RISK MANAGEMENT AND ITS APPLICATION TO TRANSPORT NETWORK MANAGEMENT

Alan Nicholson

University of Canterbury, Christchurch, New Zealand

Abstract

Risk management has been practised in one form or other for well over 3500 years. In the last few decades, its use has increased dramatically, as has the formalisation of the methodology of risk management. This paper reviews the risk management methodology, including risk identification, risk analysis, risk evaluation, risk treatment and risk communication. The paper will focus on the application of risk management to two aspects of transport network management, namely improving network resilience and network safety. Initiatives and priorities for improving transport network management are discussed.

Introduction

Risk has existed for a very long time. People have long pondered the future and worried about the things that could go wrong. Some people were fatalistic and attributed whatever happened to the will of the gods. However, the origin of the word 'risk' is the Latin word '*risicare*', which means 'to dare' (Smith, 2003), which in turn means to act with courage and boldness. Such action must be preceded by a decision by a person to act in such a way. Hence, what goes wrong is not pre-determined or pre-ordained, but depends upon the decisions and actions of people, and risk management is based on the view that we can influence what happens.

Elms (1998) notes that the first written evidence of systematic risk management can be found in the Code of Hammurabi, the King of Babylon in about 1800 BC. This Code considered both physical risk (the focus of this paper) and commercial risk. With respect to the former, it prescribed that if a building collapsed and killed the owner's son, then the builder's son would be put to death! It dealt with commercial risk by providing for a form of insurance whereby an investor would take on the risk of a voyage in exchange for a share of the profits.

It is worth noting that Hammurabi was concerned with transport network performance, and was of the view that a grid pattern was better than less regular patterns, and arranged for the Babylon's streets to be laid out in a grid pattern.

Risk has been defined (SA/SNZ, 2009) as "the effect of uncertainty on objectives", with the purpose of risk management being to coordinate the cost-effective application of resources to minimize, monitor, and control the probability and/or impact of events which might impede achievement of those objectives. Risk management has been practised in many diverse areas of human activity for many years, including dealing with uncertainty in financial markets, threats from project failures, legal liabilities, credit risk, accidents, natural disasters and deliberate attack by an adversary.

There has been a myriad of risk management guidelines developed for particular situations, but there has recently been a concerted effort to develop a generic risk management guideline (SA/SNZ, 2009), which is consistent with the ISO standard (ISO, 2009a and 2009b), and which can be applied and adapted for any public, private or community enterprise, association, group or individual. That is, the SA/SNZ (2009) guideline is 'generic' and was not developed for a particular industry group, management system or subject matter field in mind. The guideline provides best practice structure and guidance to all operations concerned with risk management.

The SA/SNZ guideline defines a risk management framework which includes five steps:

- establishing the context;
- risk identification;
- risk analysis;

- risk evaluation;
- risk treatment.

The second, third and fourth steps together comprise ‘risk assessment’.

The purpose of the first step (establishing the context) involves articulating the organization’s objectives and the internal and external factors that give rise to risk and can affect how risks are treated. It involves identifying the relevant stakeholders with whom communication and consultation will be needed. It also clarifies the scope and purpose of the subsequent risk assessment, and aids development of criteria against which risks will be evaluated.

The second step (risk identification) involves identifying risk sources, events, their causes and their potential consequences, using historical data, theoretical analysis, expert opinions and needs of stakeholders.

The third step (risk analysis) entails comprehending the nature of risk and determining the level of risk, expressed in terms of the combination of consequences and their likelihood. The term ‘likelihood’ is the chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described in general or mathematical terms. This term is preferred to probability, because the latter is often interpreted narrowly as a mathematical term.

Risk analysis involves four activities:

- estimating the consequences of events;
- estimating the qualitative, semi-quantitative or quantitative likelihood of events;
- estimating the level of risk;
- assessing the effectiveness of any existing controls.

The fourth step (risk evaluation) entails comparing the result of the risk analysis (i.e. the level of risk) with risk criteria established during the first step (establishing the context), to determine whether the level of risk is acceptable or not acceptable (i.e. whether there is a need for risk treatment).

The fifth step (risk treatment) involves deciding what action to take. If the level of risk is acceptable (e.g. the likelihood is sufficiently small and/or the consequences are sufficiently minor), one can decide to do nothing, but if it is unacceptable or intolerable, there are three options:

- avoid the risk, by making a fundamental change so the risk is no longer an issue (e.g. eliminating the risk by eliminating the hazard or the exposure to the hazard);
- reduce the risk, by taking action to reduce the likelihood of occurrence of the event causing the risk and/or to reduce the consequences of the event if it occurs (the latter option is commonly called mitigation);
- transfer the risk to another organisation.

Transferring the risk to another organisation is sensible if and only if that other organisation is better equipped to avoid or reduce the risk (e.g. possesses a higher level of expertise), or is better able to survive any adverse the consequences. For instance, if one transfers the risk to a contractor who is not better equipped to avoid or reduce the risk, or is unable to survive the consequences, the cost of dealing with the consequences might well fall back onto the client, due to the contractor failing financially.

Each of the five steps must be supported by appropriate communication and consultation, to inform and obtain the views of stakeholders. In addition, each step should be subjected to continual monitoring and review, to detect any change in the context, the information used during the risk identification and risk analysis, the acceptability of risk, and the options for treating the risk.

Figure 1 describes structure of the SA/SNZ (2009) risk management framework.

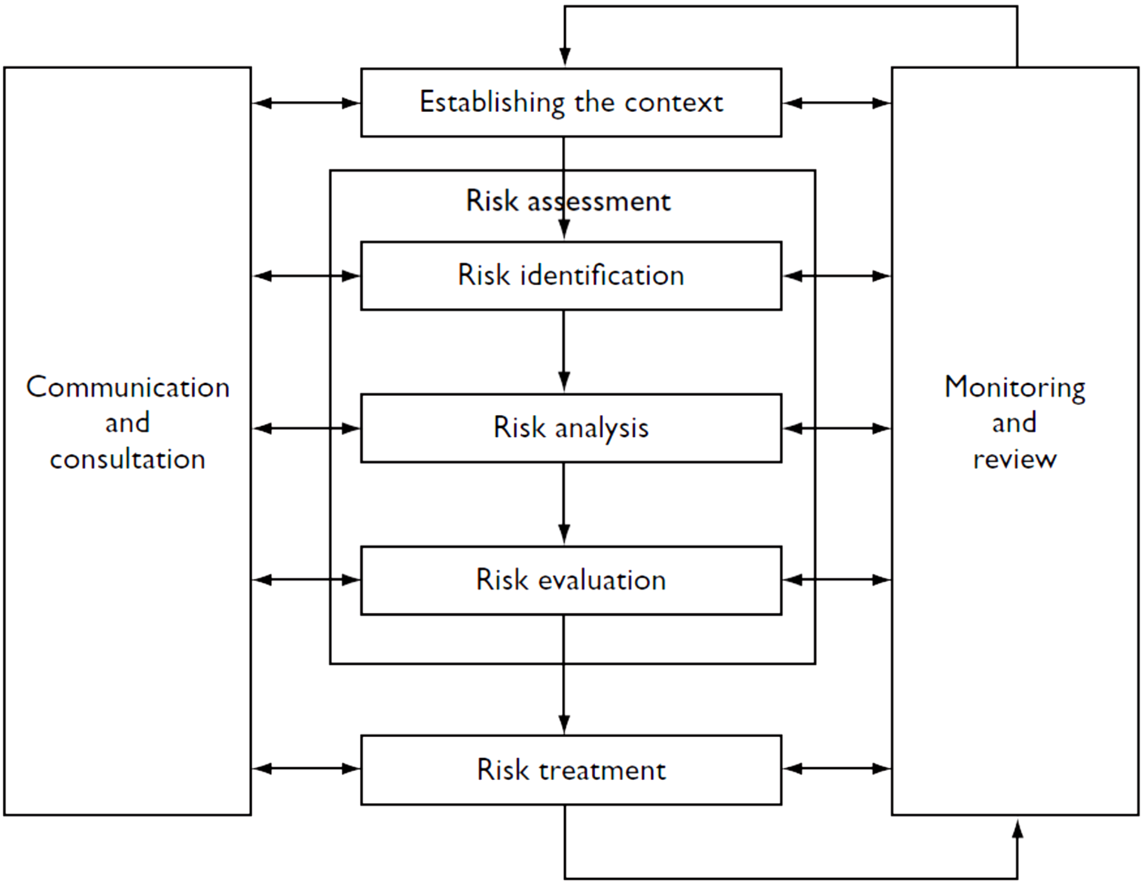

Figure 1: The ISO 31000 Risk Management Framework

Risk Assessment

Risk assessment provides decision-makers and responsible parties with an improved understanding of risks that affect achievement of objectives, and of the adequacy and effectiveness of existing methods for controlling the risk.

As noted above, the risk analysis stage can be divided in to four steps, giving, with risk identification and risk evaluation, six steps in risk the assessment stage. A recent study (SA/SNZ, 2013) has identified a total of 30 techniques which can be used during risk assessment (see Table 1), and has rated the applicability of each technique to each of the six parts of the risk assessment stage.

Brainstorming	Cause-Consequence Analysis
Structured or Semi-Structured interviews	Cause & Effect Analysis
Delphi Techniques	Layers of Protection Analysis (LOPA)
Checklists	Decision Tree Analysis
Preliminary Hazard Analysis (PHA)	Human Reliability Analysis
Hazard & Operability Studies (HAZOP)	Bow-Tie Analysis
Hazard Analysis & Critical Control Points	Sneak Circuit Analysis
Toxicological & Eco-toxicological Risk Assessment	Markov Analysis
Structured What-If Techniques (SWIFT)	Monte Carlo Simulation
Scenario Analysis	Bayes Analysis & Nets
Business Impact Analysis	F-N Curves
Root Cause Analysis	Risk Indices
Failure Mode & Effect Analysis (FMEA)	Consequence/Likelihood Matrix
Fault Tree Analysis	Cost-Benefit Analysis
Event Tree Analysis	Multi-Criteria Decision Analysis

Table 1: Risk Assessment Techniques

Each technique was assessed or rated as being either ‘strongly applicable’, ‘applicable’ or ‘not applicable’. Only one technique (the ‘Structured What-If Technique’) is strongly applicable for all six steps. The next most useful techniques are ‘Toxicological & Eco-toxicological Risk Assessment’ (five ‘strongly applicable’ and one ‘applicable’ assessments) and the ‘Failure Mode and Effect Analysis’ and ‘Consequence/Likelihood Matrix’ (both with four ‘strongly applicable’ and two ‘applicable’ assessments).

