SKID RISK ASSESSMENT OF AN URBAN NETWORK

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ABSTRACT

The measurement and assessment of skid resistance is routine on New Zealand's state highway network. Some Local Authorities are now also investigating and implementing policies with respect to the skid resistance of their networks. Skid resistance is generally accepted to be a function of

- The traffic volume and heavy goods vehicles over the life of the surfacing
- The quality of the aggregate, determined by its polished stone value (PSV), and
- The surface texture.

Texture, combined with the PSV, is desirable for high-speed skid resistance, however, within an urban environment, it is not so critical as suitable skid resistance can be achieved by specifying an appropriate aggregate PSV and selection of the surfacing type.

Auckland City has recently investigated this approach, with respect to the PSV of aggregates used for asphalt and chip seal on its networks. The closure of a major quarry has necessitated recent changes in the sources of aggregate used in the region. The purpose of the investigation was to ensure network safety would not be compromised if materials from alternative sources, but potentially having a slightly lower PSV, were used.

This paper describes an approach used to investigate potential issues related to the use of an alternative aggregate source. An assessment was undertaken using the AS/NZS 4360 "Risk Management" approach and an innovative method to develop a risk matrix table and assign hazard levels and scores to prioritise and identify high risk sites.

1. SKID RISK ASSESSMENT OF AN URBAN NETWORK

1.1 INTRODUCTION

The assessment of skid resistance on road surfaces is now a routine activity on New Zealand's state highways, with the required levels of skidding resistance described in Transit's T/10 standard (1). The level of skid resistance required for a particular road section, in both the urban and rural context, is a function of:

- Traffic speed and incident events (wet crash rate, contamination etc.)
- Traffic volume and heavy vehicle numbers over the surfacing life
- Aggregate quality and its polished stone value (PSV)
- Surface type and texture
- Location – with extra consideration required at places of high demand, such as junctions, pedestrian crossings, sharp curves, gradients and traffic lights.

Some Local Authorities are now investigating and implementing policies to improve network skid resistance. While texture, in conjunction with PSV, is essential for high-speed roads (2), (3), (4), urban environments are generally a low speed situation, so this is not so critical. Appropriate skid resistance can be provided by using aggregate of suitable PSV and surfacing type (2).

A major Auckland quarry closed in 2002-2003, so an alternative source of aggregate was required for asphalt production. The PSV of the aggregates traditionally used was in the range 54-57, while readily available and suitable materials only had a PSV in the range 52-55. The test repeatability and reproducibility for PSV is 3 & 5 units (5) indicating the alternative materials were similar to those previously used. However, Auckland City needed assurance that safety was not compromised so an investigation was undertaken where the alternative was used.

Qualitative and semi-quantitative risk assessment techniques were used, to assess the consequence of hazardous site conditions, in conjunction with the likelihood of adverse event occurrence. Physical site conditions, traffic loadings, speed environment, visibility and accident records at each site were investigated and used within a risk matrix system to rank and prioritise the hazard level at each site. This paper outlines the processes used in the investigation.

2. TEXTURE LEVELS

2.1 Existing New Zealand Standards

Macro-texture is required on the New Zealand state highway network where a minimum of 0.7 – 0.9 mm MPD (mean profile depth) is specified but is not usually specified on our urban New Zealand networks, although this is changing. In comparison, newly-laid surfacings on high-speed roads in the UK are required to have a minimum texture depth of 1.5 mm sand patch (2). A high-speed road in the UK is defined by the Highways Agency as one where the 85-percentile speed exceeds 90 km/hr (6). We do not have any such definition in New Zealand.

At the time of the investigation, Auckland City had no specified requirements for macro-texture. So, in the low speed environments considered here, texture levels were not a factor investigated. There are few locations on Auckland's network where speeds are posted as greater than 70 km/hour, and these sites were not amongst those under investigation. The actual speed environments on the sites investigated was generally between 50-60 km/hr.

