The cost effectiveness of delineation improvements for safety
July 2007

Land Transport New Zealand
Research Report 322

The cost effectiveness of delineation improvements for safety

H. W. Mackie and P. H. Baas
TERNZ Ltd

Land Transport New Zealand Research Report 322

*ISBN 0-478-28734-8
**ISSN 1177-0600

PO Box 2840, Waterloo Quay, Wellington, New Zealand
Telephone 64-4 931 8700; Facsimile 64-4 931 8701
Email: *research@landtransport.govt.nz*
Website: *www.landtransport.govt.nz*

Mackie, H. W. and Baas, P. H. 2006. The cost effectiveness of delineation improvements for safety. *Land Transport NZ Research Report 322.* 30 pp.

Transport Engineering Research New Zealand (TERNZ) Limited
PO Box 97 846, South Auckland Mail Centre, Auckland, New Zealand.

Keywords: Road safety, software, delineation, audio tactile, road markings, benefits, costs

An important note for the reader

Land Transport New Zealand is a Crown entity established under the Land Transport New Zealand Amendment Act 2004. The objective of Land Transport New Zealand is to allocate resources in a way that contributes to an integrated, safe, responsive and sustainable land transport system. Each year, Land Transport New Zealand invests a portion of its funds on research that contributes to this objective.

The research detailed in this report was commissioned by Land Transport New Zealand.

Acknowledgments

The authors would like to thank the following individuals for their assistance with this project:

Ross Ridings, Quality Surveillance Ltd
Alister Harlow, New Zealand Roadmarkers Federation Inc.
Bruce Conaghan, Manukau City Council
Stanley Chesterfield, Transit New Zealand
Colin Brodie, Transit New Zealand
Murray Clark, Transit New Zealand
John Neil, Opus International Consultants
Bobby Gong, Opus International Consultants
Neil Beckett, Transit New Zealand
John Edgar, John Edgar Consulting
Stephen Parry, Land Transport New Zealand
Paul Del Facero, Highways Systems
Philip Walton, Highway Systems
Rob Dunne, Damar Industries Ltd
The road marking contractors and product manufacturers who supplied pricing and other product information.

Abbreviations and acronyms

AADT	Annual average daily traffic
ATP	Audio tactile profiled
BCR	Benefit cost ratio
CAP	Cold applied plastic
PEM	*Project evaluation manual* (Land Transport New Zealand)
ROR	Run off road
SWATT	South Waikato and Taupo target
VPD	Vehicles per day

Contents

Executive summary

The purpose of this research was to develop a cost management tool that would assist road controlling authorities and their consultants to prioritise delineation treatments that have added safety benefits compared with standard road markings.

Audio tactile profiled (ATP) edge and ‘no overtaking’ centrelines provide an audio tactile response when driven over, making drivers less likely to leave their lane. Materials such as ATP thermoplastic and cold applied plastic (CAP) are, however, more expensive to install than conventional flat lines, leading to a trade-off between cost and safety. There may be the potential to treat a larger proportion of rural roads with safety measures such as ATP edge and centreline and bring more consistency to New Zealand’s road network.

A tool has been developed that calculates a benefit/cost ratio (BCR) for a given road segment (rural mid-block, rural curve and rural bridge) based on road parameters, delineation improvement details and an associated crash reduction factor based on the delineation improvement. A ‘route builder’ was also developed where the BCR for an entire route of a specified length could be determined.

In general, favourable BCRs were found to result from ATP treatments on roads with relatively modest traffic counts and much higher BCRs from higher traffic counts. Using the cost management tool, a typical ATP edgeline and no overtaking centreline treatment resulted in a BCR of greater than one at approximately 1300 vehicles per day for mid-block applications. Typical changes in individual variables such as treatment cost or life did not have a large affect on the BCR of ATP road marking treatments, but changes in a combination of variables such as region, daily traffic, crash reduction factor, treatment costs and treatment life could collectively have a significant effect on the BCR of a project.

The results of a limited number of analyses of the effect of ATP road markings on crashes in New Zealand were in agreement with overseas literature and provided a degree of validation for the cost management tool that had been developed. There would be a net benefit in treating a much greater proportion of the state highway network with ATP road markings immediately, where the road environment allowed for their appropriate use.

There are many other factors that need to be considered prior to the installation of ATP road markings in some situations. These factors include the possible dangers of using ATP lines with narrow or non-existent road shoulders, the limitations of overseas crash reduction data, the relative merits of other products that have excellent wet-night retroreflectivity but little or no audio tactile response, the merits of different ATP products, variations in ATP design and cost variations. The usability of ATP road markings by motorists, cyclists and nearby residents also needs to be more fully considered in some situations.

Abstract

The purpose of this research was to develop a cost management tool that would assist road controlling authorities and their consultants to prioritise delineation treatments that have added safety benefits compared with standard road markings. A spreadsheet-based cost management tool was developed and then applied to a range of typical road marking situations. It would appear that audio tactile road markings provide significant safety benefits that outweigh the treatment costs even at relatively low traffic volumes. This report recommends that audio tactile profiled road markings be installed on a much more widespread basis where road conditions allow and policy changes should reflect this. Further research should be conducted to determine the appropriateness of their use in situations where little sealed shoulder exists, such as near residential dwellings and where the road is commonly used by cyclists.

1. Introduction

In order to improve road safety, new road marking materials with greater safety and durability benefits than standard paint are increasingly being used on New Zealand roads. The introduction of glass beads has significantly increased the retroreflectivity of paint while products such as thermoplastic and cold applied plastic (CAP) generally have a longer life and allow for 'structured' and 'profiled' markings. Audio tactile profiled (ATP) edge and 'no overtaking' centrelines provide an audio tactile response when driven over, making drivers less likely to leave their lane.

Materials such as ATP thermoplastic and CAP (long-life products) are also more expensive, which leads to the need to trade off cost and safety. However, the longer life of these products makes them potentially more cost effective and profiled treatments offer safety benefits through a reduced number of injury accidents.

1.1 Background

In a previous review of the literature on the effectiveness of improved delineation technologies, a total of 57 articles were sourced from published journals, local and overseas transport engineers, and a search of reports posted on worldwide web sites (Baas et al. 2004). Twenty-four key reports (citing more than 500 source documents) were then independently reviewed and summarised and an annotated review of each article was prepared and included in the review document.

1.1.1 The effectiveness of improved delineation technology

A survey of 43 states in the USA found there was a large variation in crash reductions due to wider edgelines with an average crash reduction of 5% (Agent et al. 1996, cited in Baas et al. 2004). Reports of rumble strips' effectiveness ranged from a 2% reduction to a 44% reduction across all types of crashes with an average reduction of more than 27%. When considering only 'run off road' (ROR) crashes, shoulder rumble strips have been found to be very effective in reducing crashes by 20% to 80% (an average of 32% for all ROR crashes, 42% for fatal ROR crashes). According to the literature, the greatest benefit may occur for high-speed road segments associated with horizontal curvature (which is also associated with a higher ROR crash rate). Similarly, centreline rumble strips have been found to produce significant reductions in head-on and sideswipe crashes ranging from 21% to 37% of reported crashes.

