Risk-Based Transportation Asset Management:

Evaluating Threats, Capitalizing on Opportunities

LITERATURE REVIEW

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JUNE 2012

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7825 Wiltshire Drive
Dublin, Ohio 43016

StarIsis Corp.
3737 Woodstone Drive
Lewis Center, Ohio 43035</td><td>10. Work Unit No.

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This literature review summarizes existing research, publications and proceedings relating to risk management and how it can be applied to transportation asset management (TAM.) The review examines domestic sources from the public and private sectors, as well as reports from international public sector agencies. This report provides background for a series of five reports on how risk management can be incorporated into TAM.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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Introduction

This literature review examines published research, reports and policies relating to risk management as it can be applied to transportation asset management. Narrowly construed, the actual literature relating to risk management in asset management is relatively sparse. A relatively small number of sources were found that relate to the specific topic, particularly in regards to North American applications.

As a result, this literature review takes a broader look at the topic of risk management and how it *could* be applied to asset management. It expands the fields in which risk management is examined to include finance, systems reliability and enterprise risk management. These three disciplines foreshadow aspects of risk that will be described in the upcoming series of FHWA reports, *Risk-Based Transportation Asset Management.* Those reports will examine issues such as reducing risk to asset valuation. Asset valuation has been limited in US transportation practice to compliance with Governmental Accounting Standards Board Standard 34 (GASB34) and has not been broadly pursued as it is in the leading asset management nations of England, Australia and New Zealand. The *Risk-Based Transportation Asset Management* reports will examine how risk management can be applied as a strategy to enhance the value of transportation assets. Hence, financial-sector precedents for addressing risk will be included in this literature review.

Likewise, risk will be broadly construed to include risk of failure, including not only catastrophic failure of an asset such as a bridge but also the failure to achieve desired condition levels, failure to preserve asset value and failure to ensure desired levels of service. Such concepts are common in the fields of reliability engineering, and so will be examined in this literature review.

Some sources in this literature review are summarized in greater detail than others. A few publications are among the small body of work specifically addressing risk in asset management including the International Infrastructure Management Manual (IIMM.) These few critical sources will be described in greater detail because of their significantly richer contribution to the topic than most of the publications cited. Most of the risk management literature sources have fleeting references to asset management that can only be "teased out."

Chapter 1

General Sources Relating to Risk Management

The following sources provide a generic overview of risk management, at least as it will be applied in the asset management report series. It addresses generic risk management, financial risk management, risk management relating to transportation assets and risk as it relates to the reliability of systems or assets. This literature review only superficially addresses risk management as it would be understood in the insurance industry.

Risk and Risk Management Defined

Different industries define risk differently. The International Risk Management Institute defines risk as, "Uncertainty arising from the possible occurrence of given events." [(i)] The International Organization for Standardization (ISO) defines it as "the effect of uncertainty on objectives." One financial publication defines risk as, "the variability of returns from an investment." [(ii)] Another financial definition for investment risk is "deviation from an expected outcome." [(iii)] The World Road Association has defined risk as "the combination of the probability of a hazard and its consequences" although it notes that risk could be more broadly defined as "the possibility of a negative deviation from whatever is the desire of any human being." [(iv)] The FAA links "hazard" and "risk" with a hazard being a condition, event, object or circumstance that could lead to or contribute to an unplanned or undesired event, while risk is the future impact of a hazard that is not controlled or eliminated. The FAA also defines risk as the "degree of uncertainty." [(v)] One famous dissertation takes a different approach and defines "risk" as variability that can be quantified while variability that cannot be quantified is "uncertainty." ([vi]) The Risk Management Process Manual [(vii)] of the New Zealand transportation agency defines risk as "The chance of something happening that will have an impact on objectives. It is measured in terms of a combination of the likelihood of an event and its consequence."

These definitions illustrate differing approaches to risk. Some view it as dealing with uncertainty, some with threats, some with only unpredictable events and others with events that can be either unpredictable or predictable. Increasingly, risk has come to infer events that prevent an entity from achieving its goals, whether the events are predictable or not.

Although often cast with negative inference, risk is not always negative or synonymous with "hazard." In all fields of investment, risk is inseparable from opportunity. Investments without risk are generally ones without significant returns. Over protecting against risk means negating opportunities. [(viii)]

Risk Management
Risk management, therefore, involves protecting against *excessive* risk as well as capitalizing upon the opportunities presented by acceptable levels of risk. Risk Management is defined by ISO as, "coordinated activities to direct and control an organization with regard to risk." Another definition is, "the identification, analysis, assessment, control, and avoidance, minimization, or elimination of *unacceptable* risks." [(ix)] The New Zealand transportation agency's definition of

Risk Management is "the cultures, processes and structures that are directed towards the effective management of potential opportunities and threats.**"** It defines the risk management process as, "The systematic application of management policies, procedures and practices to the tasks of establishing the context, identifying, analyzing, evaluating, treating, monitoring and communicating risk."

Publications that define risk and risk management in detail also tend to note the changing inferences regarding definitions of risk. As PIARC notes, "To an increasing degree, risk management has come to encompass also the management of opportunities rather than 'risks'. Opportunities are the opposites of risks. There are possibilities of both gain and loss." [(x)]

Publications also note that the application of "risk management" has broadened considerably in recent decades to no longer be a narrow function associated with reducing insurance costs. Instead, risk management encompasses a broad portfolio of approaches to address all risks in an organization. [(xi)] These can be risks to assets, such as investment funds or highways; or they can be risks to functions, such as providing electricity or smooth pavements; or they can be risks to desired outcomes, such as providing substantial profits or achieving desired performance measures. The evolution of definitions of "risk" and "risk management" illustrate the expanding scope of risk and its management to ensure achievement of broader societal or institutional goals. The expansion of risk management to include reducing the risk of failure to achieve desired outcomes draws the discipline more closely to the field of reliability engineering. It also expands the scope of risk and risk management in the fields of asset management, as described in the International Infrastructure Management Manual (IIMM) and in several international sources. This more expansive view identifies risk management as a tool to prevent transportation organizations from failing to achieve their asset-condition targets.

ISO 3100:2009(E) Risk Management - Principles and guidelines

This very general international standard [(xii)] describes the basic component of sound risk management as it could be applied to any field. It notes that all organizations face internal and external risks to achieving their objectives. It provides this guideline for a systematic, transparent and credible approach to responsibly addressing risk, which it defines as the "effect of uncertainty on objectives." If risk is inevitable, then ensuring against it is a basic component of modern management that increases the likelihood of an organization's success, encourages proactive management, complies with legal and regulatory requirements, improves governance and enhances stakeholder confidence and trust.

Like nearly every other basic discussion of risk management it describes a multi-step process that includes steps similar to those seen in "quality-based" or systematic processes as derived from the work of Deming [(xiii)] or Shewhart.[(xiv)] These steps include a cyclical, ever-improving framework of:

- Developing a communicating structure with stakeholders to create understanding of the risk management process and create continuous communication about it;
- Establishing the context so that the risk management approach meets the need of the organization and its stakeholders;

- Identifying the sources of risks, areas of impacts, events and their causes and consequences;
- Analyzing risks to understand them and evaluate their consequences;
- Evaluating risks to determine which need treated and the priority for treatment;
- Treating risk involves selecting options for modifying risks;
- Monitoring and reporting includes evaluating the results of the risk process and looping back to the first step of communicating with stakeholders regarding needed improvements.

The ISO guideline emphasizes that risk management should be a fundamental business practice woven into all processes, and not treated as an "add on" function that is the responsibility of an isolated unit. It says that in mature organizations, risk management is comprehensive and recordable. That means that clear accounting for risk in all major programs can be identified.

Enterprise Risk Management from Incentives to Controls

This textbook provides a survey of enterprise risk management as used in industry today, particularly in the financial sector. [(xv)] It wryly notes that organizations either engage in risk management or they routinely engage in crisis management. It describes enterprise risk management as an organization-wide approach that uses a portfolio of tools to reduce risks to all aspects of the agency's assets, operations and stakeholders. Risk management is not only about barricading the organization against threats but rather allowing it to rationally evaluate threats and opportunities, so that it accepts a reasonable degree of risk in order to capitalize upon opportunities. Risk management is about striking the balance between risk and opportunity or finding the "sweet spot" between the two. Any person or organization operating in a fiduciary role for stakeholders faces a responsibility to reduce risk, to manage volatility, maximize value and promote continuity. Increasingly, organizations recognize that risk comes in new forms, such as risk of failing to comply with regulation, risk to reputation, and risk from changing external conditions. In an age of widespread and nearly instantaneous news media and social media reaction, these risks quickly can affect an organization's operations. An enterprise-wide assessment of all risks to success can prepare an organization to prevent negative events, and can improve its credibility if one occurs. Risk management is similar to a sound investment strategy. It assigns resources to areas of high returns and relatively low risks, and it diminishes investment of resources into high-risk, low-return areas. By having a formal risk-management framework an organization can increase its credibility with shareholders by documenting that it has rationally anticipated risk and plans to address its negative implications while capitalizing upon opportunities.

The Essentials of Risk Management

This examination of the expansion of risk management in the banking industry [(xvi)] illustrates parallels for applying risk management to many fields relating to assets, even highway ones. It notes that risk managers' roles in the financial sector have grown substantially in recent years with one analogy being that risk managers have moved from minor, back seat passengers to those who now help drive the car. The role of risk management has grown because risk management and risk taking are two sides of the same coin. The degree of rational risk that an

organization takes can determine the degree of success the organization achieves. It notes the difference between "risk" and "uncertainty" in that variability that can be quantified as a probability is risk. Variability that cannot be quantified as a probability is considered to be uncertainty. Both are to be addressed but with different strategies. Risk can be dealt with through calculations of the degree of risk that an organization is willing to accept in return for a given expected reward. Uncertainty is often addressed through processes, such as audits, training and oversight to guard against the uncertainty of theft, fraud or incompetence. The uncertainty of changing market conditions is addressed through continuous surveys of economic events. Both risk and uncertainty are managed but in different ways. This volume also emphasizes that risk management is not just a defensive effort. The more accurately an organization can analyze potential risks the more it can sift through potential risks and find those that are opportunities. Of particular relevance to the highway asset management functions are the text's discussions of "operational risks," or the risks that come from breakdowns in people, processes or technology. Of particular relevance are breakdowns in the accuracy of models or predictions of data. If an organization does not continuously assess the risks caused by the accuracy of its data and its models it will increase its own risk of making erroneous decisions. Modern managers who rely on large amounts of data and upon sophisticated models are like pilots who must fly by instruments. If the instruments are providing inaccurate data, the decisions of the enterprise are at a high risk of failure. Data that appears too bad or too good to be reasonable requires third-party evaluation as a reasonable risk-management strategy. These examples of the criticality of the accuracy of financial-risk-and-return models are directly analogous to pavement-design risks discussed by Hudson ([xvii]) who notes that a common reason for premature pavement failures is the underestimation of truck loadings. The Essentials of Risk Management emphasizes that data and models are a major source of focus for modern risk managers who are responsible for capital assets.