3. THE INVESTIGATION

3.1 Site Investigation and Assessment

The investigation and analysis was done using T/10:2002 (*Specification for Skid Resistance Investigation and Treatment Selection)* (1) and the guidelines in AS/NZS4360: 1999 (*Risk Management*) (7), to assess and prioritise the risk exposure at the 125 sites. For consistency, the same two engineers did all inspections and confirmed the discrete sections comprising

- Stop or Give Way controlled intersections (SC1)
- Approaches to junctions and roundabouts (SC1)
- Traffic lights (SC1)
- Pedestrian crossings (SC1)
- Bends with radius less than 250m (SC2)
- Sections with gradient 5-10 % and/or more than 10% (SC2).

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SC refers to the Site Category in T/10, with SC1 sites being most hazardous, requiring high skid resistance, and SC5 sites the lowest, requiring comparatively lower skid resistance. T/10, uses set investigatory and threshold levels (IL and TL), with different requirements for different levels.

T/10 assumes all sites, in a given category, present the same hazard. However, the level of consequence and risk at each site is different, due to site specific characteristics (hazards), such as:

- Traffic volume (likelihood or exposure)
- Visibility
- Speed environment
- Accident history, etc.

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All sites were assessed to identify specific characteristics and assigned to a T/10 Site Category. Some SC 2 & 3 sites were re-categorised to account for site specific features relating to traffic volumes and gradient, using procedures in T/10 (*Notes for Guidance*) (1).

4. RISK ASSESSMENT AND ANALYSIS

4.1 Overview of the AS/NZS 4360 Process

Risk has three components; the hazard, the consequence of that hazard (*safety, environmental and economic*) and the likelihood with which the hazard occurs, or is expected to occur. The three terms can be combined, as shown in Equation 4.1 below.

$$\textbf{Risk}_{\textbf{hazard}} = \textbf{Consequence x Likelihood} \qquad \textbf{(Eq. 4.1)}$$

This puts consequence and likelihood on an equal footing, implying a trade-off between the two. However, risk is subjective and can be perceived in different ways. Factors affecting risk perception on an urban network include:

- Speed levels on wide open roads, compared to congested urban streets
- Parked vehicles or obstructions impeding sight lines and causing a visibility hazard
- Driving experience, familiarity with the route, purpose of the journey
- Familiarity and acceptance of dangerous conditions (speeding on a wet night)
- Signage, etc.

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Many motorists accept risk because they perceive they are in control of the situation. However, different motorists have different perceptions. For this reason, some form of risk identification and assessment process can be useful to manage the situation. To derive a risk matrix, it is necessary to first prepare the following matrices:

- Consequence Matrix; associated with each hazardous situation and described below
- Likelihood Matrix, also considered as the hazard exposure, described at Section 6.

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A consequence matrix must take account of the hazardous situations on the network. For the network under investigation, it was decided to take account of the following hazard factors:

1. Speed environment
2. Visibility
3. Event (as described in T/10)
4. Potential skid hazard (related to the use of PSV 52-54 aggregates)

The factors were investigated, assessed and used quantitatively, to derive a consequence rating and subsequent prioritisation. Traffic volumes were taken into account as the indicator of likelihood of exposure to the risk. Surface texture was discounted, as mentioned above.

The philosophy of risk matrix processes is described in AS/NZS4360 (7) which defines a hazard as *an event having potential to cause harm or impact on a system.* In this case, the system is the individual site under investigation.

The risk level is the combination of hazard consequence and likelihood. So the objective of the investigation was to identify hazards contributing to the consequence event (road/vehicle/driver factors) and the likelihood (or exposure) of event occurrence.

4.2 Consequence Analysis

Each site was inspected and assessed to determine the specific hazards presented, to then determine the consequence of those hazards.

4.2.1 Speed Hazard

A speed check was used to assess vehicle speeds at each site, based on two factors:

- The posted speed limit in the area and
- An assessment of the actual speed environment.