Two of the steps of the risk assessment process, Risk Identification and Risk Analysis (Consequence), are the most well-endowed with suitable techniques, with both having fifteen ‘strongly applicable’ and nine ‘applicable’ techniques, and only six ‘not applicable’ techniques. The Risk Analysis (Level of Risk) step is the least well-endowed with suitable techniques, with only nine ‘strongly applicable’ and ten ‘applicable’ techniques, and eleven ‘not applicable’ techniques.

The SA/SNZ (2013) guideline suggests seven principles which should be followed in risk assessment.

- The risk assessment process should be systematic and structured:
    - contributes to efficiency and to consistent, comparable and reliable results;
    - provide a level of assurance that a logical process is followed to identify all important risks and that methods of analysing risks are valid.
- Risk assessment methods should be logically and mathematically correct.
- Risk assessment should be based on best available evidence:
    - risk assessment should be based on valid data, information and research, and it is necessary to collect such data if it is not already available;
    - expert opinion should be informed by evidence and data wherever possible;
    - perceptions about risks and the level of risk may be considered when identifying issues of concern and making decisions about acceptability, but should be supported by more objective evidence;
    - the limitations of data and information, or models and techniques used to analyse them, should be discussed.
- People with appropriate competency should be involved:
    - a thorough knowledge of risk assessment, and the techniques to be used, is required;
    - a similar earlier assessment may be used, provided that any changes that have occurred in the interim will not produce a significant difference in the results.
- Uncertainty should be addressed explicitly:
    - risk is the effect of uncertainty, and understanding risk therefore inherently involves addressing uncertainty in all steps of risk assessment, whatever technique is used;
    - a formal sensitivity analysis, or a qualitative discussion, is required.
- The form and rigour of risk assessment should be appropriate for the decision to be made:
    - the results of risk assessment should be presented in a form that is useful and informative for decision-makers.
- Human and cultural factors should be taken into account when assessing risks:
    - such factors must be considered when identifying risks, assessing controls, analysing consequences and likelihood, and assessing the significance of risk;
    - such factors must also be considered when deciding on recommendations, so they are practicable and likely to be implemented.

Finally, SA/SNZ (2013) notes that risk assessment may require a multi-disciplinary approach, as risks may cover a wide range of causes and consequences.

Communication and Consultation

Risk management, to be successful, requires effective communication and consultation with stakeholders, during all stages of the risk management process.

Communication and consultation during risk assessment is important because:

- identification of the full range of hazards is not easy and wide communication and consultation helps to ensure that as little as possible is overlooked;
- stakeholder's actions may affect the consequences and/or likelihoods, and hence affect the level of risk;
- it can be difficult to communicate the results of risk analysis to non-specialist stakeholders, and appropriate communication and consultation from the beginning helps ensure widespread awareness and acceptance of the process, and a better understanding and acceptance of the results;
- if specialists are used, they need to understand each other clearly and communicate effectively to decision-makers, and resources for communication and consultation between the stakeholders and different specialists involved in risk analysis need to be planned.
- communication and consultation help to ensure that those responsible for implementing recommendations that arise out of a risk assessment, understand the reasons for those recommendations and will implement them.

According to the US Environmental Protection Agency, while there are no easy prescriptions for successful risk communication, those involved in risk communication generally agree that there are seven cardinal rules which should be followed (EPA, 1988). Those seven cardinal rules are as follows:

- accept and involve the public as a legitimate partner;
    - people and communities have a right to participate in decisions that affect them;
    - risk communication should not be aimed at diffusing public concerns or avoiding action, but should produce an informed, involved, reasonable, solution-oriented, and collaborative public;
    - stakeholders should be consulted before important decisions are made;
- listen to the audience;
    - people are often more concerned about issues such as trust, credibility, control, competence, fairness, empathy, caring, courtesy, and compassion than about mortality statistics and the details of quantitative risk assessment;
    - if people feel or perceive that they are not being heard, they cannot be expected to listen (i.e. effective risk communication is a two-way activity).
    - do not make assumptions about what people know, think or want done about risks, but take the time to find out what people are thinking, using techniques such as interviews, facilitated discussion groups, advisory groups, and surveys;
    - let all parties that have an interest or a stake in the issue be heard, and identify with your audience and try to put yourself in their place;
    - recognize people's emotions and let people know that what they said has been understood, addressing their concerns as well as yours;
    - recognize the 'hidden agendas', symbolic meanings, and broader social, cultural, economic or political considerations that often underlie and complicate the task of risk communication;
- be honest, frank, and open;
    - before a risk communication can be accepted, the messenger must be perceived as trustworthy and credible. Therefore, the first goal of risk communication is to establish trust and credibility;
    - trust and credibility judgments are hard to change once made, and initial judgments of trust and credibility are based largely on verbal and non-verbal communications, while judgments of trust and credibility in the longer term are based largely on actions and performance;
    - in communicating risk information, trust and credibility are one's most precious assets, as they are difficult to obtain and, if lost, are almost impossible to regain;
    - do not ask or expect to be trusted by the public, as trust must be earned;
    - if an answer to a question or concern is unknown or uncertain, offer to get back to the questioner with answers;
    - acknowledge and correct any errors, and disclose risk information, as soon as possible (emphasizing appropriate reservations about reliability);

    - do not minimize or exaggerate the level of risk, and speculate only with great caution;
    - lean toward sharing more information rather than less, as people may think something significant is being hidden;
    - discuss data uncertainties, strengths and weaknesses, including those identified by other credible sources;
    - identify worst-case estimates as such, and cite ranges of risk estimates when appropriate.
- coordinate and collaborate with other credible sources;
    - allies can be effective in helping communicate risk information, and few things make risk communication more difficult than conflicts or public disagreements with other credible sources;
    - take the time to coordinate all inter-organizational and intra-organizational communications, and devote effort and resources to the slow, hard work of building bridges, partnerships, and alliances with other organizations;
    - use credible and authoritative intermediaries, and consult with others to determine who is best able to answer questions about risk;
    - try to issue communications jointly with other trustworthy sources, such as credible university scientists, physicians, citizen advisory groups, trusted local officials, and national or local opinion leaders;
- meet the needs of the media;
    - the media are a prime transmitter of information on risks, and they play a critical role in setting agendas and in determining outcomes;
    - the media are generally more interested in politics than in risk; more interested in simplicity than in complexity; and more interested in wrongdoing, blame and danger than in safety;
    - be open with and accessible to reporters, and respect their deadlines;
    - provide information tailored to the needs of each type of media, such as ‘sound bites’, graphics and other visual aids for television;
    - agree with the reporter in advance about the specific topic of the interview and stick to the topic in the interview;
    - prepare a limited number of positive key messages in advance and repeat the messages several times during the interview;
    - provide background material on complex risk issues, and say only those things that you are willing to have repeated, because everything said in an interview is ‘on the record’;
    - keep interviews short, and ‘follow-up’ on stories with praise or criticism, as warranted;
    - try to establish long-term relationships of trust with specific editors and reporters;
- speak clearly and with compassion;
    - technical language and jargon are useful as professional shorthand, but they are barriers to successful communication with the public;
    - in low trust, high concern situations, empathy and caring often carry more weight than numbers and technical facts;
    - use clear, nontechnical language, and be sensitive to local norms, such as speech and dress;
    - strive for brevity, but respect people’s information needs and offer to provide more information where appropriate;
    - use graphics and other pictorial material to clarify messages, and personalize risk data, using stories, examples, and anecdotes that make technical data come alive;
    - avoid distant, abstract and unfeeling language about deaths, injuries and illnesses, and acknowledge and respond (both in words and with actions) to emotions that people express, such as anxiety, fear, anger, outrage, and helplessness;
    - acknowledge and respond to the distinctions that the public views as important in evaluating risks, and use risk comparisons to help put risks into perspective, but avoid comparisons that ignore distinctions that people consider important;

    - always try to include a discussion of actions that are under way or can be taken, and promise only that which can be delivered, and honour any promise;
    - acknowledge (and say) that any illness, injury or death is a tragedy and to be avoided;
- plan carefully and evaluate performance;
    - different goals, audiences and media require different communication strategies, and risk communication will be successful only if carefully planned and evaluated;
    - begin with clear and explicit objectives, such as providing information to the public, providing reassurance, encouraging protective action and behavior change, stimulating emergency response, or involving stakeholders in dialogue and joint problem solving;
    - evaluate technical information about risks and know its strengths and weaknesses;
    - identify important stakeholders and subgroups within the audience, and aim communications at those stakeholders and subgroups;
    - ensure spokespersons have effective presentation and human interaction skills, and train staff (including technical staff) in communication skills;
    - pre-test messages, and carefully evaluate efforts and learn from mistakes.

The EPA (1988) noted that although many of the rules may seem obvious, "they are continually and consistently violated in practice."

Applying Risk Management in Transport

Risk has been defined as "the effect of uncertainty on objectives". Hence, if applying risk management in transport, it is necessary to define the objectives of the transport system.

The NZ Transport Strategy (Ministry of Transport, 2002) states five objectives for the NZ transport system:

- assisting economic development;
- assisting safety and personal security;
- improving access and mobility;
- protecting and promoting public health;
- ensuring environmental sustainability.

One area of transport where the risk concept has been used for many years is road safety, and the second objective above relates directly to road safety.

Another area of transport where there is scope for applying risk management is the emerging issue of transport infrastructure resilience. The reasons for the growing interest in improving transport infrastructure resilience are:

- to reduce the economic impact of infrastructure failures due to natural hazards (e.g. earthquakes);
- to maintain or restore access to goods and services after a natural hazard has occurred;
- maintaining or restoring access to medical services after the occurrence of a natural hazard, to minimise the deaths and deal with the injuries.

These relate strongly to the first, third and fourth objectives in the NZ Transport Strategy, respectively.

Risk Management and Road Safety

Defining Risk

The concept of risk has been employed in road safety studies for many years. For example, Chapman (1967) suggested that the "actual number of collisions" is simply the product of "the possible number of collisions" (i.e. the exposure) and "the probability that, given the possibility of an accident occurring, the accident does actually take place" (the conditional probability of a collision). While he did not use the term risk, he subsequently (Chapman, 1971) referred to "the number of accidents per exposure" as the risk. This use of this 'collision-risk-exposure' relationship, and the term risk for the conditional probability of a collision, became quite common in the road safety literature.

One difficulty with the above approach is defining what constitutes an exposure. Chapman (1971) did derive (from first principles) expressions for exposure for several collision types:

- single-vehicle collisions on a section of road;
- two-vehicle rear-end collisions on a section of road;
- two-vehicle head-on collisions on a section of road;
- two-vehicle right-angle collisions at an intersection of two roads.

