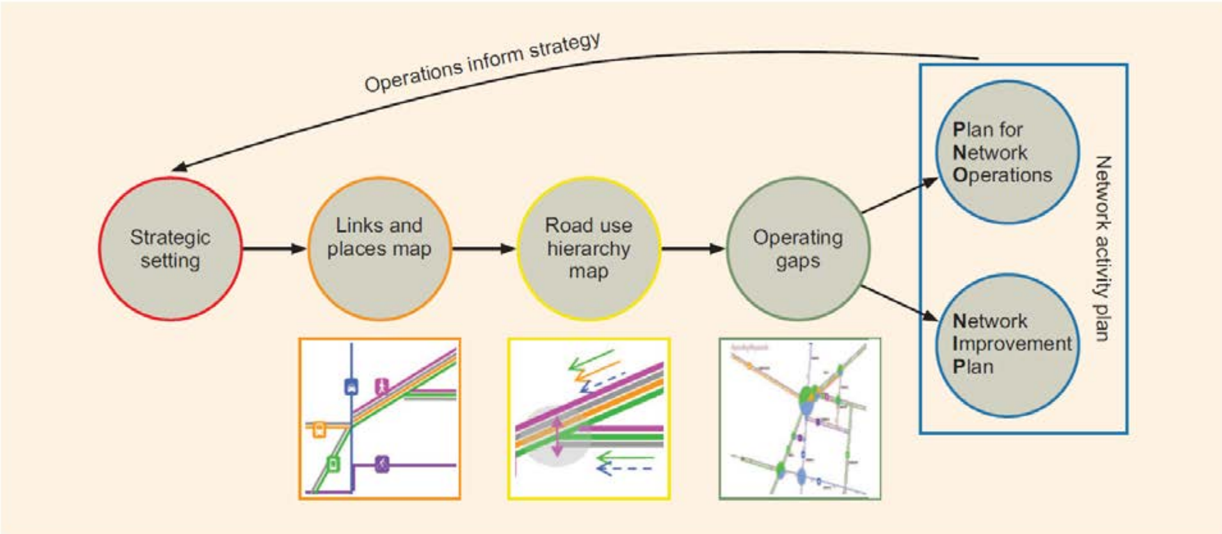
- moving people and goods, not vehicles, and viewing this by time of day
- seeing transport as supporting broader community goals
- balancing the competing demands for limited road space
- thinking ‘network’ rather than sites or routes.

It supports future planning and development of transport and travel choices by establishing future networks with modal priority attached, which deliver on strategic goals. At all stages, stakeholders agree what is expected of transport, how and to whom priority is assigned and what the effects are of interventions on the network.

Network operating frameworks consider the type of facility in defining the level of service (LoS) for pedestrians and cyclists aside from the delay-based LoS (network operating gap). However, they do not explicitly include safety performance as part of the decision-making process. The network operating gap is a measure of effectiveness developed by VicRoads to assess the performance of the network and to assess network improvement projects to determine whether there will be an overall benefit to the efficiency of the network as shown in figure 2.2. It also represents the gap between the observed LoS and the ideal LoS (free-flow conditions). The network operating gap combines the importance of the road for particular users (in the road use hierarchy), the LoS for each user group, the relative efficiency compared with a motorway traffic lane and the cost of travel. There is, however, no consideration of the safety performance within the overall framework for assessing the network operating gap. This is also true of international frameworks investigated, although due to the higher level of understanding and local familiarity, it is considered that a framework for optimising safety and efficiency outcomes can best be leveraged off New Zealand based standards and guidelines.

One of the key challenges in developing a framework is determining a means of filling the network operating gap, and ascertaining the extent to which the development of solutions through the entire planning process takes into account safety, as well as efficiency/operational considerations.

Figure 2.2 Diagram showing network operating gap process



The stages highlighted in the above diagram relate directly to the use of the framework in the following ways:

- A road use hierarchy map allows the RCA to determine what the target level of service ought to be to meet operational outcomes (which include both safety and efficiency considerations).
- Comparing the target level of service with the existing level of service in an objective way will enable consideration of treatment options to ‘bridge’ any operating gaps.

2.3.3 The role of the road safety audit

Road safety audits are a mandated part of the project development lifecycle[1]. While the implementation processes of safety audits have been updated in line with updates to the Transport Agency’s business case approach, the primary objective remains the same – to help ensure a project achieves an outcome consistent with Safer Journeys and the Safe System approach. This is centred around creating a safe road

[1] Exemptions are permitted provided it can be demonstrated that the road safety issues arising from changes are negligible.

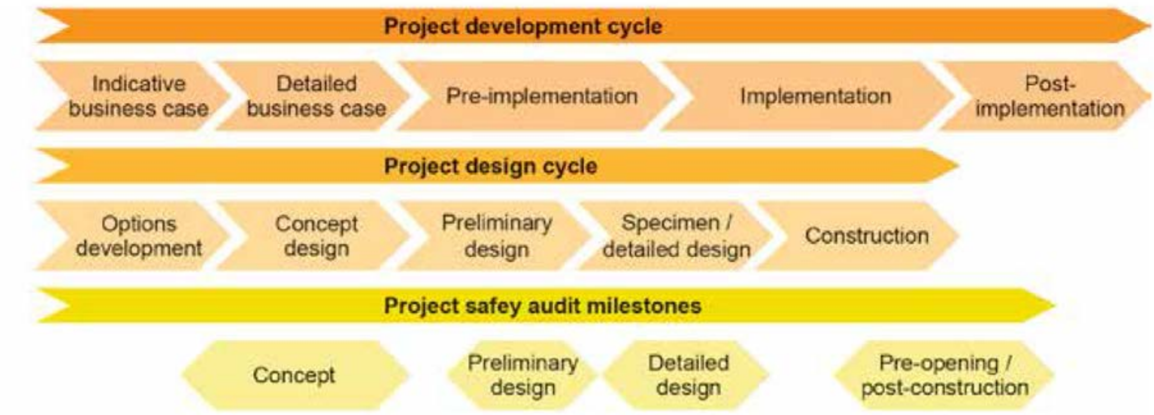
system increasingly free of death and serious injury (NZ Transport Agency 2013b). In figure 2.3 below, this demonstrates how the relevant safety audit stages are coordinated with the key stages of the project development lifecycle.

For efficiency projects, it is at the options development phase (indicative business case) that the safety audit process can influence the outcomes by advising on whether the safety audit team considers there are serious or significant issues with the proposed treatments, which in turn can be used to inform efficiency. This is considered significant, as the consideration of efficiency at this point will inevitably lead to different outcomes, compared with what the current process allows.

2.3.4 Quantification of operational efficiencies

Despite there being a robust framework for testing strategic fit of efficiency projects through the network operating framework, there is currently no formal process for undertaking an audit style process for efficiency along the lines of the safety auditing process. Notwithstanding the development of treatments in isolation, there are a number of local applications that consider both safety and efficiency in the problem definition/programme development.

Figure 2.3 Safety audit stages in relation to the project development cycle



- *Economic evaluation manual* (EEM)

  The EEM (NZ Transport Agency 2013a) provides a comprehensive suite of methodologies for evaluating the economic costs and benefits of different projects, including methodologies for assessing travel time benefits, vehicle operating costs, travel reliability benefits, safety and other benefits. A number of standardised intersection crash prediction models and crash reduction factors (CRFs) are used in the assessment. These models are effectively exposure/conflict-based models, hence the number of crashes increases with the number of conflicts (the rate of increase varies by intersection type). The EEM is one example of a local standard that is largely quantitative for assessing both safety and efficiency elements of a project (albeit independently), and was a key consideration in developing a framework later in the research to better understand the trade-offs between safety and efficiency. However, at this point, a simpler way of optimising safety and efficiency outcomes was achieved by using alternative applications (refer to chapter 6 for further information).

- Regional arterial road and corridor management plans

  In Auckland, the Regional Arterial Road Plan (RARP) outlines the efficiency deficiencies by mode plus the safety deficiencies along the arterial corridors. The Corridor Management Plan (CMP) process, which takes a long-term view of how corridors should be operated, uses the RARP as an input and identifies the constraints, conflicts and necessary trade-offs that exist in being able to provide the long-term vision and priorities. The CMP process is not quantitative but is a useful tool for highlighting user needs and strategic direction for the corridors. The strategic priorities then flow into the network operating plans, which deal primarily with efficiency, but have links with road safety requirements.

- One Network Road Classification (ONRC)

  The ONRC consists of an integrated framework for categorising all roads and state highways and provisional customer levels of service. The ONRC categorises roads based on their main function(s), such as freight, tourism and everyday travel. The ONRC was developed to provide a nationally consistent framework for the management of and investment in the road network. A LoS is provided for each road classification, which also includes the respective classification's own safety and reliability (efficiency) LoS, which can then be used to identify deficiencies.

  Together with the RARP and CMP, the ONRC can be used as an input into the network operating framework. This is likely to be a useful input into defining what would be acceptable performance, particularly for reliability at a strategic level in line with the road classification.

- *Pedestrian planning and design guide*

  As part of the *Pedestrian planning and design guide* (NZ Transport Agency 2009), a simple spreadsheet model was developed to test the effectiveness of pedestrian treatments. This spreadsheet also considered the impact on all road users when the economic efficiency of each proposed treatment was being tested. The consideration of both safety and efficiency of treatments is an outcome from this research project, hence the assessment process used in this spreadsheet model will be useful in completing the overall framework. This will, however, depend on the extent to which the impact on efficiency via this spreadsheet is reflected in any future modelling that may be required to ascertain anticipated efficiency gains for specific intersection treatments, over and above the existing intersection performance.

2.3.5 Business case approach

The Transport Agency uses a business case approach to guide the planning, investment and project development processes. It is a principles-based approach that clearly links strategy to outcomes, and defines problems and their consequences thoroughly before solutions are considered. This approach ensures a shared view of problems and benefits early in the transport planning process without requiring that the work has to be done in a particular way.

The process follows the principles from The Treasury (2015) and HM Treasury (2013).

VicRoads (2015) has taken this a step further and developed a benefits management plan, which outlines the measures and performance outcomes.

While the approach is intended at higher-level investments, the process of determining a preferred way forward is relevant for any scale of project. This process is summarised in figure 2.4.

Figure 2.4 Better business case approach

In the context of developing a framework, the strategic case and the indicative business case are the foundations for selecting a preferred option. The key activities within these stages are:

- developing measures and key performance indicators to evaluate (and monitor) the benefits of the investment
- identifying the critical success factors (and associated performance measures to demonstrate how well the options meet these success factors)
- identifying the risks, constraints and interdependencies (which allows for efficiency projects to consider safety and vice versa)
- identifying a long list of options (essentially a screening test to identify suitable treatments for the problems and opportunities identified).

While careful 'up-front' planning is key to ensuring a successful outcome for safety and efficiency as outlined above, in practice it is not uncommon for further issues to be considered at the detailed business case stage, or even the implementation stage. This is often the result of parallel feedback loops from both safety and efficiency via independent processes. For safety, meaningful/identifiable issues are often not apparent until a substantial design has been completed, which is typically after a number of other options have been discounted. By this stage, the focus has shifted to one of refining a design to address safety concerns, while not having a full appreciation of the efficiency component being sacrificed. This is because there is currently no formal process which allows the two elements to be considered together simultaneously, and potentially motivating a re-think of earlier options. It is this 'disconnect' of the two processes that must be solved if a framework that fully understands the trade-offs is to be developed.

2.4 International practice

2.4.1 Austroads

Processes for project development are outlined in Austroads (2013–2015) *Guide to traffic management* and the Austroads (2006–2013) *Guide to road safety*, with the design development covered in the Austroads (2009) *Guide to road design* series. An extract from the *Guide to road design* outlines the complexity in the project development in referencing various publications.

> *While many of the considerations in Table 4.1 relate to road planning and traffic management, it is important that road designers have an understanding of the factors that influence the functional design. Austroads Guide to Traffic Management – Part 6: Intersections, Interchanges and Crossings (Austroads 2007), provides information on traffic management considerations that influence road design including:*
>
> - *intersection control options and selection criteria (table 2.2 of the Guide to Traffic Management – Part 6)*

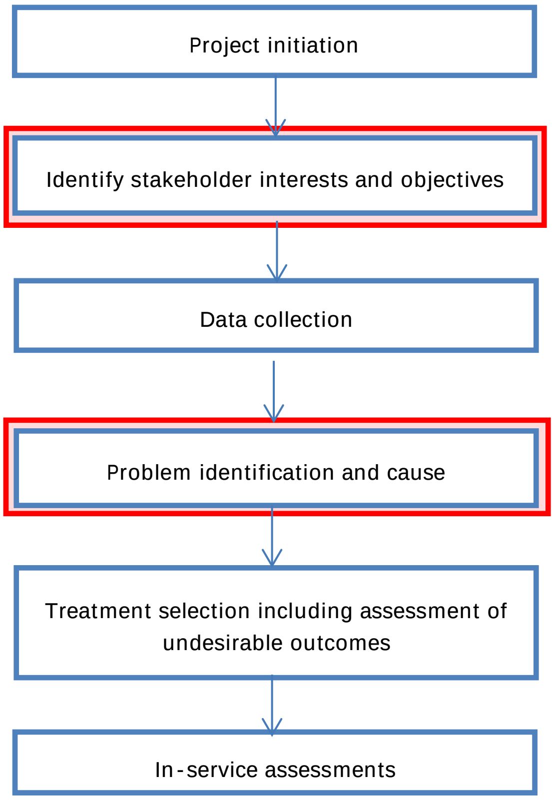
- *suitability of different types of traffic control to different road types (table 2.3 of Guide to Traffic Management – Part 6)*
- *key traffic management selection considerations for the various types of intersection (Table 2.4 of Guide to Traffic Management – Part 6)*
- *issues for different road user categories for intersection and crossing design.*

A key step in the context of project development is outlined in the Austroads (2014) *Guide to traffic management* part 4, which outlines the user needs by mode. This considers the type of facility and the performance expectations, but stops short of defining LoS for safety and efficiency.

2.4.2 Federal Highway Administration (FHWA)

Guidance by FHWA (2004) for signalised intersections provides a useful framework for considering the safety and efficiency at intersections, which is well aligned with the business case approach currently being implemented by the Transport Agency. It is also well aligned with the development of the individual safety and efficiency programmes. However, the key differences are the stakeholder engagement and the consideration of both safety and efficiency in the outcomes being sought. The process is summarised in figure 2.5.

Figure 2.5 FHWA process for assessing signalised intersections



The first key step in the process is identifying stakeholder interests and objectives, which involves canvassing the stakeholders to get a better understanding of their needs and issues.

The second key step in this process is the problem identification and cause which considers:

- the characteristics of the site (user needs, operational considerations, safety considerations and the physical characteristics of the site)

- the establishment of performance measures and criteria for the project which consider the user needs in terms of operational efficiency, accessibility and safety, recognising that these should be considered on a case-by-case basis
- the establishment of desired performance outcomes for both safety and operational efficiency.

It is this type of process that provides the best opportunity for evaluating safety and efficiency at intersections, based on what needs to be considered at each site. However, it should be recognised that this is aimed at a project level and not at a programme level. The integration of safety and efficiency at a programme development level may be best left in isolation, with the project development process used to determine the need to consider the other components of network performance (safety, efficiency, accessibility). However, there is significant opportunity for use of the framework for specific sites under this model, particularly if stakeholder engagement informs the extent of treatment options available for consideration.

2.5 Summary of processes/approaches

From sections 2.3 and 2.4 above, it is apparent there may be opportunities to take specific elements of the various approaches to create an integrated process (involving the evaluation framework) that ensures an optimum 'blend' of safety and efficiency is achieved at the end of the project development lifecycle.

The challenges are as follows:

- identifying and confirming which part of the individual processes are reinforcing/worsening the disconnect
- identifying *how* and *where* potential linkages can be established between these processes, as a starting point for creating a revised process if appropriate
- demonstrating that these changes will result in positive outcomes, when the above processes are well established within the Transport Agency.
- if an evaluation framework for intersection treatment is developed, how, and specifically why would this be adopted as a separate consideration from other parts of the network (eg segments between intersections), and is it appropriate to do so?

3 Analysis methods

3.1 Analysis integration opportunities

The literature review revealed a number of opportunities to integrate the evaluation processes, with a major emphasis on developing the evaluation framework at the outset. Opportunities include:

- form of evaluation framework – developing a framework that allows for the rapid filtering of the long list of options though to a short list by considering the suitable treatments for safety and efficiency, and discarding those that do not meet the performance expectations for safety and operational efficiency (including the functional requirements identified through the network operating framework process)
- level of detail – use of crash prediction models and/or CRFs to estimate safety performance, and use of traffic models for the assessment of operational performance in short-listed options.

It may also be possible to integrate the processes without changing the structure of the project and programme development. These opportunities include:

- defining the outcomes and objectives sought from the investment, including the performance expectations for both safety and operational efficiency (an example of performance expectations for a motorway interchange in Auckland is provided in appendix E – this gives a useful guide to scoping options)
- performance benchmarking: consider both safety and efficiency in benchmarking the operational and safety performance of the intersection under investigation
- developing a comprehensive list of available options and then comparing suitable treatments for addressing safety issues, based on operational efficiency needs (and vice versa)
- developing a common framework for detailed evaluation of subsequently shortlisted options to allow both safety and operational impacts to be traded off.

3.2 Efficiency

There are many tools available that can be used to assess the efficiency (operational performance) of both standard and non-standard intersection improvements varying from analytical methods, such as those outlined in the *Highway capacity manual* (TRB 2010) covering all user modes and the approaches set out in the EEM, through to software packages such as SIDRA, LinSig, TRANSYT and microsimulation packages such as Paramics, AimSun and VISSIM.

All of these packages require a substantial amount of data collection for calibration and validation as intersections rarely operate as modelled using the default values. However, once calibrated correctly they can be used to assess a wide range of intersection forms and design elements to test the operational efficiency of intersection treatments.

The transition to a network operating framework and process is likely to see a shift in how these models are used to assess the outcomes desired. Transport models may need to be tailored to provide a multi-modal LoS as required. This increases both the complexity of the intersection modelling and the data collection requirements.

The model outputs can then be used as inputs into the assessment of network operating gaps – the equivalent LoS measure for network performance against the agreed road user hierarchy.

It is worth noting that the development of analytical techniques for intersections has (rightly or wrongly) flowed through into the assessment processes which are now heavily reliant on model outputs to determine performance, as opposed to the use of CRFs to estimate safety benefits. This creates a mismatch in the level of detail, particularly when considering the level of effort required to identify 'suitable' treatments before considering detailed operational analysis. Alignment of the level of detail to inform a revised framework is key to ensuring positive outcomes are achieved, based on 'like for like' levels of detail for the inputs.

3.3 Safety

3.3.1 Local research

Appendix A6 of the EEM contains a large number of base models (crash prediction models) and CRFs for intersections and road links.

Turner et al (2010) identified that while there are many tools available for assessing operational performance this is not the case with road safety where there are limited tools available, most of which are unable to deal with non-standard intersection designs or non-standard elements of intersection design. Turner et al also identified that due to evidence gaps some design elements, such as signalised roundabouts and staggered junctions, are not present in sufficient numbers to develop quality crash models.

The predominant method in New Zealand for assessing the safety performance of a particular treatment is through the use of CRFs derived from local and international research. However, when considering options to improve the efficiency of intersections, the quantified prediction of the safety performance becomes an integral part of an evaluation framework.

The HRIG introduces the concept of the level of safety service, which is an assessment of observed crashes relative to similar types of intersections, and a risk profile using personal and collective risk (essentially exposure models) to determine whether an intersection is high risk.

However, the limited availability of data is restricting the ability to proactively assess the safety performance of intersections, as opposed to assessing the operational efficiency where data is available or can be collected. Also, the relatively rare nature of crashes at a given intersection does not help in establishing clear trends to validate intervention options. This is consistent with Turner et al's findings outlined above. The opportunity is therefore to provide CRFs for more specific intersection treatment forms, and to potentially use these figures in conjunction with modelling output for the intersection being investigated.

3.3.2 International research

As with the local research, the international literature also indicates some limitations in traditional safety modelling, as highlighted below:

Research undertaken by Elvik (1996) challenges the value of predictive modelling. Elvik indicates that increasing the amount of evidence predictions are based on (or increasing the level of research) does not necessarily make the predictions more accurate. This could be due in full, or in part to a range of unknown factors. This article, and a number of others, challenge whether detailed modelling can reliably predict crash reduction. Similarly, Wood et al (2013) advocate for the application of simple scale factors to well-proven historical models, rather than building newer, more complex models. However, Sobhani

(2013) goes some way to providing a framework that integrates known crash severity with known conflicts at intersections to prove that microsimulation can be applied usefully in assessing intersections for safety.