The assessment of speed involved driving in the traffic stream to approximate the free-flow speed. Elements of horizontal and vertical alignment and road side features (crossings, intersections, bends, signs etc) were also considered.

While all sites were posted as 50 km/hr, the assessment indicated most sites had a speed environment up to 60 km/hr. The assessments are considered conservative, erring to an assessed higher rather than lower speed. The speed hazard rankings assigned were:

Ranking	Description of hazard
1	Less than or equal to 50 Km/Hr
2	Between 51 and 60 Km/Hr
3	Between 61 and 80 Km/Hr
4	Between 81 and 100 Km/Hr
5	More than 101 Km/Hr

Table 1: Speed Zone Classification

Within this investigation, no sites were rated above 3. In hindsight, and to take better account of speeds within an urban area, it would have been better to use two lower speed categories (<41 km/hr & 41-50 Km/hr) rather than the two higher categories given above. All sites were in Category 1 or 2; some could have been categorised differently in alternate directions (up/down hill). However, the higher-speed, reflecting the worst case, was used in both directions, providing conservatism and recognising that cars travelling downhill might use the uphill lane to pass another vehicle.

4.2.2 Visibility Hazard

Visibility at each site was assessed by observing roadside obstructions, either permanent or temporary, and the availability of safe stopping distance for the speed environment at the specific site. The length required for safe-stopping is a function of visibility, speed, driver reaction time, road surface (wet/dry) and vehicle (the latter could not be assessed).

The hazard increases when visibility is obstructed and the length of road visible to the driver is less than the safe-stopping distance. This may be a temporary or permanent feature of the site environment, where visibility has been obstructed by signs, parked vehicles or similar. The (weighted) visibility categories determined were:

Category	**Description of hazard**	**Ranking**
Good Visibility	No obstruction to visibility from at least 30 metres before the intersection, crossing, roundabout etc.	1
Visibility affected temporarily	Parked vehicles, bus stops, and alike	3
Poor visibility	Some obstruction to sight lines due to permanent fittings, fixtures, geometry, vegetation or similar	5

Table 2: Visibility Categories[1]

4.2.3 Event Hazard

This is a perceived site specific factor taking account of signage (Give Way, Stop etc), traffic lights, gradients, bends, crossings, intersections etc. Hazards associated with physical roadside features were noted and considered. Unrecorded accident sites were identified by observation of skid marks, broken lamp glass, road furniture damage etc. and the LTSA accident database was checked. The (weighted) hazard category at each site, generally using T/10 (1) are:

Description of hazard	**Ranking**
Pedestrian Crossing and Sites with accident history	5
Railway Crossing and One Way Bridges	3
Controlled Intersections and Traffic Signals	1

Table 3: Event Categories[1]

4.2.4 Skid Hazard

The assessment of skid hazard was quantitatively based on a transformation algorithm using the T/10 Investigatory and Threshold Levels (**IL** and **TL**) and the back-calculated PSV value required for each category level. The desired PSV value for the various **TL** and **IL** was derived using the T/10 formula, (Equation 4.2) where:

$$PSV = 100*SR + 0.00663*CVD + 2.6 \qquad \text{(Eq. 4.2)}$$

[1] A weighting has been assigned due to the potential for greater consequence in the described situations

SR is the Investigatory level (**IL** or **TL**) for the site;
CVD is the Commercial Vehicles (>3.5 tonne)/lane/day at the end of surfacing life[2];
PSV is the Polished Stone Value of the surfacing aggregate.

The PSV range (IL-TL) for each site was allocated into 5 categories and a arbitrary weighting assigned, depending on in which category the PSV of aggregate supplied to specific sites fell.

An assessed deficiency of 1 was assigned when the required PSV exceeded the PSV_{IL} and a value of 5 when it was lower than the PSV_{TL}. The intervals between PSV_{IL} and PSV_{TL} were pro-rata assigned 2, 3, and 4. An example of the rating for one site was:

The PSV to meet the IL and TL requirement is 58 and 48. However, the actual PSV of the aggregate used was 54. So the weighting assigned was 3. The transformation was done within a spreadsheet by nested IF-function formulae.