It appears to be clear that improved delineation technology, especially the use of ATP road markings, is effective in reducing crashes. There is less information on the cost effectiveness of such treatments. One study in the literature reported the benefit/cost ratios (BCR) for profiled line treatment based on a review of the literature, a survey of 68 road engineers and a simulator study conducted at the University of Minnesota (Corkle et al. 2001). BCRs from treatments in New York, Nevada and Maine in the USA were found to range from 30:1 to 182:1 depending on the location.

1.1.2 New Zealand evaluations of delineation improvements

Recently, the Traffic and Road Safety Research Group (Waikato University) and TERNZ Ltd participated in a study titled *South Waikato and Taupo target 2010 remediation treatments* (SWATT) *monitoring* (Charlton 2006). In response to design and operational problems that had led to high crash rates on State Highway 1 between Piarere (near the intersection with State Highway 29) and the Desert Road summit, trial treatments were installed and four sites were evaluated. No overtaking centrelines and wider ATP edges and centrelines were laid at various sites. In order to assess the success of the delineation treatments, drivers' lane keeping, speeds and overtaking were monitored at five sites in the study corridor as the treatments were progressively introduced throughout 2005 and 2006. The no overtaking lines eliminated overtaking at the monitored sites. The ATP centre and edgelines had the effect of significantly reducing the number of vehicles with wheels over the lane lines and eliminating centreline crossings at sites where they had most often occurred. The ATP lines appeared to have their greatest effect in reducing the proportion of vehicles travelling at the extreme right or extreme left of the lane just prior to, or after a curve.

Prior to the study, roading officials (SWATT 2010 Corridor Study Team) had identified that drivers losing control and failing to stay on the road, and a high incidence of crossing centreline and head-on crashes were two key problem areas on this section of State Highway 1. This suggests that ATP edge and no overtaking centrelines may contribute significantly to reducing the crashes that have been occurring within the study area and possibly on the wider New Zealand road network, although a systematic evaluation of crash data prior to and after treatment would be required to verify this.

There are some less formal New Zealand examples of the effectiveness of ATP edge and no overtaking centrelines. These will be discussed in more detail as case studies later in this report.

1.2 Project purpose

Currently, ATP edge and no overtaking centrelines tend to be installed where there is an obvious history of injury accidents. There may be the potential to treat a larger proportion of New Zealand's rural roads with safety measures such as wider or ATP edge and no overtaking centrelines. However, the cost-effectiveness of these safety improvements needs to be calculated before their more widespread use. The purpose of this research was to develop a cost management tool that would assist road controlling authorities and their consultants to prioritise delineation treatments that have added safety benefits compared with standard road markings.

2. Development of a delineation improvement cost management tool

A spreadsheet-based cost management tool was developed that largely followed the procedures of Land Transport New Zealand's (Land Transport NZ) *Project evaluation manual* (PEM). The tool calculates a BCR for a given road segment (rural mid-block, rural curve or rural bridge) based on road parameters, delineation improvement details and an associated crash reduction factor (Figure 2.1). In the following section, the development of each part of the tool is described.

2.1 Road factors

Injury accident prediction models from Appendix 6.5 of the PEM were used to determine the expected number of injury crashes per year for a given segment of road. For the rural mid-block accident prediction equations (PEM A6.5.6), daily two-way traffic, exposure, terrain type, road width and seal shoulder width were used to determine the expected number of injury accidents per kilometre per year. For rural curves, traffic exposure in each direction, and the curve design and approach speeds in each direction were used to determine the expected number of injury accidents on the curve per year. For two-lane bridges, traffic exposure (on the bridge), two-way traffic volume and the difference between the seal width across the bridge and the total sealed lane width were used to determine the expected number of injury accidents on the bridge per year.

As an alternative to using the accident prediction equations, a dialogue box was included in the tool, which allows users to enter the number of actual injury crashes per year based on a minimum five-year accident history.

2.2 Crash costs and benefits of treatment

According to the Ministry of Transport (2006), the average social cost of an injury accident (defined as all fatal, serious and minor injury crashes) for rural environments at June 2006 was $461,000 for all of New Zealand. The expected or actual number of crashes per year is multiplied by the social cost of an injury accident ($461,000) in order to determine the social accident costs for the section of road that is being analysed.

It should be noted that the social cost of injury accidents differs for different regions, mainly because the proportions of fatal, serious and minor injury accidents differ. When the tool is being used for a specific region, the social cost of injury accidents for that region should be used.

A crash reduction factor, based on findings from the literature, will determine the savings (accident reduction benefits) that can be expected from the delineation improvements. In line with the findings of previous literature a default crash reduction of 25% was set based on the application of ATP edgelines and no overtaking centrelines. Because the benefits that arise from any treatment are realised over its lifetime, a net present value adjustment was integrated into the overall benefits gained from delineation treatment, in accordance with the PEM.

2.3 Delineation treatment costs

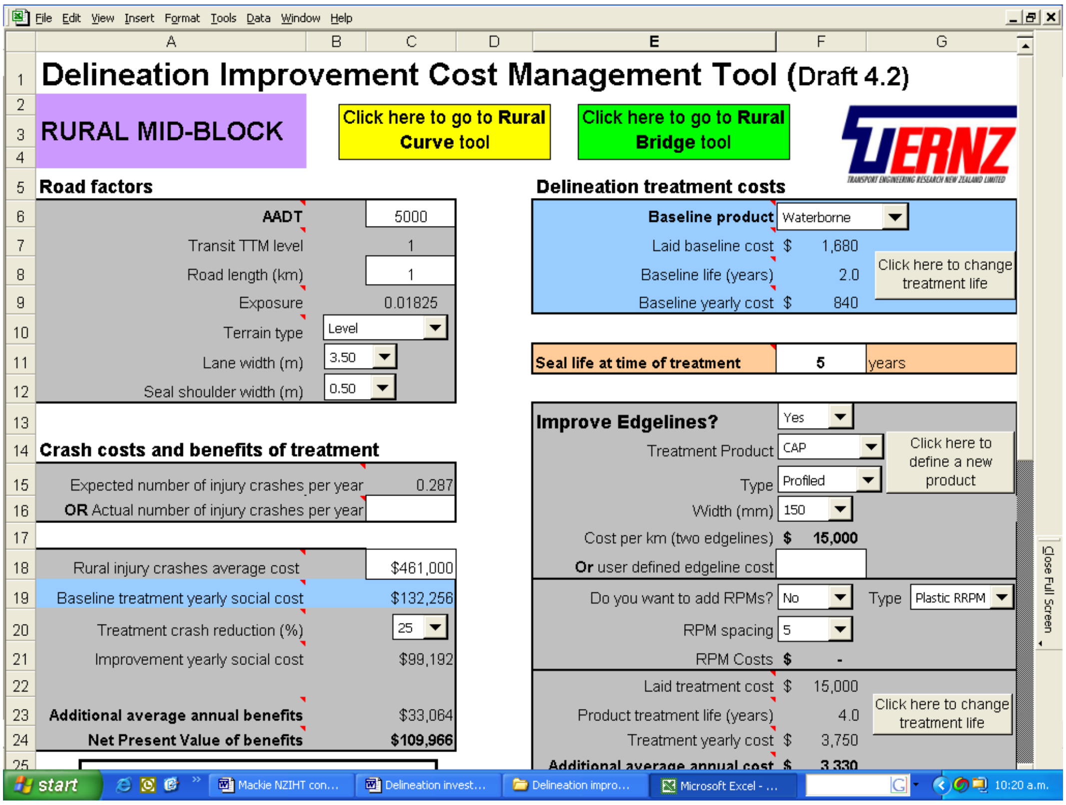
A significant level of consultation with a variety of individuals and organisations involved with road marking was undertaken to determine what products, product life and costs should be included in the cost management tool. A baseline level of delineation was established so that improvement costs could be expressed as the cost above the baseline. The baseline treatment was set as either painted (waterborne or alkyd), thermoplastic or CAP edgelines and no overtaking centrelines. No overtaking centrelines were used as the default treatment because areas that required centreline delineation improvements would be those where no overtaking was permitted and consequently where no overtaking lines already existed.