A Practical Guide to Risk Management

This text [(xviii)] also emphasizes the centrality of risk management to a modern organization responsible for capital assets. It says that managing risk is at the core of any financial organization, or organization responsible for capital assets. Managing risks is about the making of tactical and strategic decisions to control risks that should be controlled and exploiting opportunities with acceptable risk/return possibilities. It says that managing risks, and thus opportunities, is a central responsibility from the chief executive down through the line managers. This guide strongly delineates "risk management" from "risk measurement." It says the two are often used synonymously but they are very different. "Risk measurement" is a technical discipline reliant on the often-complex mathematics of probability. When risk management is confused with risk measurement, it often is relegated to an isolated, technical function. Risk management is a top-to-bottom core competency that cannot be delegated but must be inherent in the responsibilities of all management personnel. The formulae and models produced by risk measurement are very important to decision making but are only as good as representations of past occurrences. They cannot be expected to predict future unprecedented events that often create the greatest challenges or variability to success. This volume calls for a "modesty of tools and a boldness of goals," which means that organizations should have a strong commitment to managing risks and using risk management to achieve their objectives. However, they should not be reluctant to pursue risk management out of concern they lack robust mathematical models.

Risk, Reliability and Quality

The Harvard Business Review ([xix]) notes that steady, predictable growth is what investors prize above all else. The magnitude of financial return alone is not the benchmark of a preferred investment. Investors diversify their portfolio and often chose some intentionally low-return investments such as bonds in exchange for the predictability, or reliability, of their expected returns. This high value on predictability or reliability causes some overlap and synergies between the fields of risk management and reliability. Going back to the very early "quality" writings of Shewhart ([xx]) authors have focused upon how to eliminate the influences of risk, or as Shewhart called it, "chance." Shewhart's work went on to influence generations of quality-control authors who were influenced by his equating the lack of variability - or the elimination of chance - as the definition of quality itself. The less variability in a product, the higher its quality in his definition. Shewhart and his intellectual descendents did not write specifically about risk but rather about eliminating the variability in product quality. The steps they describe, however, have a clear relationship to the development of the field of reliability engineering and its related frameworks of Six Sigma, the ISO standards, Total Quality Management or the Baldrige processes. Risk management seeks to minimize the effects that risks, hazards or uncertainty have upon achievement of organizational objectives. In this sense, risk management seeks to control the negatives. Similarly, frameworks spawned by Shewhart such as reliability engineering seek also to squeeze the causes of defects out of processes and to enhance the processes that ensure reliability. As the field of Transportation Asset Management is viewed from a risk management context, the related discipline of reliability engineering will be relevant. Risks to be examined within the TAM context will be the risks of failing to achieve reliable asset conditions, risks that data and models are unreliable, and risks that the department processes fail to ensure reliable asset-treatment timing. In terms of physical assets, risk management and reliability engineering can be viewed as sister disciplines.

Reliability Theory and Practice

The linkage between risk and reliability is evident in this text, Reliability, Theory and Practice. If the definitions of risk relate to uncertainty or variability, then the definition of reliability is its near opposite. "Reliability is the probability of success." [(xxi)] The strategies to reduce risk of failure are often the same as the strategies to increase the probability of success. This text notes that the field of reliability engineering arose commensurate with industry's focus upon risk. Reliability strategies increased with the rise of railroads and other modern industries to ensure that high-value equipment and other assets performed as anticipated throughout their expected service lives. As the risks caused by technology - such as passenger aircraft - increased, so did the emphasis upon reliability. Satisfactory performance without failures while in use and readiness to perform when needed are the criteria of reliability. A well-designed, well-engineered piece of equipment should never fail and always be available to perform at its desired level of performance. This text categorizes failures as occurring in three forms:

- Premature failures at early stage of life caused by faulty manufacture or components;
- Wear-out failures caused by inadequate maintenance;
- Chance failures caused by unpredicted events.

Quality control of the manufacturing process can control premature failures. Proper preservation

and maintenance schedules can reduce the wear-out failures. Chance failures are not strictly within the purview of reliability engineering which focuses more extensively upon the first two types. Reliability engineering seeks to determine the statistical probabilities of the first two types of failure and the identification of strategies to reduce their prevalence. As such, reliability engineering seeks many of the same ends as does risk management - to identify and address the causes of failure.

Managing Risk in the New World

The lines between good risk management and overall good management are blurring, according to a recent edition of the Harvard Business Review dedicated to risk management. ([xxii]) Risk management used to be more of a specialty discipline in industry, much like human resources. Today, financial and environmental regulations create pressures on executives to ensure that their organizations are anticipating and responding to risks. Now, risk management is a core discipline and one that executives need to embrace as a personal and corporate responsibility. The modern executive must understand risks but not be paralyzed by them. A credible manager of risk is also a risk taker. He or she should weigh the risks and returns, then document that the organization has made a well-analyzed decision. In the world of corporate governance, many concerns of running a large organization are being reframed in terms of risk, which means that the role of risk managers and their tools will be increasingly important. An example is the Sarbanes-Oxley Act that creates criminal penalties for corporate officers who fail to perform due diligence in regard to financial fraud or malfeasance in publicly traded corporations.

The Standard for Portfolio Management, Second Edition

This standard from the Project Management Institute (PMI) [(xxiii)] addresses the management of risk in a portfolio. It is one of three PMI standards that address risk, the other two being the project management guide and the program management guide. Both are discussed below. This standard defines a portfolio as a collection of projects or programs and other work that are grouped together to facilitate effective management of that work to meet strategic business objectives. The projects and programs within a portfolio may or may not be interrelated. It differentiates portfolios from projects and programs by noting that projects and programs are often temporary, while portfolios are not. The portfolio is described as the programs and activities used to achieve the organization's strategic aims, its vision and its mission. It stops short of equating portfolio management with full enterprise risk management. Rather, within the full enterprise could be multiple portfolios. A significant element of portfolio management is the managing of risks and relationships between programs, projects and resources. This is because of the strong interrelationships between programs or activities within the larger portfolio. Although it does not discuss asset management per se, an example could be the interrelationship between effective preventive maintenance within a larger pavement portfolio. The elements within the pavement portfolio need to coordinate to optimize the pavement performance over its lifecycle. As such, portfolio management focuses somewhat more upon external issues, stakeholders and internal coordination issues than would the more narrowly focused project or program risk management. The standard calls for a formal portfolio risk management plan. This plan would examine not only the potential impacts of threats but also the potential benefits of opportunities. It defines portfolio risk as an uncertain event, set of events, or conditions that if they occur, have one or more effects either positive or negative, on at least one strategic business objective of the

portfolio. Such risks can be internal, such as poor management practices, or external such as changing economic conditions. The objectives of portfolio risk management are to increase the probability and impact of positive events and to decrease the probability and impact of events adverse to the portfolio. It describes risks as threats to strategic success or as opportunities to enhance the chance of or degree of success.

The Standard for Program Management

This standard from the Project Management Institute [xxiv] addresses risk management at the program level. It defines a program as a group of related projects managed in a coordinated way to obtain benefits and control not available when managing them individually. All projects through a program are related through a common goal. Its notes that the potential benefits and risks within a program are greater than the sum of benefits and risks from the individual projects. This magnification occurs because of the potential compounding benefits and risks created by the on-going and accumulating effects of the multiple projects within the program. Complexity of managing a program is greater than managing a project or small set of projects because of the interrelationship between projects. For instance, a delay or cost overrun in one project can ripple through the entire program and magnify the impacts upon subsequent or related projects. A programmatic risk that may not apply at only the project level is a breakdown in program management. Hence, there are elements of program risk that do not exist to the same degree at the project level. Risk of strategic failure can be greater at the program level than at a project level. Programs are created to achieve strategic ends for the agency. One individual project by itself is unlikely to put a strategic objective at risk, whereas failure of a program can create risk of widespread failure to achieve important organizational objectives. The standard defines program management as the centralized, coordinated management of a program to achieve the program's strategic objectives and benefits. It involves aligning multiple projects to achieve the program goals and allows for optimized or integrated cost, schedule and effort. Program management focuses upon the interdependencies of the projects, and of the resources the projects depend upon. These resources could be the management skills, information systems, financial resources, or political authorizations needed for the projects. Program management activities could include tasks such as coordinating resource supplies, providing resources, aligning organizational direction, and resolving issues of scope, schedule or budget. Program management differs from project management in that it addresses issues universal to all projects, and not just issues unique to individual projects. The individual activities of program managers shift through the life of projects. In the initial stage of a project, much information and direction may flow downward from the program to the project. This information comes in the form of authorizing, scoping and funding projects in order to achieve the organizational objectives. As the projects ramp up and grow in complexity, more information flows up from the project to the program manager. This upward information addresses project schedule, costs, risks, rewards and accomplishments. As a result, the activities and types of interfaces between programs and projects vary through the project lifecycle. Throughout the life of a project, the program manager is evaluating program-wide risks such as environmental factors, program governance, cumulative risks from the project costs and scope, and operational risks such as failure of the organization to provide needed support in a timely fashion.

The individual steps within program risk management mirror the steps in all other generic risk management frameworks. The steps involve planning for risk, identifying risk, analyzing risk,

developing responses to risk and monitoring and controlling those risks. At the program level, the concepts and steps are consistent with other risk management steps, they just occur at a higher, programmatic level and focus upon systemic, comprehensive threats and opportunities.

CHAPTER 2

Existing Risk Management Sources Related to Asset Management

International Infrastructure Management Manual

The International Infrastructure Management Manual (IIMM) provides a 23-page section on risk, however, it says little explicitly about how risk management is applied to asset management for highways. It provides a more generic discussion of risk and assets that is suitable to the public sector environment in Australia and New Zealand. In those countries, public ownership of infrastructure extends also to electric utilities, natural gas companies, hospitals and public health facilities as well as to water, sewer and roadways as is common in the United States. As a result, many of the examples cited in the IIMM risk management section relate to water and sewer companies, hospitals and electric utilities.