Jonsson et al (2009) from the US Transportation Research Board demonstrate that crash type models should be used to predict crash frequency by crash type, but universally applied assumptions are too broad and do not lend themselves to useful trends being observed. For example, it may be claimed that rear-end crashes make up 20% of intersection crashes, but specific intersection types may skew this significantly.

Ekman (1996) developed a 'transparent' system for estimating safety performance functions and risk performance functions. This system ultimately demonstrated that the relationship between vehicular conflicts (safety/efficiency) and flow (efficiency) is complex but developing a fuller understanding of the relationships through effective modelling could allow comparisons between intersections with similar geometric characteristics, albeit with different traffic volumes.

Unobserved factors can be demonstrated to contribute to a deterioration in safety, but only by a modest amount (Ye et al 2009). Meanwhile, research from Finland suggests longer-term accuracy can be achieved by more complex models (that include a calibration factor) as opposed to simpler models (Peltola and Kulmala, nd), but when compared with a research example from Canada, treatments are highly sensitive to the treatment methodology used (Mishra 2010)

The relationship between crash counts and traffic volumes on the approaches to an intersection and those within an intersection were found to be very different. This makes it unlikely that realistic models for all intersection-related crashes can be developed (Joksch and Kostyniuk 1997; Turner et al 2010).

A further consideration is being able to compare like-with-like in the evaluation of safety performance versus operational efficiency. The HRIG uses the concept of the level of safety service, which is a measure of relative performance against similar types of intersections. It is not quite the same as the delay (or saturation ratio) based LoS measures for operational efficiency. The use of collective and personal risk, combined with the analytical techniques to estimate safety performance on the basis of deaths and serious injuries (DSIs) are, to a degree, similar to a LoS concept. The appropriate performance measures will be considered further in the development of the evaluation framework.

The above highlights that historic CRFs cannot be relied on alone, and in fact there may be a case for updating CRFs on a regular basis, and/or to develop CRFs for more specific intersection types with particular characteristics. However, this must be balanced against the level of detail that will be available at the design stage; which is one of the stages in the project development when the evaluation framework is implemented.

3.4 Evaluating safety and efficiency

The research identified some examples of modelling safety considering parameters relevant to the efficiency of intersections.

Turner et al (2012) attempted to quantify the effect of signal phasing on various crash types and various travel modes at traffic signals, taking into account speed limits, intersection geometry and land-use environment. The research concluded:

- A number of intersection parameters, such as all-red time, shared turns and signal coordination, were observed to affect a specific crash type. However, the model results also highlighted the safety benefits obtained from longer cycle times and longer right-turning bays across multiple crash types.

- Free left turns for motor vehicles, more approach lanes and near-saturated or over-saturated intersections were found to increase the risk of having a crash.
- There is a need for more comprehensive and better-quality data collection for cyclists. Well-fitting models for cyclists could not be developed as part of this study, due to the lack of adequate data.
- The results for peak periods indicated that longer cycle and all-red times, and the presence of split phasing and mast arms, had a significant effect on improving the safety of right-angle turns. The presence of a raised median or central island was observed to increase right-angle and right-turn-against crashes in the peaks, as opposed to the whole day where the presence of these features improved the incidence of this crash type.
- The models confirmed the 'safety in numbers' effect, whereby crashes increase at a decreasing rate as pedestrian numbers increase.

The information provided in the appendices, specifically appendix D, are rationalised summaries of common findings throughout the research, with peripheral findings included in the bibliography in chapter 10.

It should be noted that some of the summaries provided in appendix D contradict a number of specific findings in the bibliography, but are nevertheless, reflective of a general pattern.

What can be said is that if the majority of models show an increase or decrease in crashes, then this gives us some confidence in the quality of the results.

Turner et al (2012) also found the increase in right-angle pedestrian–vehicle crashes because of longer cycle times was greater than the corresponding decrease in crashes involving a right-turning vehicle colliding with crossing pedestrians. This was in contrast to previous Transport Research Laboratory research, undertaken by Kennedy and Sexton (2010), which indicated longer cycle times were safer for pedestrians. Longer lost times (in the form of either yellow or all-red times) negatively affected both crash types. In addition, full signal protection for right-turning vehicles reduced right-turning pedestrian–vehicle crashes, while a split phasing sequence lowered right-angles.

Veneziano (2006) also undertook a similar assessment for 23 signalised intersections in the US, by examining the impacts on safety of both design and operational measures. The key findings were:

- The models developed for that research fit reasonably well with the observed data.
- The approach speed limit, opposing approach speed limit, protected/permitted phasing, median width, turn bay length and adjacent land use all had an effect on the number of intersection crashes.
- The safety countermeasures generally reduced the efficiency of the intersections, with only 4 out of 10 sites realising a benefit-cost ratio > 1.0.
- The operational improvements generally had a positive effect on safety with 11 out of the 13 sites having a benefit-cost ratio > 1.0.

The above loosely supports the notion that projects ought to be designed around optimising efficiency outcomes, while making them as safe as possible. To a large extent this is the current arrangement within the Transport Agency and other RCAs throughout New Zealand.

Veneziano (2006) also looked into past research around both safety and operational benefits, drawing on research deriving a level of safety service based on volume-capacity ratio, travel speeds and other various forms which may be useful in further developing the evaluation framework.

Svensson (1998) created a framework for the analysis of safety related road user behaviour to better understand safety processes. This exercise considered the split/relationship between low frequency of events/high severity intersections with high frequency/low severity intersections.

To do this, Svensson investigated road user behaviour at two signalised intersections and at one non-signalised intersection. A number of data sets were then collected from the trial sites, including conflict points, crash history and the ability of the road user to respond to a crash. This work found there was a definitive line between what is considered ‘safe’ and ‘unsafe’ intersections, as the ‘safe’ interactions data was widespread (wide convexity), whereas the unsafe interactions was tightly bunched. This allowed a better understanding of the safety response, and the ability to target treatments to specific intersections and turning movements.

FWHA (2014a) concluded that apart from geometric improvements, education and enforcement would greatly improve intersection safety.

On the other hand, a number of the research articles indicate that treatment selection has less impact on safety, while others have a high degree of variability, depending on the treatment options selected.

A study undertaken by Bauer and Harwood (1996) suggests that only a small fraction of intersection crashes is related to geometric design.

A number of the researched articles reveal strong correlations of specific treatments with notable improvements; particularly in safety (refer section 3.5 below). This goes some way to strengthening the case for robust CRFs to be further developed. Developing a better understanding of these specific trends, and any corresponding efficiency trade-off will greatly assist in developing a framework.

3.5 Trade-offs in practice: the effect of the give way rule

3.5.1 Observed trends

As part of developing an understanding of the trade-offs, it is possible to determine what impact, if any, key legal considerations (such as the give way rules) has on this relationship.

From the outset, it is evident that measures taken to simplify the road user’s tasks will lead to a reduction in crashes thus creating a safer section of road or intersection. It could be argued that a controlled intersection is an example of this, with an uncontrolled or priority controlled intersection (reliant on the adoption of give way rules) a consequence of funding and/or other constraints. Where such compromises need to be made, designers and RCAs need to look carefully at the specific conditions against which the scheme in question is being assessed, and to ensure that only one variable is changed at a time in undertaking an analysis.

Research undertaken by Lovell and Hauer (1986) advocated for converting four-way intersections (with two compulsory stop approaches) into four-way stop intersections on the basis of safety, but this comes with a corresponding loss of operational efficiency. It was claimed that side-on injury crashes reduced in the order of 70%, although only high crash intersections were trialled which may have skewed the results.

Similarly, McGee and Blankership (1989) observed a commensurate increase in crashes observed when converting from stop controlled to yield-type (equivalent to give way control in New Zealand) crashes.

A Finnish study (Kulmala 1990) promotes yield controls at junctions as an effective means of simplifying the decision-making process and confirming the psychological right of way, without perhaps trading off as many of the safety-related benefits as an uncontrolled intersection, or as many efficiency-related benefits as a signalised intersection.

A number of other studies support the above trend, although it is noted that the scale of the claimed crash reductions (or increases) varies greatly, depending on the source. The results also appear highly dependent on the complexity of the trials, the traffic volumes, local give way rules (highly variable across states in the US) and other site-specific conditions.

Despite the apparent reduction in efficiencies, many states in the US are also implementing compulsory four-way stops at all intersections, irrespective of safety record. This is on the basis of outright transparency/accountability in the event of a serious/fatal crash. Many RCAs are willing to make this decision, showing an apparent willingness to trade off all available efficiencies. This is an example where legislative intervention may have the ultimate 'say' in how these situations are treated, in developing a framework for dealing with the trade-offs.

3.5.2 New Zealand/Australia

The use of the give way rule also varies between jurisdictions, with both New Zealand and Australia giving way to the right, despite driving on the left-hand side of the road. This creates grounds for an interesting comparison with countries such as the US, where the legal requirement is to yield to the right at an uncontrolled intersection when vehicles on different approaches arrive simultaneously.

Australia introduced new give way rules in 1999 for all territories, yet there are still variations throughout Australia (eg Victorian traffic law). For example, in Victoria, vehicles are permitted to make a U-turn at signalised intersections unless there is a 'no U-turn' sign. There are also a number of other variations, although not exclusive to intersections (such as laws around mobile phone use, speed limits in school zones and the like).[2]

New Zealand introduced changes to its give way rules in 2012, around right of way rules at T intersections. Previously, New Zealand rules gave priority to vehicles turning right off the through route to vehicles turning left from the through route onto the same side road. While this often resulted in shorter wait times/queues in right turn bays, it also resulted in an increase in crashes, especially involving foreign drivers from countries with different give way rules. It is anticipated that the latest changes to standardise the give way rule with Australia and other jurisdictions will reduce give way crashes in the order of 7%.[3]

3.5.3 Free turn on red

Many jurisdictions permit a free unopposed turn on red to improve efficiency. In the US, this is prevalent in many states, allowing some useful comparisons to be made, to determine what the observed safety trade-off is. Zador et al (1982) observed an overall increase in the frequency of crashes of 20% for free left turn on red, when compared with states that did not allow this. This increase is particularly pronounced for vulnerable road users (elderly pedestrians, children and cyclists). Similar patterns were also observed in the work of Preusser et al (1982) and Abu-Lebdeh et al (1997)

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[2] www.racv.com.au/wps/wcm/connect/racv/Internet/Primary/road+safety/roads+_+traffic/road+rules/differences+between+australian+and+victorian+road+rules).

[3] www.nzta.govt.nz/traffic/around-nz/give-way-resources.html

3.5.4 The way forward

Relatively robust conclusions are drawn in the above cited literature around how give way rules at intersections impact on efficiency, and in particular, safety. Developing detailed CRFs for observed impacts from changes to the give way rule would add significant value in developing a framework.

4 Understanding the trade- offs

The response to safety and operational efficiency can be considered in two parts, both being ‘safety led’ (particularly 2 below). However, the treatment chosen will potentially be heavily influenced by any anticipated change in operational efficiency:

1 Conflict reduction and management – these treatments reduce the number of conflicts at intersections by separating them in time or in space. Treatments include the form of control (roundabouts, traffic signals and traffic signal phasing, grade separation, priority facilities) and the layout of facilities (eg turning bays, cycle lanes, special vehicle lanes, channelisation and intersection realignment).

2 Management of speeds – these treatments actively seek to reduce the speed of the conflicts, rather than eliminate them. Typical treatments include the form of control (eg roundabouts, speed tables, geometric improvements to manage entry speeds and speed regulation/advisory systems).

The reduction in conflicts in time and/or space generally improves the safety of intersections where speeds do not increase as a result. In terms of the operational performance of intersections, the speed is not the critical factor – the capacity is typically governed by the layout of the intersection and the form of control.

In developing an understanding of the trade-offs, it is essential that a way of quantifying a specific unit of safety can be benchmarked against a commensurate reduction of x unit(s) of efficiency. LoS bands are useful in establishing relativity between proposed treatment options and the current site characteristics, for both safety and efficiency. However, this does not allow a meaningful way to establish what the ‘offset cost’ of a 5% reduction in efficiency is, if safety is improved. LoS bands for both safety and efficiency can be converted to percentages for each scale, but cost is the common unit that provides the necessary level of understanding.

A method was developed for the evaluation framework to help understand the trade-offs and this is further detailed in chapter 6.

5 Framework development processes

The processes for developing safety or efficiency countermeasures have a strong alignment with overseas practice and also with the Transport Agency's business case approach. The project development approach can be summarised as follows:

- data collection and analysis
- deficiency analysis and problem definition
- option development
- option assessment (effectiveness of the countermeasure in addressing safety or efficiency)
- economic evaluation.
- implementation and monitoring.

With reference to the FWHA, some additional initial steps were considered prudent to ensure the best mix of outcomes was determined, and a summary of the overall process is provided in figure 2.5 in chapter 2.

It was envisaged the EEM might provide a sound starting point from which to develop a framework, as this is the only existing reference (particularly for the New Zealand component of the research) that contains quantitative methods for both safety and efficiency where outputs are expressed in a common unit (NZ$). However, it was later determined that to simplify the evaluation tool as a 'proof of concept', other applications would be more suitable from the outset (refer to chapters 6–8 for further information).

The Transport Agency's move towards a business case approach provided the opportunity to refine the approach to consider:

- defining the outcomes being sought for all users (safety and efficiency)
- developing the evaluation framework (including performance measures and targets) around those defined and agreed outcomes.
- defining the critical success factors, constraints and dependencies to take into account the social, environmental, engineering and financial constraints in the option development process.

The challenge was to develop a robust process that would not be overly onerous for practitioners developing programmes and projects.

5.1 Conclusions from the literature review

There was very little in the literature to define what could be considered an acceptable trade-off between safety and efficiency at intersections, largely due to the existing separation of the two fields in all jurisdictions researched. The literature did, however, cite many examples of post-implementation monitoring that highlighted the relative safety and efficiency benefits and impacts of various types of treatments. The validity of these findings in further understanding the trade-offs was endorsed by the EEM methods used in the case studies described in chapter 7.

It was apparent in the literature that evaluated the safety and efficiency of intersection treatments that rather than providing a combined LoS, there was a preference to continue considering them separately in order to trace the benefits and impacts to either safety or efficiency when undertaking the evaluation. To a degree the network operating plans incorporate delay-based measures and accessibility/facility measures for pedestrians and cyclists; however, incorporating safety would be a very complex exercise and would require a new approach if this avenue was explored.

Hence in developing an evaluation framework for New Zealand, combining efficiency and safety in one LoS was not considered appropriate. For the development of an evaluation method, the following needed to be considered:

- a network operating gap to report on efficiency deficit (against what the target should be for the intended road hierarchy)
- LoS at intersections not covered by network operating plans
- change in DSIs, level of safety service and changes in crash frequencies at all intersections.

6 Evaluation framework

Following considerations identified in chapter 5, a 'proof of concept' evaluation framework was developed utilising the available standards and guidelines for both safety and efficiency.

Below is a high-level explanation of how the framework functions, divided into three main categories, inputs, processing and output.

6.1 Inputs

6.1.1 Efficiency

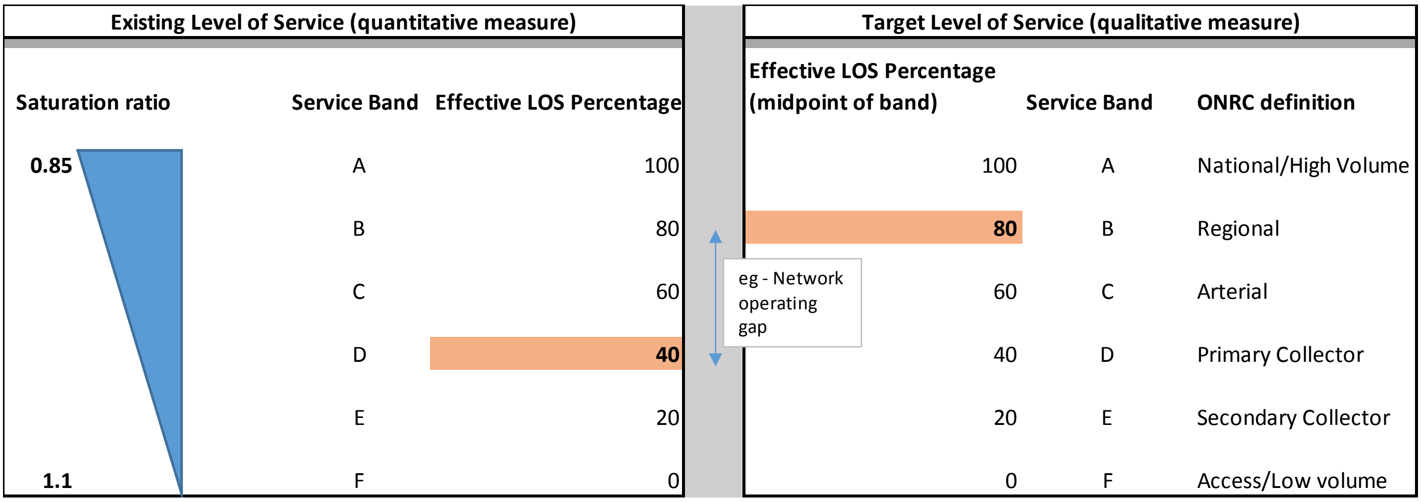
6.1.1.1 Existing level of service

Existing LoS for efficiency were taken as the saturation ratio of the worst performing approach on the intersection (calculated from TRB 2010). It was considered that saturation ratio was a measure better aligned with converting to a LoS band than delay (as used in the EEM); acknowledging that the calculation of saturation ratios includes consideration of the delay at approaches. Intersections perform relatively efficiently when saturation ratios are less than 0.85. From this point, flow breakdown occurs relatively rapidly; with complete saturation occurring when v/c=1.1.

Arbitrarily, if it is assumed that this flow breakdown occurs linearly, LoS bands can be established between these outer extremes, whereby the highest LoS (band A) is represented by any saturation ratio less than 0.85, and LoS F is when saturation ratio is greater than 1.1. LoS B through E evenly occupy the bands in between.

Figure 6.1 illustrates this:

Figure 6.1 Existing/target level of service bands



The above bands for existing LoS (specifically for efficiency) are quantitative in terms of their definition, although can be compared to the LoS band definitions described in the ONRC system. While the ONRC system is qualitative in nature (rather than quantitative), the same principles apply. While the desired efficiency-based attributes under the ONRC LoS bands may not align directly with LoS bands resulting from a more quantitative approach, if the ONRC is applied universally in establishing target LoS, outcomes consistent with ONRC principles should be achieved. In addition, as other RCAs throughout New Zealand are working to align themselves with the Transport Agency's OneNetwork approach, it was considered appropriate that these definitions should be set as targets against which specific treatment options could be measured.

6.1.1.2 Target level of service

An earlier stage of the research required that the developed framework should ultimately deliver against the following targets:

- conflict reduction and management
- management of speeds and associated operational benefits.

It was considered these targets would be met through the adoption of a modified FWHA process, provided speed management was an objective identified during the 'stakeholder interests and objectives' stage, and the options shortlisted during the 'treatment selection stage' met this objective.

The evaluation framework uses the following parameters to determine the target LoS:

- average annual daily traffic (AADT) (all vehicles)
- heavy commercial vehicles (daily flow)
- buses
- active modes
- linking places
- connectivity
- freight – inland ports
- airport passenger numbers
- tourism
- hospitals.

6.1.2 Safety

6.1.2.1 Existing and target levels of service

In developing the evaluation framework, consideration was given to determine the most suitable means of determining both the existing and target LoS. As discussed earlier, several local standards were used to achieve this. The EEM and the HRIG were considered the most suitable, with the latter ultimately being selected for the proof of concept stage. This was due to the relative simplicity of the intersection types provided, and was a useful starting point for ensuring that corresponding efficiency improvements could be estimated for relatively straightforward schemes.

The improvement in safety is based on the DSI equivalents saved as a result of the proposed scheme, with the overall number dependent on whether the intersection is located in an urban or a rural environment.

The assumption that CRFs for specific improvements are fixed, without being cognisant of the existing site characteristics, is a weakness in the evaluation and in the standards themselves, although it is considered there is an opportunity to inform CRF update processes through this framework, and in fact is encouraged, given that at this stage predictive modelling for safety reductions has not been combined with these CRFs.

6.2 Processing

This is essentially the 'engine' of the evaluation framework, where a short list of available options is generated, or possibly a single solution (for simple schemes). The evaluation framework was developed to rapidly rank treatment options based on given input criteria. (eg all uncontrolled intersection related treatment options would be eliminated if we had already specified there was a significant safety concern at the intersection).