The delineation treatment costs have been separated into edgeline and centreline sections. Options for specifying treatment product, type and width are presented to users in the form of drop-down boxes. For example, for edgelines a user may wish to improve delineation by selecting thermoplastic profiled (blocks fixed at 250 mm centres) at a width of 150 mm. Users are also able to define a new product that is not specified by the drop-down boxes. After these selections are made, the per kilometre laid cost is given (including temporary traffic management costs depending on the daily traffic volume that has been defined).

The treatment yearly cost is then given based on the product life that can be expected (which can also be changed) and the additional annual average cost, which is the annual cost over and above the baseline product costs, is also displayed. The total treatment cost of both the edge and centrelines is provided, followed by the net treatment lifetime cost, which is the total project treatment cost less the total baseline treatment costs. The product life can clearly have a large effect on yearly costs. For more discussion on product life, see section 5.5.

The ability to change the seal life has also been included as many of the people consulted suggested that re-seals could often be the main factor determining the life of a delineation product and, therefore, its cost effectiveness. Small patches of seal repair are not accounted for in the cost management tool.

Finally, the total value of the benefits over the period of the treatment life is divided by the overall treatment costs (above the baseline costs) in order to determine a BCR.



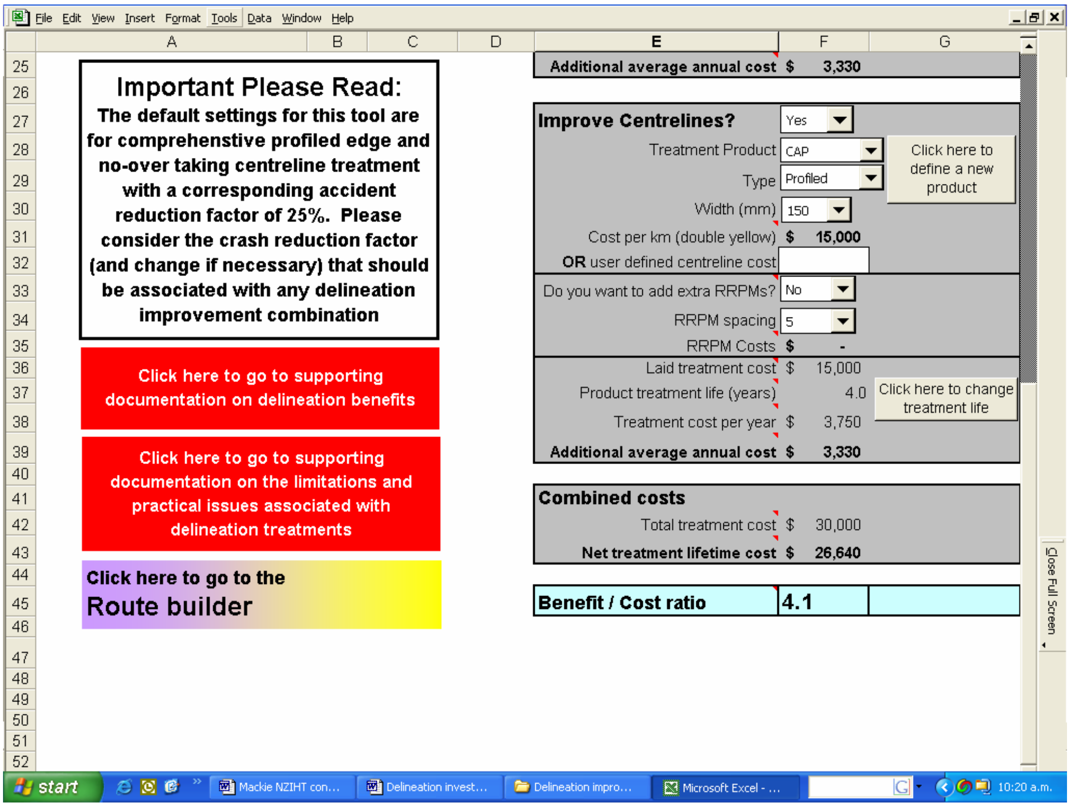


Figure 2.1 The user interface for the rural mid-block page of the cost management tool.

2.4 Supporting information

It was widely agreed that the delineation improvement cost management tool would need to be provided with supporting information. Links to evidence for the crash reduction outcomes from various treatments, as well as information highlighting the limitations and practical issues that arise from using different treatments are included within the tool. More specifically, a link to an abbreviated version of the findings of Baas et al. (2004) is provided on each of the mid-block, curve and bridge tools to give supporting information regarding treatment of safety benefits. A separate link to the New Zealand Road Markers Federation document (New Zealand Road Markers Federation 2004) is included in order to give users practical information regarding the use of the different products. A link to this report is also provided on each of the three worksheets, giving a context in which the use of the tool should be placed, as well as an explanation of the limitations and issues associated with using the tool. Comment boxes are included on most of the fields on each worksheet, elaborating on the meaning or function of the field.

2.5 The route builder

In practice, road markers do not mark individual mid-block sections, curves or bridges, but instead they mark a route, which may contain a variety of road features. For this reason, a route builder (Figure 2.2) was developed where the BCR for an entire route of a specified length could be determined. The user enters the total route distance, number of curves and number of bridges. The specifications of the mid-block, curve and bridge worksheets are then used to determine the overall route BCR. For this tool, standard treatment lengths of 200 m for curves and 60 m (30 m at each end) for bridges are used.

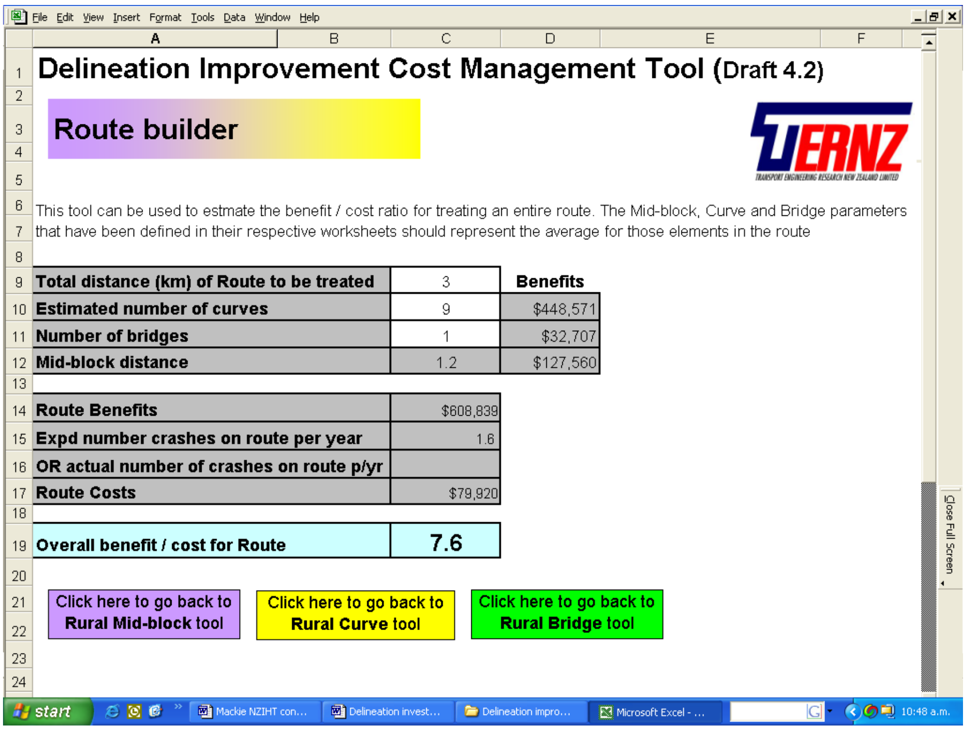


Figure 2.2 The route builder allows the BCR for an entire route to be estimated.

3. Findings: The cost effectiveness of audio tactile profiled road markings

In this section, the application of the cost management tool will be discussed using three separate approaches. First, the relationship between annual average daily traffic (AADT) and the BCR of delineation treatment improvements will be presented for different road environments. Second, the findings will be expressed in terms of the proportion of the state highway network that could be upgraded with ATP lines based on different traffic volumes for two BCR thresholds. Lastly, the sensitivity of the cost management tool will be examined by adjusting each variable within the tool separately, by a realistic amount, and comparing that adjustment with the resulting change in the BCR.

3.1 The relationship between traffic volume and the BCR of delineation treatment improvements

For the mid-block, curve and bridge cost management worksheets, a range of AADTs (500–20,000) was entered and the corresponding BCR was recorded (Figure 3.1) for the following delineation improvement:

Upgrade 100 mm waterborne painted edge and no overtaking centrelines with 150 mm ATP CAP (blocks at 250 mm centres).

This upgrade was chosen as it represented the specifications for upgrades that were used in the SWATT project and, therefore, might represent a typical treatment in the future. Also, because CAP is currently more expensive than thermoplastic, it provided a conservative estimate of the BCR.

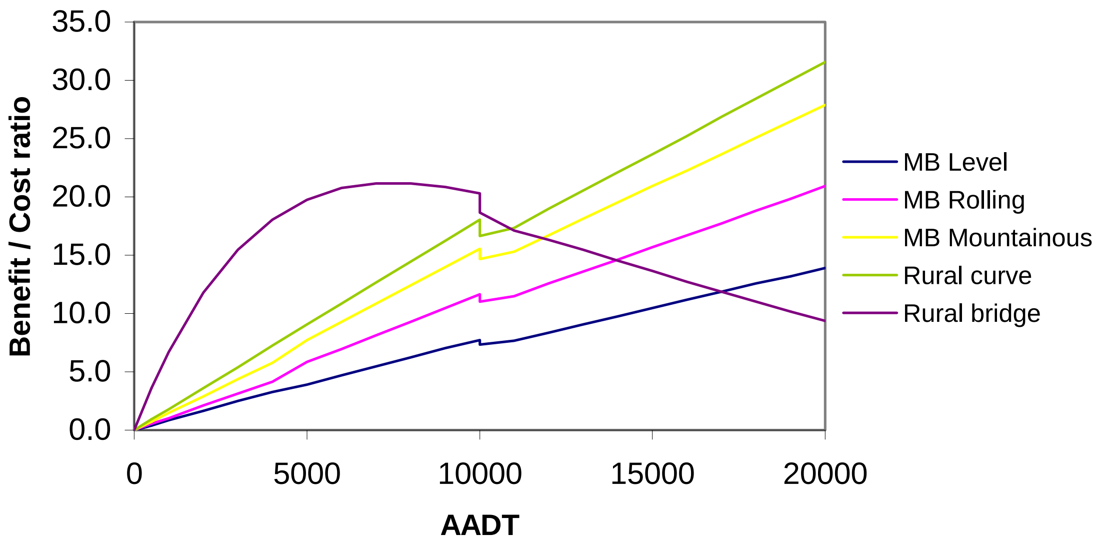


Figure 3.1 The relationship between two-way annual average daily traffic – vehicles per day (VPD) – and the BCR using the cost management tool. The delineation upgrade is from 100 mm waterborne painted edge and no overtaking centrelines to 150 mm profiled CAP

(at $7,500 per km laid and including traffic management). Note: The downward step that exists at 10,000 VPD is due to the added costs of temporary traffic management.

Figure 3.1 shows that, in general, high BCRs result from relatively modest traffic counts, and except for bridges, very high BCRs result from high traffic counts. For rural mid-block environments, a treatment of 150 mm ATP edge and no overtaking centreline reaches a BCR of greater than one at approximately 1300 vehicles per day, and for rural curve environments this point is reached at approximately 600 vehicles per day. The rural bridge relationship is different from the others with a maximum BCR of approximately 21.5 at 7000 vehicles per day and then decreases thereafter. This is a result of the crash prediction model that has been used from the PEM, which assumes that lower crash rates occur on bridges with volumes over approximately 7000 vehicles per day as these bridges are wider. The step in the curve for each road environment results from the greater level of temporary traffic management costs associated with roads where the AADT is above 10,000 vehicles per day.

3.2 What proportion of the state highway network could be treated with ATP lines?

Using Transit New Zealand's (Transit NZ) vehicle count data, it is possible to estimate the proportion of the state highway network that has a given AADT. Table 3.1 shows the proportions of the state highway network that might conceptually qualify for delineation upgrades to ATP lines using the cost management tool for BCRs of 1.0 and 4.0. In reality, a proportion of the network would not be suitable for ATP markings due to intersections, driveways and proximity to residents. This estimate is only intended to give an estimate of the extent of the state highway network that might be upgraded based on the BCR analysis.

Table 3.1 Approximate percentage of the state highway network that could be treated with ATP lines (as per the specifications in Figure 3.1) at BCRs of 1.0 and 4.0.

	BCR > 1.0	BCR > 4.0
Treat all	70% (>1300 AADT)	26% (>5000 AADT)
Treat curves	21% (>600 AADT)	44% (>2200 AADT)
Don't treat	9% (<600 AADT)	30% (<2200 AADT)

Using this approximation, it is clear that there would be a net benefit in treating a substantial amount of the state highway network with ATP road markings. Even if a BCR of 4.0 was used as a minimum criteria for treatment, 70% of the network would qualify for some degree of ATP treatment. It is estimated that currently, no more than approximately 300–500 km (approximately 3–5%) of the state highway network has been treated with ATP road markings.

3.3 Sensitivity of benefit/cost to different scenarios

Using the cost management tool, a number of factors can affect the BCR of any particular treatment. Table 3.2 gives an example of a treatment and a range of typical variations in the road environment, with benefits or treatment costings for a mid-block environment.

Again, CAP treatment has been used as it provides a conservative estimate of the expected BCR.

It is clear that typical variations in any single variable do not have a large effect on the BCR. Of the single variables, typical changes to daily traffic, changing the terrain from 'level' to 'rolling' and changes to the social cost of crashes appear to have the greatest effect. Typical changes to product price and treatment life have less effect on the BCR.

Table 3.2 Effects of different road, accident cost and treatment scenarios on the BCR.

Reference treatment: Rural mid-block; Traffic: 5000 VPD; Terrain: level; Lane width: 3.5 m; Shoulder width: 0.5 m; Average social cost of rural injury crash: $461,000; Baseline treatment: 100 mm waterborne paint edgelines and no overtaking centrelines; Delineation upgrade: edgelines and no overtaking centrelines 150 mm profiled (CAP @ $7,500 per km of line); No extra RRPMs. **BCR = 4.1**	
Change to treatment	**New BCR**
Increase daily traffic from 5000 to 8000 VPD	**6.6**
Change terrain from 'level' to 'rolling'	**6.2**
Decrease lane width from 3.5 m to 3.0 m	**5.0**
Decrease shoulder width from 0.5 m to 0.25 m	**4.3**
Increase the social cost of injury accidents from $461,000 to $507,100 (10% increase)	**4.5**
Increase the social cost of injury accidents from $461,000 to $709,000 (Most expensive region in NZ – Bay of Plenty)	**6.3**
Decrease the treatment crash reduction from 25% to 20%	**3.3**
Reduce price of audio tactile lines from $7,500 per km to $6,500 per km of line	**4.9**
Increase life of audio tactile lines from 4 years to 5 years	**5.1**
Daily traffic = 8000 VPD, 'rolling' terrain, 3.0 m lane width, Bay of Plenty region, 5-year audio tactile life	**22.7**
Daily traffic = 2000 VPD, 'flat' terrain, 3.5 m lane width, Otago region, 4-year audio tactile life	**1.0**

However, when a number of variables change (each causing a BCR change in the same direction), then large changes in the BCR can be expected. For example, increases in traffic, a change to rolling terrain (from flat), a decrease in lane width, a change of region and an increase in the life of ATP lines, can together increase the BCR greatly. The last two rows of Table 3.2 show this, along with a comparison scenario, which shows that traffic and road variables can also significantly reduce the BCR.

4. Case studies

4.1 State highways

ATP road markings have been installed at a number of North Island sites, particularly on State Highway 2. Although there has been a sufficient period of time to evaluate the effectiveness of these interventions, many other interventions such as improved signage, police presence and in some parts a reduced speed limit would confound any formal evaluation of crash rates on this section of road. There is anecdotal belief that the ATP lines have contributed to the reduction of poor driving and the number of crashes on these sections of road.

4.1.1 State Highway 1 south of Christchurch

In May 2001, approximately 29 km of ATP thermoplastic edgeline were laid on State Highway 1 south of Christchurch between Templeton and the Rakaia River bridge (Figure 4.1). The main purpose of this treatment was to reduce the number of fatigue-related and other 'run off road' and 'crossing the centreline' accidents.

Figure 4.1 Thermoplastic being laid on State Highway 1, south of Christchurch in 2001.

The ATP lines were only laid where a minimum of a 1.5 m shoulder existed. It was believed that without this shoulder, a driver could respond suddenly to the audio tactile stimulus by turning to the right, and if the left wheels had already travelled over the lines and into gravel or a grass verge, then over-steering and a possible head-on collision might occur. Although there does not appear to be any formal evidence for this rationale, current research is examining it (Transportation Research Board 2006). Furthermore, the lines were not laid across intersections or driveways.

Because there were no other significant road upgrades or changes on this section of state highway around the period of the ATP line installation, Land Transport NZ conducted an informal evaluation of the crashes that had occurred on this section of road before (five-year period) and after (three-year period) the installation of the ATP edgelines. In 1996, the AADT for this section of road was approximately 7000–8000 vehicles per day (depending on the measurement site) and in 2004 approximately 10,000–12,000 vehicles per day. A 42% reduction in all injury crashes (4.6 per year before and 2.7 crashes per year after) and a 58% reduction in fatigue crashes (1.6 per year before and 0.7 per year after) was observed. A 26% reduction in run off road crashes was also observed (1.8 per year before and 1.3 per year after). Caution needs to be given to these results as the post installation evaluation period was only three years and the magnitudes of the crash reductions in some cases is relatively small. Also, there may be some overlap in the categories of crashes, which could have a confounding effect, and the 'non-treatment' crash reduction also needs to be considered. However, the difference between the pre- and post-installation crash rates on the parts that were not treated, was much smaller than that for the treated areas. This indicates that the ATP lines resulted in a reduction in the crash rates greater than the other confounding variables.

4.1.2 State Highway 8, Twizel – Omarama, South Canterbury

In 2001, ATP edgelines were also installed on a 35 km section of State Highway 8 between Omarama and Twizel. The treatment was prompted by a history of fatigue and loss of control crashes on this section of road. In the five-year period prior to the treatment (1996–2001, AADT approximately 1050 VPD) there were two serious, three minor and two non-injury crashes that involved a loss of control due to inattention/fatigue or returning to the road from the unsealed shoulder. In the five-year period (2001–2005, AADT approximately 1300 VPD) since the installation, there have been one minor and two non-injury crashes of the same nature. A subsequent BCR analysis by Transit NZ has suggested that the benefits have outweighed the costs by 14 to 1. This result is much higher than that calculated using the cost management tool developed in the present project. This is because the costs of installing the profiled lines in the Otago project were much lower than the costs used in the cost management tool. The crash reduction achieved was 40% rather than the literature-based 25% which is the default setting in the cost management tool.

When the details of the Otago project were used to conduct a BCR analysis using the cost management tool (with a crash reduction factor of 25%), a BCR of 11 was achieved. When a 40% crash reduction was used (as per the Otago analysis) a BCR of 13.4 was achieved, which is very similar to the BCR reported by the Transit NZ evaluation. To some degree, this agreement demonstrates both the validity of the cost management tool and confirms the effectiveness of the ATP lines. It is unclear whether the Otago analysis has included the crash reduction that would have occurred had no treatment been carried out. Historically, the number of injury accidents nationwide has been decreasing by approximately 0.85% per year since 1986. This would mean that the net effect of the Otago treatment might have been closer to a 32% crash reduction, which would have the effect of reducing the BCR to approximately 11, which is at the lower bound of the BCR that has been calculated in the Transit NZ evaluation, and is still in agreement with the output from the cost management tool.

A major difference between this project and the ATP lines that were installed on State Highway 1, south of Christchurch, was that the ATP lines were installed on roads with shoulders 0.75 m and wider while south of Christchurch the ATP lines were only laid on roads where a shoulder of 1.5 m or more existed.

4.2 Non-state highway rural roads

It appears to be clear that based on the benefits and costs, ATP edge and no overtaking centrelines could be applied more widely on New Zealand's state highway network. However, of the approximately 90,000 km of road that exists in New Zealand, only about 11% is designated as state highway. There may also be a net benefit in treating many non-state highway roads with ATP lines. In order to determine whether this is true, the benefits and costs as well as some practical implications need to be explored for non-state highway roads.

4.2.1 Example: Alfriston-Ardmore Road, Manukau City

Alfriston-Ardmore Road (Figure 4.2) is a typical non-state highway rural road with the following characteristics:

- Road length: 3 km
- Terrain: flat/rolling
- Lane width: 2.9–3.0 m
- Shoulder: 0.1–0.3 m
- Traffic: approx 2600 VPD
- Curves: 9
- Bridges: 1
- Other features: one long straight followed by a 55 km/h left-hand corner
- Expected number of injury crashes per year along route: 0.70
- Actual number of injury crashes per year along route: 0.20

The delineation cost management tool was used to evaluate an upgrade on this section of road. The upgrade included:

Edge and no overtaking centrelines to ATP CAP (150 wide, with 250 mm centres)

This treatment resulted in a BCR of 3.8 using expected injury accidents and a BCR of 1.1 using actual injury accidents. Note that the BCR would be higher if thermoplastic were used due to its lower cost. Also, this evaluation is simplistic as it assumes that ATP no overtaking centrelines would be applied along the entire length of this section of road (as there are few sections of road suitable for overtaking same direction vehicles). In reality, only sections of road are likely to be applied with this treatment.

Although the cost management tool gives a BCR greater than 1.0 for both actual and expected crashes, there are some practical implications associated with installing ATP lines on rural roads such as Alfriston-Ardmore Rd that need to be considered. This road has a relatively narrow lane width and, at times, an almost non-existent shoulder. Recreational cyclists also commonly use this area. Without a sufficient shoulder width for cyclists and with a relatively narrow lane width, adding ATP edgelines may provide a safety hazard to cyclists. Also, ATP no overtaking centrelines might prevent motorists from giving cyclists a safe passing distance in the course of trying to avoid crossing the centreline. ATP edgelines may be beneficial if there were sufficient shoulder width to accommodate cyclists. An example of this is Puhinui Rd and George Bolt Memorial Drive, which serve Auckland Airport. The safety implications of ATP lines for cyclists are discussed further in the next section. Also, as has been discussed in the case study earlier in this report (4.1.1 State Highway 1 south of Christchurch), ATP lines used in conjunction with little sealed shoulder may cause problems for motorists responding to their audio tactile effect.

Figure 4.2 Typical non-state highway rural road: Alfriston-Ardmore Rd, Manukau City.

5. Practical implications and limitations

5.1 Different regional injury accident social costs

The default accident social cost that has been used in the cost management tool is for a rural injury accident (fatal, serious and minor) for New Zealand (Ministry of Transport 2006). This has been used to indicate an approximate BCR that might be expected from treatments at a nationwide level. In practice, there are different costs associated with different regions. For any regional analysis, the region-specific accident costs should be used.

5.2 Safety benefits based on overseas data

It must be remembered that the 25% crash reduction factor used as the default for ATP edge and centrelines is based mostly on North American studies where there is a greater proportion of separated carriageways and different ATP treatments. In the USA, rumble strips are often physically rolled or milled into the road surface. Indentations or raised parts of the actual road surface are used to create an audio tactile effect. Despite these overseas differences, the case studies outlined earlier in this report provide early indications that ATP lines have safety benefits that are of a similar magnitude to what has been reported overseas.

5.3 No crash reduction data for wet-night retroreflectivity

Although an audio tactile effect appears to be a significant safety feature in road marking, retroreflectivity is also an important consideration. No data could be found on the safety benefits of different levels of wet-night retroreflectivity and so evaluating the cost effectiveness of products with significant wet-night safety benefits using the cost management tool is currently limited. Obtaining sufficient wet-night retroreflectivity of markings appears to be a challenge but is increasingly being considered as a performance measure by roading authorities. If the safety benefits of wet-night retroreflectivity were known, then the benefits of delineation treatments such as thermoplastic 'Rainline' and structured CAP, which have excellent wet-night retroreflectivity, could be evaluated using the cost management tool.

5.4 Variations of audio tactile profiled lines

For the purposes of this project, standard ATP lines have been considered. Usually, ATP lines consist of extruded or sprayed thermoplastic or CAP with intermittent blocks of the same product. Variations of this process are often used so that either the safety benefits might be improved or the costs reduced. In order to save costs, blocks of thermoplastic or CAP can be laid down and then a sprayed paint line applied over the top of the bumps in a second run. This saves the material costs of thermoplastic or CAP, but results in a line which will typically wear more quickly than the blocks and will require re-spraying.

Another variation is the practice of laying CAP bumps outside of a continuous CAP or painted line (Figure 5.1). Because CAP is a two-stage process, where the blocks are laid and then a line is sprayed over the top, there is no additional cost in having the blocks adjacent to the line. This arrangement gives added safety by doubling the virtual width of the line. At present, the tangible safety benefits of this practice are unknown.

Figure 5.1 ATP cold applied plastic bumps adjacent to a continuous line (Source: Rob Dunne, Damar Industries Ltd).

The centreline treatments that have been examined in this study have been limited to no overtaking centrelines, as this is where ATP treatments are currently used. Other centrelines such as single dashed white lines, continuous white lines or continuous single yellow lines with dashed white in the opposing direction may benefit from ATP treatment, but due to the possible mixed messages that they may cause, a thorough investigation of these possibilities is needed.

5.5 Limitations of product life, treatment costs data and post installation information

Based on a considerable amount of consultation for this project, a four-year life for ATP treatments appears to be reasonable. However, there seems to be considerable variation in the product life that is achieved depending on who is providing the information, the road environment and traffic volume, product type, seal type and condition, application thickness, maintenance issues and costs, and the criteria that are used to determine the need for re-marking. Some ATP lines may remain adhered to the road surface for four or five years but lose a significant amount of their audio tactile effect after only three years. All of these factors need to be considered when determining the treatment life. Because of the many factors that can affect product life, the cost management tool provides an easy mechanism for changing product life.