For single-vehicle collisions on a section of road, he concluded that the appropriate exposure measure is the vehicle-kilometres of travel (VKT). For rear-end collisions on a section of road, the potential for a rear-end collision depends upon the headways between pairs of vehicles, and he allowed for a mixture of free flowing vehicles (i.e. vehicles travelling well apart) and vehicles travelling close together, and found that the appropriate exposure measure depends upon the link length, the concentration of vehicles and the distribution of headways for both free-flowing and 'platooned' vehicles.

For head-on collisions on a section of two-way road, he noted that there is potential for a head-on collision whenever two vehicles travelling in opposite directions pass one another, and found that the total number of exposures during a time period T is approximately equal to

$$Q_a\ Q_b\ S\ T\ [(1/V_a) + (1/V_b)]$$

where S is the length of the road section, Q_a and Q_b are the flow rates in each direction, and V_a and V_b are the corresponding mean speeds in each direction.

It can be seen that the expression for exposure depends upon the type of collision being considered. That is, the commonly used VKT measure is clearly not appropriate for all collision types. To obtain a scientifically sound exposure measure for a section of road, it is necessary to combine the exposures for the three types of accidents, taking account of the fact that when the driver of a vehicle loses control, the vehicle may cross into the path of opposing traffic, so the outcome will be a single vehicle collision if no opposing vehicle is hit and a head-on collision if one is hit.

The appearance of the inverse of speeds in the expression for the head-on collision exposure implies that the higher the speeds the less is the exposure. This may seem invalid, but for a given section of road it is true. It must be remembered that in estimating exposure, one is interested in the <u>potential</u> number of collisions and not the actual number of collisions. The faster vehicles are moving, the shorter the time they are within the section of road, and the less likely they are to encounter another vehicle moving in the opposite direction. The actual number of head-on and other collisions might well increase as vehicle speeds increase, not because the exposure increases but because of an increase in the probability of a collision given an exposure (i.e. an increase in the risk).

Chapman (2001) found that for an intersection, the number of exposures can be estimated by considering each pair of conflicting movements (crossing/merging/diverging) separately, and summing to get an overall estimate for the intersection as a whole. For a pair of conflicting movements (*a* and *b*), with flow rates Q_a and Q_b and vehicle arrivals governed by a Poisson process, the number of exposures during a period T is:

$$(T/t)\ [1\text{-}exp(\text{-}Q_a t)]\ [1\text{-}exp(\text{-}Q_b t)]$$

where t is the average time to cross the 'collision area'. The value of t increases as the average vehicle length and width increase, but it decreases as the vehicle speed increases. That is, the number of exposures (or potential collisions) decreases as vehicle speeds increase. As noted above, the actual number of collisions might well increase as vehicle speeds increase, not because the exposure increases but because of an increase in the probability of a collision given an exposure (i.e. an increase in the risk).

The difficulty in determining the most appropriate measure of exposure extends to comparing the safety performance of alternative modes of travel. For instance, Ford (2000) compared the frequency of death for nine modes of travel in the UK; aircraft, bus/coach, rail, van, ship/ferry, car, cycle, foot and motorcycle. Ford used three exposure measures:

- person-kilometres of travel;
- person-trips;
- person-hours of travel.

Ford (2000) compared the frequency of death for nine modes of travel in the UK, with the rankings of the modes varying somewhat according to which of the above three exposure measures were used. For example, travel by aircraft is fairly sensitive to the measure used; it is the safest mode in terms of deaths per person-km, the 7th safest mode in terms of deaths per person-trips, and the 3rd safest mode in terms of the deaths per person-hours. The rankings of some modes of travel are relatively insensitive to the measure (e.g. motorcycle travel is the least safe mode for all three measures). It is likely that different members of the public have different measures in mind when they assess the safety of the alternative modes.

The definition of risk as a conditional probability, as done with the collision-risk-exposure relationship, is not consistent with the definition of risk in classical risk management, where risk is not a probability but is an expectation, taking account of the probabilities and consequences of possible events. As noted by Haight (1986), the probability of death in one game of Russian roulette (one sixth) is much less than the probability of heads in the toss of a fair coin (one half), but the former would generally be considered more of a risk. This is because the probability of an event is insufficient to fully characterise the level of risk; it is necessary to incorporate the consequence of an event in defining the level of risk. This is generally done using the concept of expectation, which is simply the sum (over all possible events) of the probability and consequence of each event.

The two distinctly different meanings of risk (i.e. risk-as-probability and risk-as-expectation) persist, and can result in considerable confusion if users of the term do not clearly define what they mean by ‘risk’.

The NZ Road Assessment Programme (KiwiRAP)

KiwiRAP is part of an international collaboration of government and non-government organisations in 70 countries, under the umbrella of the International Road Assessment Programme (iRAP), for investigating and rating the risk of road networks.

KiwiRAP was developed in partnership by the NZ Transport Agency, NZ Automobile Association, Ministry of Transport, NZ Police and ACC and has played a role in reducing the number of fatal and serious crashes on our highways.

The objectives of KiwiRAP (NZAA, 2012) are:

- to reduce deaths and injuries on New Zealand’s roads by systematically assessing risk and identifying safety shortcomings that can be addressed with practical road improvement measures;
- to have risk assessment as a key factor in strategic decisions on road improvements, crash protection and standards of road management;
- to provide meaningful information on where the greatest levels of risk are faced, and in turn to influence behaviour.

The KiwiRAP philosophy is reflected in the following: “whatever we do to make drivers more alert, law abiding and competent, some will still make mistakes ... they should not, however, have to suffer unnecessarily harsh crash outcomes, such as serious injury or death … we must work on designing and operating a road network that is more forgiving and protecting of driver mistakes and crashes … all risk cannot be eliminated through infrastructure and vehicle safety improvements alone (and) drivers must always share responsibility for a safe road system.”

KiwiRAP involves three 'protocols':

- risk mapping, using historical traffic and crash data to produce colour-coded maps illustrating the relative level of risk on sections of the road network;
- performance tracking, involving comparing crash rates over time, to establish whether more or less people are being killed or injured, and to determine if measures to improve safety have been effective;
- star rating, involving inspecting the engineering features of a road, with between one and five stars being awarded to road links, depending on the level of safety 'built-in' to the road.

The level of crash risk is estimated for each highway section, using two measures:

- 'collective risk', which is the average annual number of fatal and serious injury crashes per kilometre;
- 'personal risk', which is the average annual number of fatal and serious injury crashes per vehicle-kilometre of travel.

While 'personal risk' takes account of the traffic volumes on each link, 'collective risk' does not.

'Collective risk' highlights those road sections where investing in improving safety would give the greatest road safety gains, while 'personal risk' highlights those road sections where there is a high likelihood of a driver being involved in a fatal or serious road accident. It should be noted that neither is a true measure of risk, as defined in AS/NZS (2009); each is essentially a measure of the probability of a specified consequence.

Star ratings are based on inspecting infrastructure elements known from extensive research to:

- influence the likelihood of crashes occurring (e.g. poor road alignment);
- influence the severity of crashes that do occur (e.g. the absence of crash barriers).

The more frequent the incidence of such infrastructure elements, the lower the star rating, which vary from 1-5 stars.

As noted above, one objective of KiwiRAP is to provide information to drivers and influence driver behaviour, by making drivers aware of those sections of highway where the level of 'personal risk' is high and where drivers may wish to take extra care. A survey of drivers (NZAA, 2008) involved showing drivers photographs of sections of road and asking them to assess the potential for death or injury on those sections of road. While respondents recognised the danger associated with some features (e.g. a cliff of steep bank alongside the road), they did not recognise the danger associated with trees and poles close to the side of the road (see Figure 2). This indicates a need to increase driver awareness of the hazards that exist.

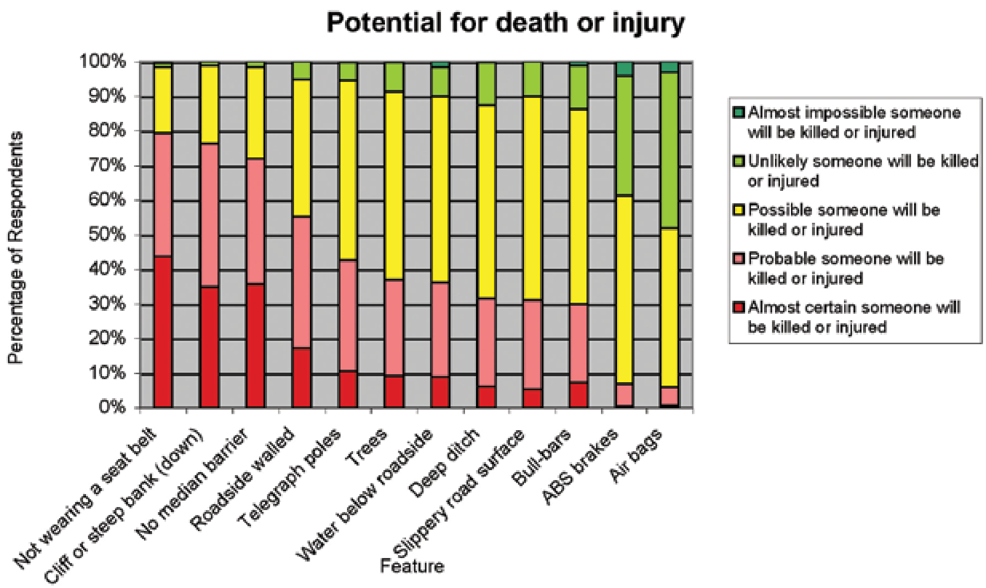

Figure 2: Driver Awareness of Hazards

The publication of information about the level of ‘personal risk’ for the highway system is intended to raise driver awareness of those sections where particular care is appropriate.

Risk tracking results (NZAA, 2012) have revealed that:

- 31% of the State Highway network was ‘high or medium-high’ for <u>personal risk</u> in 2007-2011 (down from 46% in 2002-2006).
- 4% of the State Highway network was ‘high ‘ for <u>collective risk</u> in 2007-2011 (about half the percentage in 2002-2006).

The results indicate a clear improvement trend, consistent with changes in national road accident statistics.

Finally, the achievements of KiwiRAP have been recognised internationally, with the International Road Federation’s Global Safety Achievement Award, established to recognise excellence and innovation in road development worldwide, being received by the KiwiRAP partners.

<u>Risk Management and Transport Infastructure Resilience</u>

Prompted by the occurrence of earthquakes and other natural hazard events, there has recently been a rapid increase in concern about the resilience of infrastructure in NZ and elsewhere, and the effect of infrastructure failure on the communities which rely upon the infrastructure. The situation is essentially that the level of risk is perceived to be too high to be acceptable, and there is a need to reduce the risk, by making the infrastructure more resilient. That is, increasing infrastructure resilience is essentially ‘risk treatment’, to reduce the likelihood & consequence of infrastructure failure.

The term ‘resilience’ has a range of meanings, which have evolved as different disciplines have applied the concept of resilience & adapted the definition to meet their focus, as happened with risk management. The term *resilience* was introduced into the English language in the early 17th Century from the Latin verb *resilire*, meaning to rebound or recoil (McAslan, 2010). There is no evidence of resilience being used in any scholarly work until Tredgold (1818) introduced the term to describe a property of timber, and to explain why some types of wood were able to accommodate sudden and severe loads without breaking. Four decades later, Mallet (1856) further developed this concept of resilience as a means of measuring and comparing the strength of materials.

The concept of resilience is attractive to policy makers, practitioners and academics. It suggests an ability of something or someone to recover and return to normality after confronting an abnormal, alarming and often unexpected threat. It is often used alongside security to understand how governments, local authorities and emergency services can best address the threats from terrorism, natural disasters, health pandemics and other disruptive challenges.

NZ has a National Infrastructure Plan (National Infrastructure Unit, 2011) covering the transport, telecommunications, energy, water & social infrastructure sectors. It expresses the vision that “by 2030, NZ’s infrastructure is resilient & coordinated, & contributes to economic growth & increased quality of life”, and establishe resilience as one of six objectives for infrastructure development.

Transport infrastructure is one of a number of important infrastructure systems upon which a community relies, and between which there are many interactions or inter-dependencies, as shown in Figure 3.

There are three basic causes of inter-dependence:

- physical proximity;
- operational interaction;
- stakeholder (owner, funder, operator) interactions.

All three types of inter-dependency are important and need to be taken into account when assessing the performance of the individual infrastructure system and the complete system.

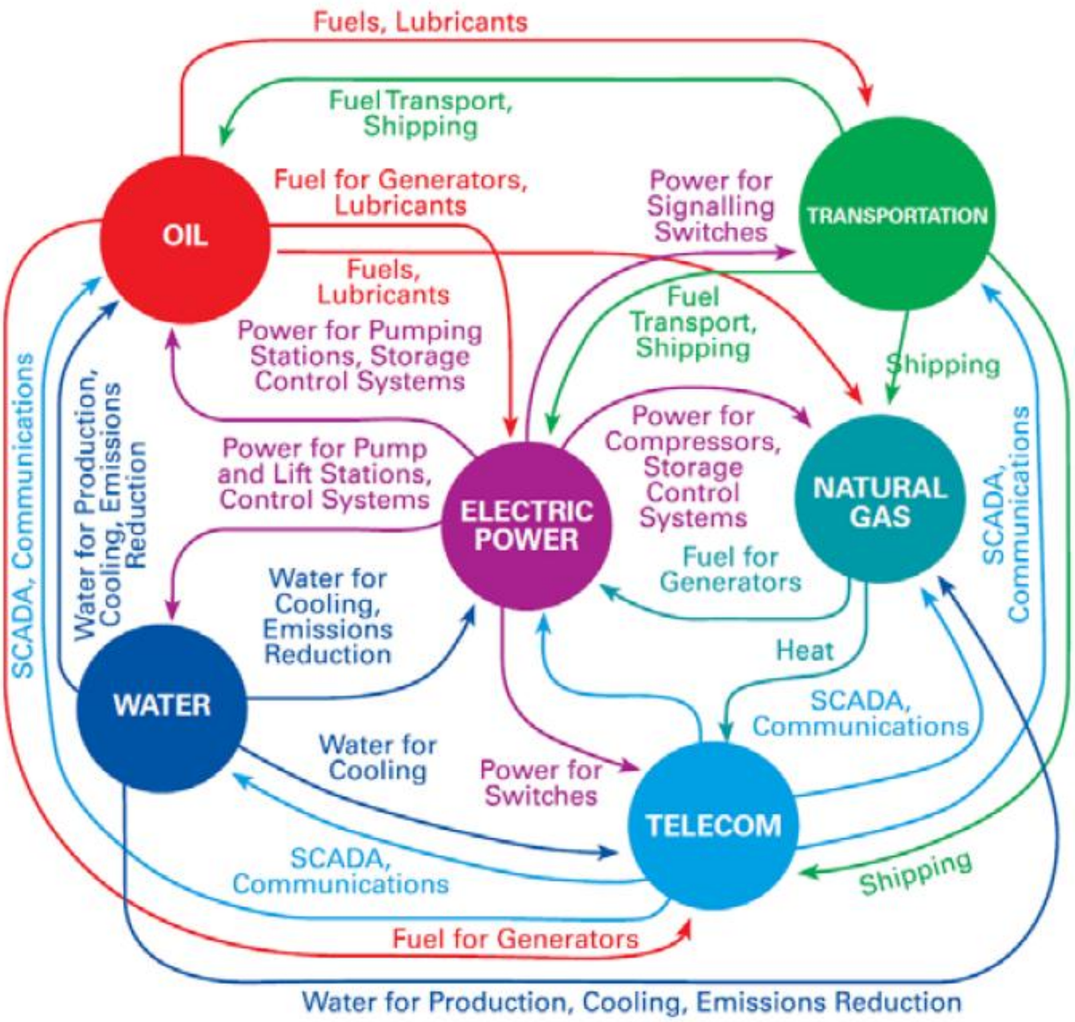

Figure 3: Complex Infrastructure Systems and the Interactions

Resilience can be defined qualitatively or quantitatively. For example, the Department of Homeland Security (2009) defines resilience qualitatively as “the ability of systems, infrastructures, government, business & citizenry to resist, absorb, & recover from or adapt to an adverse occurrence that may cause harm, destruction, or loss of national significance”. Bruneau et al. (2003) has proposed a quantitative definition of resilience (Figure 4).

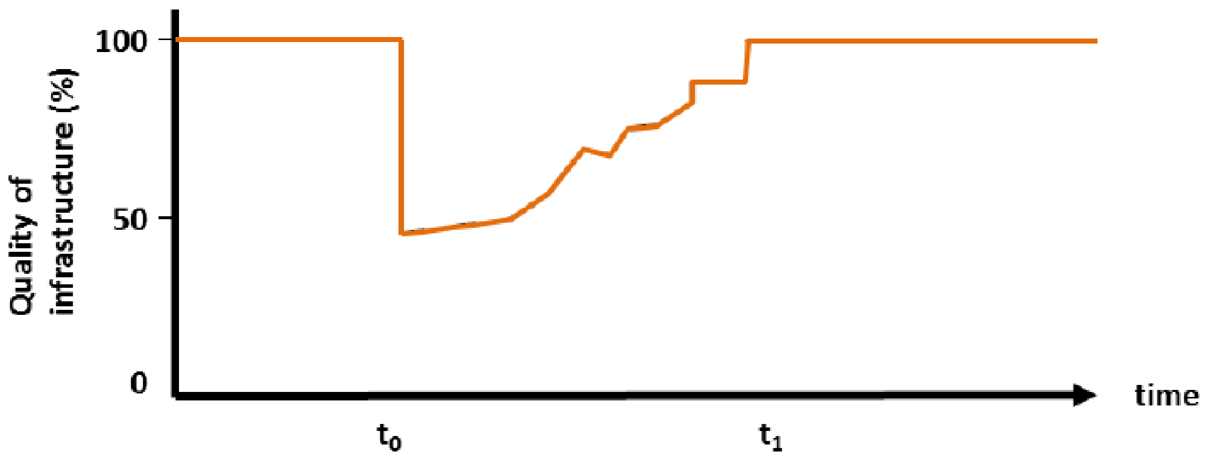

Figure 4: A Quantitative Measure of Resilience

This definition assumes a single disaster event and a sudden decrease in the quality of the infrastructure (at time t_0), with recovery to the original state (at time t_1). Bruneau et al. suggest that the area between the actual 'quality of infrastructure' profile & the '100% level' can be used as a measure of resilience, with resilience increasing as that area decreases.

The NZ National Infrastructure Plan (National Infrastructure Unit, 2011) states that "The concept of resilience is wider than natural disasters and covers the capacity of public, private and civic sectors to withstand disruption, absorb disturbance, act effectively in a crisis, adapt to changing conditions, including climate change, and grow over time." This definition is very broad, and emphasises that infrastructure resilience should cover both sudden, major events (or incidents) and gradual changes with major long-term consequences, such as rising sea level or a changing pattern of demand for transport).

The National Infrastructure Advisory Council (2010) has defined four 'resilience principles', which can be applied before, during and immediately after an incident, and includes long-term learning and adaptation (Figure 5).

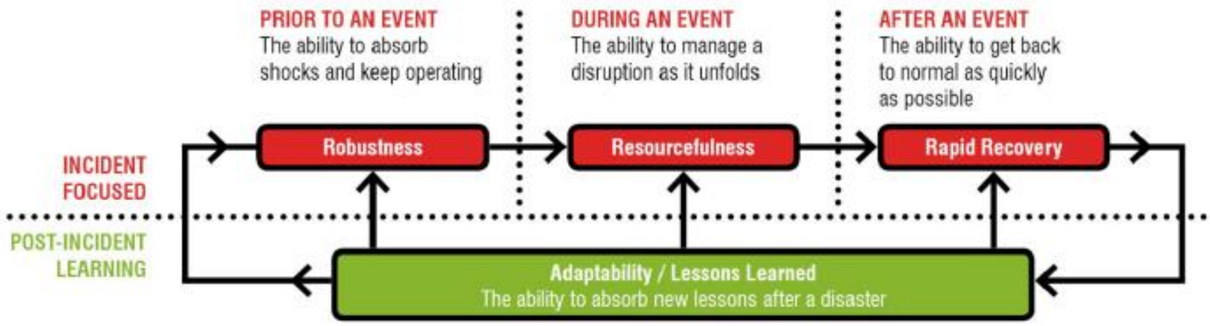

Figure 5: Four Resilience Principles

The NZ Transport Agency has recently received a recommendation (Hughes and Healy, 2014) to assess the resilience of transport infrastructure using a 4-point scale:

- low – poor performance, improvements required;
- moderate – less than desirable performance, specific improvements should be prioritised;
- high – acceptable performance, some improvements could be made;
- very high resilience – meets all requirements.

Such an approach has some similarity with the KiwiRAP 'star rating' scheme mentioned above.

Conclusion

It is concluded that risk management is 'strongly applicable' to transport network management. Its application to transport safety, albeit it in a modified form, via KiwiRAP and concurrent driver education and licensing changes in NZ, have together produced major benefits.

Resilience has become a very important issue, as a result of some major disasters related to natural and man-made hazards. It is pleasing to see, however, that there is growing awareness of the need to consider the ability of infrastructure to be modified to cope with less dramatic gradual changes, the long-term impacts of which might well be major.

It seems clear that improving infrastructure resilience is a form of risk reduction and hence is a part of the risk management process. While the study of infrastructure resilience is in its infancy, it is considered very likely that applying well-established and effective risk management methods will result in greater infrastructure resilience and major benefits for the community.

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