From the intersection treatments provided in the HRIG, a library of options addressing safety or efficiency (or both) objectives was included so a filter could be applied in determining a shortlist of suitable treatments. This gives due consideration to the following:

- where the anticipated efficiency for the options selected is sufficient to close the operating gap
- available budget (although ideally this should not be a consideration at the early stages of the assessment process)
- the degree of confidence associated with estimated costs for various schemes
- whether a major (transformational) or a minor (transitional scheme) is desired. It is anticipated that this may be partially or fully informed by the 'safety impact assessment' (as used under the Safe System approach for road safety)
- the relative weighting/percentage allocation of the various user groups.

With further development, the evaluation framework will allow the user to mix and match various combinations of treatment options that fit within existing constraints identified, particularly if 'non-conventional' CRFs can be developed from the local and international research findings identified earlier in this report, and as detailed in the appendices.

An additional feature adopted in the evaluation framework is the ability of the user to assign allocations to the various road user groups: HCVs, standard vehicles, pedestrians, cyclists and passenger transport. These allocations can be assigned as absolute numbers (via traffic surveys) or as percentages. This feature is useful in providing a more realistic score, particularly if intersection modelling data is provided as an input into the relevant cells. This modelling data input has not been developed as part of this research, and its development is recommended as a future step in refining the evaluation framework.

6.3 Output

The case studies investigated were the first step in ensuring the highest ranked outputs provided by the evaluation framework matched the scheme that was constructed, or alternatively, provided a close match. (refer to chapter 7 for the case studies).

The evaluation framework assumes specific existing intersection characteristics will change, and there is an opportunity to select existing site characteristics so that the CRFs associated with those characteristics are not considered in the analysis.

It is anticipated through the network operating plans, key decision makers will ensure the appropriate classifications have been established as targets, by cross checking the categories against the parameters in the 'fit for purpose' customer LoS that should be met under each category. These parameters include:

- travel time reliability
- network resilience

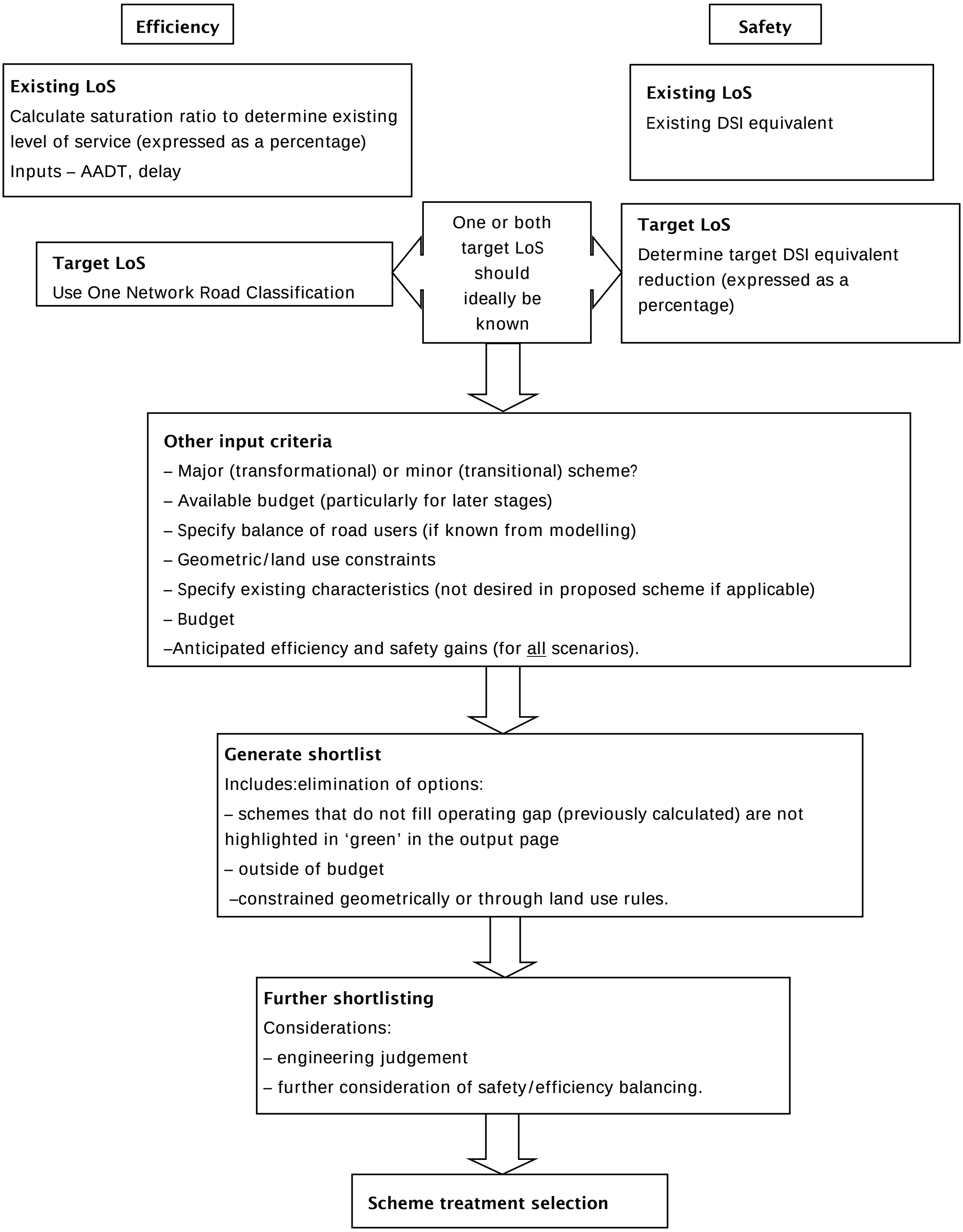
- optimal speeds
- safety
- amenity
- accessibility.

The objective for this proof of concept evaluation framework was to ensure the ranking of schemes reflected an order that would match good engineering judgement by a reasonably experienced practitioner.

The SEFT score as calculated by the evaluation framework currently assumes that a 5% improvement in efficiency is as valuable as a 5% improvement in safety. This is overly simplistic and requires further work to determine whether use of the EEM (to provide a common unit for both safety and efficiency benefits gained or traded off) will allow a more meaningful comparison to be made.

The diagram on the following page is an illustration of the SEFT evaluation framework:

Figure 6.2 Evaluation framework SEFT process



The library of treatment options can be further developed so that other standards and guidelines can be used in the options assessment process. Austroads and the EEM are two standards in particular that will enable more 'granular' levels of scheme options to be considered.

7 Case studies

7.1 Purpose

In developing an evaluation framework, it is useful to study a number of existing sites that have been recently updated, or are planned to be upgraded. This provides the opportunity to test the outputs generated from the evaluation framework, and compare them against what has been implemented on site. In the case of future schemes, the evaluation framework can be used to test the ranked order of suggested upgrades, and use these to inform the development of the design for the given scheme, if the suggested interventions differ significantly from the actual design solutions proposed to date, and are shown to be credible. This process involves a combination of analysis, and engineering judgement while also considering other inputs, such as those options deemed unsuitable for other reasons, eg conflicting stakeholder interests (refer to figure 8.1 in chapter 8).

7.2 Case study sites

Through consultation with the Steering Group for this research project, the case studies identified were:

- SH1/29, Piarere, Waikato
- SH1/26, Hillcrest, Waikato
- Whakitiki Street/SH2
- Ohaihanga/SH1
- SH1/Wayby Valley Road
- SH22/Great South Road, South Auckland
- SH10/11, Puketona, Northland
- SH22 (Glenbrook Road)/Brookside Road.

AADT figures were taken from the *State highway traffic data booklet 2010–2014* (NZ Transport Agency 2015b).

For the purpose of the analysis, the minor approach is assumed to be approximately 50% of the AADT of the major approach.

7.2.1 SH22 (Glenbrook Road)/Brookside Road

7.2.1.1 Overview

Previous/existing arrangement: Currently a three-leg channelised T intersection

Proposed design: Three-arm roundabout, with future proofing for four legs

Implemented solution: Not yet constructed.

Consideration of safety/efficiency in design stage: Efficiency based for future three arm.

Future opportunity: Balance the needs of safety/efficiency in determining whether this is the preferred solution, particularly for four-way roundabout design.

7.2.1.2 SEFT evaluation

Inputs

Crashes: Two serious, 11 minor

AADT: 12,000 vehicles per day (vpd) (approx)

Outputs

Peak hour efficiency LoS: A

ONRC (target LoS): Regional

Network operating gap (as calculated): -33%

Personal risk exposure: High:

Collective risk exposure Medium

Table 7.1 Shortlist of solutions

Measure	Installation cost	Weighted CRF	Efficiency score	SEFT evaluation
Roundabout	$3,000,000.00	75	30	52.5
T-intersection	$1,000,000.00	60	5	32.5
Roundabouts: optimal geometry	$4,000,000.00	54	5	29.5
Staggered T intersections	$3,000,000.00	45	10	27.5
Turning bays	$500,000.00	34	15	24.5
Sight distance improvements	$500,000.00	30	5	17.5
Minor road central islands	$40,000.00	27	0	13.5
Roundabouts: adverse camber rectification	$500,000.00	0	10	5.0
Roundabouts: reverse curves to reduce speeds	$1,000,000.00	0	3	1.5

Comment: The proposed design was identified with the highest SEFT score, and is highlighted in yellow above.

7.2.2 SH10/11, Puketona, Northland

7.2.2.1 Overview

Previous/existing arrangement: Currently a three-leg T intersection

Proposed design: Three-arm roundabout design completed

Implemented solution: Technology solution implemented (rural intersection activated warning system

Consideration of safety/efficiency in design stage: Balanced outcomes for both safety and efficiency.

7.2.2.2 SEFT evaluation

Inputs

Crashes: Five minor (2009–2015)

AADT: 5,000 vpd (approx)

Outputs

Peak hour efficiency LoS: A

ONRC (target LoS): Regional

Network operating gap (as calculated): -33.03

Personal risk exposure: Low

Collective risk exposure: Low

Table 7.2 Shortlist of solutions

Measure	Installation cost	Weighted CRF	Efficiency score	SEFT evaluation
Red light camera enforcement	$100,000.00	69	-3	33.0
Cyclist facilities	$50,000.00	50	-2	24.0
Coloured high friction surfacing	$50,000.00	43	0	21.5
Central lighting	$250,000.00	40	0	20.0
Transverse markings and rumble strips	$50,000.00	38	0	19.0
Intelligent active warning signs	$150,000.00	35	0	17.5
Signalisation: advanced cycle stop box	$20,000.00	35	-2	16.5
Clear or safe zones: frangible sign posts	$10,000.00	30	0	15.0
Signalisation: improved signal conspicuity	$50,000.00	25	5	15.0

Comment: The implemented solution was identified on the shortlist, and is highlighted in yellow above.

7.2.3 SH1/Wayby Valley Road

7.2.3.1 Overview

Previous/existing arrangement: Stop controlled three-way intersection

Proposed design: Roundabout, or some other form of channelised arrangement

Implemented solution: Rebuilt as a three-way channelised intersection (‘seagull’ configuration)

Consideration of safety/efficiency in design stage: Efficiency and cost-driven solution

Future opportunity: Post implementation review to determine true ‘cost’ of seagull intersection versus the more expensive, but safer roundabout.

7.2.3.2 SEFT evaluation

Inputs

Crashes: One fatal, four serious, 20 minor

AADT: 11,000 vpd (approx.)

Outputs

Peak hour efficiency LoS: A

ONRC (target LoS): Regional

Network operating gap (as calculated): -33.03

Personal risk exposure: High

Collective risk exposure High

Figure 7.3 Shortlist of solutions

Measure	Installation cost	Weighted CRF	Efficiency score	SEFT evaluation
Roundabout	$3,000,000.00	75	30	52.5
T-intersection	$1,000,000.00	60	5	32.5
Roundabouts: optimal geometry	$4,000,000.00	54	5	29.5
Staggered T intersections	$3,000,000.00	45	10	27.5
Turning bays	$500,000.00	34	15	24.5
Sight distance improvements	$500,000.00	30	5	17.5
Minor road central islands	$40,000.00	27	0	13.5
Roundabouts: adverse camber rectification	$500,000.00	0	10	5.0
Roundabouts: reverse curves to reduce speeds	$1,000,000.00	0	3	1.5

Comment: As the ‘turning bays’ solution approximately represents the ‘seagull’ arrangement implemented in terms of safety/efficiency improvement, the implemented solution was identified on the shortlist, and is highlighted in yellow above.

7.2.4 SH22/Great South Road, South Auckland

7.2.4.1 Overview

Previous/existing arrangement: T intersection (stop controlled)

Proposed design: Traffic signals (caused by developer's proposed contribution) or roundabout

Implemented solution: TBC

Consideration of safety/efficiency in design stage: TBC, although it is considered 'user pays' for upgrades will lead to cost led solution.

Future opportunity**:** Post-implementation review to determine true 'cost' of implemented solution (driven by developers)

7.2.4.2 SEFT evaluation

Inputs

Crashes: Two serious, 11 minor

AADT: 11,000 vpd (approx)

Outputs

Peak hour efficiency LoS: C

ONRC (target LoS): Arterial

Network operating gap (as calculated): -26.83

Personal risk exposure: High

Collective risk exposure Medium

Figure 7.4 Shortlist of solutions

Measure	Installation cost	Weighted CRF	Efficiency score	SEFT evaluation
Roundabout	$3,000,000.00	75	30	52.5
Signalisation: install basic traffic signals	$500,000.00	30	35	32.5
Cyclist facilities	$50,000.00	50	-2	24.0
Coloured high friction surfacing	$50,000.00	43	0	21.5
Central lighting	$250,000.00	40	0	20.0
Enhanced signing	$20,000.00	34	5	19.5
Signalisation: advanced cycle stop box	$20,000.00	35	-2	16.5
Urban pedestrian facilities	$30,000.00	30	0	15.0
Clear or safe zones: frangible sign posts	$10,000.00	30	0	15.0

Comment: The implemented solution was identified on the shortlist, and is highlighted in yellow above (currently signalisation is only available in the framework library for sites classified as 'urban').

7.2.5 SH1/29, Piarere, Waikato

7.2.5.1 Overview

Previous/existing arrangement: Three-way intersections (with slip lanes/give way control)

Proposed design: TBC (currently in indicative business case)

Implemented solution: N/A

Consideration of safety/efficiency in design stage: Also part of integrated Safe System improvements corridor study

7.2.5.2 SEFT evaluation

Inputs

Crashes: Four minor

AADT: 7,900 vpd (approx)

Outputs

Peak hour efficiency LoS: A

ONRC (target LoS): Regional

Network operating gap (as calculated): -33.33

Personal risk exposure: Low

Collective risk exposure Low

Figure 7.5 Shortlist of solutions

Measure	Installation cost	Weighted CRF	Efficiency score	SEFT evaluation
Roundabout	$3,000,000.00	75	30	52.5
Roundabouts: optimal geometry	$4,000,000.00	54	5	29.5
Staggered T intersections	$3,000,000.00	45	10	27.5
Turning bays	$500,000.00	34	15	24.5
Sight distance improvements	$500,000.00	30	5	17.5
Minor road central islands	$40,000.00	27	0	13.5
Roundabouts: adverse camber rectification	$500,000.00	0	10	5.0

Comment: No information is currently available to confirm the design solution.

7.2.6 Otaihanga Road, SH1, Paraparaumu

7.2.6.1 Overview

Previous/existing arrangement: T intersection

Proposed design: Roundabout

Implemented solution: Roundabout

Consideration of safety/efficiency in design stage: Mainly efficiency driven

Inputs

Crashes: Six minor

AADT: 24,000 vpd (approx)

Outputs

Peak hour efficiency LoS: E

ONRC (target LoS): Regional

Network operating gap (as calculated): 63.03%

Personal risk exposure: Low

Collective risk exposure Low

Figure 7.6 Shortlist of solutions

Measure	Installation cost	Weighted CRF	Efficiency score	SEFT evaluation
Roundabout	$3,000,000.00	75	30.01	52.5
Roundabouts: optimal geometry	$4,000,000.00	54.01	5.02	29.5
Staggered T intersections	$3,000,000.00	44.99	9.99	27.5
Turning bays	$100,000.00	34	15.01	24.5
Sight distance improvements	$500,000.00	30	5.02	17.5
Minor road central islands	$40,000.00	26.99	0	13.5
Roundabouts: adverse camber rectification	$500,000.00	0	9.99	5.0
Roundabouts: reverse curves to reduce speeds	$1,000,000.00	0	3.01	1.5

Comment: The implemented (roundabout) solution was identified on the shortlist, and is highlighted in green above. Either of the two highlighted schemes above would close the existing reported operating gap.

7.2.7 Whakitiki Street, SH2, Upper Hutt

7.2.7.1 Overview

Previous/existing arrangement: Channelised/seagull arrangement

Proposed design: TBC, but expected to be roundabout or traffic signals

Implemented solution: N/A

Inputs

Crashes: Eight serious, six minor (2009–2012)

AADT: 30,000 vpd (approx)

Outputs

Peak hour efficiency LoS: D

ONRC (target LoS): National

Network operating gap (as calculated): 43.33%

Personal risk exposure: High

Collective risk exposure High

Figure 7.7 Shortlist of solutions

Measure	Installation cost	Weighted CRF	Efficiency score	SEFT evaluation
Roundabout	$3,000,000.00	75	30	52.5
Roundabouts: optimal geometry	$4,000,000.00	54	25	39.5
Signalisation: install basic traffic signals	$500,000.00	30	35	32.5
Grade separation	$10,000,000.00	50	10	30.0
Sight distance improvements	$500,000.00	30	5	17.5
Minor road central islands	$40,000.00	27	0	13.5
Roundabouts: adverse camber rectification	$500,000.00	0	10	5.0
Roundabouts: reverse curves to reduce speeds	$1,000,000.00	0	3	1.5

Comment: As the 'turning bays' solution approximately represents the seagull arrangement, this was used as the existing scenario. The model correctly identified feasible treatment options, which also closes the network operating gap as calculated (highlighted in green above)

7.2.8 SH1/26, Hillcrest, Hamilton

7.2.8.1 Overview

Previous arrangement: Roundabout (four way)

Proposed design: Larger roundabout

Implemented solution: Roundabout. Largely driven by cost effectiveness.

Inputs

Crashes: Three serious, four minor (2009–2014)

AADT: 41,000 vpd (approx)

Outputs

Peak hour efficiency LoS: F

ONRC (target LoS): National (high volume)

Network operating gap (as calculated): -100.00%

Personal risk exposure: High

Collective risk exposure: Medium-high

Figure 7.8 Shortlist of solutions

Measure	Installation cost	Weighted CRF	Efficiency score	SEFT evaluation
Roundabouts: optimal geometry	$4,000,000.00	54	25	39.5
Signalisation: install basic traffic signals	$500,000.00	30	35	32.5
Grade separation	$10,000,000.00	50	10	30.0
Turning bays	$100,000.00	34.01	14.99	24.5
Sight distance improvements	$500,000.00	30	5.01	17.5
Minor road central islands	$40,000.00	27.01	0	13.5
Roundabouts: adverse camber rectification	$500,000.00	0	10.02	5.0
Roundabouts: reverse curves to reduce speeds	$1,000,000.00	0	2.98	1.5
Align opposing right turns	$500,000.00	0	0	0.0

Comment: The implemented solution was identified on the shortlist, and is highlighted in yellow above. 'Roundabouts' was not shortlisted, as this is represents the existing geometry, and was discarded early in the analysis. The efficiency score provided above would be the improvement expected, over and above the existing arrangement.

7.3 Overall observations

From the above case studies, the SEFT outputs demonstrate the SEFT framework can be used to suggest a shortlist of intervention treatments that are appropriate for the given situation. While the relative 'coarseness' of the information available in the treatment selection library is currently limited to the range of treatments presented in the HRIG, it does show that the process achieves the following outcomes:

- Identifies reasonable existing and target level of service categories based on specific input criteria.
- Generates a ranked list based on the calculated network operating gap.
- In all cases, the shortlist includes the treatment option that was ultimately constructed, or has been earmarked as an option (if not already constructed).

While the above has been achieved, it is acknowledged that the following factors are currently limiting the degree of 'refinement' of the results:

- Efficiency improvements (relative to the existing site) have not been modelled.
- Safety and efficiency improvement percentages have been left approximately the same for each treatment option, for each case study. This has resulted in rankings/scores that appear similar between case studies. It is, however, encouraging to note the order ranking changes significantly when changes are made to these percentages.
- Target levels of service are not overly sensitive to traffic volumes. Consequently, for the case studies, 'regional' was the classification used for most sites. With more urban case studies, more variability can be expected, leading to differing target levels of service and operating gaps.
- Signals are currently ranked as an 'urban' solution, and do not appear in most short lists (in rural sites). It is mainly due to the relative 'coarseness' of the HRIG solution index that 'roundabout' has been correctly identified.
- Network operating gaps reported currently appear excessively large at times. This is likely a result of the assumptions applied to the banding percentages.

It is also worth noting that a negative efficiency operating gap indicates efficiency can theoretically be sacrificed to achieve safety outcomes. This is observed to be relevant for most of the case studies, and is important in considering both the relative importance of safety at these sites, and also whether the bandings allocated for efficiency will require refinement at a later stage

Based on the above, it is recommended that additional development is undertaken to move this from a 'proof of concept' to a functional tool that the Transport Agency can use in developing projects and programmes. A summary of these steps is provided in chapter 9.

7.4 Establishing a common unit

For the purposes of the above analysis, the basis for calculating the SEFT score is dependent on an increase (or trade-off) of safety being as valuable as a commensurate value for efficiency. For example, a 5% improvement in efficiency is worth the same as a 5% improvement in safety. While for the purposes of this exercise it provides a good 'middle ground', in reality this would differ from site to site, with the extent of differences best demonstrated through thorough traffic modelling.

In reality, it is considered appropriate that cost provides the most meaningful way to compare benefits or costs between measures, and also allows a meaningful link to the EEM whereby cost effectiveness can be assessed/calculated.

As the EEM has not been used in this research paper to determine LoS, it is recommended that future work to further refine the outputs of the shortlist option includes this consideration.

To demonstrate how the safety and efficiency measures of the shortlisted/selected solution can be used in a more meaningful way, a worked example of one of the case studies is as follows:

7.4.1.1 Case study: Whakitiki Street, SH2, Upper Hutt (see section 7.2.7)

AADT = 18,000 vpd (across all approaches)

1 Safety

Cost of crashes = eight serious crashes at $360,000 each = $2.9m total over three years

Implemented solution – seagull arrangement (turning bays) with a CRF of 34%

$2.9m x 34% reduction = $900,000 over three years

2 Efficiency

Use congestion costs as basis of efficiency increase/decrease ($26.20 per vehicle hour – from EEM)

Average delay per vehicle

Previously existing site = 12 seconds per vehicle (estimated)

Revised site layout = 7 seconds per vehicle (estimated)

Congestion costs

Previously existing site = 18,000x 365 x (12/3600) hours x $26.20 = $573,780

Revised site layout = 18,000x 365 x (7/3600) hours x $26.20 = $334,705

=$239,075 saving per year

=$717,000 over three years.

This illustration is very simplistic, as other factors will be included when determining the true costs, but conceptually, it demonstrates that meaningful outputs can be established when sufficient modelling of the existing and proposed site arrangements has been carried out.

In addition, using the above approach, the following information can be determined:

- Both *absolute* and *relative* cost effectiveness comparisons can be made between options.
- The quantum of trading off between safety and efficiency can be assessed (for instances when they are competing).
- Full integration of the proposed framework with the EEM can be achieved by making use of the extensive suite of CRFs, and linking them to outputs through the use of a common monetary unit.

8 Project development integration

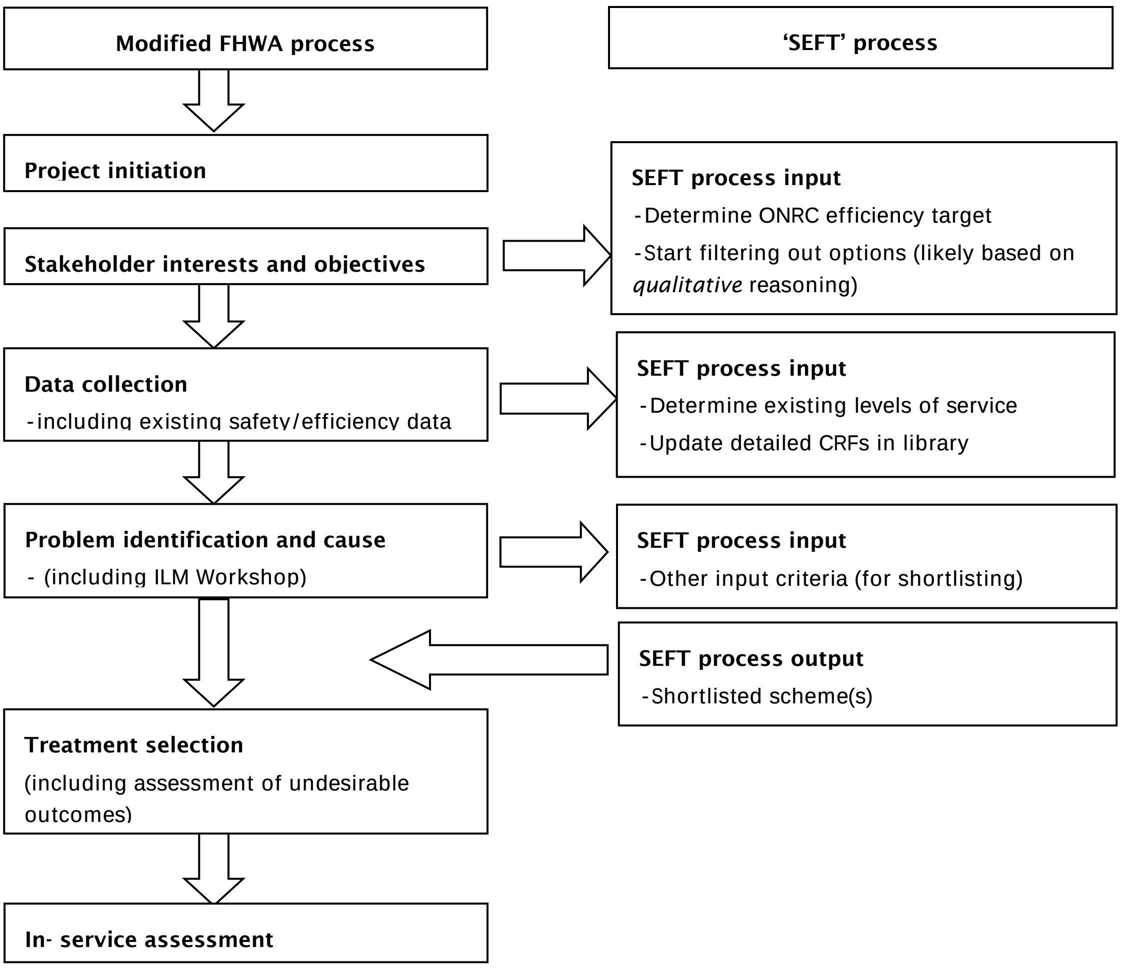
The evaluation framework is the evaluation component of a wider decision-making framework, and is not a direct substitute for well-established processes being used within the industry. This is because the evaluation framework is a decision *supporter* rather than a decision *maker* – it informs the nature of the information from which key decisions are made. It does, however, afford the opportunity to challenge how information is handled between each of the stages

In determining the best means of integrating the SEFT evaluation framework, it was considered the FHWA framework provided the best fit to ensure an optimal blend of safety and efficiency outcomes. This is because the FHWA framework:

- is well aligned with the business case approach
- takes the needs of stakeholders into account, which is an important consideration when qualitative methods are used in determining target LoS, and also for shortlisting available options.

The following is proposed as an opportunity to integrate the outcomes offered by the evaluation framework into the project development process used by the FHWA. It is envisaged this would occur in parallel with the SEFT process, as described in chapter 6 (with relevant linkages shown below):

Figure 8.1 FHWA/SEFT integration



9 Conclusions

This report provides a recommended process by which desired safety/efficiency outcomes can be measured against the existing levels of performance in a meaningful way. In many cases, improving safety at an intersection often comes at a cost to efficiency. The process developed in the 'proof of concept' evaluation framework offers some way to better understand the trade-offs. However, the extent to which it quantifies the trade-offs (as a percentage difference between existing and proposed) assumes that a 5% improvement in safety is as valuable as a 5% improvement in efficiency. This is a limitation that will be resolved in further development of the evaluation framework. A high-level example of one of the case studies has been summarised in chapter 7.

In addition, the logic by which target LoS can be set through qualitative methods (such as categorising sites in accordance with the ONRC system) appears well grounded. This is because it provides a consistent framework whereby all RCAs can work towards achieving a 'One Network'

Investigation of the case studies, by measuring the framework's ability to reproduce what was actually constructed was successful to some degree, albeit with very 'coarse' levels of information provided. Nevertheless, as more complex scenarios are tested against a more thorough database of treatment options for intersections, it is expected the evaluation framework will assist decision makers to a large degree, provided consistent application of the process is achieved.

The true validity of determining operating gaps by *quantifying* outputs from *qualitative* methods (such as ONRC), and measuring them against levels of service percentages from *quantitative* models requires further testing. However, it does appear the framework is flexible enough to allow alternative analysis methods to be used.

It is also recommended additional work is undertaken to determine whether or not a number of the claimed safety and efficiency changes from the research can be accepted by the Transport Agency and used as treatment options in the library of solutions.

From the findings, it is considered that sufficient research has been conducted to warrant development of an evaluation framework from first principles (to use as a decision support tool), rather than by combining existing frameworks. In addition, it is considered that while the research findings did not establish any significant linkages between safety and efficiency, enough evidence was gathered to provide either a means of validating some existing CRFs and/or efficiency improvements, or challenge an update to these.

10 Recommendations

It is recommended that to further progress the evaluation framework, the following activities should be considered:

- Seek approval in principle from within the Transport Agency and other RCAs for adoption of the evaluation framework.
- Investigate how the evaluation framework can be developed to assess intersections at a programme level, rather than at a project level. This will be particularly useful as the Safe System approach further promotes transformational projects which in turn inform safety-based upgrades to corridors, involving many intersections.
- Integrate components of the EEM to convert output levels of service into costs. This allows a more robust means of trading off between safety and efficiency, by working with a common unit.
- Ascertain whether outputs from SIDRA traffic models can be used to populate anticipated efficiency improvements for all possible treatment options covered by the evaluation framework. Look to develop a ‘plug-in’ if possible.
- Undertake additional work to validate the safety/efficiency findings from the research, and determine whether they can be accepted by the Transport Agency and used as treatment options in the library of solutions for the evaluation framework.
- Determine a way to maintain CRFs for relatively detailed scheme designs as required.

11 Bibliography

The below references are all source studies as part of this research. Where references contribute to, or disprove a concept or trend, they are referred to within this research report. Where the below sources do not contribute to any specific concept or trend, or are otherwise inconclusive in their findings, they are not specifically cited.

Abu-Lebdeh, G, RF Benekohal and B Al-Omari (1997) Models for right-turn-on-red and their effects on intersection delay. *Transportation research record 1572*: 131–139.

Auckland Traffic Management Unit (ATMU) (2010) *Review of filtered right turns at traffic signals*. Version 2. Accessed 8 June 2016. www.ipenz.org.nz/ipenztg/Subgroups/SNUG/Traffic_Signal_Documents/2010/Review%20of%20Filtered%20Right%20Turns%20at%20Traffic%20Signals%20V2.0.pdf

Austroads (2009) *Guide to road design*. Part 4. Sydney: Austroads.

Austroads (2006–2013) *Guide to road safety*. 9 parts. Sydney: Austroads.

Austroads (2013–2015) *Guide to traffic management*. 13 parts. Sydney: Austroads.

Austroads (2007) *Intersections, interchanges and crossings*. Sydney: Austroads.

Bauer, KM and DW Harwood (1996) Statistical models of at-grade intersection accidents. *Report no. FHWA-RD-96-125*. Washington DC: FHWA. US Department of Transportation.

Bonneson, J, K Zimmerman and M Brewer (2002) Engineering countermeasures to reduce red-light-running. *Performing Organization report 4027-2.*

Brown, T (2014) Southern Corridor improvements – journey management. NZ Transport Agency memo draft for discussion.

Campbell, D, I Jurisich and R Dunn (2005) Improved multi-lane roundabout designs for cyclists. *Land Transport NZ research report 287*. 140pp.

Ekman, L (1996) *On the treatment of flow in traffic safety analysis – a non-parametric approach applied on vulnerable road users*. Sweden: Department of Traffic Planning and Engineering

Elvik, R (1981) Effects on road safety of converting intersections to roundabouts: review of evidence from non-US studies. *Transportation Research Record 1847: Journal of the Transportation Research Board.*

Elvik, R (1996) Does prior knowledge of safety effect help to predict how effective a measure will be? *Accident Analysis Prevention 28*, no.3:339–47.

Federal Highway Administration (FHWA) (2004) *Signalized intersections: informational guide*. Accessed 3 June 2016. www.fhwa.dot.gov/publications/research/safety/04091/05.cfm#chp541

Federal Highway Administration (FHWA) (2014a) *Intersection safety*. Accessed 8 June 2016. http://safety.fhwa.dot.gov/intersection/

Federal Highway Administration (FHWA) (2014b) *Modern roundabouts: a safer choice*. Accessed 8 June 2016. www.youtube.com/watch?v=uhHzly_6lWM

Golias, JC (1995) Effects of signalisation on four-arm urban junction safety. *Accident Analysis & Prevention 29*, no.2: 181–190.

HM Treasury (2013) *The green book: appraisal and evaluation in central government*. Accessed 4 June 2016. www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-government

Institute for Road Safety Research (2012) *SWOV fact sheet – roundabouts*. Accessed 8 June 2016. www.swov.nl/rapport/Factsheets/UK/FS_Roundabouts.pdf

Jaglal, M and D Wilson (nd) *Left turn treatments at signalised intersections*. Presentation. Accessed 8 June 2016. http://hardingconsultants.co.nz/ipenz2012/downloads/1355_Jaglal__Marisha.pdf

Joksch, HC and LP Kostyniuk (1997) Modeling intersection crash counts and traffic volume. Accessed 8 June 2016. https://trid.trb.org/view.aspx?id=537634

Jonsson, T, C Lyon, J Ivan, S Washington, I van Schalkwyk and D Lord (2009) *Differences in the performance of safety performance functions estimated for total crash count and for crash count by crash type*. Transportation Research Board-http://trb.metapress.com/content/57844402x4770466/?genre=article&id=doi%3a10.3141%2f2102-15

Kennedy, J and B Sexton (2010) Literature review of road safety at traffic signals and signalised crossings *Transport Research Laboratory published project report (PPR436).*

Kulmala, R (1990) Driver behaviour at urban junctions with the right-hand rule. In *Proceedings of the third ICTCT workshop*, Cracow, Poland.

Lovell, J and E Hauer (1986) The safety effect of conversion to all-way stop control. *Transportation research record 1068*.

McGee, HW and MR Blankership (1989) Guidelines for converting stop to yield control at intersections. *NCHRP report 320*. Wahington DC: Transportation Research Board.

Ministry of Transport (MoT) (2015) *Government policy statement on land transport (GPS) 2015/16 – 2025/26*. Wellington: MoT.

Mishra, S and R Tay (2010) Expected effects of in-service road safety reviews. *The Open Transportation Journal 4*: 33–35.

NZ Transport Agency (2004) *A New Zealand guide to the treatment of crash locations.* Accessed 4 June 2016. www.nzta.govt.nz/resources/guide-to-treatment-of-crash-location/

NZ Transport Agency (2006) *Stops and goes of traffic signals*. Accessed 8 June 2016. www.nzta.govt.nz/resources/stop-and-goes-of-traffic-signals

NZ Transport Agency (2009) *Pedestrian planning and design guide*. Accessed 4 June 2016. www.nzta.govt.nz/resources/pedestrian-planning-guide/

NZ Transport Agency (2013a) *Economic evaluation manual*. Accessed 4 June 2016. www.nzta.govt.nz/resources/economic-evaluation-manual

NZ Transport Agency (2013b) *Road safety audit procedures for projects. Guidelines*. Wellington: NZ Transport Agency.

NZ Transport Agency (2013c) *High-risk intersections guide.* Accessed 4 June 2016. www.nzta.govt.nz/resources/high-risk-intersections-guide/

NZ Transport Agency (2015a) *Statement of intent 2015–19.* Accessed 4 June 2016. www.nzta.govt.nz/resources/nz-transport-agency-statement-of-intent-soi-201519/

NZ Transport Agency (2015b) *State highway traffic data booklet 2010–2014*. Accessed 8 June 2016. www.nzta.govt.nz/resources/state-highway-traffic-volumes/

Peltola, H (nd) *Evaluating road safety and safety effects using empirical Bayesian method*. Technical Research Centre of Finland.

Peltola, H and R Kulmala (nd) *Accident models*. Accessed 8 June 2016. Nvfnorden.org/lisalib/getfile.aspx?itemid=1348

Preusser, D, W Leaf, KB DeBartolo and MM Levy (1982) The effect of right-turn-on-red on pedestrian and bicyclist accidents. *The Journal of Safety Research 13*, no.2: 45–55.

Sabra, ZA, D Gettman, RD Henry and V Nallamothu (2010) Balancing safety and capacity in an adaptive signal control system – phase 1. *Report no. FHWA-HRT-10-038*. Accessed 8 June 2016. www.fhwa.dot.gov/publications/research/safety/10038/index.cfm

Sharma, A (2008) *Integrated behavioural and economic framework for improving dilemma zone protection systems.* PhD thesis. Accessed 3 June 2016. www.researchgate.net/publication/27239414_Integrated_behavioral_and_economic_framework_for_improving_dilemma_zone_protection_systems

Sobhani, A (2013) *Developing a modelling framework to assess safety performance of intersections*, http://arrow.monash.edu.au/vital/access/manager/Repository/monash:120120

Svensson, AA (1998) A method for analysing the traffic process in a safety perspective*. Bulletin 166. Department of Traffic Planning and Engineering, Lund Institute of Technology, Lund University*. Accessed 8 June 2016. www.ictct.org/ictct-library/tct-library/

The Treasury (2015) Better business cases. Accessed 4 June 2016. www.treasury.govt.nz/statesector/investmentmanagement/plan/bbc

Transportation Research Board (TRB) (2010) *Highway capacity manual*. Washington: TRB.

Turner, S and M Brown (2013) Pushing the boundaries of road safety risk analysis. *Paper presented at IPENZ Transportation Group Conference*, Dunedin, March 2013.

Turner, S, F Tate and G Koorey (2010) *A SIDRA for road safety*. Accessed 4 June 2016. www.ipenz.org.nz/ipenztg/papers/2007/A3b_TurnerTateKoorey.pdf

Turner, S, R Singh, T Allatt and G Nates (2011) Effectiveness and selection of treatments for cyclists at signalised intersections. *Austroads publication no. AP–R380/11.*

Turner, S, R Singh and GD Nates (2012) Crash prediction models for signalised intersections: signal phasing and geometry. *NZ Transport Agency research report 483*.

Veneziano, DA (2006) Assessing tradeoffs between safety and operations: an analytical framework. *Retrospective theses and dissertations. Paper 3028*. Accessed 8 June 2016. lib.dr.iastate.edu/cgi/viewcontent.cgi?article=4027&context=rtd

VicRoads (2015) *Benefit management framework, version 2*. Kew, Australia: VicRoads.

Wood, AG, LI Mountain, RD Connors, MJ Maher and K Ropkins (2013) *Updating outdated predictive accident models.* Accessed 4 June 2016. www.sciencedirect.com/science/article/pii/S0001457513000699

Ye, X, RM Pendyala, S Washington and J Oh (2009) A simultaneous equations model of crash frequency by collision type for rural intersections. *Safety Science 47*, no.3: 443–452.

Zador, P, J Moshman and L Marcus (1982) Adoption of right turn on red: Effects on crashes at signalized intersections. *Accident Analysis & Prevention 14*, no.3: 219–234.

Appendix A: One Network Road Classification levels of service

Classification	Reliability	Safety	Accessibility
National (high volume)	The majority of road users experience consistent travel times with some exceptions in major urban centres.	Mostly forgiving roads and roadsides, equivalent to KiwiRAP 4-star standard. User hazards absent or mitigated including head on risk. Active road users generally do not have access - if present, they are provided with separate space or are physically separated. Form of road provides road user guidance.	Land use access for road users rare and highly engineered, usually only to highway service centres. Strategic network connectivity for road users due to infrequent connections, generally only to national high volume roads. High volume traffic will be unimpeded by other traffic at junctions. [Mainly express bus services]. Active road users generally do not have access – if present, they are provided with network access and journey continuity by a separate space or are physically separated. Provision of quality information relevant to national road user needs.
National	The majority of road users experience consistent travel times with some exceptions in urban heavy peak, holiday or during major events.	A high KiwiRAP 3 or 4-star standard, or equivalent, with consistent and predictable alignment. User hazards mostly mitigated. Active road users (if present) are mostly provided with separate space or are physically separated. Some lower standards and/or winding sections may require lower speeds and extra care. High level of road user safety guidance provided.	Land use access for road users infrequent and highly restricted in rural areas, and often restricted in urban areas. Mainly strategic network connectivity for road users due to infrequent connections, generally only to other equal and higher category roads. [Mainly express bus services.] Network access and journey continuity for active road users (if present) mostly provided by separate space or physical separation. Easy navigation at intersections, with national road traffic given priority, unless joining with equal or higher category roads. Provision of quality information relevant to national road user needs.
Regional	The majority of road users experience consistent travel times with some exceptions in urban heavy peak, holidays, during major events or during severe weather events.	Mostly KiwiRAP 3-star equivalent or better. Active road users are mostly provided with additional space in urban areas and in some rural areas. Some lower standards and/or winding sections may require lower speeds and extra care. High level of road user safety guidance provided.	Landuse access for road users in rural areas often restricted, and some restrictions in urban areas. Limited road user connections to other National roads and Arterials, with priority over lower category road users. [Numerous bus stops with high frequency services to key destinations and interchanges.] Network access and journey continuity for active road users are mostly provided with additional space in urban areas and in some rural areas. [Parking for all modes, and facilities for mobility impaired at activity centres with some shared spaces.] Extra care required around activity centres due to mixed use, including goods vehicles. Provision of quality information relevant to regional road user needs.
Arterial	Generally road users experience consistent travel times with some exceptions in urban heavy peak, holidays, during major events or	Variable road standards, lower speeds and extra care required on some roads/sections particularly depending on topography, access, density and use. Road user safety guidance	Some land use access restrictions for road users, both urban and rural. Road user connection at junctions with national, arterial or collector roads, and some restrictions may apply in urban areas to promote arterials. Traffic on higher classified roads generally has priority over lower order

Classification	Reliability	Safety	Accessibility
	during moderate weather events.	provided at high risk locations. Some separation of road space for active road users in urban areas	roads. [Numerous bus stops with high frequency services to key destinations and interchanges.] Some separation of road space for active road users in urban areas to provide network access and journey continuity. [Parking for all modes and facilities for mobility impaired at activity centres, and some shared spaces.] Extra care required around activity centres due to mixed use, including goods vehicles. Provision of quality information relevant to arterial road user needs.
Primary collector	Generally road users experience consistent travel times except where affected by other road users (all modes) or weather conditions	Variable road standards and alignment. Lower speeds and greater driver vigilance required on some roads/sections particularly depending on topography, access, density and use. Active road users should expect mixed use environments with some variability in the road environment, including vehicle speed. Road user safety guidance provided at high risk locations.	Landuse access for road users generally permitted but some restrictions may apply. Road user connection at junctions with arterial or collector roads and some restrictions may apply in urban areas to promote arterials. Traffic on higher classification roads generally has priority over lower classification roads. [Regular bus services to key destinations and interchanges.] Active road users should expect mixed use environments with some variability in the road environment, including vehicle speed. [Parking for all modes and facilities for mobility impaired at activity centres.] Provision of quality information relevant to collector road user needs.
Secondary collector	Road users travel times may vary as a result of other road users (all modes), weather conditions or the physical condition of the road.		Landuse access for road users generally permitted but some restrictions may apply. Road user connection at junctions with other collector or access roads. Collector road traffic generally has priority over access road traffic. [Regular bus services to key destinations and interchanges.] Active road users should expect mixed use environments with some variability in the road environment, including vehicle speed. [Parking for all modes and facilities for mobility impaired at activity centres.] Provision of quality information relevant to collector road user needs.
Access	Road users experience varied travel times as a result of other road users (all modes), weather conditions or the physical condition of the road.	Variable road standards and alignment. Lower speeds and greater driver vigilance required on some roads/sections particularly depending on topography, access, density and use. Road users should expect mixed use environments with some variability in the road environment, including vehicle speed. Road user safety guidance may be provided at high risk locations.	Access to all adjacent properties for road users. Road user connection at junctions ideally with collector and other access roads. Access road traffic generally has lower priority over traffic on all higher classification roads. Active road users should expect mixed use environments with some variability in the road environment, including vehicle speed. Enhanced accessibility via ‘share the road’ philosophy (active road users, mobility impaired and drivers), journey connectivity to key destinations via all modes, and provision of quality information.

Appendix B: Auckland Transport – user experience table for network operating plan

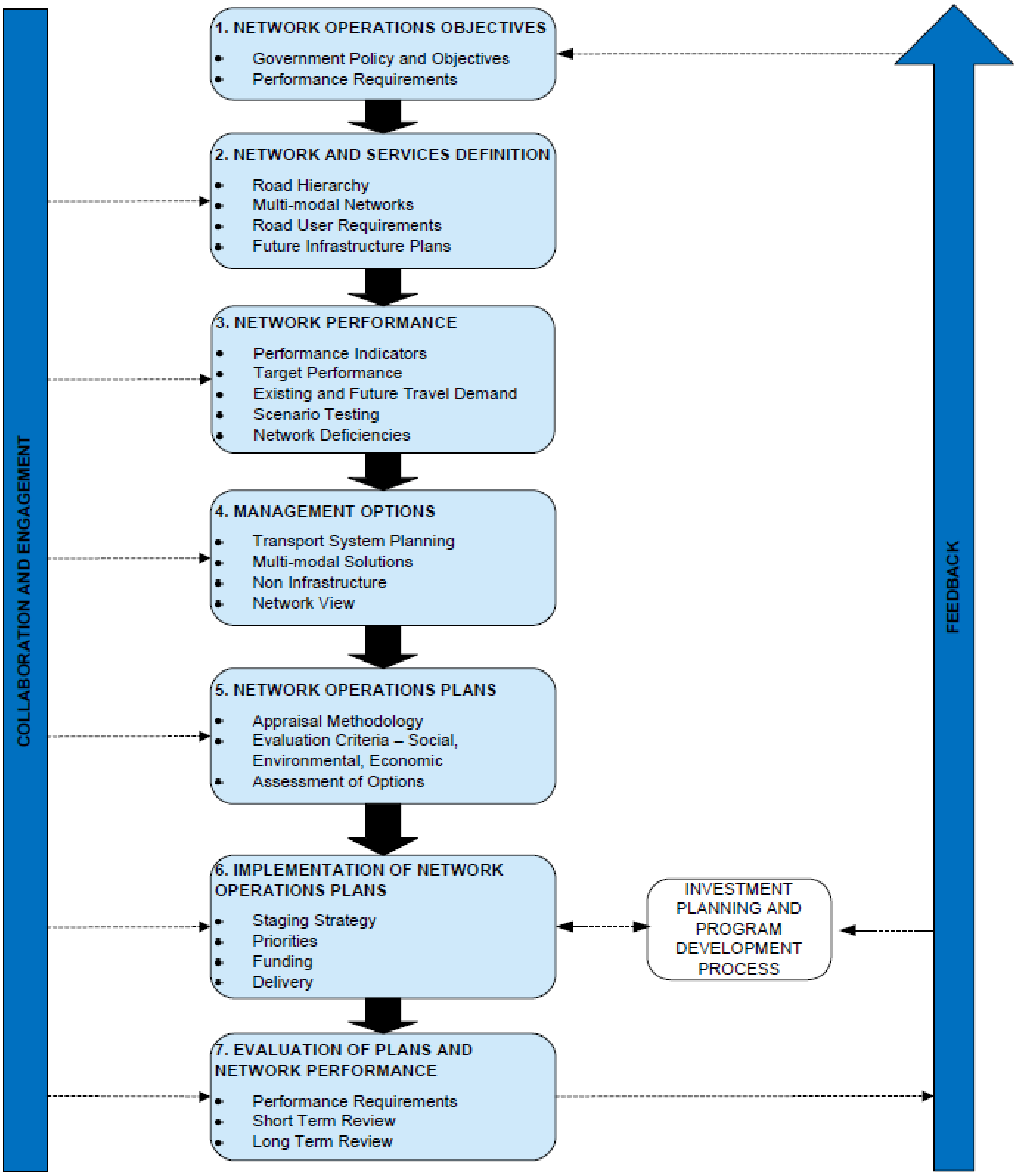
Level of service	Pedestrians			Cyclists	Public transport	Freight or general traffic
	Crossing opportunities (accessibility)	Delay	Longitudinal amenity	Facilities and separation	Travel speeds or delays	Travel speeds or delays
A	Crossing opportunity is within 25m or a shared space	Average crossing delay is less than 15s	High-quality pedestrian facilities with appropriate separation Friendly speed environment Free flowing for pedestrians No street obstacles	Separate cycle path or well separated from all modes Provision for the full range of abilities Minimal conflict with other traffic at intersections	Average travel speed greater than 90% of posted speed limit OR No delay	Average travel speed greater than 90% of posted speed limit OR No delay
B	Crossing opportunity is within 50m	Average crossing delay is between 15s and 30s	Pedestrian facilities provided with appropriate separation Some street obstacles with minor conflicts for pedestrians	Copenhagen cycle lane, some conflict with other traffic at intersections, but no multi-lane roundabouts OR Cycle lane on arterial road Operating speed less than 40km/h OR Cycle facility on a local road with minimal traffic OR Shared off-road path with low pedestrian volumes	Average travel speed greater than 70% of posted speed limit OR Minimal delay	Average travel speed greater than 70% of posted speed limit OR Minimal delay

Level of service	Pedestrians			Cyclists	Public transport	Freight or general traffic
	Crossing opportunities (accessibility)	**Delay**	**Longitudinal amenity**	**Facilities and separation**	**Travel speeds or delays**	**Travel speeds or delays**
C	Crossing opportunity is within 100m	Average crossing delay is between 30s and 45s	Pedestrian facilities provided with appropriate separation Pedestrian speeds restricted	On road cycle lane. Some conflict with turning traffic at intersections Vehicle operating speeds less than 60km/h OR Cycles share space on a local road with light traffic	Average travel speed greater than 50% of posted speed limit OR Some midblock delay Stop at most intersection and clear next cycle No side friction	Average travel speed greater than 50% of posted speed limit OR Some midblock delay Stop at most intersection and clear next cycle No side friction
D	Crossing opportunity is within 200m	Average crossing delay is between 45s and 60s	Narrow sealed footpath Restricted movement for most pedestrians	On road cycle lane, may include bus/transit lanes Conflict with turning traffic at intersections Vehicle operating speeds greater than 60km/h	Average travel speed greater than 35% of posted speed limit OR Some midblock delay Stop at most intersection and clear next cycle Noticeable side friction	Average travel speed greater than 35% of posted speed limit OR Some midblock delay Stop at most intersection and clear next cycle Noticeable side friction
E	Crossing opportunity is within 400m	Average crossing delay is between 60s and 80s	Formed footpath Significantly restricted footpath by street obstacles Restricted movement for pedestrians	Cycles share with other vehicles Lane width greater than 4.2m	Average travel speed greater than 20% of posted speed limit OR Large midblock delay Stop at each intersection and take ≥ 2 cycles to go through Significant side friction	Average travel speed greater than 20% of posted speed limit OR Large midblock delay Stop at each intersection and take ≥ 2 cycles to go through Significant side friction

Level of service	Pedestrians			Cyclists	Public transport	Freight or general traffic
	Crossing opportunities (accessibility)	**Delay**	**Longitudinal amenity**	**Facilities and separation**	**Travel speeds or delays**	**Travel speeds or delays**
F	Crossing opportunity is greater than 400m	Average crossing delay is greater than 80s	No discernible footpaths OR Shuffling movement for pedestrians	Cycles share with other vehicles Lane width less than 4.2m OR Cycles share with other vehicles Lane width less than 4.2m	Average travel speed less than 20% of posted speed limit OR Significant midblock delay Significant delay at intersection	Average travel speed less than 20% of posted speed limit OR Significant midblock delay Significant delay at intersection
Notes	* Use spacing of crossings as criterion only where there are shops both sides or other pedestrian desire lines * Spacing refers to the closest walking distance required for pedestrians to safely cross the road. Safe crossing areas can be signalised intersections or crossings, formalised unsignalised crossings (eg pedestrian refuges), zebra crossings, and school crossing areas when a school crossing		* Obstacles include street furniture (bus stop, street light/rubbish bin etc) and other obstacles from the shops * Footpath should be >1.8m wide to be considered adequate quality. Within activity areas and on shared paths, the width should be >3.0m * A lower LoS should be considered for the following aspects: - Poor quality of the surface (ie if the surface uneven or in disrepair?) - Poor environment in relation to CPTED factors	* A lower LoS should be considered, if the following are not considered appropriate - Route continuity (pinch points, driveway crossings) - High traffic volumes - Conflict with pedestrians - Surface quality - CPTED factors - Safety	* Delay can be used when no travel speed information OR to supplement assessment of travel speed * Side friction: parking, bus stops, side road, lack of enforcement * Midblock delay: pedestrian crossings * A lower LoS should be considered if the reliability is poor	* Delay can be used: - When no travel speed information; OR - To supplement assessment of travel speed * Side friction: parking, bus stops, side road, lack of enforcement * Midblock delay: pedestrian crossings * A lower LoS should be considered if the reliability is poor

Level of service	Pedestrians			Cyclists	Public transport	Freight or general traffic
	Crossing opportunities (accessibility)	**Delay**	**Longitudinal amenity**	**Facilities and separation**	**Travel speeds or delays**	**Travel speeds or delays**
	supervisor is present * Consideration must also be given to the quality of the crossing, ie is it visible and legible to approaching drivers. A lower LoS should be considered for poor quality facilities		- Poor actual safety record or perceived safety risks			

Appendix C: Network operating plan process



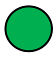
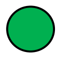
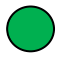
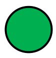
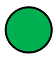
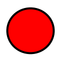
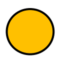
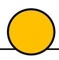
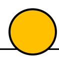
Appendix D: Intersection treatment selection

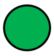
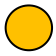
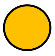
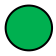
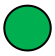
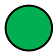
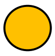
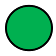
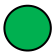
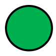
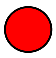
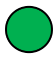
The HRIG outlines suitable countermeasures to address safety issues at various types of intersections. Austroads provides guidance on intersection treatment selection from the perspective of operational performance. Based on the information researched, the table below is an overview of the known trade-offs between operational efficiency and safety for various treatments. As the research often concluded varying degrees of success were anticipated for each treatment type, the table below is a guideline which demonstrates trends observed by the researcher. It is not anticipated that percentage improvements from the research will be used in the framework for assessing relative difference between treatment options. This is because there is a significant number of variables informing both the safety and efficiency of a given intersection. Such considerations include approach gradient, lane width of approaches, angle of approaches, sight distance, adjacent land use/presence of accessways and a host of others.

Table D.1 does however, indicate an anticipated positive, neutral (or inconclusive, or variable), or negative impact on safety and efficiency. This is denoted by an indictor colour of green, amber or red respectively.

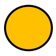
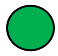
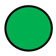
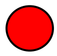
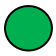
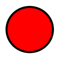
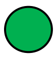
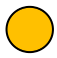
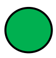
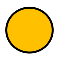
It is anticipated that as the framework is further developed, additional treatment options will be documented into table D.1.

Table D1 Observed Impact of countermeasures on Safety and Efficiency

Countermeasure	Safety	Impact	Operational efficiency	Impact
Grade separated intersection				
Convert any intersection form into a grade separated intersection	Significant safety benefits anticipated due to elimination of conflicting through vehicle movements.		Significant efficiency improvements for through movements. Notable improvement in efficiency for turning movements due to isolation of through vehicle movements in space.	 
Intersection control				
Convert sign controlled intersection to roundabout	Shows significant safety benefits of roundabouts over standard intersections. More pronounced with non-signalised intersections, 4 legged, rather than 3. Roundabouts with smaller central islands are safer (Elvik 1981).		Change in priority, therefore potential reduction in performance for the major road.	
Convert crossroads to staggered T-intersection	Usually applied to rural crossroads where there is a history of overrun crashes and sufficient land is available to accommodate this option.		Potential improvement in efficiency in through movement replaced by staggered T. Analysis shows that a right-left staggered treatment would not have a satisfactory design life in terms of intersection capacity (and hence safety), and there is room to provide for right turn bays between the staggered side roads (HRIG).	 
Convert Y intersection	Aligns drivers closer to a right-		Negligible	

Countermeasure	Safety	Impact	Operational efficiency	Impact
to T-intersection	angle when entering the major road. Legibility of the intersection is dependent on the guidance on approach (for example, refer to SH6 Y-junction and SH1/5 Y/T junction – the appearance on the approach is a straight road, rather than approaching an intersection)			
Convert sign controlled to traffic signals	Anticipated safety improvement through time-separation of conflicts. Signalised intersections maintains the safety level of service, or improves it, compared to uncontrolled 4-arm intersections (article 58) (Golias 1995)		Typically reduced efficiency for major road, but better efficiency for side road.	
Convert roundabout to traffic signals	Time separation of conflict, but higher impact speeds. (However, the DSI index in New Zealand suggests that signals and roundabouts are similar (HRIG)		Signalised intersections tend to attract efficiency benefits. Also, injury crash rates are similar between roundabouts/signalised intersections, except in high speed environments (Golias 1995)	
Fully signalised, partially signalised or metered roundabout.	Full signalisation is safer than partial signalisation (Turner and Brown 2013) due to legibility of layout and speed management.		Typically more efficient than a standard roundabout by managing the dominant flow in a manner that does not provide it greater priority over a higher functional road category.	
Alternative designs (displaced turns)	Better traffic safety performance; however not proven for public transport, pedestrians and cyclists		Better operational efficiencies by separating conflicts out to effectively multiple two-phase intersections.	
Sign controlled intersection improvement				
Minor road channelisation	Conflict separation and improved conspicuity of intersection control.		Can improve pedestrian delay based level of service by separating the crossing into two movements.	
Turning bays	Uncontrolled right turn bays can result in increased crossing crashes at crossroads, as it is more difficult to anticipate oncoming traffic due to the widened intersection, and poorly aligned right turn bays can block visibility of opposing through traffic. When introduced on rural curves, this can result in poor geometry		Improved operational efficiency by separating out turning traffic from through traffic.	

Countermeasure	Safety	Impact	Operational efficiency	Impact
	for the through traffic lane, so length of tapers needs to be carefully considered. Left turn bays can result in left-turning traffic masking faster moving through traffic to traffic emerging from the side road. This happens on typical straight main road approaches and is greater on approaches where the side road is on the inside of a curve) Where this is likely to be an issue the left turn bays must be aligned to prevent it, eg offset further left, or the left turn lanes not provided.			
Install right turning bays	Signalised right turn bays reduce the instances of accidents due to the elimination of uncontrolled opposed turning movements.	🟢	Improved overall efficiency by separating turning movements from other traffic. Depending on the geometry and/or phasing, loss of operational efficiency for right turning vehicles.	🟡
Separate shared left-through movements	Improved safety for cyclists by removing the conflict between left turning traffic and through cycle movements. Turner identified that crashes increase with slip lanes.		Improved efficiency by separating turning movements from other traffic	
Pedestrian facilities at intersections	Improved safety when provided on the desire lines. Particular consideration for the treatment of left turns when considering the use of slip lanes. Potential treatment selection based on the combination of traffic volumes and pedestrian volumes and insufficient crash data to conclude whether slip lanes are safer for pedestrians (Jaglal and Wilson 2013).	🟢	Improved pedestrian efficiency if provided on all arms of the intersection. Operational efficiency for other users is dependent on traffic signal phasing and level of pedestrian protection – opportunity to investigate non-standard phasing to achieve the best of both pedestrian protection and operational efficiency. For pedestrians at signalised intersections during long cycle times - lower pedestrian safety (mainly due to non-compliance) (Kennedy and Sexton 2010)	🟡
Cyclist facilities at intersections	Safety impacts of providing cycle facilities, in combination with a number of other features, such as width of approach kerbside lane, at traffic signals. Article indicated that the provision of cycle lanes reduce	🟢	Operational efficiencies for cyclists and potentially for all other users where cyclists and other motorists are not competing for the same space (ie with the separating of turning traffic and cyclists with slip lanes	🟢

Countermeasure	Safety	Impact	Operational efficiency	Impact
	crashes by around 10% and the installation of an advanced limit line at intersections for cyclists (storage facility) reduces crashes by around 27%. (Turner et al 2011)		or left turn bays)	
		Traffic signal phasing improvements		
Dilemma zone treatments (advance warning, yellow-time and red-time)	Engineering countermeasures were introduced at 10 intersections in Texas. The findings from these studies indicate the frequency of red-light running decreases in a predictable way with decreasing approach flow rate, longer clearance path lengths, longer headways, and longer yellow interval durations. The crash data analysed indicates right-angle crashes increase exponentially with an increasing frequency of red-light-running (Bonnesen et al 2002)		Green extension provides improved capacity of operational efficiency for the movements. Trade-off is the delay imposed on other movements, particularly under long cycle times. Inverse relationship between safety and efficiency (specifically for cyclists/peds) of intersections by providing additional warning information at end of green/start of red and vise versa (FWHA 2010).	
Protected right-turn phasing	Full protection removes conflicts and has been proven to be safer (NZ Transport Agency 2006).		Trade-off in operational efficiency by reducing the capacity of the right-turn movements, when intersection is not operating at its set maximum cycle time (ATMU 2010)	
Pedestrian protection	Removes conflicts between traffic movements and pedestrian movements.		Reduced capacity of lane/s available for turning movements. Greater impact for shared left-through movements. HCM contains equations for estimating impact, and transport models allow for specifying 'late start'	
		Roundabout controlled intersection improvement		
Geometry improvements	Speed management – modifications to address entry speed, circulating speed and sight distances. Addresses loss of control, crossing type accidents (HRIG)		Inverse relationship between safety and efficiency of roundabouts for entry speed design (Campbell et al 2005)	
Pedestrian facilities	Roundabouts safer for pedestrians - slower speeds, refuge islands create shorter crossing distances (FHWA 2014b)		Efficiency depends on the type of facility and priority afforded by the treatment. Provision of zebra crossing or signalised crossing (potentially in conjunction with speed management devices) changes the priority and efficiency for other traffic.	

Countermeasure	Safety	Impact	Operational efficiency	Impact
			Suitability dependent on the type of environment, conflict speed and intervisibility.	
Cycle facilities	Provision of cycle facilities at roundabout Institute for Road Safety Research (Netherlands) (2012) suggests to promote safety, cyclists should not have priority on roundabouts.		Negligible impact on efficiency for motorised vehicles. Efficiency for cyclists depends on the type of facility and priority afforded by the treatment.	

Appendix E: Example of performance specification for the Southern Corridor improvements

NZ TRANSPORT AGENCY
WAKA KOTAHI

MEMO

To	Jim Sephton
Cc	Graham O'Connell
From	Tim Brown
Date	3 July 2014
Subject	Southern Corridor Improvements – Journey Management **(Draft for Discussion)**

1 Purpose

The purpose of this memo is to outline the considerations for building Journey Management into the Southern Corridor Improvements both post-construction and during construction. The Scheme Design under development and the expectation for this memo is that it informs the development of the Principal's Requirement for the Scheme Assessment Report, Specimen Design and Construction Contract.

2 Context

2.1 Current Challenges

- There is severe congestion from Papakura through to Takanini (morning peak period), and SH20-1 to Walter Strevens Drive (evening peak period).
- There is very little resilience in the transport network in South Auckland with the major transport corridors (SH1, Great South Road and the North Island Main Truck Railway Line) converging at the Takanini Interchange and at the SH22 Interchange.
- Day-to-day congestion and the impacts of incidents on the motorway rarely have impacts that can be contained within the motorway because of the combination of:
  - The lack of resilience;
  - The demands for travel; and,
  - The recent capacity improvements exacerbating the previous problems (e.g. Papakura Interchange northbound improvements and SH20-1 connection).
- The current location of the Spartan Road intersection is less than ideal in terms of interchange operation. The major issue is the ability to safely manage conflicts when traffic turns across queued movements. Our preference would be to provide a much stronger east-west connection on one of the alternative routes either at Manuroa Road or Taka Street.

2.2 Future Challenges and Opportunities

- Upon completion of the Waterview Connection, increased use of Western Ring Route as an alternative commuter route between South Auckland and the Central City and North Shore is likely to bring people to the SH20-1 interchange much faster, especially if bottlenecks on SH20 south (Maioro Street through to Manukau Harbour Crossing) are alleviated.

- The Southern Area has been identified as a major growth area for Auckland. It is anticipated that there will be significant growth in the Papakura area east of the North Island Main Trunk Line through to the Mill Road corridor (currently being planned), along the SH22 corridor with the proposed Special Housing Accord areas, and west of the Papakura Interchange.
- In the foreseeable future, these are expected to place much greater strain on the transport system with this more likely to be taken by the motorway system prior to future investment in the local transport and public transport options.

3 Desired Journey Management Outcomes from the Southern Corridor Improvements

3.1 Goals

From a Journey Management perspective the desired outcomes from the Southern Corridor Improvements will provide NZTA and Auckland Transport (including the AMA and JTOC):

- The ability to be able to manage the effects of incidents, congestion and planned events.
- The ability to inform our customers by providing traveller information en-route therefore allowing them to make smarter choices.
- The ability to monitor conditions visually and through data collection.
- The ability to optimise the performance of the corridor and supporting networks.

3.2 Managing Motorway Performance

- The current proposals will make substantial improvements to the performance of the motorway corridor; however, they are unlikely to provide sufficient peak period capacity to allow to fully release the bottlenecks that currently exist along the corridor – this aligns well to manage demand during the commuter periods where there are likely to be other choices available.
- Travelling southbound, an additional lane between Hill Road and Papakura, and a 4th lane between SH20 and Hill Road will provide substantial improvements to the peak period traffic conditions; however there are 5 lanes motorway lanes feeding this section (3 lanes from SH1 including the ramp from Redoubt Road, and 2 lanes from SH20. We consider that a likely outcome is that the bottlenecks will remain, the congested peak period will reduce, and conditions downstream of the bottlenecks should improve substantially.
- Travelling northbound, the provision of an additional lane from Papakura to Takanini provides additional capacity for Papakura/Pukekohe but this is possibly at the expense of Takanini and Hill Road, in the longer term, which are the motorway access points for the large growth areas in the Papakura area. The entry points at Hill Road, Takanini, Papakura and SH22 (Drury) will need to be managed to ensure that the bottlenecks at the on-ramps can operate efficiently.
- As a result, there will need to be a heavy emphasis on managing the performance of the corridor under conditions where the demands approach the available capacity (either through day-to-day demands, event conditions or incident conditions).
- It is also anticipated that NZTA will need to manage people's expectations about the levels of congestion that they are likely to experience, as the proposed improvements will still require active management to ensure that we keeping the motorway and supporting arterials operating at sustainable levels.

- It will be necessary to provide JTOC with the tools to manage the performance of the motorway corridor whilst continuing to allow the arterial network to function appropriately, and provide information to the travelling public through the available channels.

3.3 Managing Interchange Performance

The goals for operating the interchanges are provided below. As a general guide, we are not seeking to maximise the vehicle throughput within the interchange, but are seeking to provide sufficient capacity and queue storage to ensure that queued turning movements do not block motorway and arterial through movements.

1. Managing egress of the motorway by providing sufficient capacity at the intersections, and queue storage on the ramp to ensure that queues do not interfere with the operation of the motorway lanes. To reduce the risk of queuing back into the motorway the preferred design principles are as follows:

    - Provide sufficient capacity and queue storage to cater for an offramp operating at its full capacity - 1,800 to 2,000 vehicles per hour using the model data to indicate the movement proportion.

    - Ensure that 95th percentile queues for each movement are contained within their dedicated lanes.

2. Manage access on to the motorway through the provision of ramp signals irrespective of whether the on-ramps merge with the motorway or join as a lane gain. The ramp signal system is based on the operation of the corridor, and not just the individual ramps, hence the need to manage access from all ramps. To reduce the risk of queuing back into the arterial network the preferred design principles that differ from current NZTA Specifications are to:

    - Provide greater than the current NZTA Specification for 3 minutes queue storage on the ramps if available; and,.

    - Design the merge layouts based on the congestion at the end of the priority lane and motorway merge area to consider parallel lanes.

3. Managing cross motorway movements on the arterials by providing sufficient queue storage on the ramp and approaching roads to ensure that the 95th percentile queue from the ramp signals does not impede through traffic (or off-ramp traffic) on the local road network, as far as practicable.

4. Managing priority for high value traffic i.e. freight, public transport and high occupancy vehicles through the provision of priority lanes and the potential for arterial road public transport priority. Priority lanes should extend beyond the back of the 95th percentile queue from the ramp signals to provide unimpeded access for the vehicles eligible to use the lanes.

5. Providing safe and efficient movement for pedestrians and cyclists through the interchanges.

6. Providing traveller information at key decision points to enable motorists to make smart and informed decisions about route choice based on the traffic conditions at the time.

4 Infrastructure Needs

We have identified a range of infrastructure to improve the ability to manage the performance of the corridor. The recommendations should be read in conjunction with an understanding of the physical, budgetary and time constraints for delivering the project as part of the Auckland Accelerated Program.

4.1 Motorway Layout

The elements outlined in Table 1 and Table 2 account the potential desire to provide improvements that are likely to be considered within 10 - 15 years, based on providing sufficient corridor capacity to match the capacity on the roads approaching the project area. Within the desirable elements lies the potential to construct the works to facilitate a staged opening as and when required based on localised need, and the ability for the downstream impacts to be efficiently managed.

Particular consideration will need to be given to:

- Capacity of the southbound off-ramps
- Interchanges northbound along SH20 (Puhinui/Roscommon, SH20A and Neilson Street)
- SH20B
- Waterview Connection and interchange with SH16.

The effects on Mount Wellington Interchange are not considered to be as high a priority due to:

- The Western Ring Route providing an alternative route to travel north.
- The need to manage the flows entering the Mount Wellington - Newmarket Viaduct to find an appropriate balance between the motorway performance with the performance of the heavily used on-ramps

Table 1: Motorway Layouts: SH1 Southbound

Section	Description	Priority
SH1 SB (SH20 - Hill Road)	3rd lane	**Essential**
SH1 SB (SH20 - Hill Road)	4th lane with trapped exit lane	**Essential**
SH1 SB (Hill Road - Takanini)	3rd lane	**Essential**
SH1 SB (Takanini on-ramp)	Retention of Parallel entry lane	**Essential**
SH1 SB (Takanini - Papakura)	3rd lane with trapped exit lane	**Essential**
SH1 SB (SH20 - Hill Road)	Service Lane/Link Road Concept	Desirable
SH1 SB (SH20 - Hill Road)	Provision for 5th lane	Desirable
SH1 SB (Hill Road - Takanini)	Provision for 4th lane	Desirable
SH1 SB (Papakura - Drury)	Provision for 3rd lane	In response to growth of SHA's
SH1 SB (Takanini - Papakura)	Provision for 4th lane	In response to growth of SHA's

Table 2: Motorway Layouts: SH1 Northbound

Section	Description	Priority
SH1 NB (Papakura - Takanini)	3rd lane	**Essential**
SH1 NB (Takanini – Hill Road)	3rd lane	**Essential**
SH1 NB (Hill Road – SH20)	4th lane (auxiliary lane to SH20) – construct and open as required.	Desirable
SH1 NB (Drury - Papakura)	Provision for 3rd lane	In response to growth of SHA's

4.2 Interchange Layouts

The elements outlined in Table 3 and Table 4 account the potential desire to provide improvements beyond the current scope works that are likely to be considered within 10 – 15 years, based on the principles outlined in Section 3.3.

Table 3: Interchange Layouts: Hill Road

Section	Problem/Description	Priority
Hill Road: SB Offramp – Queue Storage	A key issue is traffic queuing back onto SH1 in the evening peak. Extend two lanes as far as possible to separate queued traffic movements	**Essential**
Hill Road: SB Offramp – Intersection capacity	Queuing to the motorway caused by insufficient capacity heading away from the motorway Intersection improvements (free-flow slip lane with pedestrian control – small improvements)	**Essential**
Hill Road/Grand Vue Drive	Intersection Improvements	Optional
Hill Road	Bridge duplication to facilitate upgrade of Hill Road and to separate ramp signal movements from cross-motorway traffic. This will also reduce the risk of southbound offramp queuing in the evening peak period.	Optional

Table 4: Interchange Layouts: Takanini

Section	Description	Priority
Takanini NB On-Ramp	Truck Priority lane	**Essential**
Takanini SB Off-ramp	Extend queue storage as far as possible within the ramp and ensure that queuing for one movement does not interfere with the other movement.	**Essential**
Great South Road – Queue Storage (for NB on-ramp and SB on-ramp)	Right turn queue storage for the on-ramps under ramp signal control does not encroach on through lanes on Great South Road.	**Essential**
Great South Road – General Traffic Lanes	Number of lanes heading away from the motorway off-ramps in each direction on GSR must match the number of turn lanes from the off-ramps for each movement.	**Essential**
Great South Road/Spartan Road - access	Signalise when level crossing is closed.	**Essential - Prior agreement with external parties**
Great South Road – Bus Priority	Bus Priority – current design allows for bus queue jump lanes to be provided at the expense of an approach lane.	Optional
Great South Road – Bus Lane	Conversion of General Traffic Lane to Special Vehicle Lane through the interchange – impact to off-ramp capacity and queuing affecting motorway safety and operation.	Not Desirable

Table 5: Interchange Layouts: Papakura Interchange

Section	Description	Priority
Papakura NB On-Ramp	Combine on-ramps to form lane gain to address illegal turning movements on to diamond on-ramp	Desirable

4.3 Managed Motorway Provisions

The Southern Corridor project is the perfect opportunity to provide for the future installation of equipment which will allow the traffic to be managed in order to minimise excess congestion, provide for queue protection and to manage planned and unplanned events. This section outlines the infrastructure required to undertake Journey Management functions along the corridor.

Managed Motorway Strategy

At this stage, we do not have a Managed Motorway Strategy to considered the manner in which we want to operate the corridor, and the infrastructure to support it beyond the provision of ramp signals and variable message signs. There is an urgent need to develop this, as this will support the infrastructure signals outlined in this memo.

Document	Description	Priority
SH1 Managed Motorway Strategy	Develop a strategy to manage the motorway corridor and supporting arterials to identify infrastructure needed to support that operation	**Essential**

Hard Shoulder Running

There is the potential for the Southern Corridor Improvements to provide a carriageway width sufficient width to allow for hard shoulder running between SH20 and Takanini in the future should it be required to manage the performance of the corridor. This could take the form of:

- A full auxiliary lane between the interchanges;
- An acceleration lane to replicate a parallel entry lane from an on-ramp; or,
- A deceleration lane to replicate a parallel exit lane to an off-ramp in order to separate queued traffic.

This would require full pavement construction within the shoulder area so that it is trafficable. The form of the hard shoulder running can be determined through the design development process, and is likely to be subject to the physical constraints along the corridor; however it would be advantageous in the longer term to future proof the carriageway width or to provide a design that does not preclude hard shoulder running.

Section	Description	Priority
SH1 SB (SH20 – Hill Road)	Provision for 5th lane • Deceleration lane (marked) • Deceleration lane (hard shoulder) • Full Auxiliary lane	Desirable
SH1 SB (Hill Road – Takanini)	Provision for 4th lane • Deceleration lane (marked) • Deceleration lane (hard shoulder) • Full Auxiliary lane (necessary if 5th lane to Hill Road provided)	Desirable
SH1 SB (Papakura – Drury)	Provision for 3rd lane (Deceleration lane, full auxiliary lane and/or provision for hard shoulder running)	In response to growth of SHA's
SH1 SB (Takanini - Papakura)	Provision for 4th lane (Deceleration lane, full auxiliary lane and/or provision for hard shoulder running)	In response to growth of SHA's

Contraflow

Contraflow provides the opportunity to increase the capacity in the peak direction of travel by using spare capacity in the opposite direction. There is the opportunity to consider this as part of a managed motorway strategy in the southbound direction from SH20. Contraflwo can be provided in a number of ways including fixed reversible lanes or dynamic management using tools such as the moveable lane barrier.

Section	Description	Priority
SH1 SB (SH20 - Papakura or Takanini)	Provision for Contraflow operation	Optional

Ramp Signals

Ramp signals will continue to be the primary tool to manage access on to the motorway and to manage the performance of key bottlenecks. The specific requirements in addition to the general specifications are outlined in the table below.

Table 6: Ramp Signal Infrastructure

Ramp	Description	Priority
All on-ramps	Provision/retention of ramp signals as per ITS Specifications except as outlined below.	**Essential**
Drury Northbound On-Ramp	**Provision** of ramp signals as per ITS Specifications except as outlined below.	**Essential**
Loop Detection	As per ITS Specification 05-01 with additional queue loops on arterial roads and motorway mainline loops to be determined in conjunction with JTOC.	**Essential**
Type A signage	Prior to the start of dedicated turning lanes to the on-ramps.	**Essential**
Type D (EJT) signage	Hill Road approaching Grand Vue Drive from both directions	**Essential**

Variable Message Signs - Motorway

The goal for the provision of Variable Message Signs along the motorway is to provide one sign between each interchange in order to provide traveller information in advance of the decision points to either continue on the motorway or to exit.

VMS's are currently located within the project area at:

- Northbound between Walter Strevens Drive and Papakura Inlet
- Northbound near Orams Road.
- Southbound near Alfriston Road.

Table 7: Recommended Variable Message Signs on the Motorway

Section	Description	Priority
SH1 Southbound Orams Road	Decision point to use Hill Road as an alternative route	**Essential**
SH1 Southbound at Papakura Inlet near Rushgreen Avenue.	Decision point to use Beach Road or Hingaia Road as an alternative route	**Essential**
SH1 northbound - approaching Papakura Interchange	Decision Point before Papakura to advise on conditions and/or incidents between Papakura and Takanini or SH20.	Desirable
SH1 northbound - approaching Drury Interchange (near the Weigh-in-Motion site)	Decision point (advisory point) for travel via Great South Road through Drury and Papakura to advise on incidents between Drury Interchange and SH20.	Desirable
SH20 southbound (eastbound) - approaching Puhinui Road interchange.	Decision point (advisory point) for travel via SH20 or Roscommon Road/Mahia Road to continue south on SH1 to advise on condtions and/or incidents from Puhinui Road through to Drury.	Desirable

Lane Control Signals/Variable Mandatory Speed Limit Signs

Lane control Signals (LCS) and/or Variable Mandatory Speed Limit Signs (VMSL) are currently provided in the Harbour Bridge/CMJ area and are being provided in the Waterview tunnel and in the area around the SH16/SH20 interchange.

The southern end of the WRR at the SH20/SH1 interchange does not have such control, despite being very busy and prone to congestion should a problem arise. Whilst the current deployment of lane control signals is limited, there is an opportunity to provide the equipment to fully support a managed motorway operation.

At present, there is not a clear corridor operating strategy that has fully considered the costs and benefits of managing the corridor; however given that this a highly deficient corridor in terms of resilience, there is an urgent need to investigate opportunities to better manage the corridor and maximise the benefit of the Southern Corridor Improvements.

Table 8: Recommended Managed Motorway Investment

Section	Equipment	Priority
Northbound and Southbound	Managed Motorway Strategy	**Essential but separate to the Project**
SH1 Southbound (SH20 - Takanini)	Gantry foundations at required spacing	Desirable
SH1 Southbound (Takanini - Drury)	Gantry foundations at required spacing	Optional
SH1 Northbound (Papakura - Takanini)	Gantry foundations at required spacing	Optional

Section	Equipment	Priority
SH1 Southbound (Takanini - Drury)	Gantry foundations at required spacing	Desirable
All	VSLS/LCS Gantries and Hardware	**Pending the outcome of a agreed Managed Motorway Strategy**

Traffic Signals

The traffic signal requirements are outlined in the table below.

Section	Equipment	Priority
Signalised intersections at the interchanges	Traffic signal software and phasing specification to be developed by JTOC	Essential
Offramps (Hill Road and Takanini SB)	Queue detection to prevent queuing from off-ramps extending into motorway	Essential - based on JTOC specification

CCTV Coverage

There is currently good CCTV coverage of the motorway and Great South Road; however there are gaps on Hill Road and Beach Road that will enable better real-time management of the traffic signals and ramp signals to optimise the network during incidents, planned events, and congestion

Table 9: Recommended CCTV Cameras

Location	Priority
Intersection of Hill Road and Southbound offramp	**Essential**
Intersection of Hingaia Road and Harbourside Drive	Desirable

Miscellaneous

Other infrastructure required to maintain our operational services are outlined in the table below

Table 10: Recommended Miscellaneous Equipment

Location	Priority
Emergency Telephones	**Essential**
Cross-over gates for contraflow operation (if required for incident, event and/or construction management)	**Essential**
Overheight Detection Systems to protect Orams Road, Alfriston Road and	Desirable

Location	Priority
Provision for on-Motorway Journey Time/Traffic Conditions Signs (Scope and Specifications are likely to be developed prior to completion of Southern Corridor Improvements.	Desirable

Communications

Communications equipment is essential for motorway management. Table 11 outlines the additional communications equipment and infrastructure in order to provide for future operational requirements.

Table 11: Recommended Communications Equipment

Description	Priority
Ducting in proposed TL-5 barrier.	**Essential**
Ducting to VMS, VSLS/LCS gantries, CCTV (if installed)	**Essential**
Provision for Optasense – installation/relocation of fibre through ducting in TL-5	**Essential**
Extension of fibre backbone from Drury to SH2	Optional

5 Managing the Effects of Construction Activities

5.1 General

- We have seen a reduction of approximately 10% capacity during construction of other projects as result of narrow lane widths, narrow shoulders and sight screens. This has translated to longer peak periods in the order of 30 minutes, and longer delays.
- Possibly the 3 most relevant cases are:
    - Esmonde Road to Onewa Road (refer to AMA's performance report)
    - Upper Harbour to Greville Road (refer to Kenny's report and AMA's report)
    - Causeway Project
- The construction of the South Corridor Improvements in the southbound direction has the potential to have far greater impacts simply because of the number of lanes feeding into that section.
- Notwithstanding that concern we have seen that by managing upstream conditions, and ensuring that downstream remains clear the impacts can be effectively managed. We have recently seen works on SH16 return the corridor journey times to their pre-construction levels through a combination of bus priority, provision of bottlenecks and clearing out the downstream on-ramps.
- We can also see that there are likely to be challenges in retaining the current capacity during construction of the Takanini Interchange given that the construction program needs to facilitate the widening of the bridges over Great South Road and the North Island Main Trunk Line. Our initial thoughts indicate that the northbound on-ramp will need to be built to facilitate the lateral shifts required to widen the mainline bridges in order to maintain the capacity of the mainline. However, we are happy to work with the Project Team to advise as required.

- The potential closure of bridge structures along the corridor will redirect traffic to other parts of the network that are already under pressure. In particular the potential closure of Orams Road and Hill Road are of particular concern.
- In terms of the overall staging our preference is the construction and completion of downstream capacity prior to completing the upstream sections of work.

5.2 Construction Traffic Management Needs

We anticipate that the following will aid in managing the traffic impacts during construction and inform the Project Team on temporary traffic management requirements when considering the constructability of the proposed design.

Table 12: Recommended Construction Traffic Management Needs

Item	Priority
Network Performance Benchmarking and Monitoring Regime, including: • Length of congested conditions on motorway and supporting arterial roads • Motorway and arterial road journey times (average and 95th percentile) • Public transport patronage and journey times (average and 95th percentile) • Heat maps • Ramp signal queue lengths • Merge capacities (or maximum recorded loop volumes)	**Essential**
Estimate of impacts under traffic management conditions (5 - 10% loss in capacity, and bridge closures) to inform Principal's Requirements, based on the above.	**Essential**
Principal's Requirements to specify benchmarks for network performance impacts to allow Tenderer's methodology to be developed incorporating this criteria	**Essential**
Tender Documents and evaluation criteria to allow NZTA to evaluate methodologies that reduce corridor capacity by calculating a premium based on the cost of delays.	Desirable
Carriageway Width allows for 2 lanes to pass a broken down vehicle, and/or breakdown bays	Desirable
Dedicated Vehicle Recovery Unit	Desirable
Mobile VMS	Desirable

5.3 Staged Opening

To release the capacity in a way that the corridor performance can be effectively managed, we recommend the following with a view to informing the Principal's Requirements:

- As a general philosophy, it is better to complete the downstream works prior to releasing upstream bottlenecks.

- However, in this case, the completion of the Waterview Connection may necessitate the completion of the 3rd lane through between Hill Road and Takanini to relieve some pressure on the SH20-1 Interchange.
- The completion of the 3rd lane between Hill Road and Takanini off-ramp is likely to result in a major bottleneck at Papakura on-ramp. Currently, capacity of the Takanini southbound on-ramp is governed by the amount of traffic leaving the motorway at Takanini.
- The completion of the 3rd lane will mean that all off-ramp traffic will be contained in the left lane allowing two full lanes of motorway traffic to continue through Takanini. The result is likely to be a significant bottleneck because the motorway lanes will not be able to accept any more traffic without exceeding their capacity.
- To alleviate this we recommend that the final layout (parallel entry lane at Papakura on-ramp) through to Papakura Inlet be constructed prior to completion of the 3rd lane between Hill Road and Takanini. This will allow merging to be completed over a much longer section therefore reducing the "shockwave" generated by merging.
- We also recommend that the construction staging for the interchange be undertaken in such a way that ensures that cross-motorway movements on Great South Road at Takanini are not impacted any more than they currently by queues from the ramp signals.
- In the northbound direction, we anticipate than the northbound on-ramp will be completed prior to completing the 3rd lane between Papakura and Takanini. This will provide two full motorway lanes plus a lane gain during this period, potentially resulting in a higher level of service for both the motorway and Takanini on-ramp traffic.
- The ramp signalling system will be operational to balance this potential improvement in level of service with the reduction in the level of service at the Hill Road on-ramp which is likely to become the bottleneck.
- Upon completion of the project, the Takanini on-ramp will be converted from a lane gain during construction to a merge. It is not clear as to whether this will result in a reduced level of service for this ramp, or whether the level of service will be balanced across all on-ramps between Drury and Hill Road.
- As a minimum, we would recommend that the current level of service for the Papakura, Takanini and Hill Road is maintained upon the completion of the project; however the direction for the Operational Strategy will need to be specified by NZTA and Auckland Transport to provide direction for JTOC to manage.

6 Network Integration

The Southern Corridor Improvements on SH1 are part of the wider suite of land use and transport initiatives to enable the growth envisaged in the Southern Area.

The Southern Area has been identified as a major growth area for Auckland as the Southern Transformation Initiative through Auckland Council's Unitary Plan. It is anticipated that there will be significant growth in the Papakura area east of the North Island Main Trunk Line through to the Mill Road corridor (currently being planned), along the SH22 corridor with the proposed Special Housing Accord areas, and west of the Drury Interchange (as outlined in Figure 1) .

There is also very little resilience in the transport network in South Auckland with the major transport corridors (SH1, Great South Road and the North Island Main Truck Railway Line) converging at the Takanini Interchange and at the SH22 Interchanges.

Upon completion of the Waterview Connection, increased use of Western Ring Route as an alternative commuter route between South Auckland and the Central City and North Shore is likely to bring people to the SH20-1 interchange much faster, especially if bottlenecks on SH20 south (Maioro Street through to Manukau Harbour Crossing) are alleviated.

As a result, it is anticipated that traffic demands for Hill Road and Takanini Interchanges which form the main gateways to this area, without consideration of a further transport response.

There is a major opportunity to provide a large scale grid network with eastern and western interceptors, a central spine, and stronger east-west connections to improve the resilience and balance the demands and functions for multi-modal travel through the area. This opportunity, if realised will provide much greater connectivity between activity centres and better connectivity for where people need to travel by which ever mode they choose.

To help realise the full benefits of the investment of the Southern Corridor Improvements, a workshop was held with Auckland Council, Auckland Transport to review and refine the Road User Hierarchy.

The output from this workshop is provided in Appendix A. Some key features are identified in Figure 2 include:

- The desire to promote Great South Road as a primary public transport route alongside the rail spine.
- The desire to promote Hill Road over Alfriston Road for access to the motorway.
- The need to strengthen the east-west connection to Takanini Interchange to offset the increase in train frequencies.

From this process, there is an opportunity to accelerate projects submitted by Auckland Transport in the Integrated Transport Program in order to fully realise the benefits of investing in the Southern Corridor Improvements. There is also an opportunity to improve the local road network in order to cater for increased demands to and from the motorway network with projects that have not been identified through the ITP process.

Figure 1: Growth Pressures

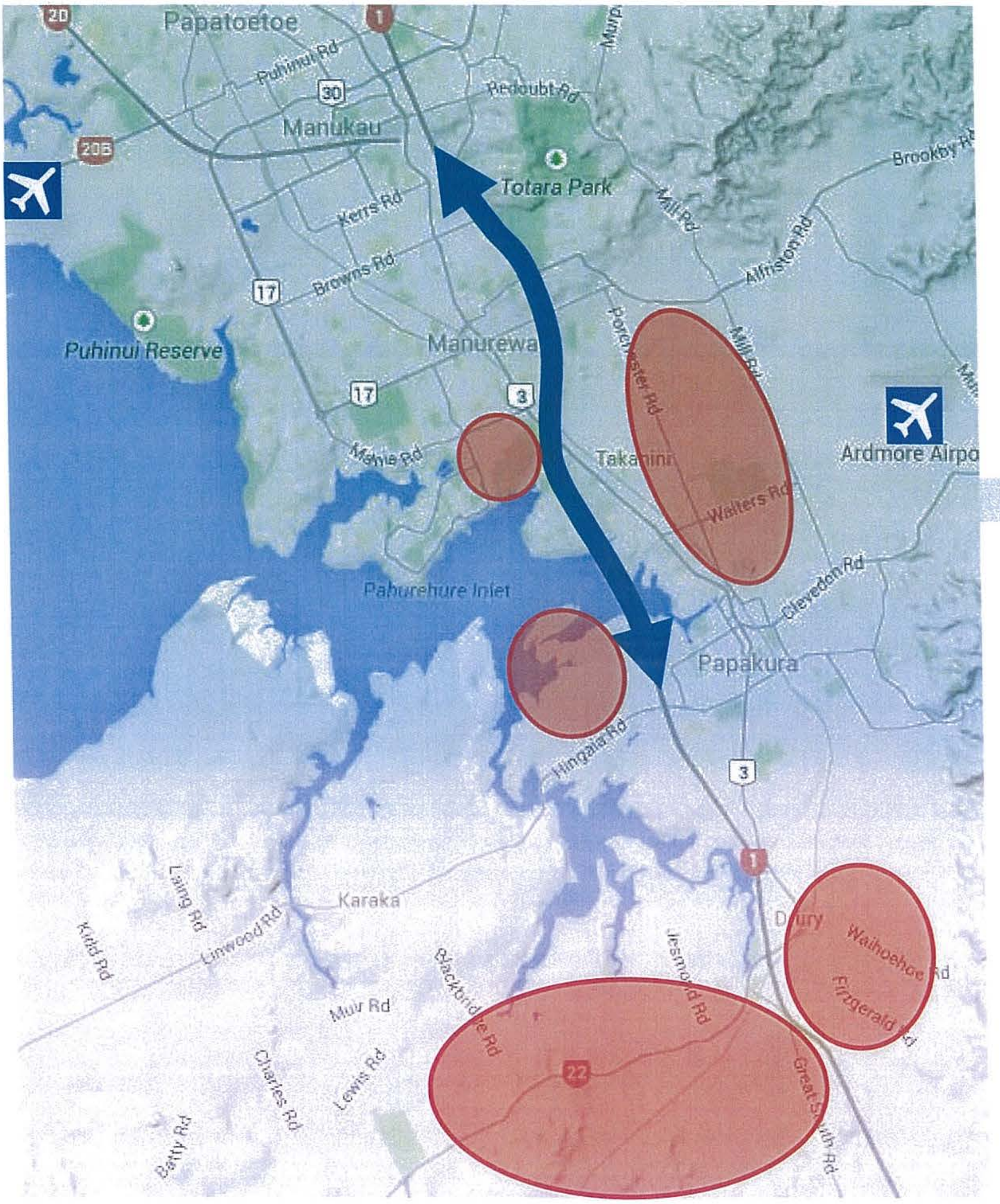
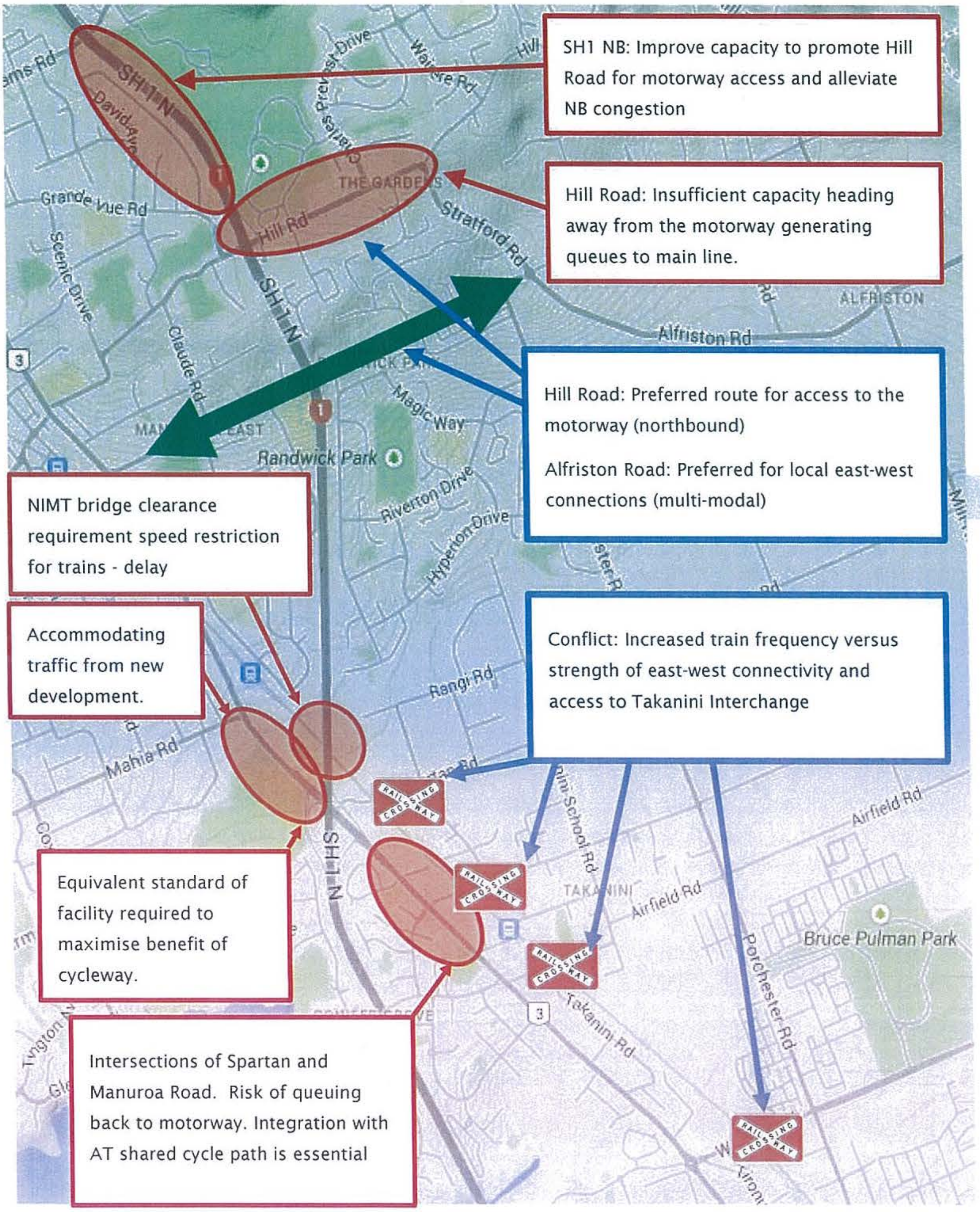


Figure 2: Network Integration Issues



6.1 Freight Access

There are key freight generators within the corridor including Halls, Quarry traffic (Alfriston & Hunua), Dominion Road Industrial Park and Takanini Growth Area. It was agreed that Takanini and Drury interchanges would provide a significant freight function and that both the local road network and the Interchanges themselves would need to cater for this movement.

Challenge	Desired outcome	Network Integration Projects
Accommodating Freight	Providing high quality facilities to promote the use of key access routes for Freight movement.	NZTA - Freight priority at Takanini Interchange Auckland Transport - Appropriately designed facilities as part of other projects where route is a preferred freight route.

6.2 Hill Road

In the RUH workshop, it was agreed that:

- Hill Road be retained as the primary motorway access road to avoid the use of Alfriston Road for competing functions if an interchange was constructed there.
- Alfriston Road provides a strong east-west link for local movements including pedestrians, cyclists, buses and traffic - *so focus on Hill Road*
- Improvements on Hill Road will be developed by NZTA and AT as an integrated response

Currently the narrow bridge on Hill Road over the motorway results in two problems

1. Traffic turning right onto the motorway queues on the bridge and conflicts with local movements and off-ramp movements.
2. Limited space for pedestrians and cyclists

Furthermore, the desire to retain Hill Road as the primary access route may necessitate the need to upgrade it in response to the growth in the Takanini Area.

Challenge	Desired outcome	Network Integration Projects
Capacity of receiving environment	Ensuring that off-ramp queues do not extend to the motorway lanes	NZTA - Queue separation on the ramp. Extend 2 lanes as far as practicable NZTA - Improved off-ramp left turn capacity Auckland Transport - two lanes heading eastbound on Hill Road through to roundabout and signalisation of Botanic Gardens
Maintaining cross-motorway access and pedestrian/cyclist connectivity	Ensuring that queues for the northbound on-ramp do not interfere with cross-motorway (westbound) through movements and improving pedestrian and cycling facilities	NZTA - Provision of a second westbound lane over the motorway (bridge widening/replacement) NZTA/Auckland Transport - Improvements to intersection of Hill Road and Grand Vue Drive

Challenge	Desired outcome	Network Integration Projects
Growth in Takanini	Promote use of Hill Road to access the motorway to relieve pressure on the Takanini Interchange	NZTA - Auxiliary lane between Hill Road and SH20 Auckland Transport - Mill Road Corridor Auckland Transport - Upgrade of Hill Road

6.3 Bus Priority Along Great South Road

The Corridor Management Plan prepared by Auckland Transport identifies the desire to provide bus and high-occupancy vehicle priority on both sides of the interchange, and a desire for this to be considered through the interchange aswell. Great South Road is identified as part of the longer term Frequent Transport Network. It will provide for a high frequency service connecting Papakura and Manukau - one bus every ten minutes.

The implementation of bus priority along Great South Road has been identified a longer term measure. Bus priority on the approaches to the interchange is achievable with the current design by re-allocating the short kerbside approach lanes as bus queue jump lanes (combined with left turn movements).

The benefit of bus priority measures as part of a longer term initiative would be realised through a whole-of-corridor implementation. Bus priority through the interchange would need to be carefully considered. The primary concern is the ability to ensure that there are two traffic lanes for the off-ramps to turn into in order to prevent queues from extending to the motorway.

Challenge	Desired outcome	Network Integration Projects
Bus priority on Great South Road	Improve reliability of public transport without impacts on motorway operations.	NZTA - Maximise efficiency for all users without active priority Auckland Transport - Bus queue jump lanes in the short term. Auckland Transport - Bus/HOV lanes as a whole-of-corridor approach

6.4 Cycling

Great South Road is identified as a key cycling corridor. There are currently no facilities within the interchange. The agreed RUH identifies the route between Papakura and Manukau as part of the Cycle Highway. The definition of this level of service is a fully segregated facility providing capacity for high volumes of cyclists.

Initial investigations have determined that this will be included as part of the investigation between Papakura and Takanini; however it will not be provided within the motorway corridor between Takanini and Manukau as part of the Southern Corridor Improvement.

Challenge	Desired outcome	Network Integration Projects
Integration of Cycling Facilities at Takanini	Provide safe and efficient cycling facilities through the interchange to connect with the proposed cycle highway between Takanini and Papakura Interchanges.	NZTA – Integrate with Auckland Transport's Great South Road Cycling Facilities Auckland Transport - Great South Road Cycling Facilities Auckland Transport - Cycle facilities along Beach Road, Papakura Auckland Transport/NZTA - Cycle highway between Takanini Interchange and Manukau utilising rail corridor, motorway corridor or Great South Road corridor.

6.5 East-West Connectivity

The NIMT line runs adjacent to Great South Road and passes beneath SH1. Between Takanini Interchange and Papakura township, there are 4 at grade level crossings. Current the conflict between rail operations (note not yet running electric trains) and road user movements result in safety issues and frequent interruptions.

The current location of the Spartan Road intersection is less than ideal in terms of interchange operation and we understand that this intersection will be retained for the purpose of this project. It is also acknowledged that Spartan Road will be closed at the level crossing thus reducing the traffic levels at the intersection with Great South Road.

Current rail operations [note not yet running electric trains] result in safety issues and frequent interruption to road users crossing at the level crossings, impacting the operation of Great South Road. It has been acknowledged that the conflict between the level crossings and the NIMT needs to be mitigated to facilitate growth in the Takanini area.

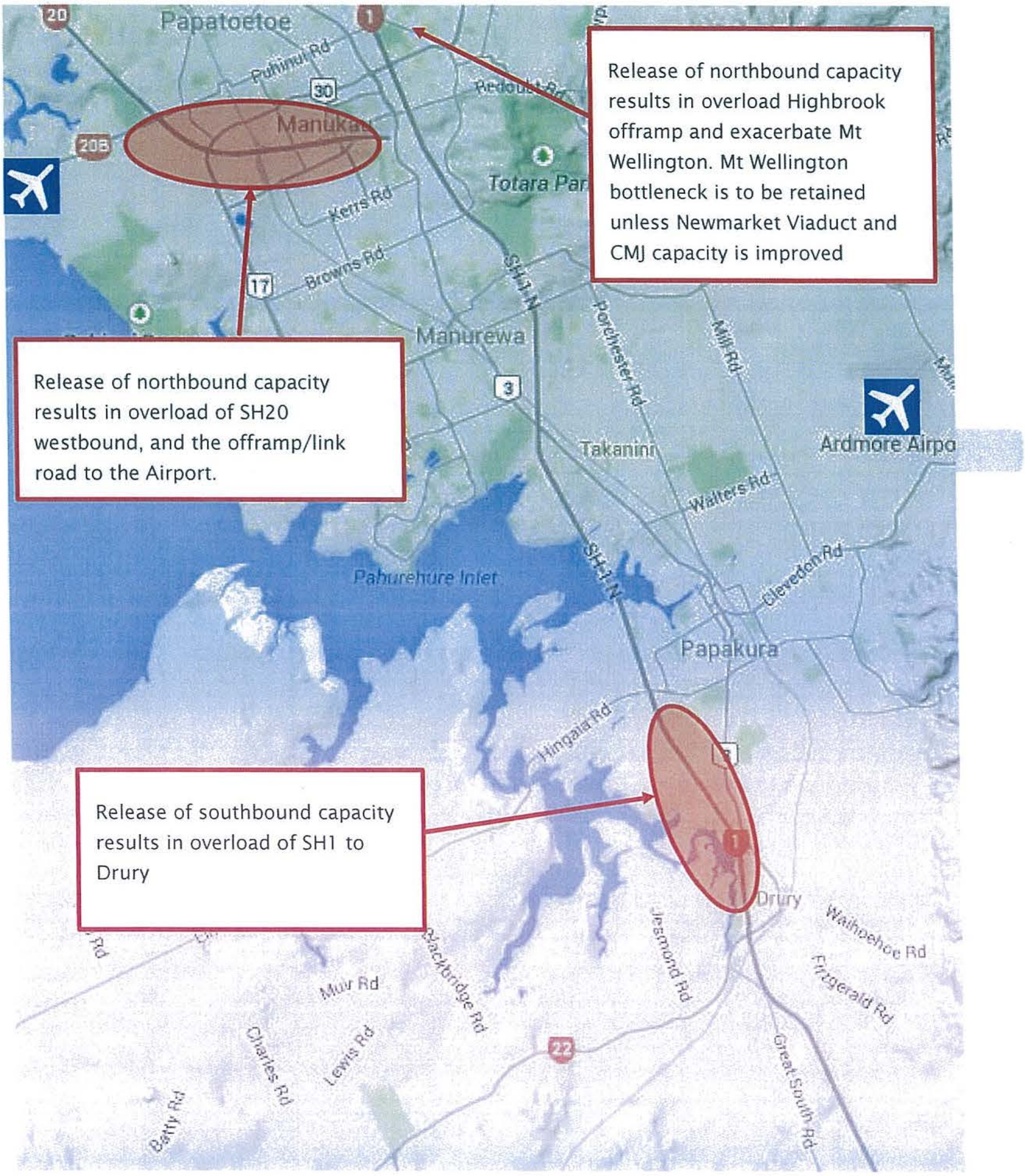
Challenge	Desired outcome	Network Integration Projects
Growth to east of Takanini Interchange [Takanini Plan Change and SHA]	A stronger east-west connection recognising Hill Road and Takanini Interchanges as key gateways	Auckland Transport – local network improvements including potential grade separation of Manuroa Road, Taka Street, or new alignment Auckland Transport - local network between Hill Road and Takanini development area.

6.6 Potential New Bottlenecks

Upon completion of the Southern Corridor Improvements, the release in capacity may result in additional pressures downstream of the works, as highlighted in Figure 3. The suggested responses are provided below.

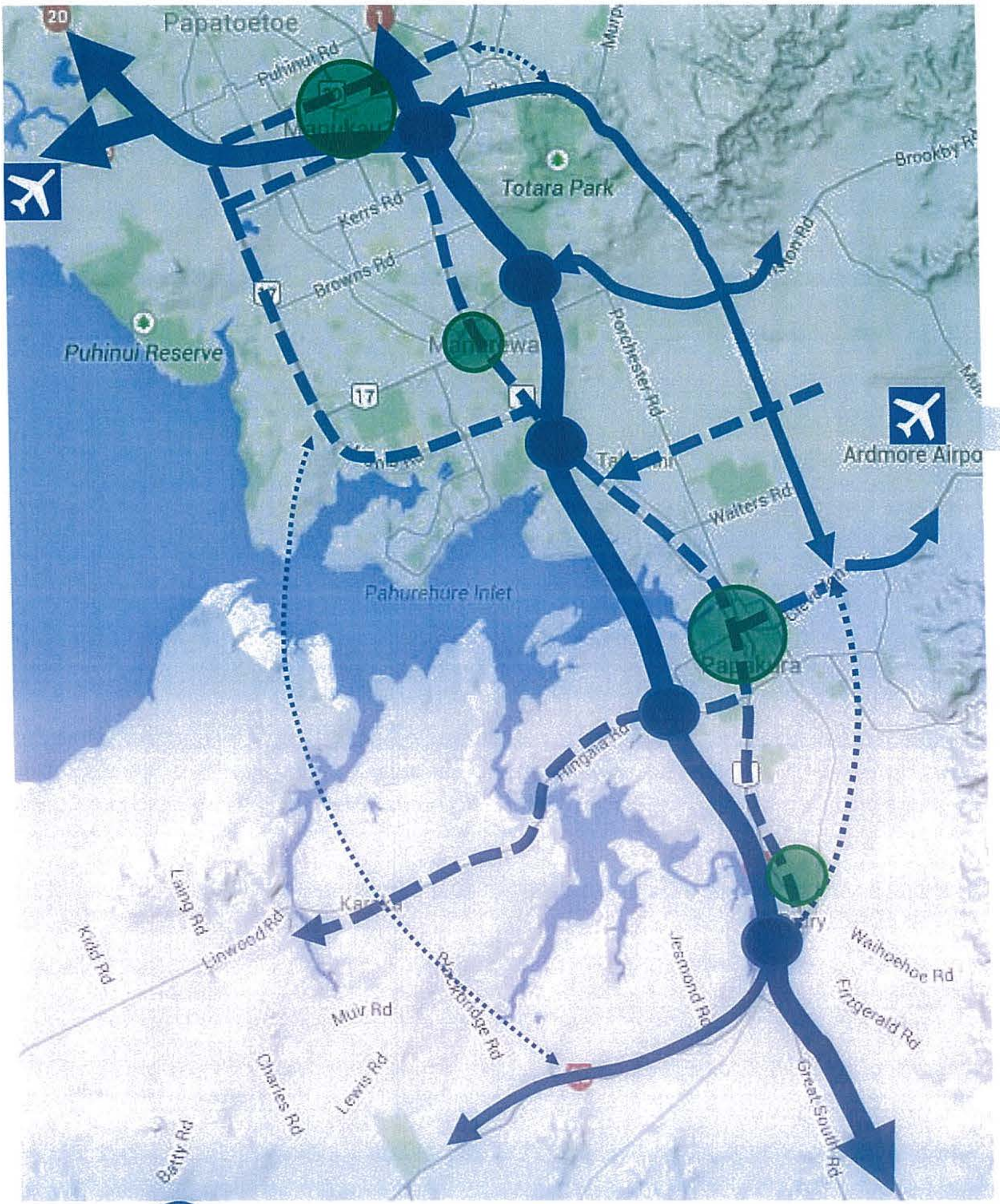
Challenge	Desired outcome	Network Integration Projects
Creating new bottlenecks by releasing constraints	Plan for mitigation measures to address downstream congestion	NZTA - 3rd westbound lane from Lambie to Roscommon and capacity improvements for off-ramp through to SH20B NZTA - Queue management for Highbrook offramp. NZTA - 3rd southbound lane to Drury.

Figure 3: Potential Bottlenecks Away from Southern Corridor Improvements



Appendix A: Preferred Road User Hierarchy (High Level)

Figure 4: Preferred Traffic Routes



Preferred Traffic Route (Through) and Interchange

Preferred Access Route/Secondary Through Route

Potential Future Preferred Route

Town or Metropolitan Centre

Figure 5: Preferred Freight Routes

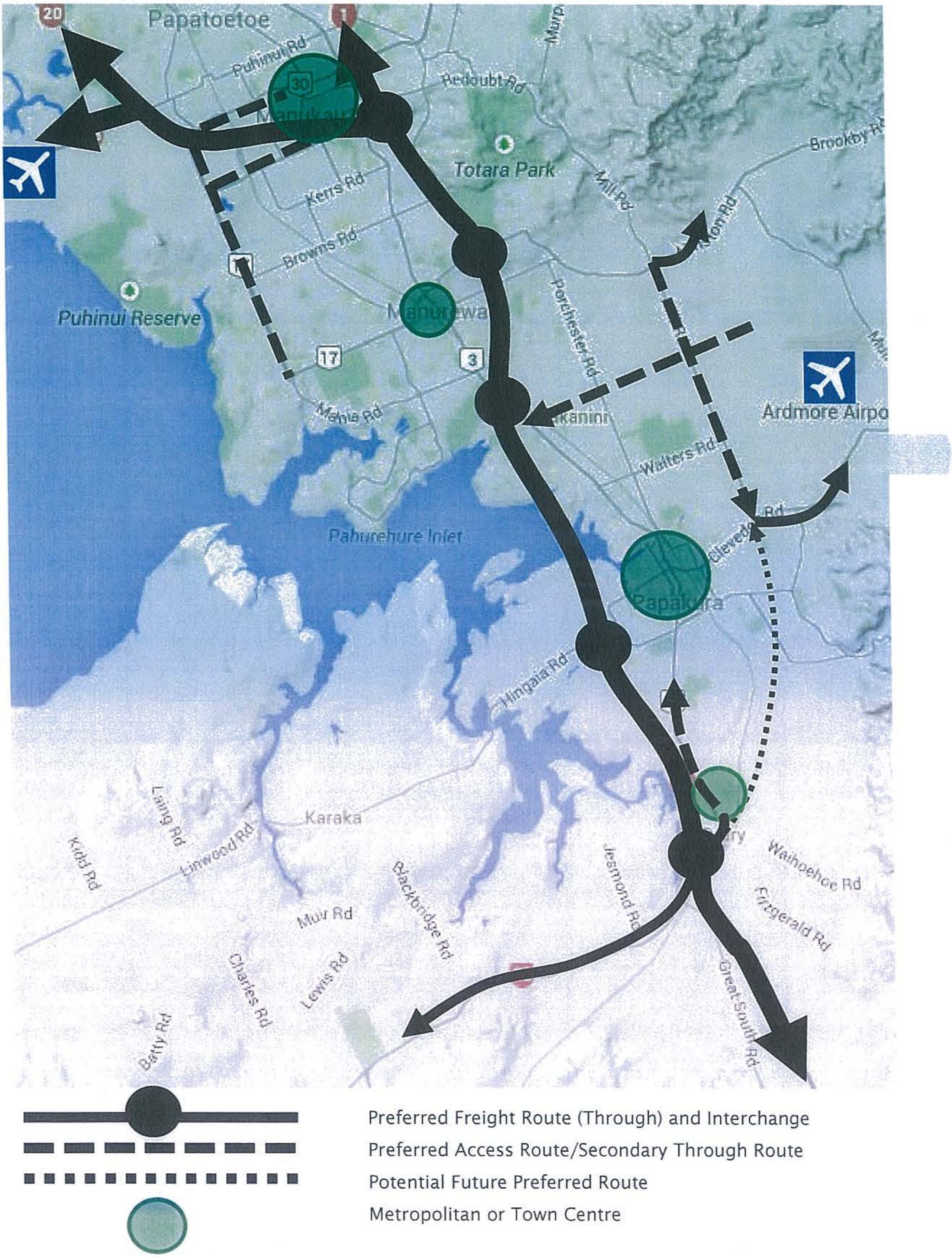


Figure 6: Preferred Public Transport Routes

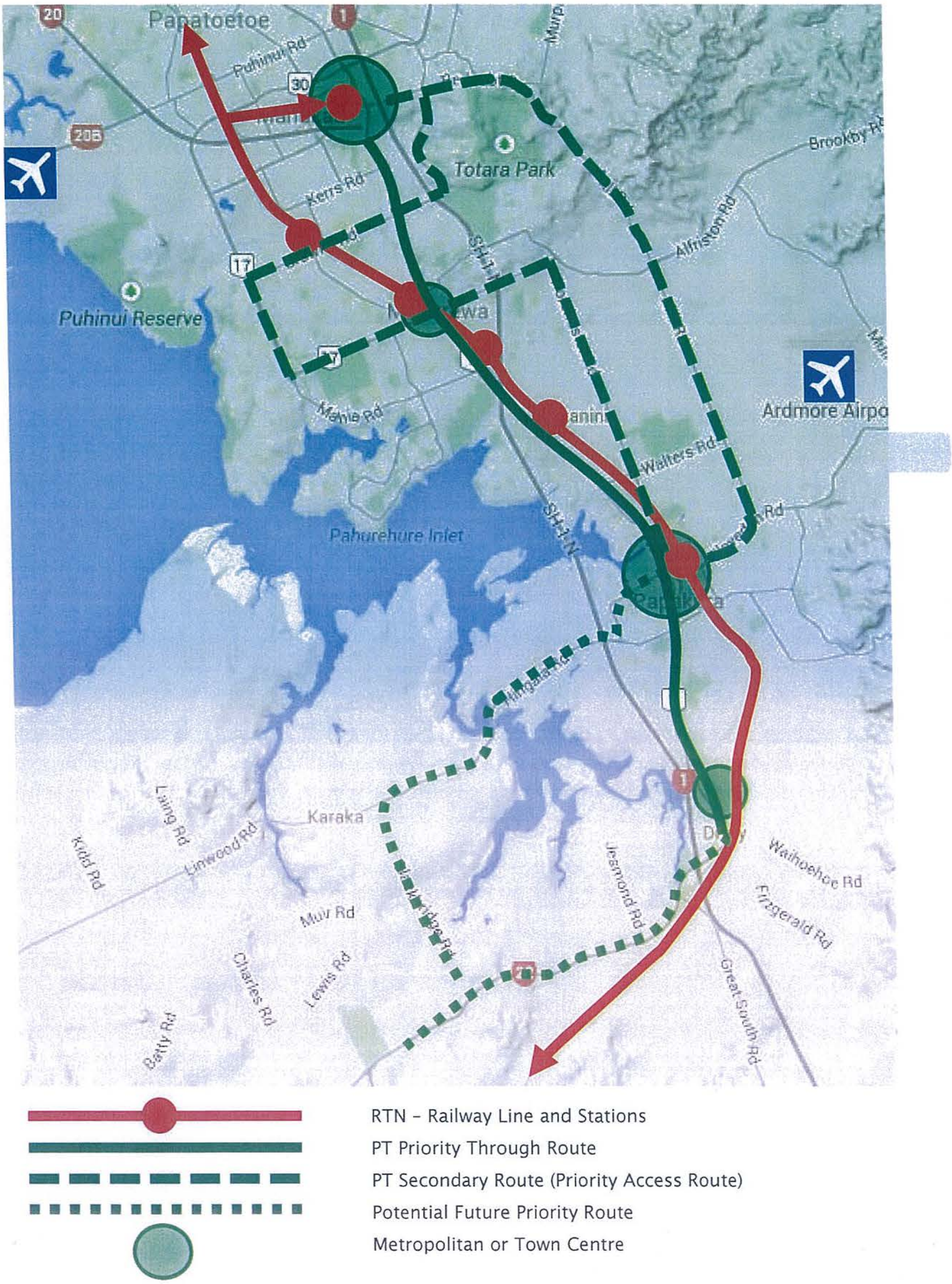
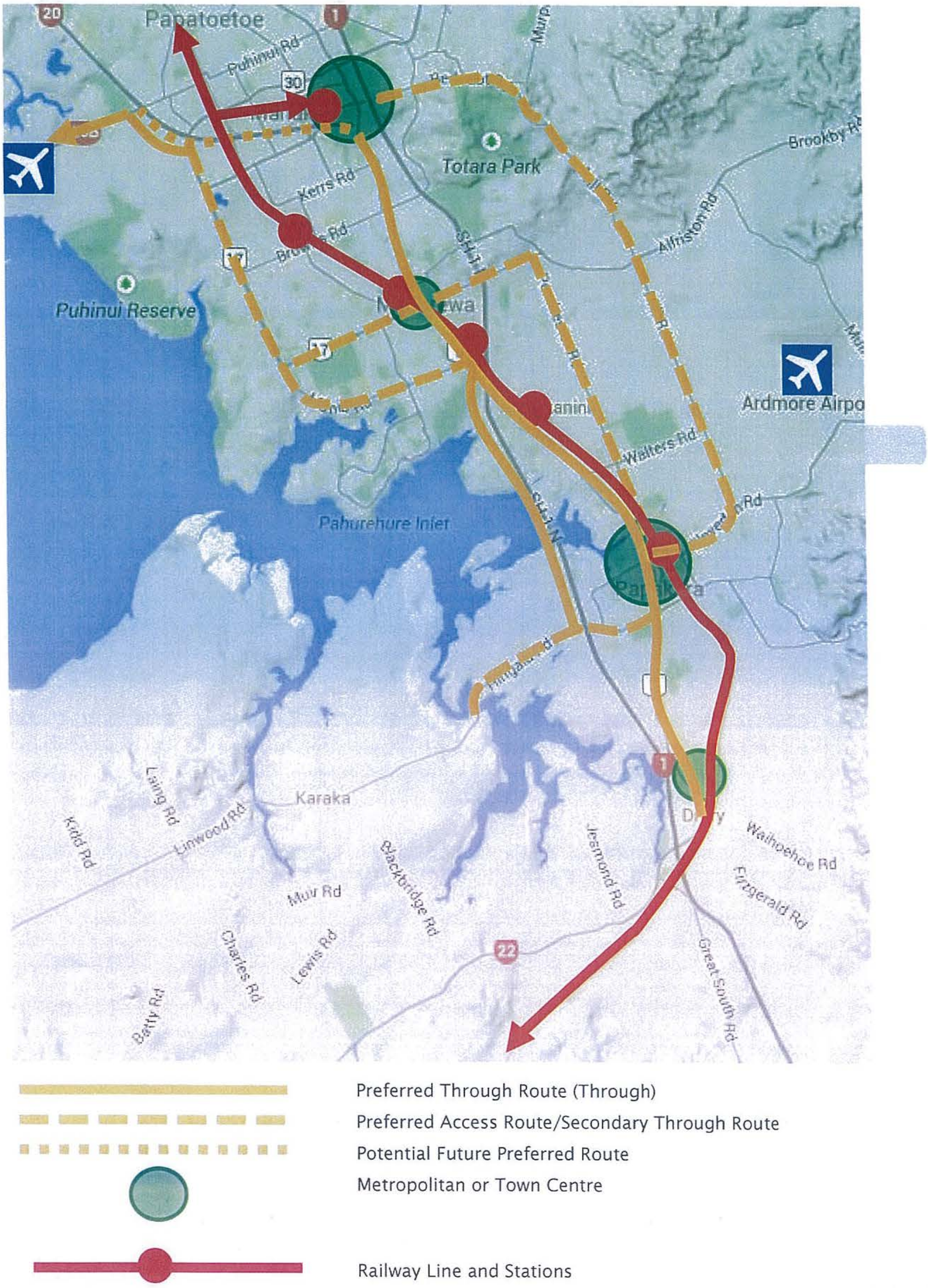


Figure 7: Preferred Cycling Routes



Appendix F: Balancing safety and efficiency at intersections: a tool- based approach

Appendix F is an Excel file attached separately at www.nzta.govt.nz/resources/research/reports/600