The cost management tool that has been developed does not differentiate between all of the performance measures that might be associated with different products. For example both thermoplastic and CAP ATP lines may be attributed with a 25% crash reduction based on previous studies, yet they may differ in terms of their wet-night retroreflectivity, durability, skid resistance and overall cost. It appears that thermoplastic is currently cheaper to install than CAP and so would perform better in a BCR analysis. However, until information regarding other factors such as the safety benefits of retroreflectivity, treatment life, environmental and health considerations are determined, it is difficult to consider objectively the merits of using different products. Anecdotally, it has been claimed that CAP ATP lines may offer superior overall performance to thermoplastic, but are more expensive.

Different products are also prone to price fluctuations, which can affect the rationale for their use. In Australia, laying ATP thermoplastic in the 1990s has been reported as costing $5,400 per km, based on a 150 mm wide edgeline (Woolley and McLean 2006). Currently, in South Australia, thermoplastic audio tactile marking costs approximately $1,500 to $1,800 per km to install on larger projects.

Post-installation costs and practical issues also need to be considered further. Attempts were made to determine some of the on-going maintenance costs and issues such as line removal, but much of this information could not be obtained. This is at least partly because some of the products used are relatively new and so many of these issues are still being worked through. Over-spraying and removal of ATP lines and snow ploughing are examples of areas where more information is needed.

In refining our understanding of the costs and benefits of improved road markings, the extra costs and practical considerations associated with them should be examined.

5.6 Practical implications for cyclists

It has been suggested that ATP lines may represent a hazard to cyclists. Walton et al. (2005) stated that 'The concept of locking cyclists into a cycling space and locking motorists out of this same space with a continuous raised profiled marking, or another type of restricting device (eg close-spaced raised pavement marker) is strongly not recommended'. However, the authors also found that a line marking of as low as 0.5 mm can induce a similar level of cycle instability to an ATP line, and so perhaps more consideration of the instability caused by ATP lines needs to be given. Recently, Charlton (2006) found that ATP lines were associated with improved lane keeping and less instances of line crossing among motorists. Given these findings, it would be prudent to compare the risk of accidents associated with cyclists losing control when riding over ATP lines with the benefit that ATP lines bring by improving the separation between motorists and cyclists. If the benefits associated with improved separation outweigh the risks associated with the presence of an ATP line, then their use should be promoted rather than discouraged. Clearly, a reasonable cycle lane width or road shoulder would need to be present in order to justify the use of ATP lines between cyclists and motorists. Cyclists are not allowed on motorways so the use of ATP edgelines in relation to cyclists is not an issue.

A number of North American studies have addressed the safety of rumble strips and in many cases have suggested more cyclist friendly designs (Bachman 2001, Outcalt 2001, Torbic et al. 2001). However, comparisons with North American rumble strips need to be treated cautiously as their design is very different from the ATP lines that are used in New Zealand. North American rumble strips are typically rolled or milled into the pavement's surface, are typically 300–400 mm wide and are located in the middle of the shoulder or on the outside of the edgeline. (More details of North American rumble strips are given in the review of land delineation by Baas et al. 2004.) Clearly this design would provide more of an obstacle for cyclists than the ATP lines that exist in New Zealand.

Despite the lack of evidence for the danger caused by ATP lines to cyclists (and more work needs to be carried out in this area), it would clearly be beneficial if cyclists didn't have to ride over them. Some of the improvements in rumble strip design that have been suggested include variations in the gaps between the ATP blocks and the height of the blocks themselves. Another cycle friendly approach that has been suggested is to create frequent gaps between the rumble strip treatments so that cyclists can navigate between them periodically if they need to leave the shoulder and enter the traffic lane. Outcalt (2001) cites the Colorado Department of Transportation, which has suggested that rumble strips should not be used when the road shoulder is less than 1.2 m. However, it must be remembered that the rumble strips can be up to 400 mm wide in the United States, with a 100 mm gap between the edgeline and the rumble strip. This would mean that 700 mm would be a minimum shoulder width when New Zealand style ATP lines are considered (although a minimum of 1 m is generally accepted as a minimum cycle lane design envelope). The recent practice of placing audio tactile bumps outside of a line (as mentioned previously), may reduce the available shoulder width to cyclists, which may become problematic when the shoulder width is already marginal.

In the United Kingdom, ATP road markings (called 'raised rib' markings) are essentially the same design as that used in New Zealand, with thermoplastic being the most common material. The *London cycling design standards* (Transport for London 2007) states that:

> *Additional protection of cycle lanes from motor traffic on the rest of the carriageway by physical features will increase cyclists' comfort and encourage use. Protection to cycle lanes can be provided by the following methods:*
>
> - *Hatched road markings outside the cycle lane*
> - *Intermittent traffic islands (which should not reduce the cycle lane width)*
> - *Reflective road-studs (authorised for advisory but not mandatory lanes)*
> - *Raised rib markings (requires DfT authorisation).*

This suggests that in London, ATP lines are considered to be an effective way of separating traffic and cyclists. A difference is that the height of the blocks recommended for cyclists is 6 mm (maximum 8 mm)[1] instead of the target 7 mm bumps (11 mm maximum overall height) specified in New Zealand.

According to the Taupo District Council, ATP edgelines have recently been installed on some sections of the route used for the Lake Taupo cycle challenge which is a ride/race that circumnavigates Lake Taupo and is 160 km in length. This event will provide a test of the usability of the ATP lines by cyclists in an open road setting. Responses to ATP lines by cyclists in the Lake Taupo challenge would probably be more negative than expected in an urban commuting environment, as speeds are likely to be faster, most of the bicycles would have narrow racing tyres and there would be more cyclist fatigue.

5.7 Use in urban situations

It is widely regarded that ATP lines are not suitable for urban use (except on motorways and expressways) as the noise generated when a vehicle travels over them can be annoying for residents. In South Australia's Department of Transport, Energy and Infrastructure, the practice is to avoid installing profiled lines within 500 m of a residence (Woolley and McLean 2006). In New Zealand, the *Manual of traffic signs and markings* (MOTSAM) (Transit NZ 2004) states that '…care must be exercised when considering the use of profiled line markings in urban situations, eg urban motorways and rural township bypasses'. Although the focus of this report is on rural non-motorway roads, it is possible that rural residents may be affected by the noise created by motorists driving over ATP lines. The extent of this potential annoyance does not appear to have been formally investigated.

5.8 Specifications for ATP lines

There is currently a degree of variation in the design of ATP lines in New Zealand. This is sometimes warranted when they are placed in different locations. For example, more separation between bumps might be needed in rural open-road situations than the lower speeds that might be encountered on a motorway on-ramp. However, currently line width, bump height and spacing often differ for no obvious functional reason, although it is accepted that over time ATP lines have generally become wider. MOTSAM has a section on ATP line marking, however many of the lines that are currently being laid do not comply with MOTSAM. For example, MOTSAM states that ATP lines should be 100 mm wide with bumps at 250 mm centres, yet one of the most common ATP lines currently being laid (and accepted by road authorities) is 150 mm in width with bumps at 500 mm centres.

Transit NZ has recently published specifications for the use of ATP lines (TNZ M/24: Specification for audio tactile profiled markings), including tolerances on the dimensions of the line stripe and block. In order to simplify audit procedures, the audio tactile response of lines is represented by the height of the block. Transit NZ's specification should help to create more consistency in the design and performance of ATP lines.

---

[1] *www.dft.gov.uk/pgr/roads/tss/tsmanual/trafficsignsmanualchapter5ro4183* p 22

6. Consultation

The project required a good understanding of many aspects of road marking including product types and specifications, where and when they are typically used, estimates of product costs and the effects of associated factors such as temporary traffic management. At the beginning of the project, industry consultants (especially Ross Ridings), the New Zealand Roadmarkers Federation (Alister Harlow) and a number of other industry-related personnel were generous in the expertise they contributed to this project, so that the cost management tool reflected the practical requirements of the industry.

As the project progressed, specific product life and product costing information was required so that the default values in the cost management tool were realistic. This information was provided by road marking contractors and Transit NZ staff who had information on previous road marking contracts that included ATP lines. While the people who provided this information must be commended for their contributions given the sensitive nature of pricing and product performance information, further strength could have been given to the product pricing values through contributions from a greater number of sources, but some people were clearly not comfortable with sharing this information. Nevertheless, the more important component of the cost management tool is the ability for users to add their own project-specific product costs and this is likely to have a greater long-term benefit.

In order to give the project a realistic and practical context, a number of case studies were used. For these case studies Transit NZ and Land Transport NZ staff were very helpful in providing details of some of the delineation improvement projects that have been carried out around the country, as well as the analyses of crash rates and benefit/costs that supported the projects.

7. Further research

Many practical implications associated with the use of ATP lines and delineation improvements in general have been outlined in the previous section. Although this project has found that delineation safety improvements such as ATP lines could be implemented cost effectively in a more widespread manner, the practical implications of their use in some situations need to be more fully investigated. The design of ATP lines, their use in residential environments, minimum acceptable lane and shoulder widths and their usability by cyclists are examples of issues that have been raised. In all of these examples, there appears to be a lack of systematic information on which recommendations and guidelines should be based. There are also inconsistencies in how ATP lines are currently implemented. This may be the result of a lack of relevant and up-to-date guidance on their use and is another reason why further work should be carried out in this area.

Although some case studies have been outlined in this report, more structured research evaluating the safety benefits of ATP and other road markings needs to be carried out. This work would make estimates of the benefits associated with safety treatments such as ATP lines more accurate as current estimates are based on North American studies where different road environments exist. There appears to be little information on the safety benefits of delineation products that do not provide audio tactile feedback, but provide good wet-night visibility. This is especially relevant as conventional road markings offer poor wet-night visibility and this problem is becoming increasingly important for road controlling authorities.

8. Conclusion and emerging policy issues

A cost management tool for delineation improvements for safety has been developed. The findings of previous literature, realistic scenarios using the cost management tool and the limited New Zealand evaluations that have taken place all suggest there are significant safety benefits associated with ATP road markings. It also appears that a much greater proportion of New Zealand's road network could benefit from ATP road markings. There are a number of practical considerations that need to be more fully considered when using ATP road markings in marginal situations. Although the safety benefits that support the cost management tool are currently restricted to ATP road markings, the capability of the tool will evolve as further information regarding the safety benefits of other treatments, such as those that have excellent wet-night retroreflectivity, become available.

Based on the significant net benefits of ATP road markings presented in this report, it is recommended that policy be developed to enable the more widespread use of ATP road markings. A two-stage implementation process is needed. ATP road markings could be installed immediately where a significant shoulder exists (1.5 m is the Transit NZ shoulder width requirement where traffic exceeds 4000 vehicles per day) and where there is little chance of residents being affected by noise. The use of ATP road markings in rural environments where little sealed shoulder exists or where residents live nearby, should be avoided until further research is carried out to determine if they would have any adverse affects on residents and road users.

The cost management tool has been developed for road controlling authorities and they should be encouraged to use it. The tool will help to inform and give objectivity to highway managers' decision-making regarding the use of delineation improvements such as ATP road markings. If the use of the cost management tool is valued, then further efforts are required in order to facilitate its use and develop it further.

9. References

Agent, K. R., Stamatiadis, N. and Jones, S. 1996. Development of accident reduction factors. *Research Report KTC-96–13*, Kentucky Transportation Center, College of Engineering, University of Kentucky.

Baas, P. H., Charlton, S. and de Jong, D. 2004. *Review of lane delineation.* A report prepared by TERNZ for Transit New Zealand.

Bachman, D. 2001. Rumble strips: Finding a design for bicycles and motor vehicles. *Transportation Research News 215*, 28–29.

Charlton, S. 2006. *South Waikato and Taupo target 2010 remediation treatments monitoring.* Prepared for SWATT 2010 Corridor Study Team by TERNZ Ltd and TARS (Waikato University).

Corkle, J., Marti, M. and Montebello, D. 2001. Synthesis on the effectiveness of rumble strips. *MN/RC – 2002–07*. St Paul: Minnesota Local Road Research Board. 60 pp.

Land Transport New Zealand. 2005. *Project evaluation manual* (PEM). Wellington.

Ministry of Transport. 2006. The social cost of road crashes and injuries: June 2006 update. *www.transport.govt.nz/assets/NewPDFs/NewFolder/Social-cost-June-2006-update.pdf*

New Zealand Road Markers Federation. 2004. Safety, Health and Environment Guide: Roadmarking materials. *www.nzrf.co.nz/docs/MaterialsGuide0404.pdf*

Outcalt, W. 2001. Bicycle-friendly rumble strips. *Report No. CDOT-DTD-R-2001-4*. Colorado Department of Transportation.

Torbic, D, El-Gindy, M. and Elefteriadou, L. 2003. Methodology for quantifying whole-body vibration experienced by bicyclists. *International Journal of Vehicle Design* 31(4): 452–480.

Transit New Zealand. 2004. *Manual of traffic signs and markings* (MOTSAM). *Part II: Markings.* 3rd ed. Wellington.

Transport for London. 2007. London cycling design standards. *www.tfl.gov.uk/cycles/downloads/pdf/lcds_chapter4.pdf*

Transportation Research Board. 2006. Operational effects of shoulder and centerline rumble strips on two-lane undivided highways. *http://rip.trb.org/browse/dproject.asp?n=12006*

Walton, D., Dravitzki, V. K., Cleland, B. S., Thomas, J. A. and Jackett, R. 2005. Balancing the needs of cyclists and motorists. *Land Transport New Zealand Research Report 273.* 92 pp.

Woolley, J. E., and McLean, A. J. 2006. Edge delineations. *CASR025.* Centre for Automotive Safety Research, University of Adelaide.