NCHRP 08-93

Managing Risk Across the Enterprise: A Guidebook for State Departments of Transportation

Final Literature Review

Prepared for

The National Cooperative Highway Research Program

Transportation Research Board

Of

The National Academies

Gordon Proctor & Associates, Dublin, Ohio

Shobna Varma, StarIsis, Corp. Lewis Center, Ohio

Jeff Roorda and Associates, Inc.

June 2016

This page intentionally is blank.

Table of Contents

Purpose and Organization of Literature Review

This literature review was developed to support NHCRP Project 08-93, Managing Risk Across the Enterprise: A Guidebook for State Departments of Transportation. The literature review addresses many areas of risk management given the project's objective of developing a guide to manage risks across the entire enterprise of a state transportation department. The literature review is categorized into eight general areas:

1. The frameworks, history, definitions, and rationale for enterprise risk management;
2. Managing risks to transportation assets;
3. Managing risks related to highway traffic crashes;
4. Managing risks created by external threats such as extreme climatic events or seismic events;
5. Managing risks to financial resources such as revenues or asset values caused by inflation or investment decisions;
6. Managing risks to information and decision making;
7. Managing risks to business operations such as purchasing, contracting, worker safety, and;
8. Managing risks to program and project development.

Figure 1 illustrates how the eight categories represent major programs or portfolios whose risks can be managed within an enterprise risk management framework. Depending upon how an agency was organized or its priorities, many other programs or portfolios could be added. This literature review settles on these eight as representing the major program areas in most departments.

The literature review differs from others in two ways. First, it is intended to support a user guide that

Figure 1 Framework of the literature review.

will be written for a broad audience and not for specialists in risk management. The guide will be developed to be understandable to all disciplines within a state transportation agency. The literature review is developed with the same intent, which is to support a generalist who may want additional information related to some aspect of the guide or to risk management in general. The literature review particularly focuses on specialized risk management guides relevant to the eight areas listed above.

Secondly, the literature review summarizes and incorporates an earlier literature review developed in 2012 for the FHWA Office of Asset Management, Construction and Pavements. That literature review can be accessed at http://www.fhwa.dot.gov/asset/pubs/hif12036.pdf

That literature review was developed 24 months before this one and addressed many aspects relevant to this guide. Hence, the project panel agreed not to duplicate, but rather summarize and reference, that literature review. As a result, this literature review builds from the earlier one. That review was written to support a series of reports of how risk management can be applied to transportation assets, such as roads, bridges, traffic control devices and even information assets. It emphasized sources relating to the definition of risk management, the role of risk management, the managing of risks to physical assets and the addressing of threats caused by external events that could impact transportation networks.

Section 1: History, Rationale, Definitions and Frameworks for Risk Management

History of Risk Management

Many authors (Beattie, 2010, RandMark, 2010, Bernstein, 1996) trace the origins of risk management back to the earliest forms of insurance and credit risk laws or practices that were identified soon after the invention of writing began to document business transactions. They cite examples from Hammurabi's Code, ancient Persian statutes and Middle Eastern caravan practices as examples of merchants taking steps to identify and treat risks. These authors describe steps to identify and treat risks as maturing as the complexity and sophistication of societies increased. By the Middle Ages, European trade guilds provided forms of insurance, or the spreading of risk, by tradesmen providing support to one another when beset by illness, fire or other loss. These authors trace the modern Western insurance industry risk-management practices to Lloyd's coffeehouse in London where traders shared investments and risk in overseas shipping, a practice the eventually led to creation of the Lloyds of London insurance company.

Bernstein (1996) contends that modern civilization is in significant part defined by its efforts to understand and control risk. Efforts by modern societies to understand and reduce the causes of disease, crime and warfare are viewed within the broad context of identifying, analyzing, treating and monitoring risks to their citizens. Bernstein was a successful investment fund manager and first editor of the Journal of Portfolio Management. Among his six books were "Against the Gods: The Remarkable Story of Risk" that traces risk management from a practice in which similar merchants or tradesmen protected each other against catastrophic loss to the evolution of sophisticated mathematical-based risk management strategies. The development of mathematical models of probability and statistical analysis by such well-known figures as Bayes, Pascal, and Fermat provided the mathematical foundations for quantified risk management.

Today, risk management is a broadly applied field with its application specialized by profession. Risk managers are common in fields as diverse as retailing, in which they focus on reducing inventory theft, to aviation, in which they focus upon safety, to investing, in which they focus upon providing guaranteed returns and hedging against significant losses. A central premise of Bernstein is that sophisticated management and responsible social leadership are not possible without managing risks.

Buehler, Freeman and Hulme (2008) write that before the 1970s risk management was largely defined by purchasing insurance. That strategy hedged risks against losses but ignored opportunities for potential gain caused by a risk. In the financial and banking sector, few tools existed to measure risk – such as the risk a bank takes when it issues a 30-year mortgage to a homeowner. If the bank will in the

future pay much higher rates to borrow short-term funds than it brings in from long-term loans, the bank risks financial loss. Buehler et al note that beginning in the 1970s the banking and financial industry developed a series of increasingly sophisticated tools and practices. These gradually spread to other fields when legal reforms were enacted to protect investors following crises, such as the savings and loan industry collapse in the 1980s. Buehler et al note that interest in risk management tended to ebb and flow based upon the occurrence of financial or other crises. Eventually, however, risk management evolved to be seen as a basic competency that any manager of assets is required to deploy.

Martin and Fone (2005) say risk management in the British public sector lagged about two decades behind the practice of risk management in the private sector. They say by the 1980s, British governments had risk management units that focused on pooling insurance purchases to lower costs, reduce accidents and lower insurance costs and claims. They note that by the 1990s, the concept of organizational risk management arose to manage risks to all functions in an agency. They say that managing risks has always been an inferred function of government, such as controlling risks to invasion or disease. By the 1990s in the British government risk management protocols expanded to expectations that risk managers would identify and manage all risks to an agency's objectives. Now, they say, risk management is an expected basic competency for British units of government.

Definitions of Risk Management

Understanding of risk and risk management is complicated by the wide use of terms by different industries. As noted in the literature review produced for the FHWA Office of Asset Management, Construction and Pavements in 2012:

> "Different industries define risk differently. The International Risk Management Institute (2006) defines risk as, 'Uncertainty arising from the possible occurrence of given events.' The International Organization for Standardization (2009) (ISO) defines it as 'the effect of uncertainty on objectives.' Scott (2003) defines risk as, 'the variability of returns from an investment.' Lamb's (2012) definition for investment risk is 'deviation from an expected outcome.' The World Road Association (2010) 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.' The U.S. Federal Aviation Administration (FAA) (2009) 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.' Knight (2012) takes a different approach and defines 'risk' as variability that can be quantified while variability that cannot be quantified is 'uncertainty.'

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. Lam (2003) notes that over protecting against risk means negating opportunities.

A comparison of three widely purchased books on risk management illustrates the breadth of different approaches to risk management. Croughy, Galai and Mark (2006) illustrate dozens of different risk concepts, approaches and models – but all relating only to investing. In their book, risk management is about reducing the volatility or unpredictability of an organization achieving its financial targets. Treishman, Hoyt and Sommer (2005) take a much broader view, such as that taken by an insurance industry executive. They examine risk management strategies relating to a much broader range of business activities, such as:

- managing risks to physical property such as vehicles and buildings;
- protecting against legal or tort liability;
- protecting against criminal activity, theft or fraud;
- taking steps to ensure against negligence;
- alternative risk transfer, or the purchase of insurance or risk “swaps”;
- worker’s compensation, including reducing workforce injuries and reducing claim costs, and;
- managing risks to corporate assets, such as employee pension funds.

Lam (2012) reiterates many of these areas of risks as ones to be addressed in an enterprise risk management framework. He adds “business risks” or the risks to the organization’s profits and “reputational risks” that can drive away customers and increase regulatory oversight. Lam also adds emerging areas such as “operational risks.” He defines operational risk as, “…the risk of direct or indirect lost resulting from inadequate or failed internal processes, people, systems or from external events.”

The project panel for the 08-93 risk management guide evaluated these widely varying definitions and settled upon these three as key for the guide. They represent a variation of the ISO definitions. For the purpose of the 08-93 risk guide:

> “Risk is the positive or negative effects of uncertainty or variability upon agency objectives.”

This broader definition is intended to clarify for an audience that may be new to risk management the scope and breadth of issues that could be considered in a risk management framework.

The panel chose to define risk management as:

> “Risk management is the cultures, processes and structures that are directed towards the effective management of potential opportunities and threats.”

For the risk management process, the panel chose the definition of:

> "The risk management process is the systematic application of policies, procedures, and practices to the identification and management of uncertainty or variability upon achievement of agency objectives."

The three definitions will support an approach in the guide that:

- risks are things, events or actions that create uncertainty for objectives;
- risk management is the architecture of managing risks, and;
- the risk process is the active use of the architecture for managing risks.

The tripartite concept reflects recommendations from Lam and other that emphasize the need for active, dynamic application of the risk management process for risk management to be successful. Defining risks and establishing the architecture may not be effective unless leaders engage in the active application of the architecture.

Another commonly used definition is for Enterprise Risk Management which generally is defined as managing risks to the organization's strategic objectives, or managing risks that could affect the entire organization. Others describe portfolio risk, program risk, project risk or activity risk. These levels reflect a stratified, but integrated, management of risks at different levels of the organizations. Enterprise risks may be managed by senior leaders who cascade down through the organization strategies to manage those broad risks. Concurrently, risks at the portfolio or program level may be communicated up to senior leaders and down to project or activity managers. Similarly, risks down at the project or activity levels are reported up the organization so they can be monitored so that they do not expand and affect entire programs, portfolios or the organization itself.

The Risk Management Society (RIMS) (2014) reports an increasing tendency for risk management practices to expand from specialized application at the project or activity level to be applied across the organization as Enterprise Risk Management (ERM).

Rationale for Enterprise Risk Management

Various risk management standards and guidelines cite similar rationales or benefits for adopting risk management. (ISO:3100 2009, AS/NZS4360 2008, Treasury Board 2008). Because risk is common, people and organizations have always managed risks informally even if they didn't adopt a formal or rigorous risk process. The modern rationale for formal risk management is to acknowledge the universality of risks and to systematically adopt processes to identify and manage them. The alternative to risk management is accepting informal decisions and occasional threats, disruption and setbacks caused by one of the many threats or risks existing in the natural, economic, social or political environments. The many frameworks for risk generally cite similar benefits such as risk management results in fewer surprises for an organization, it exploits opportunities, it improves planning and decision making, it protects value and it increases the wellbeing of stakeholders, be they citizens, customers or employees. Increasingly, risk management is considered a basic component of sound governance. Much like having acceptable accounting and fiscal controls, managing risks is expected as a basic corporate competency. If risks are inevitable, not managing them is irresponsible.

A rationale always existed for leaders and organizations to protect their citizens, customers or partners from threats. The modern frameworks add a new rationale for managing risks which is to improve organizational performance. As leaders increasingly are expected to meet performance expectations, they are increasingly expected to reduce risks to their organization's success.

Lam's discussion of operational risks reflects the rationale to expand risk management from focusing upon the narrow application to insurance, safety or investment to a much broader application to organizational performance. The linkage of risk management to performance can be seen in two parallel industries seeking to control variability or volatility in performance – one is manufacturing and the other finance. In both industries the rational for risk management increased as performance targets were established and the executive's role increasingly grew to include managing the risks to achieving those targets.

In financial markets, Gunter (2012) 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 provides the rationale for managing risks to predicted investment returns.

In manufacturing, going back to the very early "quality" writings of Shewhart (1931) authors have focused upon how to eliminate the influences of risk, or as Shewhart called it, "chance." Shewhart's work was among the early research on statistical analysis of the variability of manufactured products. He advocated statistical analysis of defects and analysis of the root cause of them. 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 compared to its specifications, the higher its quality in his definition. Shewhart and his intellectual descendants 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 fields of Transportation Performance or Asset Management are viewed from a risk management context, the related discipline of reliability engineering will be relevant. Risks to be examined within the TAM or Performance Management 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 performance or asset conditions. In terms of physical assets, risk management and reliability engineering can be viewed as sister disciplines.

Managing Risk to Increase Reliability

Bazovsky (2004) provides another rational to link organizational performance and the control of risk or variance. In a performance-based environment, the elimination of risk, chance or uncertainty in

performance equates to improved performance. Bazovsky illustrates how activities such as scheduled and routine maintenance, preservation, sound inventories and condition assessments provide risk-mitigation strategies to ameliorate defects in performance. He discusses manufacturing but his concepts apply equally to managing bridges or pavements.

If the definitions of risk relate to uncertainty or variability, then the definition of reliability is its near opposite. According to Bazovsky, "reliability is the probability of success." 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-maintained 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 which were written for manufacturing but also apply to transportation assets;

- 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 is the risk-management strategy to control premature failures. Proper preservation and maintenance schedules are risk-management strategies to reduce the wear-out failures. The risk of chance failures can be managed through contingency planning to react quickly to restore service levels after fires, floods and other events. As such, reliability engineering seeks many of the same ends as does risk management - to identify and address the causes of failure.

Kaplan (2009) says another rationale for risk management is that the lines between good risk management and overall good management are blurring in today's environment of high performance expectations. 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. 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. Sound financial and operational risk management have become a basic component of managerial competency essential for an executive to demonstrate due diligence in the post-Sarbanes-Oxley era.

Managing Risk to Protect Assets

A strong rationale for enterprise risk management arose in the 2000s because of several high-profile corporate bankruptcies. The Securities and Exchange Commission (2009) says The Public Company

Accounting Reform and Investor Protection Act, otherwise known as the Sarbanes-Oxley Act, was enacted in July 2002 after a series of corporate scandals involving companies such as Enron and Worldcom. Section 404(a) of the Act requires management to assess and report on the effectiveness of internal control over financial reporting ("ICFR"). Section 404(b) requires that an independent auditor attest to management's assessment of the effectiveness of those internal controls, including extensive risk management controls.

Coates (2007) says the intent of Sarbanes Oxley was for Investors to face a lower risk of losses from fraud and theft, and benefit from more reliable financial reporting, greater transparency, and accountability.

Rittenberg (2012) in a white paper for the American Institute of Certified Public Accountants (2014) says that the Sarbanes-Oxley Act, often known as SOX, introduced major changes to the regulation of financial practice and corporate governance, including strengthening risk management practices. Section 404 require publicly traded companies to publish information in their annual reports concerning the scope and adequacy of the internal control structure and procedures for financial reporting. This statement shall also assess the effectiveness of such internal controls and procedures, such as managing financial and operational risks. These risk management practices generally are broad ranging and cover investment risks, internal financial controls, hedging against risks for interest rates, currency fluctuations and market volatility. They also include "operational risk" or the management's responsibility to ensure that all aspects of the operations are performing honestly, competently and are safeguarding investors' interest.

Doney (2013) said SEC guidance emanating from SOX established a comprehensive framework for conducting a "top-down" financial reporting risk assessment. For example, management is required to identify material misstatement risks and related controls, which then must be tested. Techniques used in top-down risk assessment are applicable to other risk categories. Risks fall into strategic, operational, legal/regulatory, and financial reporting categories. SOX compliance implies substantial coverage of financial reporting risks. The SOX compliance process also provides a framework that relates processes, risks, and controls,

In simpler language, SOX basically makes executives liable if they do not institute effective risk management controls to ensure that their organizations are not "cooking the books," or engaging in reckless behavior that could bankrupt the company and lose investor's money.

The collapse of Barings Bank in 1995 provided one of the strongest rationales for controlling risk to an organization's assets. (The Bank of England 2005) Barings was Britain's oldest merchant bank and had financed the Napoleonic wars, the Louisiana Purchase, and the Erie Canal. The collapse of Barings was particularly noteworthy to regulators because its failure happened in days and was caused by the actions of a single trader based at a small office in Singapore. The Barings collapse was followed in 2001 by the $62 billion collapse of Enron that led to unemployment for 21,000 workers and caused investor's shares to fall from $90 the month before to 61 cents. (Oppel and Sorkin, 2001) At the time, the Enron collapse was history's largest bankruptcy and was widely credited to management's failure to accurately report earnings. A year later, an even larger bankruptcy occurred when the $102 billion WorldCom

collapsed, again because of exaggerated earnings and irresponsible debt. (Romero 2002) The following year, Congress enacted the Sarbanes-Oxley Act increasing management's responsibility to control risks.

Managing Risks to Provide Effective Public Services

Although Sarbanes-Oxley is focused upon publicly traded corporations, in Europe and Australia the rationale for adopting enterprise risk management was extended to the public sectors as well.

The New South Wales Treasury (2012) says in the Risk Management Toolkit for New South Wales (Australia) Public Sector agencies:

> "In a globally connected world, both the types and magnitude of risk we face are increasing, while our tolerance for ineffective risk management is diminishing. Simply put, many more things can go wrong and with more far-reaching consequences. At the same time, the community increasingly expects public sector agencies to manage these risks to minimize any negative consequences. But increased uncertainty in the world today can also offer possibilities. Recognizing and responding to opportunities, as well as effectively managing for things that could go wrong, will not only support the success of your agency in meeting its objectives but also ensure that your agency remains relevant and resilient into the future."

The Treasury tool kit goes on to say that risk management is a core requirement for New South Wales departments and boards. State law requires agencies to establish risk management processes that are consistent with the AS/NZS 31000 standard.

In the State of Victoria in Australia the Victoria Government Risk Management Framework (2011) says that managing risks is an important component of public sector governance. The state commits substantial resources to sustain and improve both services and infrastructure for the public. Sound corporate governance practices and sound risk management are essential to delivering both services and infrastructure to the public.

The Victoria framework requires each state agency to adopt an enterprise risk management framework and for the executives to attest, as must U.S. corporate executives under SOX, that they have a robust risk management program in effect. The framework prescribes the risk management practices required of state agencies, including the transportation agency, 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. The framework emphasizes that risk management creates and protects value and helps achieve organizational objectives.

The VicRoads Risk Management Policy (2008) provides another rational for managing risk because 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.

The British Treasury (2009) issued a Risk Management Assessment Framework as a tool for assessing the standard of risk management in an organization. It is to be used to support the Statement on Internal Control, or the attestation that an agency is adequately managing its resources, objectives, and assets. The framework helps leadership address seven key questions related to risk and good governance:

1. Do senior management support and promote risk management?
2. Are people equipped and supported to manage risk?
3. Is there a clear strategy and risk priorities?
4. Are there effective arrangements for managing risks with partners?
5. Do the organization’s processes incorporate effective risk management?
6. Are risks handled well?
7. Does risk management contribute to achieving outcomes?

Another international framework that provides a rationale for enterprise risk management for public and private-sector organizations is COSO, or the Committee of Sponsoring Organizations of the Treadway Commission (2004). It is a joint initiative of five organizations that provides frameworks and guidance on enterprise risk management, internal controls and fraud deterrence. Its members include the American Accounting Association, the American Institute of CPAs, Financial Executives International, The Association of Accountants and Financial Professionals in Business and the Institute of Internal Auditors.

It published in 2012 an update to its internationally recognized internal control guidelines to ensure transparency in financial reporting. The COSO guidelines, as they are known, emphasize a strong enterprise risk management program as essential to effective management and control. Among its basic principles of strong organizational control and management are:

- The organization specifies objectives with sufficient clarity to enable the identification and assessment of risks relating to objectives.
- The organization identifies risks to the achievement of its objectives across the entity and analyzes risks as a basis for determining how the risks should be managed.
- The organization considers the potential for fraud in assessing risks to the achievement of objectives.
- The organization identifies and assesses changes that could significantly impact the system of internal control.

Managing Risk to Improve Performance

Palermo (2011) of the London School of Economics and Political Science in writing for the Chartered Institute of Management Accountants in London says the rational for managing risks is to achieve objectives. Senior managers are expected to build sustainable performance and create value while accepting reasonable risk levels. Managing risk is not an optional management strategy, but a required one. Managers cannot achieve meaningful profits or achieve substantial organization performance without accepting some risks. For organizational executives it is not a question of whether to manage risk but rather how to acquire sufficient performance information to understand which risks are worth the returns they provide. He advocates for integrating risk and performance management such as using key performance indicators that can inform when risk levels are increasing. Indicators of the number of monthly workplace injuries can inform a manager of a potential risk arising to worker safety, for instance.

Legace (2008) reports that Kaplan updated his well-known performance framework called the Balanced Scorecard in 2008 to integrate a stronger enterprise risk management element into his performance-management framework. Kaplan said the lack of an enterprise risk management program represents a gap in an organization's performance management system. Organizations need to strengthen their internal controls to have an effective performance management system. He advocates that regularly reporting enterprise risks along with regularly reporting key performance metrics is a basic element sound modern management.

Monda and Giorgino (2013) contend that the linkage of performance management and enterprise risk management is one of the key indicators of maturity in risk and enterprise risk management systems. They conducted a Delphi analysis of 60 ERM practitioners internationally. The respondents answered 22 questions, the answers to which were compiled in a maturity model of ERM. Among the key questions was whether the organization's performance management system and risk management programs were linked. The extent to which the two systems were linked was among one of the key indicators of risk management maturity.

Lam (2008) says that effective risk management includes the tracking of key risk indicators (KRIs) just as performance management includes the tracking of key performance indicators (KPIs). The two operate

in parallel to determine not only if performance is tracking as planned but also to indicate if precursors of poor performance may be increasing. A KRI for a company may be an increase in customer complaints which indicates a developing manufacturing problem or flaw. An increase in late payments may indicate looming credit card losses for a bank. KRI's are leading metrics that can indicate if risks to achieving performance objectives are increasing.

An FHWA international scan team saw abroad the convergence not only of performance management and risk management but also the convergence of those two with asset management. Curtis, Dailey et al (2012) explicitly draw the linkage between risk management, performance management and transportation asset management in the report they produced for the Federal Highway Administration (FHWA) International technology scanning program. Their report on practices by international transportation agencies describes the use of enterprise risk management as a corollary discipline to support transportation asset management and performance management. They devised the accompanying graphic to illustrate the linkage between the disciplines. With the practice of performance management an agency seeks to reliably achieve and sustain performance at targeted performance levels. With transportation asset management, agencies seek to achieve and sustain targeted asset condition levels with reasonable levels of investment. Both performance management and asset management seek to push an agency toward reliable, predictable levels of performance while risk management assists agencies with identifying the unpredictable events and variability that could impede that performance.

Figure 2 The risk, asset, and performance triangle.

Proctor and Varma (2012) carried this linkage further in a series of reports they produced for the FHWA Office of Asset management. They portrayed asset management and performance management as drivers of performance, similar to an engine in a vehicle. Risk management serves as both a guidance system and a suspension system. Active identification and managing or risks serves to identify potential problems and opportunities and helps an organization to smooth out the "bumps" that those risks could cause.

The World Road Federation, or PIARC as it is known by its French acronym, (2010) provides an expansive rationale for risk management and how it can be applied to public transportation agencies. It describes

risk management as a fundamental management approach for optimizing positive opportunities as well as minimizing the negative ones. It 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.

PIARC says risk management is now a rapidly developing discipline, or rather set of disciplines.

> "The operational, political and social risk environment is in constant change. The aspects of risk management differ considerably between a multitude of applications. Given the above, the importance of making well supported, transparent decisions has grown, not only for traditional risk decisions but for all decisions. The field of risk management has consequently expanded from traditional safety, security, quality and efficiency into general management. The traditional fields are often labeled safety, security or loss prevention. The emerging fields, in an attempt to distinguish themselves, are called enterprise risk management (ERM), corporate governance, business continuity planning, corporate responsibility, critical issues management etc. They have even invented the term traditional risk management (TRM) for the already widely established management discipline."

Risk Management as a Core Competency

Crouhy, Galai et al (2006) examine the expansion of risk management in the banking industry but provide the rationale for applying risk management to many fields relating to assets, even highway ones. They note 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.

Coleman (2001) also emphasizes the centrality of risk management to a modern organization responsible for capital assets. He 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. He 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.

Lam (2003) wryly notes that organizations either engage in risk management or they routinely engage in crisis management. He 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.

Frameworks for Enterprise Risk Management

As the impetus for risk management has expanded, various industries have adopted frameworks for applying risk management to their disciplines

The ISO 31000:2009 (E) Risk Management Principles and Guidelines (2009) encapsulates the basic component of sound risk management as it could be applied to any field. The ISO 31000:2009 standard was adopted verbatim by Canadian organizations as the CAN/CSA-ISO 31000-10 standard. The ISO standard closely follows the earlier Australian/New Zealand standard, AS/NZA ISO 31000:2009 standard, which is an update to the AS/NZS 4360:2004 risk management guidelines. All four use nearly identify frameworks across the English-speaking world. Figure 3 that is common to all of these frameworks dates back to at least 2004 in the Australian/New Zealand 4360 guidelines, illustrating the common links and widespread recognition of these frameworks.

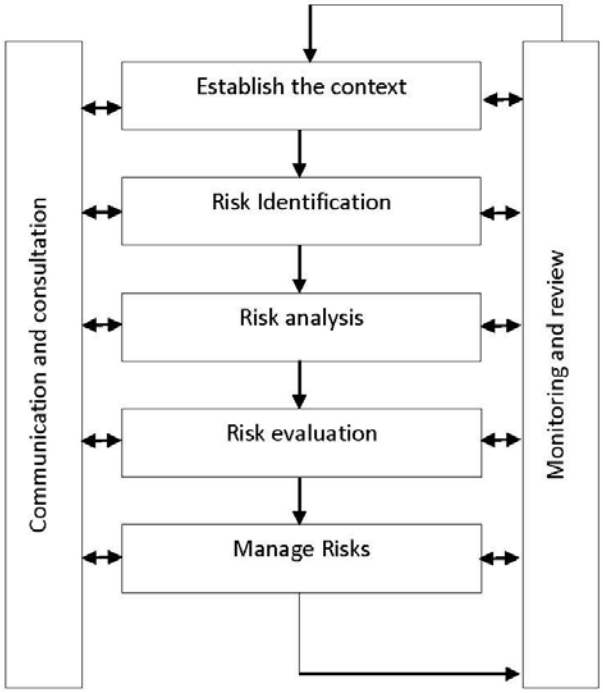

Figure 3 ISO's risk framework.

ISO 3100:2009 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 (Walton 1986) or Shewhart. These steps include a cyclical, ever-improving framework of:

- Developing a communication 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 needs of the organization and its stakeholders;
- Identifying the sources of risks, areas of impacts, events and their causes and consequences;
- Analyzing risks to understand the risk and preparing to evaluate its consequences;
- Risk evaluation assists decision making by providing scenarios of risk analysis as to which risks need treated and the priority for treatment;
- Risk managing involves selecting options for modifying or tolerating 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.

Private Sector Frameworks

COSO (2004) published its Enterprise Risk Management Integrated Framework because of the recognition for the need of strong internal controls after the financial scandals of the early 2000s. It says the underlying premise of all organizations is to create value for its stakeholders. The challenge for every organization is to decide how much risk to accept while trying to create stakeholder value. Its framework says maximum value is developed when management balances returns with the level of risk stakeholders are willing to accept.

It defines enterprise risk management as:

> Enterprise risk management is a process, effected by an entity's board of directors, management and other personnel, applied in strategy setting and across the enterprise, designed to identify potential events that may affect the entity, and manage risk to be within its risk appetite, to provide reasonable assurance regarding the achievement of entity objectives.

The COSO definition reflects fundamental concepts about risk management such as it is an ongoing process flowing throughout the organization, it should effect people at all levels, it supports strategy, it identifies potential events that could exceed the entity's risk appetite, and it supports achievement of organizational goals.

While ISO has seven components, COSO identifies eight components for ERM. They are:

- *Internal Environment* – The internal environment encompasses the tone of an organization, and sets the basis for how risk is viewed and addressed by an entity's people, including risk management philosophy and risk appetite, integrity and ethical values, and the environment in which they operate.
- *Objective Setting* – Objectives must exist before management can identify potential events affecting their achievement. Enterprise risk management ensures that management has in place a process to set objectives and that the chosen objectives support and align with the entity's mission and are consistent with its risk appetite.
- *Event Identification* – Internal and external events affecting achievement of an entity's objectives must be identified, distinguishing between risks and opportunities. Opportunities are channeled back to management's strategy or objective-setting processes.
- *Risk Assessment* – Risks are analyzed, considering likelihood and impact, as a basis for determining how they should be managed. Risks are assessed on an inherent and a residual basis.
- *Risk Response* – Management selects risk responses – avoiding, accepting, reducing, or sharing risk – developing a set of actions to align risks with the entity's risk tolerances and risk appetite.

- *Control Activities* – Policies and procedures are established and implemented to help ensure the risk responses are effectively carried out.
- *Information and Communication* – Relevant information is identified, captured, and communicated in a form and timeframe that enable people to carry out their responsibilities. Effective communication also occurs in a broader sense, flowing down, across, and up the entity.
- *Monitoring* – The entirety of enterprise risk management is monitored and modifications made as necessary. Monitoring is accomplished through ongoing management activities, separate evaluations, or both.

COSO emphasizes more strongly than ISO the interrelationships between risks. An event that can be an opportunity for one division of an organization could create a risk for another division. Or, a risk could cascade across multiple functions magnifying the impact. Instead of illustrating the risk framework as ISO does in figure 2, COSO uses a more complex Rubic's Cube-like graphic to illustrate how risk management works vertically and horizontally across an organization to both identify risks and to management them.

COSO says an organization can determine if its framework is operating effectively if management and outside reviewers are convinced that the ERM process is achieving the strategic, operational, reporting and compliance objectives set for it.

The Risk Management Association (RMA) (2012) framework uses a circular process with eight steps that help an organization's management answer the following questions:

1. What are all the risks to our business strategy and operations ***(coverage)***?
2. How much risk are we willing to take ***(risk appetite)***?
3. How do we govern risk taking ***(culture, governance, and policies)***?
4. How do we capture the information we need to manage these risks ***(risk data and infrastructure)***?
5. How do we control the risks ***(control environment)***?
6. How do we know the size of the various risks ***(measurement and evaluation)***?
7. What are we doing about these risks ***(response)***?
8. What possible scenarios could hurt us ***(stress testing)***?
9. How are various risks interrelated ***(stress testing)***?

The RMA also ties risk management closely to organizational strategy and objective. It says risk management answers the questions of "what is our business strategy and associated risks?" It says an organization must first state its goals and objectives. Then the risk management framework helps it identify risks created by financial challenges, reputational risks, operational breakdowns or risks, and whether it has the capital adequacy to achieve its objectives.

The International Risk Governance Council (IRGIC) (2008) published a Risk Governance Framework. The IRGIC is s an independent organization whose purpose is to improve the understanding and management of emerging systemic risks that may have significant impacts on human health and safety, the environment, the economy and society at large. Its focus upon managing risks to larger societal stakeholders influenced its framework to more clearly classify risks so as to later identify how they may affect different members of society.

Its framework has five steps:

1. Pre-assessment which begins with framing the risk in order to more clearly define it and identify how it could be managed. The pre-assessment can include analyzing the issues different stakeholder associate with the risk, and what are the existing conventions for addressing the risk?
2. Appraising the risk identifies the knowledge base for the decision of whether the risk should be taken or not, or how the risk can be reduced or managed. Risk appraisal includes a scientific risk assessment and a "concern" assessment. The concern assessment captures information on how different stakeholders perceive the consequences of the risk.
3. Characterization and evaluation weighs a risk management strategy by both its technical or scientific mitigation strategy but also by its perceived social acceptance. It cites public concerns over "mad cow" disease that prompted widespread bans on cattle imports even if scientific evidence did not exist to support such bans. In the IRGIC framework, public perceptions are considered in addition to analytical results.
4. In the risk management stage, responsibility for managing the risk is clearly assigned and management options identified.
5. In the communication stage, the risk and its mitigation is communicated to the public and to stakeholders. It says that effective communication is the key to creating trust in risk management.

The Risk Management Society (RIMS) (2014) produces a maturity model and several other tools for businesses and organizations to establish and assess their risk management processes. Although it does not produce a framework per se, its recommended best practices and maturity model provide recommended components and processes for an enterprise risk management framework.

The private sector and its trade associations produce numerous other frameworks and recommended approaches to enterprise risk management. ERM is a product line for international accounting, insurance and business management consulting firms. Frameworks and recommended approaches are available through the major accounting firms such as Price Waterhouse Coopers, KPMG, