RISK MANAGEMENT:
A NEW APPROACH TO IMPROVING SAFETY

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STRATEGIC THEME 3
SAFETY AND ROAD OPERATIONS

INTRODUCTORY REPORT

CONTENTS

EXECUTIVE SUMMARY

In recent years, the importance of making well-supported, transparent decisions has grown, not only for traditional risk decisions but for all decisions. The field of risk management has consequently expanded from traditional safety, security, quality and efficiency into general management.[1] As a management discipline, risk management provides a structured, iterative sequence of steps for risk identification, analysis, evaluation and treatment. The risk management process forms a loop to provide decision-making support that introduces continual systematic analysis and evaluation.

At the same time, worldwide attention is required to reduce fatalities due to traffic crashes. Recent disasters—both natural and manmade—have emphasized the importance of roads and heightened our sense of vulnerability. Risks on the world's roadways are posed by traffic crashes, transport of dangerous goods, overloaded vehicles, tunnel fires, floods, earthquakes, landslides, windstorms, waves and surges, tsunamis, snow damage, volcanic eruptions, avalanches, fallen rocks, bushfires and forest fires, fog, ice and drought. Indirect events—such as crashes near roads that are not caused by traffic users, fire, industrial accidents, and acts of terrorism or war—also can affect roads. Reducing the risks posed by road crashes, as well as natural and manmade disasters that affect roads, is important for industrialized nations and developing nations alike. Determining which choices represent the most informed decisions on the appropriate allocation of resources forms the basis of risk management and introduces a scientific approach to what is often an intuitive process.

The Technical Committee on Risk Management for Roads (TC 3.2) is one of 18 PIARC technical committees. TC 3.2 places special emphasis on integrated risk management, with expanded research into risk assessment, decision-making processes and security issues. To accomplish its mission, TC 3.2 has been actively engaged in various activities, such as launching an international survey, collecting good practices of risk management, developing a risk management toolbox and organizing international seminars to facilitate knowledge exchange.

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[1] J. Hansen and L. Nilsson, Risk Management: A New Approach To Improving Safety, Sweden National Report, Strategic Direction Session ST 3, (Borlänge, Sweden: The Swedish Road Administration, 2007).

1. INTRODUCTION

Road safety is a global concern. As deaths and injuries resulting from road crashes attract more international interest, numerous umbrella organizations and national or local agencies are working to increase awareness of road safety issues, promote road safety in general and reduce traffic fatalities specifically. The United Nations raised awareness of this very serious problem, in part, with the 2004 passage of Resolution 58/290[2] urging member states to cooperatively address the issues.

1.1. The Global Impact of Traffic Fatalities and Injuries

The Organisation for Economic Co-operation and Development (OECD) has found that the number of road motor vehicles is high and rising among OECD countries, and reducing road accidents is a concern in all countries.[3] According to the World Bank, every year more than 1.17 million people die in road crashes around the world, and road crashes cost approximately 1 to 3 percent of a country's annual gross national product (GNP). These are resources that no country can afford to lose.Throughout the world, many groups are working to increase awareness of road safety issues, promote road safety and reduce road fatalities.

The majority (about 70 percent) of the 1.17 million deaths due to road crashes occur in developing countries, where management practices and associated management tools (such as database and modelling software) are less sophisticated than in other parts of the world. Contributors to road deaths and injuries include rapid increases in the number of vehicles and drivers, inadequate infrastructure, crowded and congested roads and insufficient access to medical services. Sixty-five percent of deaths involve pedestrians and 35 percent of pedestrian deaths are children. More than 10 million are crippled or injured each year. It has been estimated that at least 6 million will die and 60 million will be injured during the next 10 years in developing countries unless urgent action is taken. The majority of road crash victims (injuries and fatalities) in developing countries are not the motorized vehicle occupants, but pedestrians, motorcyclists, bicyclists and nonmotorized-vehicle occupants.

Road traffic deaths in low- and middle-income countries are expected to increase by 83 percent by 2020, while in high-income countries, the annual number of road traffic deaths is expected to decrease by 27 percent.[4] Africa as a whole was found to have about 10 percent of global road deaths in 1999 but contained only 4 percent of global motor vehicles.[5]

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[2] United Nations: Resolution adopted by the General Assembly, 58/289, http://daccessdds.un.org/doc/UNDOC/GEN/N03/511/86/PDF/ N0351186.pdf?OpenElement.

[3] Organisation for Economic Co-operation and Development: OECD Factbook 2006—Economic, Environmental and Social Statistics, http://puck.sourceoecd.org/vl=4113641/cl=16/nw=1/rpsv/factbook/10-05-02.htm.

[4] World Health Organization. World Report on Road Traffic Injury Prevention: Summary (Geneva, 2004).

[5] U.S. Department of Transportation, Federal Highway Administration: Africa Road Safety Review Final Report, No. PR/INT/2000, http://safety.fhwa.dot.gov/about/international/africa/chap8.htm.

The average growth in road deaths over the period 1985–1986 to 1995–1996 (excluding the two dominant countries of Nigeria and South Africa) was found to be more than 40 percent; in comparison, road fatalities in Western Europe and North America fell over the same time period by about 20 percent. As nations determine how to allocate their resources, estimating of the total national cost of road crashes will help their governments realize the heavy economic losses being incurred annually and the socio-economic aspects of road crashes in developing countries. Governments must try to reduce these losses by providing road safety improvements and should see expenditure on road safety as an investment and not as a cost. Nevertheless, as alarming as the road fatality statistics of developing nations such as those in Africa are, they must be seen in the context of other causes of morbidity, such as HIV/AIDS and malaria. Although Africa's road safety record is the worst in the world in terms of deaths on a per-vehicle basis, the region's other and much greater causes of premature mortality mean road safety is unlikely to become a top medical or political priority in any of the countries with the highest road fatality rates. International knowledge sharing is critical to reducing the road fatalities and injuries in these countries.

The Technical Committee on Risk Management for Roads (TC 3.2) is one of 18 PIARC technical committees. TC 3.2 places special emphasis on integrated risk management with expanded research into risk assessment, decision-making processes and security issues. More specifically, TC 3.2's three strategic themes are to introduce risk management techniques in the road sector, introduce risk management for megaprojects and improve highway systems security. To accomplish its mission, TC 3.2 has been actively engaged in activities such as launching an international survey, collecting good practices of risk management, developing a risk management toolbox and organizing international seminars to facilitate knowledge exchange. More information is available in the TC 3.2 final report.[6]

1.2. Natural and Man-made Disasters

In addition to global concerns regarding road safety due to crashes, recent events have raised concerns regarding the impact of disasters, both natural and manmade, on roadways. In many disasters, access and transport infrastructure is damaged or destroyed at a time when it is needed most for rescue, relief and reconstruction operations.

Worldwide road engineers, influenced by the United Nations' 1987 launch of the International Decade for Natural Disaster Reduction (IDNDR) in the 1990s, on their own initiative, established efficient countermeasures for natural-disaster prevention and reduction for roads.[7] Reducing the risk of human suffering and loss of life, property damage and social and economic disruption is the goal of risk management when applied to natural disasters, such as the devastating 2004 tsunami in Sri Lanka that killed 35,322 people and will require a projected 3–5 years and US$2.2 billion before services and livelihoods are restored[8]; and to manmade disasters, such as the September 11, 2001, terrorist attacks on the World Trade Center in New York.

[6] World Road Association: Towards Development of a Risk Management Approach, February 2007 Version, Final Report from PIARC Technical Committee 3.2, Risk Management for Roads, 2007.
[7] World Road Association: Study on Risk Management for Roads, 2005.
[8] World Road Association: International Seminar on Risk Management for Roads, April 26–28, 2006, Hanoi, Viet Nam.

Manmade disasters can be either accidental (for example, a hazardous-materials spill on a busy roadway) or, as in the case 9/11, intentional. Regardless of their cause, disasters share a catastrophic potential for loss of infrastructure and lives, as well as disruption to mobility and vital services for extended periods of time.

In some cases, it is not possible to avoid placing roads in areas prone to natural events, such as earthquakes, landslides, snow, heavy wind or rain. To be prepared to mitigate these and other risks, agencies that provide essential services should have a process for identifying risks and managing them by avoidance or reduction. That process may begin with understanding the discipline of risk management as a tool that supports decision-making. As is shown in the following section, an integrated risk management process is comprehensive but complicated and performs best when accurate and robust data are available.

1.3. A Risk Management Approach

The risks to road users are overwhelming: how does a road authority determine where to concentrate its efforts? Determining which choices represent the best, most informed decisions forms the basis of risk management and introduces a scientific approach to what is often an intuitive process. Managing risks, particularly those caused by natural or manmade disasters that often occur in a rapidly evolving context, is often an attempt to control the unknown before it occurs. How does a road authority plan for the unforeseeable? Although eliminating risk is not possible, analyzing and evaluating risk to minimize negative outcomes is an achievable goal. As noted above, TC 3.2 has placed special emphasis on integrated risk management—with expanded research into risk assessment, decision-making processes and security issues—to advance worldwide road improvements, as found in the TC 3.2 final report.[9]

In recent years, the importance of making well-supported, transparent decisions has grown, not only for traditional risk decisions but for all decisions. The field of risk management has consequently expanded from traditional safety, security, quality and efficiency into general management.[10] As a management discipline, risk management provides a structured, iterative sequence of steps for risk identification, analysis, evaluation and treatment. The risk management process, described in Section 2, forms a loop to provide decision-making support that introduces continual systematic analysis and evaluation.

Sections 3 and 4 discuss road safety and security, respectively. Road-related risk management examples, successes and shortcomings throughout the world are highlighted in these sections. Tools, techniques and relevant publications are also mentioned.

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[9] World Road Association: Towards Development of a Risk Management Approach.
[10] Hansen, J.; and Nilsson, L. Risk Management: A New Approach to Improving Safety.

2. THE SCIENCE OF RISK MANAGEMENT

Risk management facilitates sound decision-making. Risk management applied to transportation also helps make highways safer and improves operations and maintenance, thereby increasing the overall safety of the travelling public.

Risk management is a complex process that is perhaps made more complex by being defined differently in various industries and countries, and even different agencies within the same organization. Being able to customize the risk management process so that it is responsive to the specific values and goals of the organization is necessary to the success of the risk management process. That same flexibility, however, can lead to different use of identical terms and create confusion. It is dubious whether it is possible to develop one simple, common language for all purposes. The terms defined here, however, offer a starting point for understanding how they are used in risk management in the context of transportation and within this paper.

2.1. Lexicon of Terms

Risk is a human concept, a possible and usually negative outcome differing from a desired status. It may be the chance of injury, damage or loss, or uncertainty about potentially harmful consequences associated with an event.

Risk management methods are specific approaches applied to a problem or situation.

Risk audits are a method of identifying causes, frequency and consequences of risks. Risk audits should include project identification, audit by an interdisciplinary team, pre-audit information, a field review, or multiple reviews under various conditions, analysis, reporting and implementation of findings where appropriate.

The *risk management plan* should propose appropriate and effective measures to control and manage risks. It should contain a schedule for implementation and define personnel responsibilities. It should remain flexible and be periodically reviewed and updated.

Resiliency is the ability to recover from negative consequences. A quick recovery indicates greater resiliency.

Tolerance is the level of comfort with a risk or a situation, a willingness to accept a nonperfect situation or solution.

Risk events are incidents or events that threaten the status quo and may be natural or man-made.

Risk management models are used to predict risk.

Risk management was defined by ISO/IEC Guide 73:2002 as "Coordinated activities to direct and control an organization with regard to risk." [11] More specifically, risk management is the structured process of identifying, analyzing and assessing risk, and making decisions based on goals, vulnerability, resiliency, tolerance, knowledge and experience. It specifically focuses on strategies to avoid, reduce or mitigate risk. It conveys the possibility of negative departures from the desired state. Risk management includes cultural, structural, and process-oriented determination of potential opportunities. Each decision needs relevant analysis, treatment and continual monitoring.

Risk identification places risk in context. It may start with a problem or identify the source of a problem. Conventional methods to identify risks are objective-based, scenario-based, category-based, and risk listing or charting. Critical assets should be identified and catalogued in terms of condition and vulnerability points. In road transportation terms, critical assets may include highways, roads, tunnels and bridges.

Risk assessment is the determination process of *analysis* and *evaluation*. *Risk analysis* uses available information and experience to determine the likely frequency and magnitude of an event. The probability of occurrence and the potential impact may be difficult to determine but are important factors to be addressed in evaluations.

Risk assessment may be expressed as a mathematical equation:

$R = O \times V \times I$
where
O = Occurrence factor—or the likelihood that an event will occur at some target.
V = Vulnerability factor—the weakness or sensitivity to a hazard of the target.
I = Importance factor—the consequence of damage or loss.

In terms of security risks, these risk assessment factors exhibit special attributes. Occurrence is more likely if the target is attractive, highly visible and likely to generate large amounts of publicity, and has a history of prior threats or attacks. Vulnerability reflects the anticipated degree of damage, expected downtime, number of casualties, and other variables.

Importance of a target is measured by the consequence of loss, regardless of the type of hazard. Aside from the cost and time needed to rebuild or replace, the loss of revenue and the effect on the regional economy and critical utilities, importance can also be assessed in terms of exposed population, military value, historical or cultural value, loss of use, and other factors.

[11] International Organization for Standardization: ISO Guide 73: Risk Management—Vocabulary—Guidelines for Use in Standards, 2002.

Risk evaluation compares risk levels, consequences and options against a predetermined, desired status or standard. Consequences, either minor or catastrophic, relate to the risk tolerance or level of acceptable risk. Options are opportunities for risk avoidance or risk mitigation strategies. Options related to prevention or reduction and mitigation need to be investigated. A structured cost–benefit analysis should reflect political, social, behavioural, economic and engineering factors, as well as resource allocation and implementation strategies.

Risk treatment can result in avoidance, reduction with the special case of elimination, retention and transfer.

2.2. Types of Risk

Risk management tools, such as England's Highways Agency Risk Management (HARM) and Netherlands Public Sector Comparator and Public-Private Comparator (PSC/PPC), are used to guard against cost overruns of capital projects and to ensure more accurate cost and time estimates for highway construction.[12] However, in this paper, risk management is not focused on financial goals but rather on its potential to reduce the impact of both safety and security risks on roadways throughout the world. Risks can be categorized using a variety of schemes but are conceptualized here as being either of natural or man-made origin.

Risks can also be viewed as a chain of events that trigger the loss of existing assets or values. The risk of a lost opportunity is the nonachievement of plans and efforts. Using this basis, risk management as performed in Sweden deals with assessing and balancing risks against opportunities in a way that would be perceived as most favourable.[13]

2.3. The Risk Management Process

The risk management process gives a formal structure and logic to decision-making. It can be customized to different goals, values and organizations. No single approach will fit every situation. The flexibility of the process provides multiple means of addressing risk management issues.

Figure 1 shows the general risk management process that has been widely adopted by countries around the world. Different road authorities will approach risk management in different ways by placing priorities on that which is most important in their organization. This process can be tailored to the specific circumstances of the various agencies responsible for roads.

[12] U.S. Department of Transportation, Federal Highway Administration: Risk Assessment and Allocation for Highway Construction Management, Report No. FFHWA-PL-06-032, Washington, D.C., 2006.
[13] J. Hansen and L. Milsson. Risk Management: A New Approach To Improving Safety.

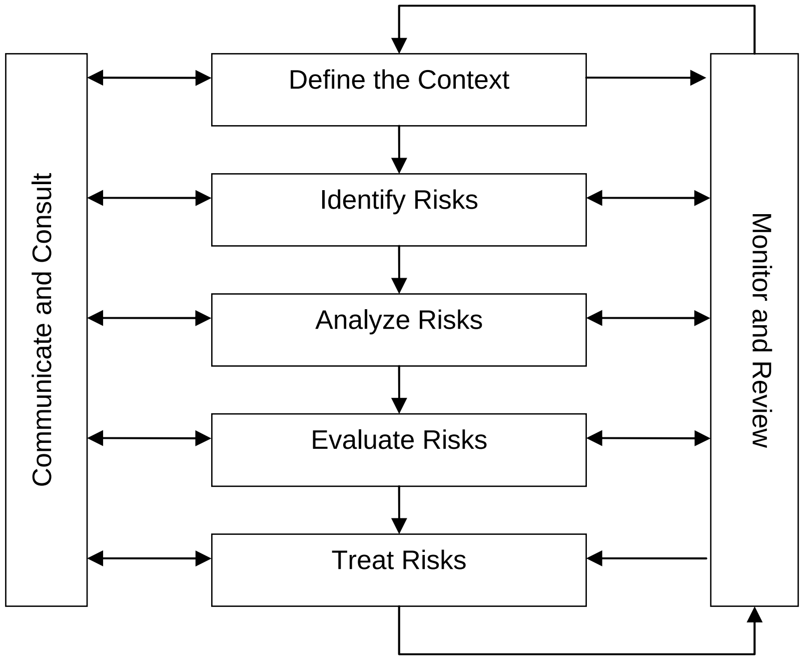

Figure 1. Risk Management Process[14]

Define the Context

Road authorities work with other agencies in a legislative and organizational framework. A major task for a road authority is to identify all the stakeholders with whom they may need to consult, develop plans and cooperate during risk assessment and emergency response. Risk management must be done within the road authority consistent with the roles and capability of organizational units, but coordinated to meet the strategic objectives of the agency and to communicate with stakeholders. A road authority must define the context of risk management within these parameters.

Identify Risks

After defining the context, the road authority may then proceed to inventory and identify its individual risks—those targets, prerequisites, budgets, compliance areas, plans or assets of any kind (physical or intangible) to which events that may cause disruption or destruction which would have negative outcomes.

This process should ensure that all risks are identified. The possibility of rare and unusual events and deliberate acts of war or terrorism must be considered: What can happen? How and why can it happen?

[14] Source: Adapted from Towards Development of a Risk Management Approach, February 2007 version, Final Report from PIARC TC 3.2.

The tools and techniques in this process include checklists, judgments, experience, records, flow charts, brainstorming, systems analysis and scenario analysis and systems engineering techniques. In general, natural environmental risks are easier to identify and to codify into magnitude of event versus frequency of occurrence. Manmade risks are often harder to identify, especially in new transport systems built in the last few decades, where there is no history to estimate the effect of rare and highly damaging events.

The criteria for risk evaluation must also be identified at this stage. These criteria may include the following:

- operational,
- technical/engineering,
- financial,
- legal,
- social/political,
- environmental.

Some of these criteria may be established by the road authority, while others may be dictated by legislation or policy, or established through public consultation. Care must be taken to keep the criteria in balance.

Analyze Risks

Risk analysis should be the foundation for prudent decisions that support governance. It should be the main part of what could be called a preparative system.[15] Since risk management generally depends on information from other management systems, this is the point at which it is important to identify other existing management technical systems and procedures to control risk and to assess the strengths and weaknesses of those systems. Errors or biases in these systems will otherwise be carried over into the risk management process.

Risks can never be reduced to zero, only to an "acceptable level." The objectives of this analysis are to separate minor (and acceptable) risks from major risks that require some actions to manage (reduce or avoid) and to provide data to assist in the evaluation and treatment steps. This is the step of the risk management process where it is possible and advantageous to introduce the precision of mathematical quantification and probability to the topic of risk, which is otherwise often subjective. Risk can be calculated; and by use of accepted lines of decision science, a rational decision can be reached. Structural design codes that use limit states and probabilistic methods usually have the risks clearly defined in terms of probability of occurrence (for example, 100-year flood, with an annual probability of occurrence of 0.01) and "defined acceptable outcomes" or limit states (for example, limited damage or collapse). Generally risk will be measured by two variables: frequency (for example, a 100-year flood) and severity (for example, floodwaters 3 meters above average). Using measurement tools, identified risks can be evaluated through calculating or estimating the size and frequency of events and the combinations of the two.

[15] H. Hansen and L. Milsson. Risk Management: A New Approach To Improving Safety.

To do so, two basic statistical concepts—mean and deviation—must be understood. These concepts are used to describe a particular item or event in its “normal” or average state (the mean) and provide a scale for possible deviations from that norm. The deviation denotes the risk inherent in making decisions based on the mean. Therefore, to measure risk it is necessary to know not only the frequency and severity of a phenomenon but also its potential deviation from the mean.

It should be noted that the availability of data that are shared internationally, particularly for rare but major events, is of great help to road authorities performing realistic statistical analysis. For example, crash data for a large number of similar systems in different countries provide a broader context from which to base conclusions. Data sources may include the following:

- past records,
- experience and judgment by experts,
- industry practice and experience,
- relevant published literature and surveys,
- system models and computer analysis,
- experiments and prototypes.

Evaluate Risks

Risk evaluation involves comparing the level of risk found during the analysis process with the previously established risk criteria. Risk analysis and criteria used in an evaluation should be of the same type (qualitative or quantitative). The output of a risk evaluation study is a prioritized list of risks for further action. The objectives of an organization and the extent of opportunity that could result from taking a risk should be considered. Costs and benefits to all stakeholders and the community should be considered, not just to the road organization.

Treat Risks

Typical options, which are not necessarily mutually exclusive or always appropriate, include the following:

- Avoid the risk by deciding not to proceed with the activity or project that generates the risk (where this is practical).
- Reduce the likelihood of occurrence through appropriate management and technical systems and procedures.
- Reduce the consequences through planning, design, construction standards, disaster management planning, etc.
- Transfer the risk. (This is only appropriate for financial losses through insurance; it is not practical to transfer the risk of death and injury.)
- Retain the risk and plan to manage the consequences if the risk occurs.

2.4. Tools: Concept of Risk Analysis by Scenario (RAS)

Risk analysis by scenario as described here is a basic, universal methodology or template for risk analyses. A universal methodology must be adjusted, adapted or amended for special applications. Therefore, input from various other specially developed methods or models could and should be used as a support or, if used separately, be structured or presented afterward in accordance with the template.

In general, a scenario is a description of a future situation based on the present situation and a presumed path of transition from the present into the future. Here, each set of interest, peril and risk factors make one scenario. One interest at a time is in focus for analysis. What this means and how the analysis is done is briefly described below.

Focus

The focal point is a specific "interest" that is to be either created or preserved through the activities performed by an organization. Here an interest could be a target, a prerequisite, a budget, a compliance area, a plan or an asset of any kind, physical or intangible. A crucial part of a risk analysis assessing the sensitivity of an organization (that is, its resources, operation and performance) to deviations or harm.

Peril

The force that is potentially harmful to an interest is here called a "peril." A peril is to be taken in the broadest possible sense. What constitutes a peril varies depending on the nature of the interest.

Risk factors

Causes of perils are here called "risk factors." Risk factors are seen as contributors. The causation of a peril may depend on one or more risk factors. Some risk factors may have to be present in combination to trigger the peril. The appearance of risk factors can be affected by preventive measures.

Chain of Events

This methodology of risk analysis is considered to by "by scenario" because it analyzes a chain of events starting with the emergence of a peril and an interest being in harm's way and ends with an evaluation of the resulting total harm. It is therefore necessary to describe, accurately enough for the analysis at hand, what happens from the beginning to the end. The scenario could and should include relevant estimations and calculations and can also be repeated with a number of variations to form a space of outcomes (lucky case = minimum; typical case = mode; worst case = maximum).

A chain of events is a representation of cause-and-effect theory. In a chain of events, everything upstream of a specific point is considered a cause and everything downstream an effect or consequence. It all depends on which point is selected. Often the term "consequence" is used for impact or size, which is another aspect.

Process

The analysis process is depicted in Figure 2. The essential part is deciding on an action plan for high-ranking risks and monitoring to see that the plan is executed. Some guidelines are included to facilitate the analysis. These include guidelines for ranking risks by a given universal matrix table, as indicated in the diagram. The relevant stakeholder, however, is to determine (calibrate) the matrix table.

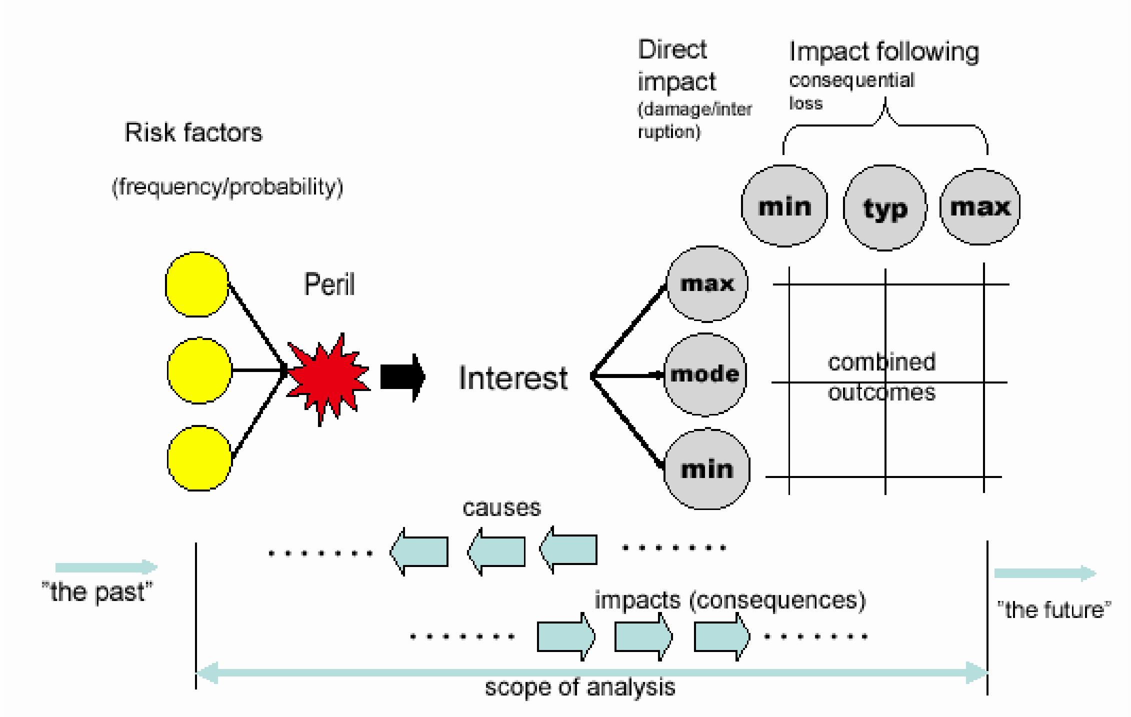

Figure 2. Process of Risk Analysis by Scenario

2.5. PIARC Technical Committee 3.2's Risk Management Toolbox

As shown, the risk management process is highly comprehensive but complex. TC 3.2's technical toolbox for risk management will share risk management best practices from nations throughout the world. The committee began development of the toolbox by conducting two international surveys among member countries to assess the status of the use of risk management principles as a tool for improving use of the road system.

Twenty-three countries responded to the first part of the survey with 25 answers. (Two answers were received from Canada and Norway.) Contrary to expectations, more countries have general models for risk management than countries that have developed risk management policies or guidelines. It was found that 76 percent (19 of the 25) use risk management in the organization's decision-making system, 53 percent (13 of the 25) have risk management guidelines and 60 percent (15 of the 25) have general models for risk management. Risk management for road network projects is used by 68 percent (17 of the 25) for planning, 80 percent (20 of the 25) for infrastructure projects and 32 percent (8 of the 25) have specific risk management models for road networks. Total Time–Quality Budget models are used by 36 percent (9 of the 25 countries). Of the countries responding to the survey, 68 percent (17 of the 25) use risk management methods for detailed studies of the environment, transportation of dangerous goods and construction of roads, tunnels and bridges. For specific projects, 76 percent (19 of the 25) of the countries consider security aspects during the design stage, 72 percent (18 of the 25) in the planning stage and 76 percent (19 of the 25) in the operating stage.

The risk management toolbox was designed to disseminate best practices through international information sharing. The toolbox is intended to aid in risk assessment and reduction. Its database of best practices provides a practical means of assisting the decision-making process by making available a defined sequence for risk analysis, treatment and monitoring. It can transform the management of an issue into a systematic approach that ensures all facets are reviewed for strategic choice (approvals, funding and subsequent orientation of the development or implementation, consensus building) and value enhancement (optimum quality, functionality and cost parameters).

The toolbox includes inventory sheets to record the effectiveness and cost of individual risk management technologies and tools. As shown in Figure 3, the inventory sheets are separated into managing two kinds of events: natural and manmade. The sheets are structured according to execution phases of road management—planning, design, construction, operation/maintenance/administration and reconstruction. They are classified by risk management process steps—analysis, assessment, treatment, communication and management.

Inventory Sheet 68

Project phase	Measures
Classification	Hard measures
Item	Slope countermeasures
Category	Stabilizing structures
Technology	Slope framework

Technical summary

Slope framework construction is applicable to slopes for which vegetation is unsuitable or for which vegetation cannot assure long term stability. The shape is normally rectangular frames, so precast, in-situ poured concrete, or in-situ sprayed construction methods are used.

Effect

By changing the shape of a slope, slope framework has various uses, such as forming a foundation for vegetation, construction to restrain surface layer collapse, anchor pressure plates, etc. Slope framework generally does not have resistance to soil pressure, but those with large cross-section and weight or used with anchors can provide resistance to earth pressure. This method has great resistance to erosion, and if sprayed on site, can be constructed on unshaped slopes and has the advantage that slope drainage is not prevented.

Considerations

For slope framework construction it is necessary to understand the characteristics of the construction location, and to consider the optimum construction method. The precasting, in-situ poured concrete, and in-situ sprayed methods each have their advantages and disadvantages. Also, it should be noted that when combined with drainage construction, vegetation, anchors, etc., their effect and range of application changes.

Cost/resources	In-situ spraying 1,000m3			Units
Framework	Slope cleaning, lath lining		1000	m^2
	Lay slope framework		600.0	m
	Main anchors	D19×1.0m	60.0	No.
	10 - 20 million yen per location	Mortar spray	150.0	m^3
Anchors	Excavation	115.0	900.0	m
	Insert & tension anchors and packing		40	No.
	Pouring concrete		30	m^3
Temporary works			1	Set

Cost basis: Calculated based upon results within

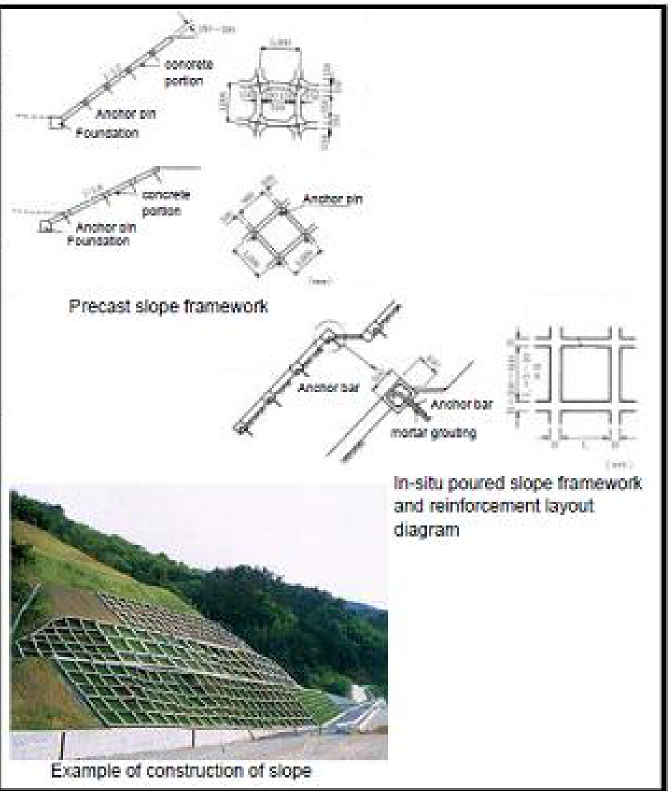

Figure 3. Sample Inventory Sheet on Slope Framework[16]

[16] Source: Towards Development of a Risk Management Approach, February 2007 Version, Final Report from PIARC TC 3.2, Appendix C, Figure 5.

The inventory sheets are easily revised electronically and provide general information about technologies/tools, use, costs and other aspects of construction. The summary on each sheet helps the decision-makers adopt the best technologies/tools for risk management, and promotes technology transfer to other countries. Appendices provide further information.

Currently available are 115 sheets for natural events management and 11 sheets for manmade events. Additional examples from countries and additional inventory sheets are planned, and the toolbox is expected to continue to grow. The sheets will be distributed in electronic and hard-copy formats.

3. SAFETY

The world has recognized road safety as a growing concern. The World Health Organization, World Bank and United Nations have particularly focused on the problem, as have other regional and national agencies. In addition to the World Road Association, the Association of Southeast Asian Nations, the European Union, the International Road Safety Organization, OECD and many others are addressing the problem, which has reached crisis levels in some areas.

OECD data show that in 2004 road fatalities per million inhabitants ranged from more than 240 per million inhabitants in the Russian Federation to 50 in the Netherlands. Rates have decreased in all other countries, with particularly sharp falls in Portugal, New Zealand, Hungary, Luxembourg and France. OECD cautions that road fatality rates per million inhabitants are an ambiguous indicator of road safety, since the number of accidents depends to a great extent on the number of vehicles in each country. Rates per million vehicles are affected by driving habits, traffic legislation and the effectiveness of its enforcement, road design and other factors over which governments may exercise control. In 2004, fatality rates per million vehicles were less than 110 in the Netherlands, Sweden, Norway and the United Kingdom, but exceeded 400 in Poland, Hungary, Korea and Turkey and exceeded 1,200 in the Russian Federation.[17]

Data on traffic fatalities often fall into categories involving three causes: driver, roadway or vehicle. Driver-related issues account for 93 percent of crash causes, roadway for 34 percent and vehicle for 12 percent,[18] with some overlap in causes. This is a gross estimation, and not all countries exhibit the same trends in traffic crashes and fatalities. Most low-income and middle-income countries experience a higher rate of crashes and crash fatalities. The Department of Road Transport and Highways in India reported 282,600 road crashes in 1990 and 429,800 in 2004—an increase of 52 percent. In the same period, injuries jumped from 229,700 to 464,600—an increase of 102 percent. Fatalities increased from 54,100 to 92,500—an increase of 71 percent. Africa, as a region, exhibits the world's worst death rate from road crashes at 28 deaths per 100,000 population—and road crashes are the second leading cause of death for Africa's 5-to-44 age group.[19]

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[17] OECD: OECD Factbook 2006—Economic, Environmental and Social Statistics.
[18] E. Alicandri. Road Safety Fundamentals (paper presented at International Road Safety Seminar, Lome, Togo, October 2006).
[19] "Africa addressing road safety," *Road Ahead,* 6 (June 2006): 8.

By contrast, in the United States, the fatality rate is 1.5 deaths per 100 million miles of travel.[20] The number of traffic fatalities during the 1995–2005 period increased by 1 percent. Crash injuries declined to nearly 2.7 million in 2004, the latest year for which data are available, from an estimated 3.5 million in 1995. Vehicle miles travelled increased 22 percent—to nearly 3 trillion in 2005 from almost 2.5 trillion in 1995.[21] While the number of vehicle miles travelled has increased significantly, the number of total crashes has decreased, with a significant decrease in injuries. At the same time, the number of fatal crashes and fatalities has increased. The conclusion to be drawn is that many more people are travelling on U.S. roads and that, although crashes are fewer per vehicle miles travelled, they are more severe.

Improving road safety is important for both industrialized nations and developing nations alike. For example, the European Union’s goal to save 25,000 lives annually by 2010 and Canada’s “Road Safety Vision 2010,” which has the national goal of making Canadian roads the safest in the world,[22] are representative of many ambitious programs to increase road safety in industrialized nations.[23] In developing countries, it is estimated that approximately US$100 billion are lost every year because of road crashes—a figure that is almost twice as much as the total development assistance received by developing countries worldwide. These losses undoubtedly inhibit the economic and social development of these countries.

According to the World Bank, every year more than 1.17 million people die in road crashes around the world. The majority of these deaths, about 70 percent, occur in developing countries. As economic conditions improve, the use of motor vehicles usually increases more rapidly than the infrastructure to handle the additional volume. The rate of traffic crashes also increases. This linear progression peaks at the income level of approximately $8,600 in 1985 international dollars and then drops as the relationship between motor-vehicle fatality rate and per capita income then declines.[24]

How can risk management practices or portions of the overarching risk management process be implemented worldwide to provide a means of achieving safer roads, particularly by nations that do not possess the resources to institute fully developed, integrated risk management in their road programs? The risk management toolbox may be one means of achieving this goal by introducing risk management best practices from around the world. Risk management examples, successes and shortcomings focused on road safety practices throughout the world are highlighted in the following subsection.

[20] U.S. Department of Transportation, Federal Highway Administration: Road Safety Fact Sheet, http://safety.fhwa.dot.gov/facts/road_factsheet.htm.

[21] National Center for Statistics and Analysis: Fatality Analysis Reporting System (FARS) Web-Based Encyclopedia, http://www-fars.nhtsa.dot.gov.

[22] Risk Management: A New Approach to Improving Safety, Canada National Report for Strategic Direction Session ST3, Paris, 2007.

[23] Commission of the European Communities: “European Transport Policy for 2010: Time to Decide”(Transport White Paper), Brussels, Commission of the European Communities. 12.9.2001 COM(2001)370 final, 2001.

[24] Elizabeth Kopits and Maureen Cropper, Traffic Fatalities and Economic Growth, Vol 1 (Washington, D.C.: World Bank, 2003).

3.1. An Integrated Strategy to Reduce Risk

Actions implemented by Spain's Directorate General of Roads, which is part of the Spanish Ministry for Development, are aimed at successfully meeting the government's commitment to cut traffic crashes to half the 2002 rate by 2010 and to one-quarter by 2020, in line with the Strategic Infrastructure and Transport Plan (known by its Spanish acronym PEIT).

To help improve driving safety on the road network managed by the directorate, a series of procedures specifically designed to take safety into account from the actual conception of a road right through its service life—from planning to design, construction, start-of-service operation and maintenance—are being adopted. This integrated strategy attempts to meet all the conditioning factors derived from human factors, handling road design in such a way that the interactions between environment, roadway and user take place with the lowest possible level of risk. A road safety auditing system is implemented during the planning and design stages constituting a separate section of the design process. This system involves an independent team of road engineering and road safety experts' examining the configuration of the physical elements of a road and their interrelations with a view to detecting potential risks to user safety. The team would then make recommendations to the planning or design team concerning adequate measures for avoiding any such risks before the construction stage. In addition, an audit is being carried out on the state-run roads currently in service. This audit concerns the state of road safety and aims to guarantee that the safety features of each road section are compatible with the road's functional classification. This cross-check is being performed to detect any situation that could eventually become a safety problem. To this end, in 2006, nine teams of experts examined the road infrastructure and the way it relates to the environment, drawing up corresponding proposals for improvement.

In addition to these safety-focused efforts, Spain's annual safety-improvement campaigns that first began in 1986 continue to be carried out every year for existing Spanish roads. These programs include a set of actions designed to decrease crashes on road sections that exhibit high crash concentrations and to make preventive improvements to road safety conditions by rectifying the functional shortcomings detected. These actions should cut down the risk of potential crashes on the network as a whole.

3.2. Mega Complexity

Mega projects, which are in a class by themselves for complexity and risk exposure, provide many areas in which risk management practices may be used. Mega-project construction work involves risks for all parties directly, and often indirectly, involved in the project. By their nature, these projects also entail considerable risks for the owner. Often the project scope or level of ambition will change during project development and implementation. Changes may be due to uncertainty at the early project stages (for example, the exact corridor, the technical standards, project interfaces or the geotechnical and environmental conditions). Significant cost overrun and delay risks may arise from these uncertainties. In addition, there is a potential for large-scale accidents during megaproject work; and, for megaprojects in inhabited areas, there is a risk of damage to a range of third parties and property.

Finally, there is a risk that the course of the project may be affected by public protest and political reactions arising from the problems that the megaproject may cause to the public. For these reasons, megaprojects have been described as "a different breed."[25]

Several new Danish megaprojects[26] have applied systematic risk management in various forms to significantly improve the quality of engineers' decisions. The use of these techniques has shown that potential problems can be identified clearly so that appropriate risk reduction initiatives can be implemented in time to be effective. One megaproject using risk management throughout the organization is the Oresund Link tunnel and bridge project connecting Sweden and Denmark.

Opened on July 1, 2000, the Oresund Link includes 8 km of bridge and 4 km of immersed tunnel, which are joined by 4 km of artificial island. An operational risk analysis (ORA) was compiled as an integrated part of the Oresund Link Risk Management System. The purpose of the ORA is to summarize the risk facilities and major disruptions in the operational phase of the Oresund Link, to compare the risk with the acceptance criteria outline and, if possible or required, to take measures to reduce risk.

Practical examples of the proactive and consistent management of risk throughout the project include the following:

- hazard identification (fire, explosion, toxic release; design and construction errors or operator and procedure errors; train derailment or collision; wind);
- ALARP (as low as reasonably practical) risk acceptance criteria that, for the road portion, equalled fewer than 33 fatalities per 1 billion passages; and, for the rail portion, equalled fewer than 4 fatalities per 1 billion passages;
- user risk as individual risk and societal risk (for example, 93.2 percent risk of being involved in an ordinary accident if travelling by road versus 64.4 percent risk of being involved in an ordinary accident if travelling by rail on the Link);
- risk reducing measures (assumptions) stating that vehicles and trains should be stopped in the event of a collapse of the tunnel or the bridge and that ventilation in the road tunnel tubes is working in case of an accident with dangerous goods, toxic materials, or other hazardous materials.

3.3. Risk Analysis to Address Patterns of Fatal Collisions and the Road System

In working toward achieving the goals of "Road Safety Vision 2010," Canada initiated an effort to observe trends in past collision data to determine what features of the road system require improvement. Twenty years of Canadian collision data from 1984 to 2003 were extracted from Transport Canada's Traffic Accident Information Database (TRAID). The data were analyzed at a 20-year (1984–2003) level and compared with a 5-year (1999–2003) level, observed trends were documented and recommendations were made on ways to improve the road safety condition in Canada. From this risk analysis, Canada has culled a group of priority issues that require attention in addressing fatal collisions throughout the country.

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[25] J. R. Capka. "Megaprojects—They Are a Different Breed," Public Roads Magazine, 68 (July/August 2004):1.

[26] World Road Association: Technical Committee 3.2 Introductory Report, Section 4, "Risk Management on Mega Projects: An Example of an Operational Risk Analysis," Plovgaard Anders, Denmark, September 19, 2007.

The country concluded that values in the data elements should be analyzed further to narrow down specific causes and characteristics of collisions in preparation for recommending the necessary countermeasures that have the best chance of increasing safety on Canadian roads.

3.4. Using Risk Identification, Analysis, Evaluation and Treatment in Practice

In the United States, although the Michigan Office of Highway Safety Planning does not claim risk management principles are directing their operations per se, they do have a similar process to help focus their efforts in road safety. Michigan, which has a very good road safety record with 1.1 fatalities per 100 million vehicle miles travelled (versus the U.S. national average of 1.46 deaths),[27] is collecting crash data, analyzing the data, identifying problem areas, setting goals, developing a strategic plan and action plans, implementing remedies, reviewing and monitoring progress toward these goals and reviewing and revising the strategic plan as new data become available and remedies taken affect crash statistics.

Similar to national efforts to increase road safety, this state is working toward a 15 percent reduction in traffic fatalities and an equal reduction in serious injuries by 2008.[28] To further this effort, a review of the current traffic safety situation has been performed and data from the Michigan Traffic Crash Facts website analyzed. This website contains a database of well-developed crash statistics that are compiled annually.[29] The data are supplied by law enforcement and other agencies and organized according to the emphasis areas of the American Association of State Highway Transportation Officials (AASHTO) strategic plan. Datasets are crash, vehicle/unit and occupant/person/party. The data include more than 135 separate items that can be sorted by geographic area as well as AASHTO strategic plan area. The richness of data available and the query capabilities of the system provide an abundant number of options for report statistics and enable further analysis. The system provides very detailed information through which government and law enforcement agencies can assess risk, define countermeasures and propose actions or programs related to road safety issues.

3.5. Improving Road Safety for Motorcyclists30

In Spain, crashes involving motorcycles over the 1999–2003 period amounted to 12 percent of total crashes with casualties occurring on the Spanish state-run road network. Crashes as a result of motorcycles veering off the road equalled 2.4 percent of total fatal crashes. The number of crashes with casualties has led to the gradual attempt to improve the design of these retaining systems with a view to minimizing harm to motorcyclists. Spanish legislation, adapted to the directives issued by the European Commission's Standardisation Organisation, provides the supply of C-shaped guardrails on expressways and tubular posts on conventional roads.

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[27] Governor's Traffic Safety Advisory Commission: State of Michigan Strategic Highway Safety Plan…all roadway users arrive safely at their destination, Lansing, 2006.
[28] Governor's Traffic Safety Advisory Commission. State of Michigan Strategic Highway Safety Plan.
[29] Michigan Traffic Crash Facts website (http://www.michigantrafficcrashfacts.org).
[30] A. García-Garay. Risk Management: A New Approach To Improving Safety
Spain—National Report , Strategic Direction Session St 3, Xxiii[rd] World Road Congress
Paris 2007,

These guardrails and posts are designed to prevent cuts to motorcyclists crashing into guardrails and thereby constituting an improvement over the previous L-shaped guardrails. Notwithstanding, although installation of new metal guardrails and the repair of any crash-damaged rails are always done using the new C-shaped or tubular post designs, many of the old-design L-shaped guardrails still exist and are being protected by special fenders to buffer the possible impact to motorcyclists.

However, the most important advance in guardrail improvement to protect motorcyclists has involved the installation of a new design, defined in Circular Order 18/2004, "Criteria for the Use of Motorcyclist Protection Systems," which, after numerous trials, came into force on January 10, 2005, and consists of incorporating a second metal guardrail under the existing one in the conventional guardrail design. This system prevents motorcyclists from passing under the guardrail and possibly colliding with the posts yet does not harm other vehicles in the event of a crash.

In Hungary, where the share of motorcyclists has risen slightly since 2002, the approach to reducing injuries and fatalities is to increase the safety of passenger-car drivers and passengers. This may involve safety programs aimed at educating the travelling public, particularly regarding seat belt use, and by more efficiently enforcing existing legislation. [31]

These safety improvements and strategies may be very useful in developing countries, where the majority of road crash victims (injuries and fatalities) are not motorized vehicle occupants, but motorcyclists, pedestrians, bicyclists and nonmotorized vehicle occupants.

3.6. Roads and Health

Although a great deal of attention is currently focused on reducing road crashes to improve safety, protecting public health and the environment is another aspect of road safety.

Viet Nam[32] has implemented risk management strategies, such as proactive technologies for landslide protection and continuous reinforcement of concrete pavement, as countermeasures to mitigate the damage that transportation infrastructure receives, particularly from typhoons, torrential rain and flooding. These efforts help road transportation in Viet Nam better play its critical role in socio-economic development. Increases in traffic, however, have come at the cost of increased air pollution, particularly in major cities such as the nation's capital of Ha Noi, Ho Chi Minh City, Da Nang and Bien Hoa. In Viet Nam, the percentage of CO, HC, NO_x and SO_x exceeds national air quality specifications and the standards of the World Health Organization. A 2005 study of environmental pollution at a number of toll collection stations examined the health of toll workers. A finding of the study was that 68 percent of the samples showed levels of unhealthy pollutants that were 4 to 6 times the sanitation standards and the free silica concentration in dust was 24–28 percent. Medical examinations of toll workers at five different collection stations also revealed health issues related to air pollution.

[31] P. Holló. Risk Management: A New Approach to Improving Safety, Hungary—National Report, Strategic Direction Session St 3, 23rd World Road Congress, Paris 2007.
[32] Vietnam Road Administration: Risk Management in Road Transport and Measures, presented at International Seminar on Risk Management for Roads, April 26-28, 2006, Hanoi, Viet Nam.

3.7. The Need for Good Underlying Data

The risk management process relies on extensive, reliable and consistent data. Data are used to help identify dangerous spots in the road network, determine where crashes happen, target spots for enforcement and support public safety campaigns.[33] Other means of collecting related information may include using a road safety audit or guidelines to assess problem areas proactively. Including performance of road safety audits in the road design, construction and pre-opening phases should reduce the need to collect crash statistics on these roads. In 2005, Norway created a useful handbook on road safety audits and inspections.[34]

Most crash data are based on fatalities, and much of the extensive research that has been conducted on road safety has focused on fatality rates. One major barrier to risk management analysis can be a lack of consistent data. Not all countries collect data the same way, or in the same temporal formats. For example, in Canada (as in many industrialized nations), each province uses its own unique collision report form, with different variables and criteria; it is the responsibility of police officers to analyze the collisions and assess their contributing factors on the basis of their own knowledge and judgment of the incident. To get a national perspective on the overall collision situation, Transport Canada merges collision data from all provinces and territories into its own collision database where it may be analyzed. This enables the federal government to cater road safety projects and programs to emerging problems and be proactive by studying collision trends over time.

A lack of consistency in data from different countries or even from different agencies within the same country makes it difficult to draw comparisons across countries or regions, or between years. Efforts to standardize data collection and improve the ability to make such comparisons are facilitated by systems such as the European Union's Community database on Accidents on the Roads in Europe (CARE), the U.S. Department of Transportation's Crash Outcome Data Evaluation System (CODES) and the International Traffic Safety Data and Analysis Group (IRTAD).

This global importance of road safety improvements prompted PIARC's Technical Committee on Road Safety to compile the PIARC *Road Safety Manual*, which summarizes the experience of different countries and presents state-of-the-art information and guidance on the design and operation of road infrastructure. While preparing the *Road Safety Manual*, the Committee developed international guidelines and forms for police work at the crash locations. The standardization of this information collection will provide similar data from which those performing the engineering work of crash investigations and road safety inspections (RSIs) can draw. RSIs are on-site systematic review of an existing road or section of road to identify hazardous conditions, faults, or deficiencies that may lead to serious crashes. This standardization of data is critical to those attempting to use integrated risk management processes that rely on the ability to compare data in order to evaluate risks. A lack of standardized data can be a barrier to integrated risk management. A World Road Association presentation, "Road Safety Inspections," provided by Australia at the 2006 Road Safety Seminar, also provides a good overview of the RSI process.

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[33] L. Ágústsson. "The Importance of Good Accident Data" (paper presented at International Road Safety Seminar, Lome, Togo, October 2006.)

Although risk management processes are being developed in many road authorities throughout the world, implementation of the integrated risk management framework remains challenging, even in the developed nations, and is yet to reach its full potential in the field. In many countries, new projects—such as California's Coronado Tunnel project in the United States, which is in the very preliminary planning stages—are using elements of risk management. In Coronado, for example, risk matrices are being developed.[35]

In addition to the efforts of TC 3.2 to advance the implementation of risk management processes throughout the world, Technical Committee 3.1 (Road Safety) is working on developing guidelines for accident databases that may be of particular help to developing nations. This effort includes methods for diagnosing the nature of safety problems.

4. SECURITY

One of the basic tenets of an organized government is to provide for the security of its citizens. In Canada, for example, civil protection planning[36] is defined as an ongoing, six-stage process that encompasses

- knowledge of the environment,
- a vulnerability study,
- the implementation of prevention measures,
- the implementation of measures to facilitate intervention,
- follow-up and
- updating.

The government's and, by extension, road authority's duty to provide secure roadways for the travelling public and to ensure the mobility required for economic prosperity has grown increasingly difficult in the past decade. The watershed event for many is seen as the 9/11 attacks on U.S. targets in 2001, which destroyed both World Trade Center towers in New York and damaged the Pentagon outside Washington, D.C. For the United States, it was an "eye-opening realization that we are all vulnerable to terrorist attacks"[37] and a reaffirmation of the critical role transportation systems play in disaster relief efforts.[38] Unfortunately, other coordinated attacks carried out on multiple targets simultaneously followed throughout the world; for example:

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[34] Norwegian Public Roads Administration: Norwegian Public Roads Administration Handbook series, Number 222.

[35] Jesus Rohena, Complex Structure Engineer, US Department of Transportation, Federal Highway Administration, Office of Bridge Technology, phone conversation, March 7, 2007.

[36] World Road Association: Strategic Sites in an Autoroute Network: A Planning and Operating Tool in the Realm of Civil Protection, Alexandre Debs, 2004.

[37] James C. Ray. "Risk-Based Prioritization of Terrorist Threat Mitigation Measures on Bridges," *Journal of Bridge Engineering,* March/April 2007: 140–146.

[38] U.S. Department of Transportation, Federal Highway Administration, Office of Operations: Public Safety and Security Program, http://ops.fhwa.dot.gov/OpsSecurity.

- On Indonesia's resort island of Bali in 2002, terrorist bombings of nightclubs killed 202 people, most of whom were tourists.[39]
- In Madrid, during morning rush hour on March 11, 2004, a coordinated terrorist attack on four commuter trains killed 191 people in what has been called the worst terrorist attack in Spain's history.
- In London during the July 7, 2005, morning rush hour, coordinated bombings on three Underground trains and one public bus killed 52 people, injured 700 and disrupted transportation. Two weeks later, a second set of coordinated explosions affected a bus and three Underground stations.[40]
- In France, during multiple nights of gang violence in October and November 2005, dissatisfied children and grandchildren of Muslim Arab and African immigrants burned more than 1,000 vehicles and ambushed fire-fighters and police.[41]

The world's sense of security was further shattered by natural disasters of epic proportions that seemed to culminate in 2005 with the most active hurricane season in 154 years. These natural disasters included the following:

- A magnitude 6.6 earthquake in Iran that devastated the ancient historic city of Bam in southeast Iran in 2003, killing 26,200 people, injuring 30,000 and leaving 75,000 homeless, as mud-brick buildings collapsed.
- In 2004, four major hurricanes in six weeks hit Florida, killing 167 in the United States and 66 in the Caribbean. Total U.S. damages from the four hurricanes were estimated to exceed US$35 billion.
- A magnitude 9.0 earthquake in Indonesia, off the west coast of Sumatra on December 26, 2004, caused the deadliest tsunami in history in the Indian Ocean. Twelve Asian countries were hit by the tsunami, which killed more than 225,000 and left millions homeless.
- A magnitude 7.6 earthquake centered in the Pakistani-controlled part of the Kashmir region killed more than 80,000 and injured 65,000 in 2005. About half of the region's capital city, Muzaffarabad, was destroyed, other towns and villages reduced to rubble, and an estimated 4 million left homeless.
- In 2005, Hurricane Katrina shut down the U.S. Gulf Coast, destroying hundreds of homes and businesses and causing massive flooding, particularly in New Orleans, where the levees failed. The death toll was approximately 1,800, and damages were estimated at US$100 billion.
- Also in 2005, Hurricane Wilma took 11 lives in Haiti, then moved on to Jamaica and Mexico, where the storm settled over the Yucatan Peninsula for more than 24 hours before moving on to Cuba and southern Florida in the United States. Extensive damage left more than 6 million people without power and killed 35, with estimated costs exceeding US$10 billion.[42]

Many losses from natural disaster are a predictable result of the interaction between the natural environment and the human system, rather than stemming from unexpected events. Nevertheless, both the human and the natural system are chaotic and random.

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[39] Zakki Hakim. "Asia Winning Some Battles in Terror War", Associated Press, March 5, 2007, http://www.washingtonpost.com/wp-dyn/content/article/2007/03/05/AR2007030500034.html.
[40] CNN.com. "Bombers target London." http://www.cnn.com/SPECIALS/2005/london.bombing.
[41] Christopher Dickey. "Europe's Time Bomb," *Newsweek*, November 21, 2005.

Risk analysis methods may help us to understand what possibly might happen. In most cases, however, we are still not able to predict the detailed chain of events and the chain of human reactions.[43]

In many disasters, but particularly major disasters—such as the 2004 tsunami, the 2005 Pakistani earthquake, the 9/11 terrorist attacks in the United States, or others of this magnitude—access and transport infrastructure often is damaged or destroyed at a time when it is needed most to provide

- quick access to victims needing treatment,
- relief operations and
- reconstruction operations.

As noted in the previous discussion on safety, in many countries, integrated risk management is evolving from theory to practice and is yet to reach its full potential. From the United States, which cautions local road jurisdictions, “If your community is not actively planning to optimize the operation and coordination of its transportation system during natural disasters or national security events, there’s a missing link in your emergency preparedness plans”[44] to Sri Lanka, which enacted a legislative framework for more proactive disaster risk management in the aftermath of the 2004 tsunami, there appears to be a global consensus that we could all be better prepared.[45]

It must be noted that some of the world’s worst disasters occur in impoverished areas where—without effective reconstruction operations to build houses, schools, heath centers and the infrastructure for people to be able to reach social and economic opportunities, such as employment to re-establish livelihoods—disaster recovery is severely limited. Without dependable access to social and economic opportunities, poverty flourishes and economic growth declines. Not surprisingly, efficient and affordable transportation, particularly for poor communities where options are limited, is a necessary precondition to accessing trade and delivering health and education services. In rural communities, improved access is directly linked to improved standards of living. [46]

It is in this context of the major disasters of the current decade that world attention has turned to issues of security and crisis management. The recent heightening of security awareness is changing how risk management practices are being applied by road authorities. From the planning stage forward, project managers must consider normal, serious and crisis conditions.

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[42] Data for entire bullet list is from http://www.infoplease.com/ipa/A0001439.html.
[43] World Road Association: Study on Risk and Crisis Management for Roads, PIARC C18, 2004.
[44] U.S. Department of Transportation, Federal Highway Administration, Office of Operations: “Public Safety and Security Program,” http://ops.fhwa.dot.gov/OpsSecurity.
[45] World Road Association: Recent Tsunami Disaster Stricken to Sri Lanka and Recovery (paper presented at PIARC Technical Committee 3.2, Fourth Reunion in Tokyo, Japan, October 25–28, 2005).
[46] Fergus Gleeson et al. South East Asia Community Access Programme (SEACAP): A new Approach—Rural Road Research Applications in Crisis Situations” (paper presented at International Seminar on Risk Management for Roads, Hanoi, Viet Nam, April 26–28, 2006).

Those responding to both of the TC 3.2 international surveys reported that the top five manmade sources of risks are transportation of dangerous goods, overloaded vehicles, traffic crashes, traffic congestion and fire; the top five natural sources of risks for roads are flood, landslide (see Figure 3, Inventory Sheet Sample Inventory Sheet on Slope Framework, in Section 2), rock fall, snow storm/ice storm/heavy snowfall, and wind storm/rain storm/heavy rainfall.[47]

It is PIARC TC 3.2's intention that the risk management toolbox will cover most of the actions and countermeasures to be taken to mitigate risks for roads when facing each disaster type.[48] The following sections look first at manmade disasters (including terrorism) and then at natural disasters. Throughout, special attention is focused on risk management applications, tools or technology.

4.1. Risk Analysis to Improve Road Tunnel Safety

No report discussing road safety and security would be complete without addressing tunnels. Management of road tunnel safety is one of the most challenging topics in engineering. Fires such as the 1999 Mont Blanc tunnel fire that killed 40 who succumbed to fumes from the fire and that closed the tunnel for two years, and the 2001 Baltimore, Maryland, rail tunnel fire in the U.S. have drawn attention to this topic.

To reach a unified minimum standard in European road tunnels regarding safety facilities, the European Union issued the directive 2004/54/EC on minimum safety requirements for tunnels in the Trans-European Road Network. The directive requires the realization of risk analysis procedures for the assessment of safety measures in certain cases. In Germany, for example, this directive was applied in the form of an amendment of the "Guidelines for the Equipment and Operation of Road Tunnels,"[49] which applies to all tunnels on the federal trunk road network and for road tunnels owned and operated by the Länder. The directive also applies to the construction of new tunnels, such as the Tiergarten Tunnel in Berlin. Safety in road tunnels that are not part of the Trans-European Road Network and do not fall within the scope of application of the EU Directive is ensured by similar provisions.

By carrying out risk analyses, a quantitative measure of risks and possible consequences resulting from triggering initial events (for example, fire in tunnels)—in terms of admissible fatalities and injuries as well as the probability of occurrence—can be provided. According to the directive, member states are asked to develop and use a well-defined and unified methodology for risk analyses. In response to this directive, Germany has been developing a quantitative risk assessment model.

[47] World Road Association: Towards Development of a Risk Management Approach.
[48] PIARC: Technical Committee on Risk Management, Minutes of October 2005 meeting.
[49] Wolfgang Hahn and Hans-Joachim Vollpracht. Risk Management: A New Approach to Improving Safety, Germany—National Report, Strategic Direction Session St 3, 23rd World Road Congress, Paris 2007.

The use of risk analysis measures in other countries, such as Spain, has also led to improvements in both new and existing tunnels. Upgrades have particularly involved tunnel ventilation systems, which prior analysis and evaluation determined to be in need of improvement. Spain has recently upgraded the Monrepós Tunnel, a nonurban, two-way, 1500-m tunnel on an extremely important road linking North East Spain to France that is unavoidable for crossborder traffic that also uses another tunnel (Somport Tunnel). Due to the enormous difficulty of building escape galleries to the exterior of Monrepós Tunnel, the designers introduced a number of risk-reducing compensatory measures to improve safety. These actions took into account future plans for doubling the current road, which will involve converting the existing two-way tunnels into one-way configurations for which the most suitable ventilation system is a longitudinal design.

The Fréjus motorway tunnel[50] connects the city of Bardonecchia in Italy to the city of Modane in France through a bidirectional tunnel, 12.985 m long. In the first six months of 2005, the Fréjus alpine tunnel recorded an average daily traffic of 5,360 vehicles. Since its opening in July 1980, traffic has constantly and proportionately increased with the flow of trade crossing the Alps. As an Italian/French international tunnel, Fréjus is part of the trans-European network.

In 2001, the Intergovernmental Commission assessed the technical and natural risks related to the operation of the Fréjus tunnel in order to define any corrective or compensation actions that could reduce risk. The tunnel operators performed a risk analysis on the Fréjus tunnel and the relevant plazas to assess all the risks related to the operation of this motorway tunnel. Traffic flow was taken into account, as well as the relevant split in terms of light and heavy vehicles, coaches, vehicles carrying dangerous goods and exceptional convoys. The operation of the tunnel was then analyzed in terms of human resources, organizational structure, safety installations and equipment and relevant criteria of use.

This risk-scenario study not only considered the interactions of various traffic anomalies but also considered the potential effects of a fire and human reactions to emergency situations, as shown in Figure 4.

[50] World Road Association: Example of a risk management process in Italy: "The Frejus Tunnel," Robert Arditi Sina, Joel Faure Sftrf and Ugo Jallasse Sitaf, Technical Committee 3.2, Introductory Report, Section 4, Italy, September 19, 2007.

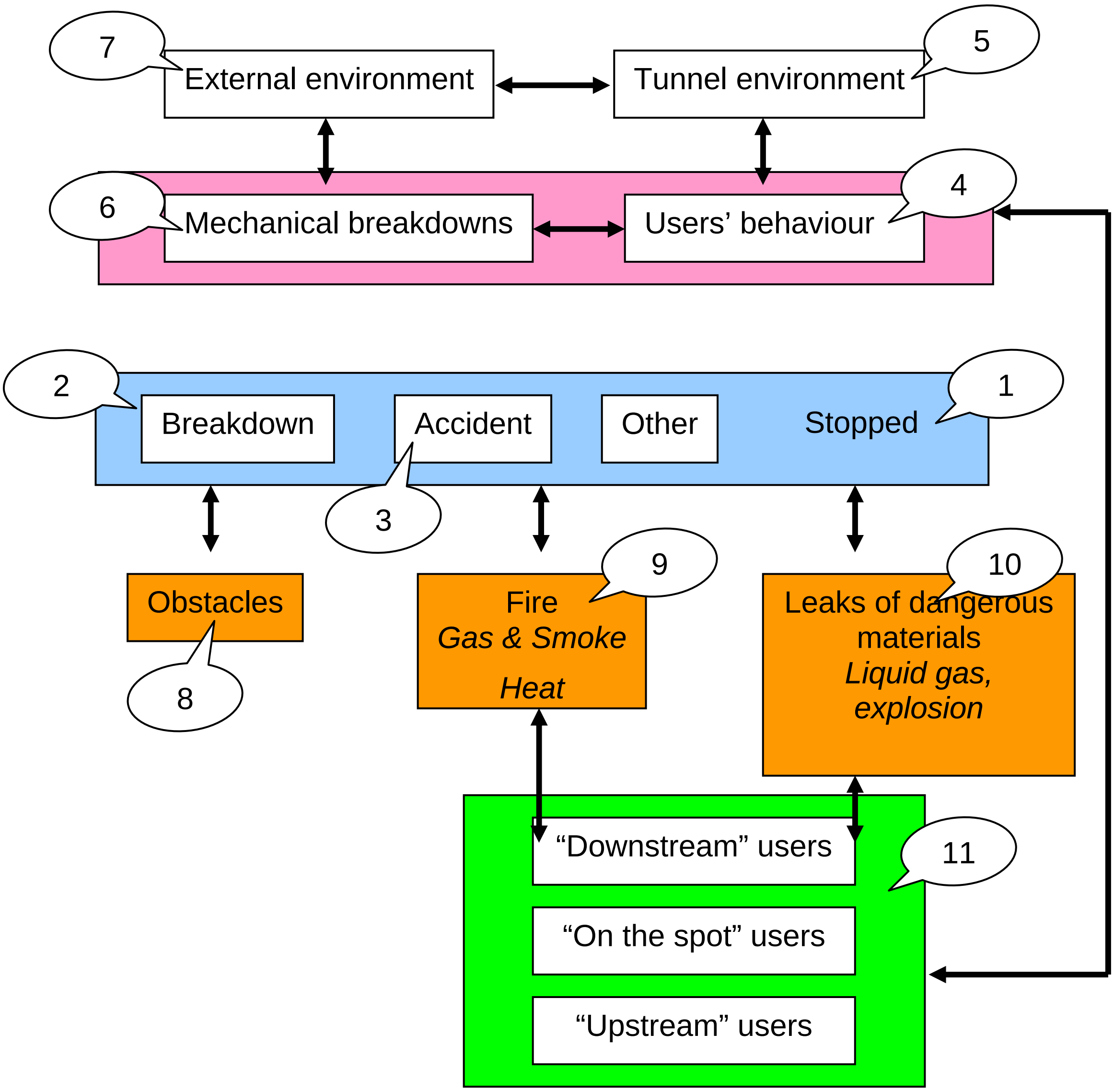

Figure 4. Overview of the Fréjus Tunnel Risk Scenarios Study

Helpful PIARC tools on this topic include "Fire and Smoke Control in Road Tunnels," created by Technical Committee 3.3. This report provides those interested in road tunnel design, construction, operation or safety with recommendations and background information on how to provide reasonably efficient and cost-effective protection against fire and smoke in tunnels.

4.2. Risk Analysis in the Transportation of Dangerous Goods

One example of the use of risk management tools aimed at reducing the risks inherent in the transport of dangerous goods is the use of a model[51] to study the potential consequences of transporting chlorine through a populated area on a major roadway in Argentina. The city of Rosario, Argentina, is located on the west bank of the Paraná River in an agricultural and livestock producing area. Two major transportation corridors and the Paraguay-Paraná-Rio de la Plata Hydroway cross the area. As a result, Rosario has become an industrial and commercial center with more than one million persons.

For Rosario, risk analysis is performed by using a mathematical modelling for prediction. The model contains variables and uses mathematical language to describe a system and relationships of the variables that depict some features of the system. Variables can be represented as numbers or as Boolean strings to identify inputs, outputs, decisions or external constraint variables.

Risk analysis for the transportation of hazardous materials includes the assumptions that a vehicle carrying dangerous goods is involved in a crash and that breakage or release occurs. From those assumptions, a calculation of individual or societal risk for each road segment and a calculation of the risk distribution over a given area for each scenario are developed.[52]

The model not only considers the geographical characteristics of the area, but also includes random meteorological parameters (for example, wind direction, wind velocity, atmospheric stability, humidity, temperature) that may affect the diffusion of a toxic gas cloud over the area. External variables are noted over a time horizon by a probability-density function. Population density along the roadways and traffic volume at various times is included.

Such a model can provide risk analysis information to industry and government agencies to assist in scheduling dangerous goods movement and to plan for crisis management responses in the event of a crash, terrorist attack or any other event that causes the release of toxic material into the environment.

4.3. Man-made Events Caused by Terrorism

In addition to the five common risks identified in the TC 3.2 surveys, a great deal of new research, much of it from North America, has been done on improving security in response to terrorism. Throughout the world, many approaches to security have changed in recent years. Lessons learned[53] include the following:

- people are the intended target,
- advance warnings are unlikely,
- multiple simultaneous attacks are possible,
- emergency responders may be targets,

[51] N. J. Scenna and A. S. M. Santa Cruz. “Road Risk Analysis Due to the Transportation of Chlorine in Rosario City.” *Reliability Engineering and System Safety* 90, no. 1 (2005): 83–90.
[52] F.F. Saccomanno, and K. Cassidy. “QRA and Decision-making in the Transportation of Dangerous Goods.” *Transportation Research Record* 1430 (1995):19–25.
[53] Transportation Research Board. A Self-Study Course on Terrorism Related Risk Management of Highway Infrastructure, NCHRP Report 525: Surface Transportation Security (vol. 4), 2005.

- the weapons may introduce serious and long-lasting hazards,
- the weapons may introduce large-scale damage or contamination to critical equipment and facilities,
- public reaction is unpredictable.

According to a recent report, “A credible and constant threat to the United States is use of transportation as a weapon, as a target, and as a means to deliver a weapon to a target.”[54] A similar report notes, “The 1995 sarin gas attack on the Tokyo subway system raised the stakes of transport terrorism further by introducing weapons of mass destruction (WMD) into the terrorist repertoire.”[55] Another warns that “the actions of terrorists can impose critical damage to some bridges, and, with explosive forces, exert loads that exceed those for which components are currently being designed.…In some cases, the loads can be in the opposite direction of the conventional design loads.”[56] With terrorism on the minds and agendas of many road agencies throughout the world, several methodologies and approaches have been developed to assist responsible authorities in the assessment of vulnerabilities of their infrastructure and the identification of critical assets[57] (see Table 1). A form of risk management is used that takes into account three major factors:

- the importance of the asset in terms of the consequences of its loss,
- the probability or likelihood that an undesirable event (for example, an intentional attack or a natural or manmade disaster) will occur,
- the vulnerability of the asset of interest to the threat (for example, how much damage will occur).

The first factor involves understanding how a particular asset contributes to public safety, homeland and national security, economic well-being and other factors that help determine how important an asset is and what consequences (loss of life, symbolic value and economic impact) would result from loss of the asset. The second factor is largely a matter of judgment (estimating threat) or using actuarial data (historical occurrences) to project future likelihood. The third requires both theoretical models and experimental data to estimate potential damage resulting from specified threats.

In the United States, AASHTO and National Cooperative Highway Research Program have summarized the assessment phase of terrorism-related risk management of highway infrastructure as follows:

- identify critical assets,
- assess vulnerabilities,
- assess consequences,
- identify countermeasures,
- estimate countermeasure cost,
- review operational security planning.

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[54] American Association of State Highway Transportation Officials Task Force on Security: Transportation Agency Security Principles, Discussion Draft, Washington, D.C., January 2004.
[55] Institute For Security Technology Studies at Dartmouth College: On The Road to Transportation Security, 2003.
[56] U.S. Department of Transportation, Federal Highway Administration: Recommendations for Bridge and Tunnel Security, FHWA-IF-03-036. September 2003.
[57] Michel Cloutier, “Introduction of RM for Highway Systems Security” (paper presented at International Seminar on Risk Management for Roads, April 26–28, 2006, Hanoi, Viet Nam).

Table 1. Risk Identification: Creating an All-Inclusive List of Critical Assets[58]

INFRASTRUCTURE	***FACILITIES***	***EQUIPMENT***	***PERSONNEL***
▪ Arterial Roads ▪ Interstate Roads ▪ Bridges ▪ Overpasses ▪ Barriers ▪ Roads Upon Dams ▪ Tunnels	▪ Chemical Storage Areas ▪ Fueling Stations ▪ Headquarters Buildings ▪ Maintenance Stations/Yards ▪ Material Testing Labs ▪ Ports of Entry ▪ District/Regional Complexes ▪ Rest Areas ▪ Storm Water Pump Stations ▪ Toll Booths ▪ Traffic Operations Centers ▪ Vehicle Inspection Stations ▪ Weigh Stations	▪ Hazardous Materials ▪ Roadway Monitoring ▪ Signal & Control Systems ▪ Variable Messaging System ▪ Vehicles ▪ Communications Systems	▪ Contractors ▪ Employees ▪ Vendors ▪ Visitors

One of the tools available for risk management is a self-study course to provide a general background in risk management related to terrorism threats for bridge, tunnel and other highway infrastructure. The course book provides the content of the workshops developed by the AASHTO Task Force on Transportation Security and introduces key bridge and structure engineers and managers to the current state of the art in the field of bridge, tunnel and other measures for analyzing and protecting highway infrastructure vulnerability. This course book is tailored to convey sufficient information in order that transportation agencies may understand the concepts and methodologies in vulnerability assessment of their bridges and tunnels and be able to develop appropriate threat protection plans.

Other resources for road agencies interested in forming or revising security principles is AASHTO’s “Transportation Agency Security Principles,” a discussion draft that proposes five common security principles (surety, partnership, differentiation, system and interdependence) that acknowledge the diversity among transportation agencies while providing common tenets on which all may find consensus. Also of interest may be “Effects of Catastrophic Events on Transportation System Management and Operations: Cross Cutting Study,” which analyzes four past events and the actions taken by responders in the transportation sector. Related PIARC studies include the “Study on Risk and Crisis Management for Roads" (2004), which compiles essential findings and valuable information.

[58] Source: Transportation Research Board, Surface Transportation Security, “A Self-Study Course on Terrorism Related Risk Management of Highway Infrastructure” (vol. 4), Chapter II, 19, NCHRP Report 525 2005.

4.4. Anticipating a Landslide Can Lead to Avoiding It

In Japan, where the topology necessitates building many roads close to unstable slopes, risk management that involves evaluation and control of existing risks is widely used[59] to identify potential landslide areas before a serious landslide occurs, take effective preventive measures and perform efficient restoration.

After detecting cracks on the retaining walls of a section of Japan's National Highway No. 168, a road used heavily by truck traffic, the road administrator, Gojo Public Engineering Office of Nara Prefecture, precisely monitored movement on the slope from February 2004 until the landslide occurred more than six months later. During this period, appropriate risk management measures were taken, (for example, installation of an automatic monitoring system and permanent stationing of watch persons). In the intervening months, landslide activity increased because of heavy rainfall from three different typhoons.

In July, an efficient monitoring system was constructed, which consisted of a warning system based on extensometers (control standard: displacement of 2 mm/hr for two continuous hours), an automatic notification system to mobile phones of the staff when warning was given and a real-time automatic monitoring system that enabled movements to be monitored at the office. A road was constructed and opened on the opposite bank as a detour in preparation of the worst-case occurrence of a landslide.[60] Precise monitoring enabled the road administrator to successfully predict the landslide and close the affected roads the day before the landslide occurred. Highway restoration work is being executed by monitoring the unstable points to ensure the safety of workers. Thus, three years are likely needed to restore the highway, showing that effects of a landslide may continue over a long period of time.

An important finding[61] related to the use of risk management has been that "crisis mitigation," which is widely used for landslides, involves only quick measures *after* the landslides. Conventional risk management has previously lacked the viewpoint of mid- to long-term preliminary crisis mitigation before an event such as a landslide has occurred. To minimize the social impacts of landslides, the experience of dealing with risks should be fed back to preliminary risk control.

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[59] Saburo Ikeda. *Encyclopedia of Risks, Strategies and Policies against Risks and Accuracy* (in Japanese), p. 310, 2000.

[60] World Road Association: Technical Committee 3.2 Introductory Report, Section 4, "Quantitative Risk Estimation of Road Slope Disaster," Kohashi, Tsuneoka, Tanaka, Takahara, Hamada, Japan, September 19, 2007.

[61] World Road Association: "An Analysis of Landslide Risk Management on the Basis of the Movement Characteristics." (paper presented at PIARC Technical Committee 3.2, Fourth Reunion, Tokyo, Japan, October, 25–28, 2005).

Building on this work, Japan is now applying a concept from the disaster insurance industry called a "risk curve."[62] Risk curve analysis is being used to quantify the level of risk in road slope disasters. First, the fragility curve is calculated based on data such as past records of failures, precipitation records and results of slope stability inspection. Then the risk, defined as socio-economical damages and losses, is estimated in the form of a risk curve on the basis of data such as the estimated scale of failures and the amount of traffic. A loss exceedance probability curve (that is, a risk curve) depicts the probability that a certain level of loss will be exceeded on an annual basis. The risk curve for a road section is developed by summing up the risk curves for all slopes within this section. This quantitative risk estimation method could help road administrators undertake effective and efficient risk management.

Landslide risks in New Zealand[63] also have fostered slope stability evaluation using a risk management approach. State Highway 73 runs 255 km between Christchurch and the West Coast on the South Island of New Zealand. The route includes the Arthur's Pass through the Southern Alps, where the mountains rise to some 2,200 m and the road reaches an elevation of 920 m. Lewis Pass, the alternative route, is 332 km long on SH7 and, point to point, is 77 km longer than SH 73.

A review process included a comprehensive assessment and prioritization of the risks due to slope instability. The main objectives of the project were to determine a cost optimal preventive maintenance program at various detritus cleanup sections of SH 73 between Springfield and Arthur's Pass and to provide a procedure for demonstrating an appropriate standard of highway care where road users are subject to risk from slope instability hazards.

For SH 73, the risks have been identified for different slope instability events that could pose a threat to road users, Transit New Zealand and the wider community. The types of events considered range from small-scale debris events that would affect only part of a single lane, up to large-scale instability that would involve the overall slope above and below the highway. The risk to life as well as financial risk to Transit New Zealand and the wider community were identified for 55 highway cuttings. The risks have been prioritized and various mitigation options evaluated. The methodology used allows the economic consequences of various geotechnical events to be incorporated into the calculations, which were used to develop benefit-cost ratios for the various mitigation options.

On an updated risk assessment, there are 26 cuttings where the level of calculated annualized lives risk (ALR) exceeds an internationally recognized intolerable limit of 1 in 1,000 (equivalent to 0.001 chance of fatality per year). This intolerable limit for ALR of 0.001 is used within the dams industry in Australasia and has been ratified by the New South Wales Coroners Court in recent proceedings relating to societal lives risk from potential events that cannot be managed by the general public.

[62] World Road Association: Technical Committee 3.2 Introductory Report, Section 4, "Quantitative Risk Estimation of Road Slope Disaster."

[63] World Road Association: Technical Committee 3.2 Introductory Report, Section 4, "SH73 Springfield to Arthur's Pass Slope Stability Evaluation," Terry Brown, Transit New Zealand, September 19, 2007.

Current trends in the application of lives risk criteria for hazardous industry and dams indicate that, where the risk receptors cannot manage the level of risk that they are exposed to, a level of risk above which is unacceptable (the intolerable limit) is adopted. Below this threshold the decision on whether or not the risk is tolerable is being made based on the ALARP principle. In essence, risk reduction measures should be implemented until no further reduction is possible without very significant capital or other resource expenditure that would be grossly disproportionate to the amount of risk reduction achieved.

4.5. Risk Analysis to Improve Bridge Pier Standards

On January 17, 1995, the South Hyogo Earthquake caused the worst recorded damage in Japanese history and marked a significant turning point in Japanese road structure design.[64] In Japan, the risks created by bridge pier designs that were insufficient to withstand large-scale earthquakes are being managed through the refinement of standards and systematic nationwide replacement of older piers that do not meet current seismic design standards. In recent years, earthquake-resistant measures are carried out not only to improve seismic performance of new bridge and road structures but also to retrofit existing old structures that were built prior to the standards changes prompted by the South Hyogo Earthquake. In Japan's expressway network, there were 14,100 bridge piers that were designed before 1980 seismic design standards and require reinforcement. Currently, approximately 90 percent of these bridge piers have undergone a proper retrofit.

The country's institution of a three-year plan (2005–2007) of seismic rehabilitation of highway bridges is ensuring that bridge infrastructure is in compliance with the required seismic performance as based on criteria from no later than 1980, when design concepts were greatly revised. This rehabilitation plan was formulated through a risk analysis that used the survey of bridge-pier damage conducted in response to the 1995 South Hyogo Earthquake. By sorting the damage conditions for national highway, Hanshin Expressway, Meishin Expressway and Chugoku Expressway according to the publication year of the seismic design standard to which they were built, it was determined that the degree of damage was significantly reduced in bridge piers designed according to 1980 or later standards. From this assessment, it was concluded that the seismic performance level of bridge piers in Japan should satisfy or exceed the 1980 standard.

[64] Y. Maeda, and T. Isayama. "Typical Damages and Risk Management of Expressways Due to Recent Strong Earthquakes in Japan" (paper presented at PIARC International Seminar on Risk Management for Roads, Hanoi, Vietnam, April 26–28, 2006).

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DRAFT CONCLUSIONS

Risk management is an important process and has become increasingly important in recent years. It is an effective tool in the decision-making process. It gives structure to a complex and intuitive process. Within a defined context, risk management is a means to identify, analyze, evaluate and treat risks. The expanded use of risk management principles in the area of road safety will help fight the global road safety crisis, advance highway safety and improve operations and maintenance.

As we look at risk management, several points need to be remembered:

- *No single integrated approach to risk management exists*. The flexibility of the risk management process permits the use of a variety of tools—including safety audits, road safety inspections, checklists and guidelines, analysis of past trends in data, scenario analysis, system models, computer analysis, experiments, prototypes, local knowledge and experience. PIARC is helping develop such risk management tools through TC 3.2—for example, the risk management toolbox where TC 3.2 members can share their expertise and introduce world-class best practices to developing countries.

- *The risk management process can be very broad*. It is most effective when objectives, goals and performance measures are clearly defined. Input from all stakeholders, including the community at large, leads to a comprehensive and more successful risk management process.

- *Good and consistent data are important* for risk management and realistic statistical analysis. It is the basis for much of the risk management analysis. The lack of consistent data hampers analysis of information between agencies, countries or over time. Standardized data collection improves the ability to make such comparisons and enhances the risk management process. PIARC has already developed international guidelines and forms for police work at crash locations and is developing guidelines for crash databases.

- *Data access, information exchange and technology transfer are vital* to combat the growing world road safety problems. PIARC, as an association, brings together transport organizations from around the world. PIARC is well positioned to facilitate information exchange and technology transfer, particularly from high-income to low- and middle-income countries, where road fatalities and injuries are increasing and the economic and social impact is greatest.