5. CONSEQUENCE MATRIX FOR THE HAZARDS

Following the assessment above, the consequence rating at each site was transformed using an algorithm and the weightings in Table 4 below, Equation 5.1.

Factor	**Weighting**[3]
Speed Environment	0.20
Visibility	0.15
Event	0.35
Skid Deficiency	0.30

Table 4: Weighting of Consequences

Consequence = (Speed x 0.20) + (Visibility x 0.15) + (Event x 0.35) + (Deficiency x 0.30) (Eq. 5.1)

This transformation gave an overall consequence score which was then converted to a numerical measure (1 to 5), to produce the Consequence Matrix, where higher scores lead to higher consequence levels, Table 5 below:

Measure of Consequence	Consequence Level Score
1	Between 0% and 20%
2	Between 21 % and 40%
3	Between 41 % and 60%
4	Between 61 % and 80%
5	Between 81 % and 100%

Table 5: Consequence Matrix

[2] The expected surfacing life was taken as 10 years, with traffic over this period calculated using a Growth Rate of 2 percent pa and 10 percent CVD in Year 1. These figures err to the conservative, overestimating CVD levels and GR for developed urban streets.

[3] These weightings were checked by using the LTSA crash database for New Zealand and Auckland City, which was incorporated within a sensitivity analysis, to ensure Auckland's local environment of traffic and crash-types was correctly modelled and interpreted. See also Figure 2 attached.

6. LIKELIHOOD MATRIX FOR THE HAZARDS

Traffic volume is an indicator of the measure of the likelihood or exposure to the risk, where high traffic volumes are usually equated with greater exposure or risk. Higher traffic volumes and congestion often results in lower speeds, lowering the consequent severity of an accident or adverse event.

This effect was ignored in this investigation, in the interest of taking the most adverse consequence. The traffic data was taken from RAMM records and the distribution of flow was assumed equal in both directions[4]. The traffic categories were assessed as:

Measure of Likelihood	Traffic Flow (AADT)
A	More than 15,000
B	Between 10,001 and 15,000
C	Between 5,001 and 10,000
D	Between 1,001 and 5,000
E	Less than or equal to 1,000

Table 6: Likelihood Matrix

Equation 5.1 was used to derive a ranked prioritisation for all sites under investigation and the matrix above provided an exposure or likelihood assessment.

7. RISK MATRIX FOR THE NETWORK

Following derivation of the matrices for consequence and likelihood, it was now possible to develop the final matrix for risk assessment, with the results above used to prepare a combined risk matrix of consequence and likelihood, using the descriptors given below, Table 7. In the measures of consequence below, the levels have been assigned descriptors, in keeping with routine accident investigation descriptors, showing the transformation from the quantitative score process used for site prioritisation to the qualitative measure required for the risk matrix. The descriptors accept an implied link exists between increased traffic levels and outcomes.

Level	Descriptor	Description of the Event Outcome
5	Critical	Fatality or very serious injury
4	Major	Extensive injuries
3	Moderate	Medical or hospital treatment or similar
2	Minor	First aid treatment required
1	Insignificant	No injuries

Table 7: Qualitative Measures of Consequence

Level	Descriptor	Description
A	Almost certain	Expected to occur (AADT > 15,000)
B	Likely	Will probably occur (AADT between 10,001 and 15,000)
C	Possible	Might occur (AADT between 5,001 and 10,000)
D	Unlikely	Could occur (AADT between 1001 and 5,000)
E	Rare	May occur (AADT # 1000)

Table 8: Qualitative Measures of Likelihood

[4] HGV content of the traffic stream was considered within the sensitivity analysis

The risk assessment matrix prepared is shown below, where the E, H, M & L descriptors represent extreme, high medium and low levels in the typical AS/NZS 4360 matrix and the category descriptors are the standard terms used, Figure 1.

Consequence					
Likelihood	**Insignificant (No injuries) 1**	**Minor (1st Aid Required) 2**	**Moderate (Med/Hospital treatement) 3**	**Major (Extensive injury) 4**	**Critical (Fatal, v.serious injury) 5**
A (almost certain)	H-0	H-0	E-0	E-0	E-0
B (likely)	M-0	H-6	H-0	E-0	E-0
C (possible)	L-9	M-29	H-9	E-3	E-0
D (unlikely)	L-15	L-22	M-10	H-4	E-0
E (rare)	L-59	L-65	M-7	H-4	H-0

Figure 1 Skid Risk Matrix for Auckland City Network (the numbers refer to location risk – See Outcomes, Section 8 below)

In conjunction with the prioritisation and the above matrix, the management action recommended, for each risk level, was as follows, Table 9 below, derived using AS/NZS 4360 guidelines. The timelines suggested below are for consideration only.

Level of Risk	Situation
E: Extreme	Immediate action and mitigation strategy required to manage skid risk
H: High	Mitigation strategy needed to manage skid risk; schedule regular review
M: Moderate	Review and monitoring required so the skid resistance will not deteriorate into the High or Extreme risk category
L: Low	Routine Review required so it does not deteriorate further

Table 9 Network Management Actions

8. OUTCOMES

From a network management perspective, it would be desirable for all sites to be in the **M** to **L** region of a risk matrix. Alternatively, if we know where potential **E** and **H** sites are, we can prioritise action. While the approach described is both qualitative and quantitative, it can identify and prioritise action at individual sites, to maintain skid resistance within a skid category.

Using the process described above, the potential for risk at each site was assessed, along with the likelihood of occurrence, to assign a rating (**E, H, M** & **L**) at each site.

Using this approach, some 242 stretches of urban road network were assessed in 125 RAMM sections. The results indicated that the safety level on the network was not compromised, the actual PSV of the material used being more than adequate to satisfy most demand requirements. Similarly, there were no issues with durability so the expected life cycle was not compromised.

The following outcomes of the investigation are highlighted:

- A pedestrian crossing and two major intersections were identified as sites of extreme (E) risk. It was recommended that these SC1 sites should be considered for treatment with calcined bauxite or similar high skid resistance treatment. Traffic volume and the actual speed environment contribute significantly to the high risk at these sites.

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- Although their assessed skid resistance was above the IL, four locations are exposed to (H) high risk due to very high traffic volumes only. Another four locations are similarly exposed, to a lesser degree. Most sites fall in the low-medium risk categories (Figure 1 above).
- Some sites, where aggregates of PSV higher than the specified 55 is required, in accordance with the T/10 approach, were found to be exposed to low-moderate risk, due to low traffic volumes.
- About 15 percent of the area investigated would require aggregate with PSV up to 66, significantly higher than specified, to satisfy T/10 IL criteria.
- The analysis demonstrates that the residual risk, associated with using aggregate of PSV in the range of 52-55, is minimal.
- A sensitivity analysis was used to determine if changes in traffic growth rate or heavy vehicle content would have much affect on the outcomes. Figure 2 below indicates minimal effect. Table 2 also indicates the relative proportions of the network in the various risk categories.

9. DISCUSSION

Using the process outlined, it was demonstrated that the use of aggregate with lower PSV than that traditionally used will not constitute an unacceptable level of risk acceptance.

To use the process, reasonable definitions of the various hazards etc. were required to estimate the consequence of an event. Defining a "*rule-set*" to identify the hazards, Section 4 above, helps to prioritise consequences for each hazard event then defined by the descriptors above. The descriptors are indicative and could be modified, depending on the situation encountered. The overall consequence of the various hazards can then be assessed using the weighted summation approach or other similar techniques.

It is also desirable to agree *rule-sets* (8) for the consequence and likelihood ranking, Tables 7 & 8. Without a good *rule-set*, the prioritisation may be astray. Some issues to consider when using an AS/NZS4360 matrix for prioritising skid sites are:

a) The matrix values and classifications should be matched to the potential consequences and likelihood of exposure. A 3x3 matrix could have used in this investigation; although the upper levels of speed, and also exposure, were above the levels encountered in this investigation, an early decision was to go with the 5x5 matrix to develop a tool that could be used in other situations.

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b) Analysts must be aware of the potential, when using a 3x3 matrix, of the possibility of introducing bias to the mean. A 5x5 matrix can also suffer from this problem but the extra two categories usually will overcome issues with the 3x3 matrix. Using more than a 5x5 matrix introduces unnecessary complexity.

c) A matrix is a good tool for low consequence, high likelihood incidents. It is not a good tool for high consequence, low likelihood events (i.e. major hazards), when other factors might need to be considered. In this instance, the procedure is acceptable.

d) The approach can be applied to hazards in (d), if the rule-set is carefully selected, i.e. full understanding of the risk of high consequence and low likelihood of some events.

e) High consequence and low likelihood events require specific analysis. (*The pedestrian crossing mentioned above is on a major arterial road with high morning and evening peak traffic – but with low pedestrian crossing movements. Although the crash database does not indicate a problem, the consequence of an event involving a pedestrian will probably lead to an H-E event at this site*).

An outcome of this investigation, in conjunction with other work more recently completed by Auckland City, has been a revision to its requirements for surfacing aggregates. This has been revised in its current asphalt specifications to reflect the findings described, with a minimum PSV value of 52 now specified, with provision to use higher levels where warranted. The use of a lower level PSV reflects the general scarcity of high PSV aggregate in the Auckland region.

The investigation provided an ideal opportunity for the Traffic and Roading Services Group (TARS) of Auckland City to consider whether a T/10-type approach should be used within its urban environments. The investigation indicates that within Auckland's low speed environments, a T/10 approach might result in the specification of inappropriately high PSV aggregate, when simply using Eq. 5.1 above without consideration of other factors, such as speed and location.

This is not a criticism of the T/10 approach, merely an observation on its appropriateness within an urban city environment. T/10 was used in this investigation to benchmark and assess the identified issues due to the use of an aggregate that potentially had failed the specification.

There is no doubt, however, that a T/10 approach should be considered for use on high speed roads, arterials and collector routes within an urban area.

Finally, the investigation is a good example of engineering and risk management used in combination to find a solution to a potential resource problem.

10. RECOMMENDATIONS

The method of assessment used a risk assessment process to individually assess sites within the broad banding inherent within the Transit T/10 specification. Therefore, site hazard and risk analysis based upon T/10 and AS/NZS: 4360, and the principles outlined in this paper, can be used as the basis of an urban road skid risk prioritisation.

The framework developed can be also used for network management and decision making. The investigation has indicated the Auckland City urban area can be surfaced with lower PSV aggregates than indicated by the T/10 approach (Eq 5.1), with less than 4 km of the total Auckland network requiring aggregate with PSV exceeding 53.

Routine network level investigations for assessment of skid resistance should not be necessary if appropriate surfacing aggregate selection policies are followed. Using the framework described, a network wide inspection could be carried out a regular intervals, say every three years and a specific database could be developed to include sites to be considered for provision of a higher level of skid resistance, such as the sites identified above.

The investigation described here was reasonably intensive; however, a full network review could focus on major arterials and collector roads, junctions, crossings, schools and other such locations where local traffic and pedestrian conflicts with passing traffic might occur.

Local Authorities could usefully consider the practicality and advisability of adopting a process similar to that undertaken in this investigation, to manage the risk-related skid issues that might arise from time to time on their networks. A process such as described provides a prioritisation tool and the evidential record of a sound asset management system. It also provides a means to avoid the use of scarce high PSV aggregates in locations where they are not necessarily required.

11 ACKNOWLEDGEMENTS

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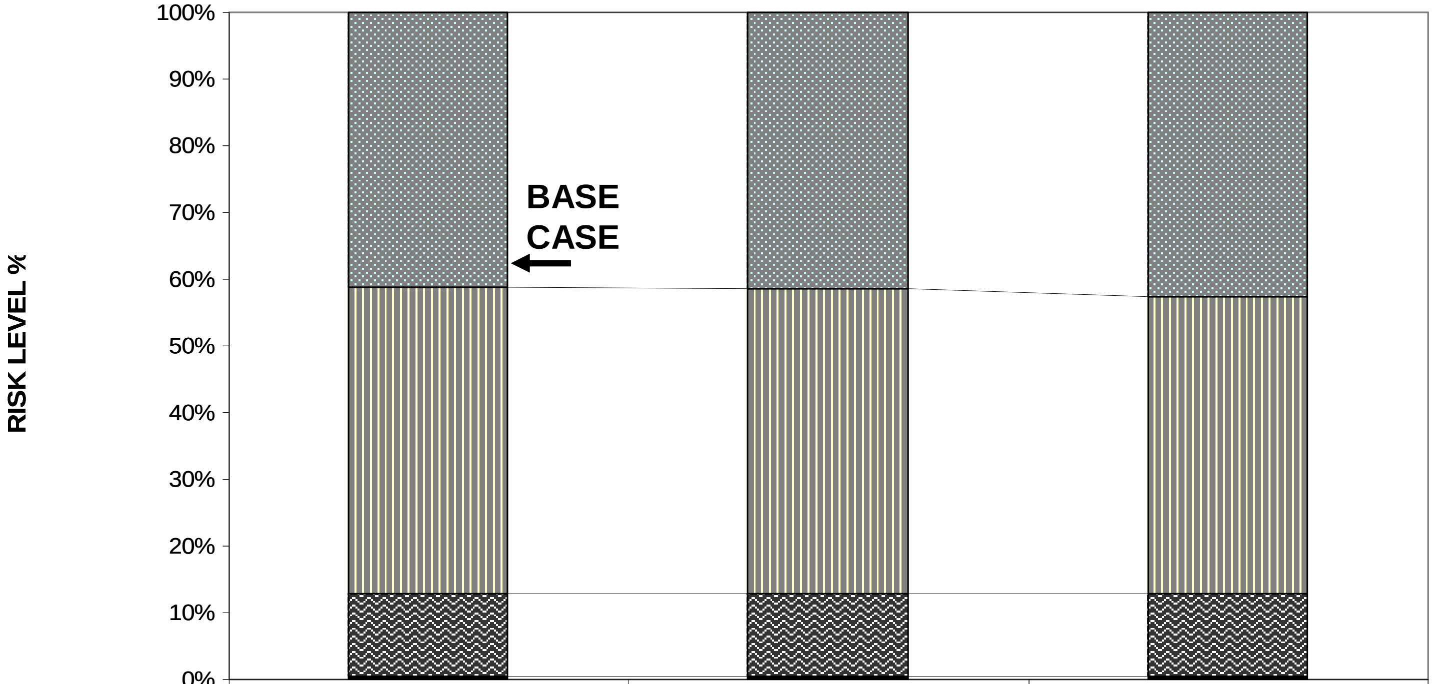
13. DISCLAIMER

Any opinions expressed above are those of the authors. They should not be taken as those of Works Infrastructure Ltd or Auckland City Council.

Any recommendations offered are in the context of improving the state of art in New Zealand and the application of risk management processes within the wider context of highway network management.

Figure 2: SENSITIVITY ANALYSIS - % OF TOTAL AREA AT DIFFERENT RISK LEVEL WITH VARYING %HCV AND TRAFFIC GROWTH RATE



	HCV=10%	HCV=10-3%	HCV=8-2%
Low Risk	41.2%	41.4%	42.5%
Moderate Risk	45.9%	45.8%	44.6%
High Risk	12.4%	12.4%	12.4%
Extreme Risk	0.5%	0.5%	0.5%