The relevance of the IIMM risk management discussion to transportation asset management primarily is in identifying and preventing *physical* asset failures. This type of roadway risk management is in contrast to fields such as aviation where the primary risks are to passenger and pilot safety caused by pilot error or mechanical failure. In the IIMM risk management discussion, the asset failures referenced often occur incrementally, as opposed to instantly and catastrophically, as they can in aviation or with a bridge collapse. "Failure" is described by IIMM not only as acute and complete, but also as incremental failure including:

- Structural: where the physical condition of the asset is the measure of deterioration, service potential or remaining life;
- Capacity/utilization: where it is necessary to understand the degree to which an asset is under-or-over-utilized compared to the desired level of service;
- Level of service failures: where reliability or performance targets cannot be met;
- Obsolescence: when technological change or lack of replacement parts render the asset uneconomic to operate;
- Cost or economic impact: where the cost to maintain and operate an asset is likely to exceed the economic return expected, or is more than the customer is willing to pay.

Understanding these modes of failure allows the organization to take the appropriate countermeasure. The scope and cost of the countermeasures can be commensurate with two critically important factors: 1) the consequences of failure, and; 2) the probability of failure. The consequence-and-probability calculation lies at the heart of risk management in asset management, as it does in most other applications of risk management.

Asset failure consequences can include:

- repair costs;

- income loss;
- service loss;
- death or injury;
- property damage;
- failure to meet statutory requirements;
- third party losses;
- credibility or image loss.

The IIMM illustrates with a simple table how consequences can be plotted along a continuum of insignificant to catastrophic based upon perceived impacts. "Perceived" impacts are emphasized because the degree of significance can be scaled to the priorities or context of an agency. The values or functions important to the particular agency can be weighed more highly, providing greater weight to mission-critical failure consequences, or consequences that could result in loss of life.

The IIMM states that the probability of failure relates directly to the current condition of the asset requiring realistic and accurate condition assessments. Also affecting probability is the degree of redundancy built into the asset. Other factors affecting probability of failure are external events such as earthquakes, floods, crashes or terrorist events. These tend to be less predictable than condition-related risks.

The IIMM notes that probability can be assessed qualitatively or quantitatively. Qualitative rankings or assessments can be on an A-F scale based on professional judgment. Quantitative rankings can be based upon a more mathematically based set of probabilities. It does not include guidelines for quantitatively establishing risk probabilities other than on an annualized basis. For instance, an event characterized as "rare" may occur once between every 20 to 50 years resulting in a conservative probability of .02. Events that are "common" may occur more than once every two years resulting in a liberal probability of .7 of it occurring in any one year. As shown in

Table 1 Conceptual model for risk rating

Likelihood	Consequence				
	1	2	3	4	5
A	L	L	L	M	S
B	L	L	M	S	H
C	L	M	S	H	H
D	M	M	S	H	H
E	M	S	H	H	H
F	S	H	H	H	H
Scale: Low, Moderate, Significant, High					

Table 1, the higher the probability and the greater the impacts, the greater the risk rating.

Once risk ratings are determined, both for key individual assets such as large bridges as well as for categories of assets such as pavement markings, the appropriate risk management strategies can be applied. The cost of managing the risk can be commensurate with the impacts. Risk can be managed through strategies such as:

- reducing the risk by capital or maintenance expenditure;
- preparing emergency response plans;
- accepting a certain degree of risk;
- acquiring insurance;
- or a combination of all the above.

In many private sector organizations, risk costs can be avoided through insurance, although that strategy is seldom available or feasible for large publicly owned facilities.

As mentioned above, the categories of risk and their weighting can be set by the organization to reflect its priorities. Among the categories of risk suggested by the IIMM are loss of life, loss of service, community impacts, property damage, statutory obligations, repair or replacement costs or a loss of efficiency, among others.

Categories not mentioned by the IIMM are: 1) loss of asset value, and; 2) risk that optimal treatment timing windows will be missed leading to higher future repair costs.

The IIMM describes methods to use risk to assemble construction or maintenance programs. Using the simplified ranking illustrated in Table 1, values are developed by multiplying the estimated cost of failure by the probability of failure. The higher the probability and cost of failure the higher a project or maintenance activity would rank. "Cost" would be not only financial but also the cost to other values such as public safety or agency credibility. Projects rated through a process such as shown in Table 1 would be sorted by highest risk to lowest risks. As a result, risk would be a major consideration in developing capital and maintenance programs.

The International Infrastructure Management Manual [(xxv)] describes risk management as a major component of what it calls comprehensive Optimized Decision Making (ODM) and not as a stand-alone activity. ODM is a systematic, fact-based, comprehensive approach that seeks to quantify variables in support of decision-making. As such, risk management is viewed as a core business driver that influences all decision making, rather than an activity undertaken as an isolated process.

The IIMM recommends a corporate risk management framework be consistently applied across an organization's asset management processes. Risk management usually deploys these processes:

1. Risk management context: establish the corporate risk framework, including the criteria against which risk can be evaluated and the responsibilities established;
2. Risk identification: the risks an organization may encounter and explain the impact of those risks on the organization;
3. Risk analysis: establish a risk rating for all assets or asset groups, and determine which assets represent the greatest risk to the organization;
4. Risk treatment: identify what actions to take to minimize risk at asset or asset group level;
5. Monitor and review: the ongoing process for ensuring risk levels remain acceptable even if risks change.

Once the organization's risk framework is established, processes to implement the risk management program are necessary: The processes include:

- creating support for risk management at all levels of the organization through training, education and explanation;
- developing and communicating organizational policy;
- managing the risk at the organization, program, project and service level;
- monitoring and reviewing of risk programs and their effectiveness.

AASHTO Transportation Asset Management Guide, A Focus on Implementation

The guide defines risk management as a process of identifying sources of risk, evaluating them, and integrating mitigation actions and strategies into routine business functions of the agency. The guide associates risk with uncertainty. This association with uncertainty causes risk in the Guide to be viewed in a narrower context than is considered when risk is discussed in other fields, such as financial asset management. This contrast will be discussed later.

While focusing on risk as an aspect of uncertainty, the Guide notes that all types of transportation assets have risk that accrue as risks to the agency. This accumulation of risk leads to recommending that risk be viewed as a core business driver for the agency, and not as an isolated function.

The guide says that risk in asset management is assessed as vulnerability to a variety of natural and man-made hazards. The assessment is conducted in three steps: 1) what is the likelihood of an extreme event such as a flood or asset failure? 2) what are the consequences of that in terms of damage or loss of function? 3) what is the effect upon the agency's mission, life, property, users and others?

As in the IIMM, the guide describes risk as coming from four categories, natural events and hazards, external impacts such as power failure or providing faulty materials, physical asset failures and operation risk events such a barge striking a bridge pier. The consequences cited are also like those from the IIMM and include risks to public safety, liability, physical loss of asset, financial losses and others.

Once risks are described in quantitative or qualitative ways, they can be managed as any other form of performance measurement. Like with the IIMM, the guide discusses how to develop a risk score based upon likelihood, consequence and impact. Then, the score can be used for prioritizing action. Each mitigation alternative has a cost and an effect on the risk. In this way, risk management can be integrated into the same priority setting and trade off analysis process as all other types of asset management concerns. Risks also can be associated with specific assets and recorded with other key asset inventory data.

The guide notes that some assets are more important than others in terms of the function they play or the number of customers they serve. The guide says the risk identification process should also identify critical assets with high consequences when they fail. This identification

can lead to renewed emphasis upon the timely treatment of the asset at critical points in its lifecycle. The identification also can lead to continuity plans that anticipate continuing service through the unexpected loss of the asset, or developing an emergency response plan to deal with the failure if it occurs.

The guide's focus on addressing uncertainty and addressing the disproportionate importance of some key assets leads to an emphasis on network resilience and asset criticality. Assets can be ranked based upon their importance to public safety, network continuity, connectivity, economic activity or social well-being. Resiliency generally is viewed from a network, not an asset level. Therefore, redundancy in the highway network can improve resiliency.

The guide's focus on criticality leads to the conclusions that consideration of risk management in TAM requires:

- Identification of critical assets;
- Consideration of the network's ability to cope with identified risk events;
- Consideration of risk events that could affect multiple assets, such as an earthquake, and;
- Development of risk management plans that reduce risks to an agency.

If the Asset Management Guide is reviewed with a broader interpretation of risk, there are many other references in the guide that relate to risk as it will be described in the upcoming FHWA risk management briefing publications. Two of these additional perspectives are risk that the asset will fail to perform as desired and risk that the value of the transportation assets will decline. The asset management guide addresses these issues indirectly with little reference to risk, however, they easily could be categorized as important risks.

In section 6.1.2.2, the guide discusses performance monitoring and reporting. It cites as important for monitoring and reporting assets that are at risk of failing to perform at the desired level of performance. Also important to report are the causes or countermeasures that could ensure the desired performance. If such monitoring is viewed as a monitoring of risk and not just a monitoring of asset condition, it could encourage the application of preservation and preventive maintenance as risk-reduction strategies. Both strategies forestall asset degradation and could be included within the categories of risk mitigation if the concept of risk were expanded to the risk of assets failing to remain at a desired condition target.

Likewise, in section 6.2 the guide touches upon the impacts to asset conditions that result from what it describes as the "unrelenting deterioration" caused by traffic, weather and environmental conditions. These impacts to asset condition are predictable, hence, they don't tend to fall under the uncertain threats that the guide addresses in the risk management section. However, later in the FHWA risk briefing papers these predictable threats will be discussed within a broader definition of risk. Re-reading the asset management guide with this broader perspective reveals this and other sections of the guide that are relevant to risk management. If the "unrelenting deterioration" of traffic, weather and environment are anticipated as risks, then strategies such as preservation and preventive maintenance become key drivers in the agency's risk-reduction strategies.

Similarly, in section 6.2.8 the guide discusses strategies to optimize lifecycle costs of assets. If the incurring of excess costs is viewed as a risk the agency wants to manage, then strategies to achieve lowest lifecycle costs also become components of risk management. The guide notes that proper design that anticipates not only an asset's construction costs but also its whole-of-life maintenance and operations costs is the most critical component of lowering lifecycle costs. Therefore, the ensuring of sound designs becomes a component of risk management. Similar considerations of systematic strategies to ensure the appropriate timing of maintenance treatments at critical points in the asset's lifecycle also become risk-reduction strategies.

In section 7.3 the guide discusses the importance of asset valuation and the monitoring of depreciation within the context of asset management. The guide notes that some agencies incorporate the concept of preserving asset values and investing sufficiently to offset depreciation as considerations in asset management. However, the guide does not discuss asset valuation in the context of risk. In the financial sector, preventing or mitigating risks to the organization's financial assets is an overriding concern. Portfolio managers focus upon mitigating risks cause by inflation, market downturns, poor investment decisions, lack of diversification and fraud or malfeasance. Portfolio managers seek to not only protect but to grow the monetary value of the assets. In Australian contexts that will be discussed later in this literature review.

If the value of highway assets are considered as community equity to be preserved and grown by the highway agency, then the asset management strategies in the guide can be interpreted as risk-management strategies. The risks avoided are risks to the value of the community's highway assets.

Conclusion

The AASHTO Asset Management Guide A Focus on Implementation explicitly addresses risks, and is one of the earliest US asset management publications to do so. It provides an overview of risk management as a component of certain aspects of asset management, in particular relating to uncertainty caused by hard-to-predict events or threats. A re-reading of the guide within the context of preserving equity and of forestalling risks to asset conditions sheds new light on how asset management can be an effective risk management strategy. These broader concepts will be elaborated in the international risk management reports to be summarized later in this literature review.

International Scan of Risk Management Practices for Program Development and Project Delivery

This unpublished report is an interim summary of the 2011 international scan trip that examined risk management practices in England, Scotland, the Netherlands, Germany, and Australia. The theme of the summary is "keep it simple." The scan team's summary emphasizes that although they found impressive and mature enterprise risk managements systems in the visited countries, the systems featured simple, easily understood analyses. A few of the agency officials interviewed emphasized that they preferred simple spread-sheet based risk registers and risk plans over complex, proprietary and highly quantified software. The more complex outputs are less transparent to stakeholders and required agency officials to spend their time managing the software instead of managing risks. Spreadsheets, heat maps and simple graphics were used

primarily to illustrate the outcomes of the risk analyses. The team reported the following benefits of risk management:

- Helps with making the business case for transportation and building public trust;
- Avoids “managing-by-crisis” and promotes proactive management strategies;
- Explicitly recognizes risks in multiple investment options with uncertain outcomes;
- Provides a broader set of viable solution options earlier in the process;
- Communicates uncertainty and helps to focus on key strategic issues;
- Promotes an understanding of the repercussions of failure;
- Helps to apportion risks to the party best able to manage them;
- Facilitates good decision-making and accountability at all levels of the organization.

The summary does not explicitly address the role of risk in asset management. It addresses some related areas such how geotechnical risks are illustrated, how funding risks are anticipated, how risk is used in bridge inspection, and how risk influences maintenance priorities.

An Asset-Management Framework for the Interstate Highway System

This report [(xxvi)] examines risk management as a component of a proposed asset management framework for the US Interstate Highway System. The report recommends that each owner of an IHS section create an asset management plan for its sections of the IHS and incorporate a risk-management strategy. This NCHRP Report 632 approaches risk from the context of IHS system failure from unintentional hazards, intentional threats, natural hazards or substandard performance, however, it de-emphasizes substandard performance as likely to create a long-term threat to IHS closure. It distinguishes between what it calls "internal programmatic risks" such as failure to adequately perform planning, design, construction or maintenance with "external non-programmatic risks" such as earthquakes, terrorism or vehicle/infrastructure crashes. As do most other risk management reports it recommends a four-step process of defining risk tolerances, identification of threats, development of counter measures and monitoring of strategies. It calls for a broad, cross-sectional team of internal subject matter experts to coordinate on the broad spectrum of potential risks that should be mitigated.

Uses of Risk Management and Data Management to Support Target-Setting for Performance-Based Resource Allocation by Transportation Agencies

This National Cooperative Highway Research Program Report 706 [(xxvii)] addresses the nascent use of risk management at selected US transportation agencies including the Minnesota, Washington, Georgia, Texas DOTs and Caltrans. The application of risk to asset management is embryonic in the case studies examined and applies primarily to bridges in an asset management context, except for Georgia which is beginning to consider risk in its pavement programs. Risk in the agencies' decision-making process is viewed as only one factor in the decision-making process and not a single determining factor for investment.

NCHRP 706 notes that Georgia DOT wants to move from a "worst-first" pavement and bridge selection approach to a "most-at-risk" approach that considers the current condition of the asset

and its risk of failure. Failure is not only catastrophic failure but failure to provide the desired level of service. In Minnesota, the department is applying risk-based decision making to bridge rehabilitation and replacement projects as part of the commissioner's effort to broaden application of risk management to many key departmental functions. Texas DOT applied a risk approach to freight mobility by evaluating the resiliency or redundancy of the statewide network to continue moving freight if key nodes were taken out of service by events such as earthquakes, floods or terrorism. Washington DOT uses risk as a consideration in bridge retrofits while Caltrans has used risk for more than a decade for its seismic retrofit program.

NCHRP706 follows a traditional risk management approach that recommends several key steps. First is the establishment of risk tolerances. For instance, an agency may accept little risk for high-volume, high-profile bridges but accept substantial risk for low-volume, low-profile assets. Second, threats and hazards are identified and ranked either qualitatively, or quantitatively. The consequences of the risks are assessed, again either qualitatively or quantitatively. Third, potential strategies or counter measures are identified and fourth risk management efforts are monitored for effectiveness.

As developing systems, the risk-management systems are relatively straight-forward and are based on readily available data, with the exception of Caltrans' more-mature seismic retrofit program. In the other systems, the agencies are using factors such as condition assessments, average daily traffic (ADT) bridge size, roadway functional classification and so forth to assess which assets are most at risk. Low-condition, high-volume facilities rise to the top of the risk matrices. Then, the risk rankings are taken as a factor in decision making along with engineering judgment, benefit/cost, departmental policies, and other traditional decision-making factors.

2005 International Asset Management Scan

One of the earliest FHWA documents to discuss risk management in asset management was the 2005 FHWA international scan examining asset management practices in Australia, Canada, England and New Zealand. [(xxviii)] This report noted that all of the agencies visited used risk assessment in developing their asset management programs. The officials in those agencies viewed risk assessment as a way to educate and obtain support for asset management from elected officials.

In England, risk management is cited in national guidelines as a basic component of good stewardship of assets along with the use of life-cycle costing, long-term strategies, performance monitoring, sustaining assets and continuous improvement. Risk management is among a suite of complementary strategies that enhance asset management. Among the English Highway Agency's practices, risk is incorporated in numerous policies and guidance documents such as the code of practice for lighting and standards for bridge project selection. In New Zealand, the national Asset Management Plan includes an entire section on risk management. The New Zealand agency's risk process manual describes risk management as supporting improved decision making. The evaluation of risk enhances the agency's ability to overcome obstacles that could cause it to fail to achieve it assets management objectives. (The New Zealand risk manual will be reviewed in the International section.)

In New South Wales, Australia, the Roads and Traffic Authority (now called Roads and Maritime Services) includes risk as a basic component of its vision along with ensuring "value for money" and providing effective governance. The NSW Treasury also incorporates risk management as a basic component of sound governance and requires agencies such as the RTA to develop risk management plans for their assets and for its efforts that ensure compliance with regulatory programs. As a result of this strong focus, risk management permeates the RTA's asset management practices.

The Queensland Main Roads (since renamed Transport and Main Roads) likewise incorporates risk as a major departmental consideration, including in its asset management plans and strategies. Risk considerations run through the agency operations in areas such as ensuring that sound data supports sound decision-making. Risk management is evident programmatically in that it is a strong component of the bridge management system whose guidance notes that using the management system provides defensible, risk-based bridge-investment decision making. In bridge decision making, the agency's management system multiplies a bridge's probability of failure by its consequence of failure to assist with investment decision making. The risk of individual bridges is aggregated to a programmatic level, showing total risk by state, and by region, in addition to the risk to individual structures. The agency tallies department-wide bridge risk compared to an optimum or preferred risk. By speaking of bridges in terms of "risk", the Queensland officials believe they are using verbiage that elected officials understand.

In the Australian state of Victoria, the VicRoads transportation agency integrated risk management into its asset management practices after analyzing investments and realizing that programs such as cutting grass reduced far less risk than other programs such as slope stabilization. As a result, risk became a basic component of programmatic decision-making. The incorporation of risk was further emphasized by a 2004 act that reduced road officials' immunity and required them to have in place a process for reasonably reducing risks. The emphasis on risk within asset management also created renewed interest in pavement friction as a crash-reduction strategy and elevated friction's consideration in pavement-management activities.

The City of Edmonton, Alberta, also was reported to use explicit risk management analysis to rank the risk to all categories of infrastructure. Risk was categorized as the risk to the infrastructure not providing the level of condition or services that was desired. The infrastructure was segmented into logical groupings, such as roadway links, and the conditions were assessed through workshops and independent analysis. Risks to various asset types were plotted in tables from those with the greatest risks to those with the least. The analysis supports investment decisions.

Transportation Performance Measures in Australia, Canada, Japan and New Zealand

This 2004 report [(xxix)], also by the FHWA Office of International Programs, examined the use of performance metrics in the listed countries. It reported less risk management influence in the overall performance-management processes of the visited governments than was reported when the asset management programs were examined in 2005. It found that in the British Columbia Ministry of Transport in Canada that a province-wide risk management program was required. In Japan, evacuation plans were required as a risk-management strategy given the nation's threat

from earthquakes. It noted in Queensland Main Roads and the Victoria RTA that risk is part of the overall management framework that includes the widespread use of performance measures. The agencies incorporate risk into their traffic safety program, their asset management programs and into their security plans. As the report was published in 2004, the agencies visited viewed security as a significant focus of risk management in the years following the 9/11 terrorist attacks. The report appears to indicate that at that time risk was a relatively small component of the agencies' performance management systems, in contrast to the large role risk played in asset management systems.

Linking Transportation Performance and Accountability

This 2010 FHWA scan report also found consistent use of risk in asset management among the agencies visited in Sweden, England, Australia and New Zealand. [xxx] This report found that the concept of risk was rapidly emerging among the agencies that were seeking to demonstrate the financial prudence of their decisions. By managing risk, they could demonstrate they were intelligently investing scarce resources among competing investment needs. In the New South Wales RTA, risk was prominent in many areas of decision making from how new drivers are licensed, to how it selects locations for guardrail, how it manages slopes and even how it decided whether used timber piles were safe for reuse. The NSW Total Asset Management Manual includes extensive discussion of risk and it will be reviewed in more detail later.

In Queensland, Road Alliances of local governments cooperate to share resources and prioritize investments regionally. A software developed by the alliances to aid in investment decision making is call NetRisk and it allows users to identify high-risk areas of the local road network for safety countermeasures and to deploy asset management strategies. This was but one example of how risk management has spread as an asset management tool since the first scan on performance measurement in 2004.

Guide to Risk Assessment and Allocation for Highway Construction Management

This 2006 international scan report [xxxi] examines the use of risk management in design and construction phases of the project-development process in Canada, Finland, Germany, the Netherlands, Scotland and the United Kingdom. It notes that risk management during the project-development and construction phases was more extensive than was common in the United States at that time. However, the report did not examine risk as a component of asset management, except to note that risk management strategies to achieve desired asset conditions are included in the scopes of public-private-partnership (PPP) projects.

Assuring Bridge Safety and Serviceability in Europe

This 2010 report [xxxii] did not specifically examine risk management but did examine a related concept, that of reliability in bridges in Europe. The European agencies' focus on reliability include extensive analysis and practices that are very similar to risk management. The bridge rating systems found by the team use probability of failure as a prime consideration for bridge design, maintenance, repair and replacement. The team concluded that the international agencies visited quantify bridge safety in a manner similar to that used in the United States but stated it as a "probability of failure" rather than as a reliability index, return period or factor of safety. In

general, the team found an increasing emphasis upon risk analysis for both design and rating. As an example, in France the team found that the transportation agency was conducting a probabilistic analysis of 116 multi-span post-tensioned girder bridges to develop a surveillance plan. The team made a recommendation that risk could be incorporated into the bridge inspection processes in the United States. It recommended a tiered approach that limits the need for in-depth inspections if preliminary inspections indicate low-risk of structural problems with a bridge. (Such an approach used in Illinois will be cited below.)

Underground Transportation Systems in Europe: Safety, Operations and Emergency Response

This 2006 scanning report [xxxiii] examines the widespread use of risk management in the design, maintenance and operation of tunnels in Europe. Tunnels are treated as particularly risk-prone facilities because of their additional safety considerations attributable to crashes, fires, hazardous materials, and localized air-quality issues. The report does not specifically address asset management directly, but indirectly the strategies pursued by the tunnel owners serve as surrogate strategies for sound risk management within asset management. For instance, most of the agencies reviewed incorporate risk-reduction to motorists into the tunnel design and therefore favor tunnels with reduced curvature, adequate sight distance, sufficient ventilation, constructed of non-flammable materials and incorporating self-evident egress points for motorists who must flee crashes or fires. This initial consideration of risk has some analogies to the lowest-cost-lifecycle design options discussed in the Asset Management Guide. The concepts are similar in that the lowest risks to both safety and operations costs are achieved in the initial design of the facility. Similarly, high risk components of the tunnels such as lighting, ventilation and continuous monitoring systems are subject to routine, cyclical testing, preventive maintenance and replacement to reduce chance of failure. Although the report does not discuss highway asset management per se, the approaches it describes for tunnels incorporate many of the risk-reduction strategies that in other cases could be applied to non-enclosed highways or asset classes.

Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

One of the few sources of specific discussion of risk management in a US asset management application is this report [xxxiv] conducted for the Georgia Department of Transportation. It notes that the international scan reports found common use of risk management abroad but a domestic scan found little comparable application in the US. It notes that in asset management, risk can be applied to non-catastrophic as well as to catastrophic failure. This study restates the findings of the international scan reports and notes that risk equates to uncertainty, which the George DOT should seek to minimize as it develops asset management-related performance measures. The risk and uncertainty can be related to data errors, modeling errors and forecasting efforts. Of these, forecasting errors tend to be the most significant.

Risk-Based Asset Management Methodology for Highway Infrastructure Systems

The study develops a risk-based asset management methodology based on qualitative assessment by subject matter experts as to the relative importance of various classes of assets and their

recommended treatment regimens. [xxxv] The decision-making methodology is used to harmonize and coordinate the actions of the different units and levels in a hierarchical organization. The methodology enables the filtering and assessment of assets for maintenance while addressing the potential for extreme events. The methodology balances the costs, benefits, and risks of maintenance and inspection policies as applied to various types of assets. Three objective functions are used in evaluating options and strategies: minimizing short-term cost, minimizing long-term cost, and maximizing the remaining service life of highway assets.

Executive Strategies for Risk Management by State Departments of Transportation

The objective of this study is to describe how state department of transportation (DOT) leadership currently uses risk management techniques in the conduct of their business and to identify executive strategies that may be useful to DOT leadership for enterprise-wide risk management. ([xxxvi]) The report is based on a national survey of state transportation agencies regarding their risk-management practices. While most DOT personnel say they inherently evaluate risk, only 13 DOTs have formalized enterprise risk-management programs and even fewer have comprehensive risk management. The report differentiates between enterprise risk management, program risk management and project risk management. It restates general guidance on risk management from sources such as the Project Management Institute (PMI) but makes only passing reference to asset management. It offers executives guidance on how to organize from the top-down an enterprise risk management process for the organization.

Multi-hazard Applications in Bridge Management

This paper does not examine risk management per se but incorporates several relevant and analogous strategies as it proposes a process to evaluate what it describes as "hazards", several of which fall into the typical types of risks affecting bridges. These hazards include not only seismic events, floods and scouring, but also the gradual incremental hazards that occur through climate, use, corrosion and aging. The paper states that these individual hazards are often examined separately, even during separate and specific types of inspections and evaluations. However, the effects of these hazards are cumulative and multiplicative and should be viewed comprehensively. The paper recommends that inspections and evaluations of structures should consider all these hazards and the paper recommends formulae for calculating the cumulative effects of the hazards and the cumulative benefits of viewing them collectively. Its relevance to risk management is that it advocates the consideration of hazards, or risks, and their cumulative effect upon each other when hazard-mitigation steps are taken.

National Bridge Management, Inspection and Preservation Conference: Beyond the Short Term

This summary of the proceedings of a 2011 conference captured several US examples of how risk management principles are applied to the management of bridge inventories. [xxxvii] Several states reported using remote sensing technology to monitor stream flow on scour-critical structures. Most, increased inspections of fracture-critical structures. Others, however, illustrated examples of using risk management to identify opportunities. Illinois DOT performs some inspections on high-condition, low-risk bridges less frequently than the required two-year

intervals in order to increase inspection and monitoring of high-risk, low-condition bridges. Washington DOT described using video vans used for pavement analysis to inspect bridge deck surfaces if the deck was low-risk, high-condition and required intrusive lane closures to perform a manual, visual inspection. The use of video technology avoided putting inspectors at risk in traffic and avoided inconvenience to the public caused by closing lanes. The Michigan DOT described a risk-based approach to managing its overall inventory of bridges. If a bridge was at risk of falling from a structural deficiency rating of 5 into a rating of 4, it was singled out for maintenance or repair to restore to an acceptable condition. The slipping of condition from acceptable to unacceptable was treated as a risk for which bridges were monitored and actions were prioritized. Several states described intensive training and testing procedures for inspectors to reduce the risk that inspection data would be erroneous. One described ensuring the quality of inspections as being foundational to all other bridge management decisions, therefore the reduction of risk of poor-quality inspection warrants intensive training and quality control.

Storm Related Closure of I-5 and I-90: Freight Transportation Economic Impact Assessment Report- Winter 2007-2008

This report [(xxxviii)] documents the economic impact in Washington State of the 2007-2008 closure of I-5 due to floods and closure of I-90 due to a winter storm and discusses potential steps that can be taken to manage similar risks in the future.

WSDOT defines risk as, “Sum of conscious action taken to avoid or mitigate related loss which impairs operational capabilities or financial status of the DOT.”

The report provides recommendations and strategies to minimize the impact of the recurrence of similar events in the future. The report also proposes, “a new economic assessment methodology that would provide the state’s citizens and decision-makers with a reality-based, comprehensive analysis of the effects of the closures on the state’s freight industry and economy as a whole.”

This is an example of WSDOT conducting risk analysis to address a section of the network asset being unavailable for a period of time.

International Risk Management Examples

Towards Development of a Risk Management Approach

This report by the World Road Council, also known as PIARC, provides an overview of the emergence of risk management in the highway sector. [(xxxix)] In particular, it provides a succinct articulation of a point emphasized by the Office of Asset Management which is that risk management is about optimizing positive opportunities as well as minimizing the negative ones. The report notes that "risk management" also could be called "opportunity management" because it allows evaluation of the potential benefits of new possibilities. It differentiates between what it calls traditional or "static" risk management that focuses on reducing the likelihood of or preparing for negative occurrences. What it says is developing is a more "dynamic risk management" that seeks to capitalize upon new processes, technologies and attitudes. These possibilities can be assessed for their inherent risk and when risk is tolerable, they can be pursued as new opportunities to save resources, improve service, preserve infrastructure and

reduce crashes. Newer approaches to risk management can extend the formal evaluation of risks and rewards into areas such as achieving organizational goals and achieving the public's aspirations. The report also examines risk management in mega projects and to health, safety and environmental issues but those sections hold less relevance to asset management. This report also includes a useful explanation of the types of risk management, and how the different disciplines of risk management can be related to the highway application of risk.

Study on Risk Management for Roads

This 2005 PIARC study provides little inherently regarding the application of risk to transportation asset management. Its focus is upon risks to highways caused by natural and man-made disasters. Its benefit is only in contrast to the preceding study from 2010 that describes the emergence of much broader applications of risk from merely disaster assessment and prevention to enterprise risk management. This study began in 2000 and was published in 2005 and does not address enterprise risk management at all. The juxtaposition of the two studies illustrates the rapidly expanding scope of risk management as applied to highway infrastructure and programs.

Queensland Transport and Main Roads Guide to Risk Management

This guide [(xl)] provides general direction for the Queensland transportation agency for comprehensive risk management that is stratified from the top-down at the levels of strategy, portfolio, divisional, program, project and operational. For each level, it provides guidance, tools, techniques, templates and direction. The guide draws heavily from the Australia/New Zealand risk management standards, AS/NZS ISO 31000:2009, which is the Australian/New Zealand versions of the ISO risk management guidance. It uses many of the same definitions and uses the same graphic to illustrate the comprehensive, cyclical nature of risk management. It also uses the same categorization of risk management steps. The guide notes that the Queensland state has legislation requiring agencies to adopt and publish risk management plans. The guide says risk management should be embedded into all business activities and should provide a platform for innovation and opportunity. It reiterates the universality of the key steps from communication and consultation through risk monitoring that is common through all the earlier risk management frameworks cited. It applies those same risk management techniques to all levels, from the strategic down to the operational. The concepts, steps and tactics are very similar, they just occur at different levels. Strategic risk management looks at the agency overall, while portfolio risk management focuses on all programs and activities while program risk management examines risk to individual programs. Within programs, risk management of projects and operations are inherent in managing risks to the program. In this "nesting" fashion, the same approach to risk management is incorporated from broad organization-wide strategies down to individual projects.

Risk in Queensland Asset Management Documents

References to risk can be found integrated through asset-management related publications developed by the Queensland Department of Transport and Main Roads. For instance, the Skid Resistance Management Plan [(xli)] notes that it takes a risk-based approach to managing skid resistance. Low skid resistance and surface texture can increase the risk of crashes. The department's central strategy is to provide appropriate levels of skid resistance and surface

texture across the highway network. Its risk-based approach is consistent with the department's risk-management requirements, it is proactive and does not rely only on reactive assessment of crash sites and it aims to provide a level of skid resistance appropriate to the road environment. A comprehensive skid-resistance program also helps defend the department in liability lawsuits resulting from crashes. Risk also is cited in the Pavement Maintenance chapter of the asset-management guidance. ([xlii]) It notes its pavement inspection practices reduce the risk of providing low levels of service and help to defend the department against lawsuits. The Bridge Inspection Manual ([xliii]) integrates risk extensively with high-risk bridges singled out for more frequent inspections. Structure Management Plans are developed when a bridge's risk reaches a certain threshold. The WhichBridge software uses a risk-based multi-criteria calculation to identify bridges for maintenance, repair and replacement. It notes that certain categories of structures, such as timber ones built before modern design standards, pose elevated risks and are singled out for specific inspection and treatment. Several of these asset management publications make reference to the Financial Accountability Act of 2009, which states that risk management is a core business function for state and local governments in Queensland. [(xliv)] The department also has an Audit and Risk Committee that addresses risk and liability throughout the department.

Risk Management Process Manual - New Zealand

This document [(xlv)] discusses risk management in detail as interpreted and applied in New Zealand. In the overview section of the document all risk management terms are defined to provide clarity to the users. The document discusses the risk management process with examples. This document can serve as a starting point to US transportation agencies that are in the early phase of developing risk management processes.

The document discusses risk as both *threat and opportunity*. In the overview section, it provides the definition for each term used in the document. This is extremely useful for understanding the types of risk being discussed as well the treatments being applied as well as in communicating the impact and severity of the risk being managed.

The highway agency is referred to as “Transit” and is “responsible for the stewardship of New Zealand s state highways, which comprise approximately 11,000km of roads with an asset value of over $10 billion. In developing, maintaining and operating this asset, Transit has responsibility for the expenditure of over $.5 billion of road sector funds." The main sponsor of the Risk Management process in New Zealand Transit as discussed in the manual is the Chief Executive.

The manual defines risk as applied in New Zealand as “The chance of something happening that will have an impact on objectives. It is measured in terms of a combination of the likelihood of an event and its consequence.”

It defines risk management as, “the cultures, processes and structures that are directed towards the effective management of potential opportunities and threats.**”**

It defines the risk management process as, “The systematic application of management policies, procedures and practices to the tasks of establishing the context, identifying, analyzing, evaluating, treating, monitoring and communicating risk.”

The manual describes in detail how to rate a threat and an opportunity. It also discusses the consequences and how to treat threats and minimize the consequence of threats and how to treat opportunities to enhance the consequences. It discusses three approaches to practicing risk management - an "Informal Approach", "General Approach", and "Advanced Approach." The manual describes the steps in managing risk. It also discusses and provides examples of developing treatment plans and treating risks while using the three approaches. The manual notes that, "Too often organizations put emphasis on threats, and so they miss valuable opportunities to improve their performance through effective risk management."

In discussing the intended end results of risk management the manual focuses on minimizing threats and treating threats, and enhancing and realizing opportunities. The manual notes that, "better decisions, processes, plans, and programs are the intended results. The goal is to enhance our chances of success and to minimize the potential for failure, through greater risk awareness and proactive management." Therefore risk treatments are focused upon "limiting the impacts of potential threats **and** optimizing the impact of potential opportunities."

The intent of the risk management process as explained in the manual, "is to provide a set of tools that will help minimize threats to Transit's business and maximize opportunities to enhance it. Specifically, the risk management process is designed to raise awareness of threats and opportunities and to minimize such risks as: program/project overrun (in cost or time); litigation, network unavailability/delay**,** death/injury, community and road user concern, and environmental damage**."**

The desired outputs from Transit's risk management process are:

- effective and continuous management of all risks;
- reporting and elevation of all significant risks;
- risk-adjusted programming;
- risk-adjusted cost estimation.

The manual notes that risk management is more than dealing with financial uncertainty and is about managing, "all sources of uncertainty that may impact upon Transit's ability to meet objectives, obligations, and stakeholder expectations in relation to all anticipated outcomes."

Various sections of this document can serve as starting points for risk management practices that can be reviewed, modified or adopted as is by transportation agencies in the US.

State Highway Asset Management Plan 2012-2015

The report [xlvi] discusses the services provided by the New Zealand Transport Agency and states that these are based on statutory requirement and strategic direction from the government in particular the Government Policy Statement on transport funding-2012/12-2021/22. The state highway network consists of $25 billion worth of physical structures, including 11,367 kilometers of roads, 4328 bridges and 1438 kilometers of barriers. The New Zealand State Highway Asset Management Plan covers all infrastructure assets that form the highway network. It includes carriageways, structures, drainage features, traffic facilities, lighting, traffic

management and other services. The Plan addresses current and future demands on the network, its performance and the risk to those services. The Plan covers all forms of expenditures from capital investment to operations, maintenance, renewal and disposal of assets. All of this helps with the prioritization of actions. The plan also describes how the agency manages the assets effectively and efficiently. The New Zealand AM Plan provides the framework by which all asset management decisions are made. It provides forecasts of long-term capital and operational needs. The strategic objectives are focused around safety, reliable journey and freight efficiency**.** The targeted services are based on highway classification. The three classifications are 1) Regional Strategic (moderate to high journey speeds (70-90 Km/h rural and 50 km/h urban), 2) Regional Connectors (60-90 km/h rural, 50km/h urban) and 3) Regional Distributors (50-80km/h rural, 50 km/h urban). The agency considers alternative maintenance and renewal programs with differing levels of funding and level of service delivered.

The prioritization of actions occurs as a result of reviewing the current services provided by the highway network to the customers and considering the current and future needs and demands on the network, performance needs and expectations and risk to the services provided.

The agency demonstrates value for money in maintenance and operations activities by analyzing the cost of work relative to volume of traffic. The numbers show that the state highways are half as expensive when compared with local roads using the same criteria. Performance measurements and monitoring frameworks help the agency provide evidence of value for money.

Risk management is considered a fundamental facet of the agency's operations. The Plan states that, "Risks occur at strategic, portfolio, project and operational levels, and each requires a different management tactic. When we indentify, analyze and assess risks, an evaluation is then made on whether it is possible to eliminate them completely, whether we should mitigate but retain some residual risk, or if we should accept the full possible impact and decide whether to have the resources to respond appropriately, should the need arise."

Risk management is applied both to internal staff and suppliers. Managing risks relates to both asset improvement and asset management. The agency has a risk register that it uses as a tool to manage key risks. Contracts stipulate the requirement for risk management to be conducted following the provisions detailed in the Transit Risk Management Process Manual.

Risk is addressed at three tiers, the strategic risk, the portfolio and network level risk and the project and operational level risk. They are:

Strategic Risk

- Risk of a lack of or deferred funding;
- Risk of unanticipated occurrence of a natural event, e.g. flood, earthquake, landslip, avalanche, bush fire, adverse weather;

At portfolio and network level

- Risk of catastrophic failure of a network structure;
- Risk of pollution and/or negative impacts on flora and fauna;
- Risk of damage to the asset;

- Risk of premature deterioration or obsolescence of the asset;
- Risk of overspend;

Risk at project and operational level

- Risk of schedule slippage;
- Risk of suboptimal design and/or construction practices or materials;
- Risk of failure of integration of new projects with existing asset;
- Risk of failure to gain property access;
- Risk of poor contract execution and ensuring outcomes.

Developing and delivering a targeted program is based on prioritization and by considering the widest benefit with the greatest impact. Programming is done at three levels and Network, Corridor and Maintenance Operations and Improvement plans are developed.

The plan discusses Network plans as

- Cross agency
- Multi-modal
- Incorporate land-use
- Define sub-networks/corridors
- Set required role and function of each agency and transport corridor in the network

Corridor Plans do the following:

- Describe how the road is going to be developed and managed to deliver its role
- Set specific service targets, such as speed environment, feasible improvements and maintenance targets
- Identify route-long treatments
- Outline a program of feasible improvements
- Detailed enough to enable development of operations, maintenance and improvement plans

Maintenance Operation and Improvement Plan

- List in detail the activities that will efficiently implement the specific service targets set in the corridor and network plans
- Coordinated across corridors and work types
- Reflected in asset management plans every three years

The regional network plans and corridor plans are used to understand regional and corridor issues in terms of integrated transportation requirements and are used to identify service gaps and plan for a complete journey. The corridor plan is focused on the role of state highways within the network plan and helps identify service gaps that require improvements on a distinct network. Maintenance efforts look at the likelihood and consequence of failures to deliver the target level of service by the network. The routine maintenance and renewal efforts helps preserve the highway assets and ensure that the agency delivers the target level of service for performance that is timed to reduce the risk of service failures from deterioration of asset condition. Using the appropriate combination of routine maintenance, inspection of asset condition, evidence-based

assessment, reactive maintenance, asset renewal and maintenance and deferral ensure whole-of-life costs and minimal risk to service targets.

Case Studies and best-practices guideline for risk management on road-networks, September 2010

This study [xlvii] was aimed at establishing an integrated risk management framework designed for local agencies specifically tied to the area of transportation. The objective of the New Zealand report was to improve the risk management framework and risk management process in NZ as part of integrated asset management. The report states, "In its most basic form, risk is about awareness of, and reaction to, potential circumstances that could impede an entity's ability to achieve its goals and objectives."

The objectives of the report were to:

- improve risk management processes and the risk management framework as part of integrated asset management;
- improve planning and make decision-making more transparent;
- provide guidance on risk management on the interface of roadway network with other infrastructure areas;
- identify and apply risk management procedures and risk profiling as factors in optimizing 'hard-asset' solutions and/or 'non-asset' solutions in decision making;
- how best to link risk management in road networks to the organizational risk management framework.

One of the weaknesses identified in the report is the need to identify risks associated with critical road network assets. The report also references various international reports that can be useful. Of special mention is the paper from Queensland Audit Office titled, "Better practice guide: Risk management."

It looked at risk management of road networks and its link to organizational risk management including other corporate wide risks such as corporate, environmental, and financial risks. It also looks at transportation risks tied to risks linked to interfacing infrastructure such as utilities and storm water. The study also looked at data management issues associated with good risk management practices. The research study notes that though a 2002 Local Government Act required a more holistic approach to risk management, practical application is still lacking in the area of transportation.

The study report goes into details of identifying transportation risks, linking them to organizational risks, evaluation and prioritization of transportation risks; practices to avoid risks, developing actions and mitigating risks; monitoring and reporting and integrating risk management with asset management plans as well as effectiveness and suitability of risk management processes. The study also notes that though the nine councils that were part of the study understood the theory of risk management in practice there was little evidence of risk management strategies being implemented.

The report in the conclusion noted that risk of asset failure ranged from financial loss to loss of life. Difficulties in implementation and maintenance of the risk management framework include:

- Starting issues- establishing the framework, identifying and registering risks;

- Lack of records of implemented strategies that reduced risks and the strategies' effectiveness;
- Minimal follow through from risk identification to implementing corrective action;
- Ensuring the risk management framework was at a suitable level of complexity that allowed commitment of the appropriate level of necessary resources and not over commitment;
- Lack of integration of risk management with the council's decision-making process.

The paper also cautions against complicated and involved risk scoring processes. "There should not be undue effort applied to scoring risk beyond the expertise of the staff contributing to the scoring."

The report quotes the following about risk management by Robinson et al (1998) in the book Road Maintenance Management, that "Risk management provides a basis for judging the relative merits of alternative decisions, but, in itself, does nothing to diminish the risk."

In case studies discussed, the policy, context and guidelines for risk management tended to be established within asset management plans (AMPs). The update of the AMPs in many cases triggered the review of the risk management process.

When reviewing the risk framework at the different levels, i.e. corporate level, transport level, the roles and responsibility assignment and culture of risk awareness, the study found that where corporate risk policy was established the Asset Manager had the key responsibility to manage risk via the need to address risk for incorporation in the asset management plan.

For success of risk management, the study recommends integrating risk management into the corporate culture by creating "risk awareness" and keeping it simple for usability, so engineers can understand it and apply it.

The general recommendation was to use Excel file format to track risks. The recommendation was to keep it simple and use color to indicate risk levels, use of columns that are intuitive and reflective of the content. Involving more people in risk management ensures the propagation of risk awareness.

The Risk Management Framework was seen to capture "the 'inherent risk' regarding knowledge that existed in the heads of experienced staff members, and to communicate this clearly, usually via the Risk section in the AMP.

Other benefits are:

- increased direction and focus;
- underlining the importance of justifying existing courses of action;
- obtaining a more realistic assessment of perceived risk, which otherwise could be exaggerated;
- cross-pollination with other sections and activities of council, resulting in a better appreciation and understanding of risk;

- obviously reduced risks.

The study identifies the following as perceived values of a Risk Management Framework:

- awareness;
- succession planning;
- direction and focus;
- justification of current practices and courses of action;
- realistic assessment of perceived risks – improved perspective;
- increased appreciation of other council activities;
- reduced risk exposure for the activity.

The study identifies the following as factors to consider in evaluating if the risk framework is successful:

- results in the successful implementation of any improvement actions;
- reinforces or justifies current practices;
- influences strategic decision making;
- raises issues not previously considered;
- justifies a reduction in, or cessation of, an existing program or action;
- justifies an increase in resource or urgency of a current program or action.

The report states that "Risk management should be firmly established within asset management planning, with the AMPs being the vehicle for establishing, publishing and reviewing the risks faced by the activity" and suggests that "Risk results should be discussed within other key sections of the AMP, e.g. levels of service, and life cycle management (LCM) for various asset types and services."

New South Wales Risk Management Guideline

This guideline is a component of the New South Wales Total Asset Management Manual. [(xlviii)] It applies to all public works and not just to transportation assets. Although its name is promising to this project, the guidance has limited relevance to applying risk to transportation assets in the United States. Its application is mainly to new construction not only for highways but also for other major capital expenditures. The guidance describes how to develop a risk management plan at the initial stages of a project's concept. The guidance addresses many issues that are addressed in construction risk-management guidance such as the control of scope, identifying external factors that could influence project cost or schedule and anticipating how to manage the asset through its life. It does not address managing risk for existing assets.

Transport Scotland Risk Management

Transport Scotland (TS) is the transportation agency for the nation of Scotland which operates autonomously within Great Britain. Its Road Asset Management Plan (RAMP) includes a chapter on risk management, illustrating the common use of risk management in that nation's government. Transport Scotland applies risk management at the strategic, tactical and operational levels to identify, analyze, assess and manage risks associated with service delivery, and in some cases to determine the service required. It notes that a simple definition of risk

could be "the chance of something happening that will impact on safety or service." Risk management plays an important role by ensuring that decisions on the control and management of risk are made in an informed, rational and structured manner. It says that it is developing a Corporate Risk Management Strategy to align and promote synergy between its divisions and to set out a clear system for identifying, managing and mitigating risks. Among the elements of the Corporate Risk Management Strategy will be an up-to-date risk register of all risks, appropriate controls to manage those risks, regular reviews of the risk strategies and prioritized risks to escalate them to appropriate levels for decision-making. Specific risk management strategies for roads include risk-based inspection schedules. Transport Scotland uses many private contractors to perform maintenance and inherent in their contracts are specified risk-based activities such as inspections. Road safety inspections which look for items such as missing signs or other immediate hazards are required twice weekly with detailed inspections annually. Serious defects must be addressed on major routes by 6 a.m. the day following identification while less critical ones are scheduled for repair within 24 hours of identification. Maintenance needs not classified as urgent or safety critical are scheduled on a needs basis using a value-management approach.

VicRoads Risk Management Summary

This information was included in an unpublished response to questions asked by a US scanning team that visited VicRoads in 2011. The team traveled as part of FHWA's International Technology Scanning Program. The team presented questions in advance to the VicRoads officials who provided brief, written responses. The responses indicate that risk management is a comprehensive undertaking at VicRoads that flows both from the top down through policy and from the bottom up through identification and response to risks at the front lines. The VicRoads chief executive has the primary responsibility for organizational risk management, along with the Executive Corporate Management Group. All VicRoads managers have responsibility for effective risk management within their business areas. The director of VicRoads risk management has the responsibility for the development and oversight of corporate risk management policies, processes, systems, coordination and communication. In addition, that position is responsible for the monitoring and reporting of risk status and actions to the executive management. The corporate risk management practices of VicRoads occur within a larger statewide risk management framework. The statewide and organizational frameworks are included in a series of official policies and guidelines from the state level down to the project level. Risk management at VicRoads originated as a top-down requirement in 1999. VicRoads officials reported that it is now an integrated approach that is incorporated in all major business areas. The organization develops a three year risk register and risk management plan. Staff in each business area has training and responsibility for identifying, coordinating and monitoring risk in their units. Training is provided to all staff that require risk expertise. The agency developed a Corporate Risk Management Assessment Guide that identifies key risk areas and provides for risk severities and corresponding mitigation action. VicRoads uses as a definition of risk the ISO definition of "risk is the effect of uncertainty on objectives." VicRoads officials advised their US counterparts that risk management should be viewed as a tool that should focus upon how uncertainty could affect the organization's objectives. Risk at VicRoads is a major input to strategic plans, programs and projects to ensure that desired levels of service are achieved. At the same time, risk analysis should not lead to paralysis. The agency seeks a healthy balance of taking acceptable risk to achieve acceptable returns while avoiding excessive risks.

Victorian Government Risk Management Framework

This policy document ([xlix]) prescribes the risk management practices required of state agencies, including Vic Roads. It uses the ISO definition of risk as the effect of uncertainty upon objectives. It defines risk management as the combination of organizational systems, processes, procedures and culture that facilitate the identification, assessment evaluation and treatment of risk in order to protect the organization and assist in the successful pursuit of its strategies and performance objectives. The framework strongly emphasizes embedding risk management into the culture of an organization. It provides a simple definition of culture as "the way we work around here." It says that risk needs to be considered and addressed by everyone, whether positive opportunities or negative threats. The traditional approach of addressing risk as individual hazards is no longer appropriate. Risks need to be managed in the context of achieving organizational goals and objectives. Risk management should be integrated into strategic planning, performance management and governance across the public sector.

Risk management is a key component of good governance, and as such, managers are required to attest that they have risk-management processes in place that conform with the ISO standards and that these processes effectively control risks to a satisfactory level. It defines 11 principles of risk managing including:

- Risk management creates and protects value;
- It helps achieve organizational objectives;
- It is an integral part of all levels of management;
- It facilitates informed decisions;
- It explicitly address uncertainty;
- It is based on best available information;
- It aligns with the agency's operating profile;
- It takes human and cultural factors into account:
- It is transparent and inclusive;
- It is dynamic and responsive to change;
- It facilitates continuous improvement.

It categorizes at least four kinds of risks: event risks, creeping risks, recurrent risks and emerging risks.

VicRoads Risk Policy

The VicRoads Risk Management Policy [l] states that risk is inherent in all day-to-day operations. Risk management is therefore not an "add-on" but a primary activity of the organization. It says that the organization needs to manage risk to enable it to "get on with the job confidently and responsibly, knowing that relevant risks have been identified and dealt with appropriately." It says that all staff need to identify, evaluate and manage risks during their normal business activities.

It emphasizes that VicRoads has statutory obligations to ensure that its risk profile is critically reviewed at least annually. It must ensure that its risk management framework is implemented across the organization at all levels and operates effectively to control risks to a satisfactory

level. The Chief Executive will attest in VicRoads Annual Report to the implementation of an effective risk management system, consistent with the Risk Management Standard AS/NZS 31000:2009, and the achievement of satisfactory risk management outcomes. VicRoads will reinforce a culture of risk management and ensure that risk management principles are adopted in its business procedures. To achieve its risk-management objectives it will ensure staff are property trained and that risk management will be incorporated into its management systems.

Risk-Based Bridge Asset Management

This paper examines how a risk-based bridge asset management program can serve as legal defense for liability claims in Australia. [(li)] Although the article is narrowly focused upon legal defense, the logic it applies is relevant to using risk-based asset management as a defense against other questions, such as whether or not the agency is applying a rational and comprehensive approach to resource allocation. The paper notes that in May 2001, an Australian court effectively revoked long-standing immunity highway agencies had against claims that infrastructure deficiencies contributed to crashes. As a result, agencies must rely on a "policy defense" or the defense that they have acted prudently by using a risk-based asset management process. By demonstrating the use of a rational, risk-based asset management system they can demonstrate due diligence and provide an effective defense to liability if a crash occurs. The elements of a defensible risk-based asset management program would include:

- Regular documented inspection programs;
- Documented allocation of funding for repair and maintenance;
- Documented competing demands on resources;
- Determined intervention levels;
- Prioritization actions and documented reasons for prioritization;
- Determination if further proactive inspections are required.

Highways Agency Risk Manage Policy and Guidance

This guidance document [(lii)] from the English Highways Agency within the Department for Transport explains the importance of risk management, explains roles and responsibilities, provides details of the "risk appetite" or risk tolerance, and provides details of the department's policy of managing risks as part of its performance management processes. It notes that risk management is key to success and allows an organization to have increased confidence it will achieve its objectives, effectively constrain threats and make informed decisions about opportunities. It instructs users to measure risks against a known "risk appetite" or level of risk exposure the agency is willing to accept. Once risk threshold is exceeded, the risk owner needs to escalate the issue to higher levels for decision making regarding the risks. The guidance says the agency welcomes and encourages well-managed risk where the potential rewards are improved customer service, time or cost savings or improvement in quality. It says no one need fear the consequences for failure if risks were anticipated, appropriately managed and escalated to senior management. The agency will not tolerate risk to integrity, propriety, stewardship of public funds or risks to public safety that have not been reduced to as low as reasonably possible. It provides simple tables for risk descriptions. Rare risks would be ones likely to occur only 0.02 percent of the time, or less than one in 5,000 chances. The scale of risk would rise to Almost Certain, which

represents a 75 percent chance of occurrence. Likewise, impacts are scaled from insignificant to catastrophic. Color coding is associated with the BRAG scaling, or Black for critical, Red for High, Amber for Medium and Green and low. Risks are identified and prioritized with these simple tools into a risk register which is just an Excel spreadsheet. When risks are identified then risk owners are advised to deploy one of the "5 Ts." These are treat, tolerate, terminate, transfer or take advantage of. Those are the five strategies that must be considered and one of them assigned as the risk-mitigation strategy. Treat and tolerate are self-evident. Terminate means to end the process that creates the risk. Transfer means to buy insurance or shift the risk to a third party, such as a contractor. Take advantage of means that the risk is an opportunity to be exploited. Risks are categorized in the following ways. Strategic risk are risks of failing to operate in accordance with agency policy. Reputational risk links to negative public reaction. Operational risk is loss from failed internal processes. Transaction risk relates to flawed service or product delivery. Compliance risk exists when third parties fail to comply with laws, regulations or rules. Escalation paths are spelled when risks exceed acceptable thresholds. Eventually, they could be escalated to the governing board.

Contribution to Risk Management of Existing Slopes

This 2000 PIARC report [(liii)] examines risk management as it applies to high-risk slopes that can fail from earthquakes, saturation or inherent instability. As a subset of risk management in asset management, the slope-management report recommends a series of steps that serve as analogous examples for the larger application of risk to all facets of asset management. These include: incorporate risk considerations initially and avoid locations or designs that have unacceptable risks; ensure communication among stakeholders so they can act to minimize slope failure and can react quickly if it occurs, particularly during abnormal weather conditions; provide education and training to monitor the slopes; use promising new technology to improve data on dynamic slope conditions; continue pursuing basic research on slope failures and prevention; develop databases of slopes, and; promote use of databases for systematic slope management.

Project Risk Management

In the United States, one of the more mature areas of risk management as it relates to transportation infrastructure is in the area of project management. Costly project overruns and delays led decision makers to adopt risk management strategies and to pursue national research on project management in general, and risk management as a particular strategy. This section examines several examples of risk management resources relating to project management. In many of the examples, the term "management of assets" could be substituted for "project management" and the strategies could be transferred from project risk management to the risk management for transportation assets.

A Guide to the Project Management Body of Knowledge

The Project Management Institute (PMI) includes a chapter on risk management in its project-management guide. [liv] Project risk management includes the processes concerned with conducting risk management planning, identification, analysis, response, monitoring and control on a project. Risk management on a project is not a one-time activity but an ongoing, iterative process throughout the project lifecycle. It begins with risk management planning, proceeds to risk identification, then risk analysis, risk-response planning and then monitoring and control. As others have noted, risk is an uncertain event or condition that can create a positive or a negative impact. Some strategies, such as pursuing concurrent and not consecutive phases of development, can create risks but also opportunities. The role of risk management is to identify, quantify and respond to the positive and negative possibilities. The PMI guide describes tools to visually plot the factors that could influence each aspect of the project cost, quality or schedule. These risks are entered into a risk register that is then tracked and updated throughout the project. Risks can be assessed qualitatively through the experience of the organization or it can be assessed quantitatively. Qualitative assessments may put risks on a "low to high" scale or a 0-10 scale based on the collective experience of the participants and organization. The "Delphi" method can be used in which the opinions of the participants are synthesized into a more formal, quantified probability of risk. In a more quantified analysis, probabilities are assigned to factors that can affect the cost, quality or schedule of a project. The factors are then calculated based on the numeric values of the probability of each potential factor. The quantified analysis can provide a more formal-appearing risk assessment but its accuracy is limited by the validity of the data forming the individual calculations of probability. After the risks are identified and their potential magnitude of impact estimated, a risk management plan is developed. It includes the strategies to controls the risk factors, assign responsibilities, and monitor results.

Guidebook on Risk Analysis and Management Practices to Control Project Costs

NCHRP Report 658 provides a comprehensive guidebook on risk-related analysis tools and management practices for estimating and controlling transportation project costs. Specifically, the guidebook addresses (1) the inconsistent application of contingency to risk management and cost estimation, (2) the lack of uniformity in methods of documenting and tracking risk within a comprehensive cost-control strategy or program, (3) insufficient procedures for determining timing of risk management within various phases of project development, the need for matching appropriate tools to different project scales, (4) insufficient organizational structure, (5) organizational commitment, performance measurement, and accountability within transportation

agencies, (6) policy and political issues, and (7) the regulatory environment. Although focused on project cost estimating, the guide illustrates the universality of the steps involved in risk management. It proposes a framework for estimating that is built around the commonly used steps of risk identification, assessment, mitigation, risk allocation and risk monitoring. It notes that a lack of risk management can lead to cost overruns and loss of agency credibility. Highway construction can face many uncertainties but a thorough risk-management protocol can help an agency manage the risks and exploit the opportunities created by uncertainties. It says that a process that directly addresses uncertainty and risk is the core of a comprehensive risk-management program. However, risk management should be viewed as a comprehensive management process and not as only a tool of cost estimating. It stresses that risk management is cyclical and repetitive, continuously "learning" from past estimates and improving its accuracy. The goal is not to eliminate all risks but rather to initiate the appropriate management responses to the inevitable risks that are identified.

Project Risk Management Handbook

"Threats and opportunities" is the subtitle of this handbook by Caltrans. [lv] It intends to aid in the effective management of risks, both those that are threats and those that are opportunities. It says that risk management goes further than planning and that risk management needs to be executed effectively and monitored closely. It defines project risk as an uncertain event or condition that, if it occurs, has a positive or negative effect on at least one project objective. It defines risk management as the systematic process of planning, identifying, analyzing, responding to and monitoring project risks. It helps the project manager maximize the probability of positive events and minimize the probability and consequences of adverse ones. It is most effective when performed early in the life of a project and carried through its lifecycle. As other authors have noted, risk management improves decision-making. By identifying likely risks, the project manager can evaluate alternative approaches that can reduce risk and capitalize on opportunities. Risk management allows the minimization of impacts, maximizing of opportunity and the reduction of management by crisis. It describes openness and transparency as a key success factor for successful risk management. It should promote an atmosphere where risks can be freely discussed and brought up by anyone in the process, regardless of their place in the organizational hierarchy. Like other frameworks, it emphasizes a cyclical process that begins with planning, moves through risk identification and analysis and proceeds through continuous monitoring. It emphasizes not only the identification of threats but also of opportunities and triggers. Triggers are symptoms and warning signs that indicate whether a risk is becoming a near-certain event. It also notes that addressing one risk can create another. Hiring specialized services to address a high-risk task creates the risk of expensive or ineffective consultant management. Teams should be aware not only of the primary risks, but residual risks, secondary risks and risk interactions. When a risk is identified, the project team can decide whether to avoid it, transfer it, mitigate it or accept it. Likewise, when opportunities are found they can be exploited, shared or enhanced.

Project Risk Management Guidance for WSDOT Projects

This 2010 guidance from the Washington State Department of Transportation provides a comprehensive framework for deploying risk-management strategies for construction projects. Although focused only on construction projects, the guide easily could be modified to address

risks of almost any type, including risk to asset management programs. It lays out a series of steps and tools that could be modified for most risk management topic areas. Like nearly all the other documents cited in this review, the guide defines risk and explains the role of risk management in controlling uncertainty, maximizing likelihood of success, preserving value and complying with policy. At 96 pages, it goes into more detail than many of the other documents. It provides step-by-step activities for risk management planning meetings as the team begins the process of identifying, mitigating and monitoring project risks. It notes that much of the risk identification is conducted qualitatively, often relying on the judgment and discernment of veteran staff. Although probability-based tools can be used, their assumptions are reliant on the experience of the past practitioners. The steps described in the manual are very similar to the basic steps described in the ISO guidance and elsewhere. The risk analysis begins with planning, followed by risk identification, qualitative risk assessment followed by quantified risk assessment if possible, leading to risk response and concluding with risk monitoring and control. It provides spreadsheet templates for staff to follow and a template for a risk management plan.

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[iv] World Road Association, Towards Development of a Risk Management Approach, PIARC Technical Committee 3.2. 2010, p.196
[v] FAA, Risk Management Handbook, 2009 pp. 1-2,1-5
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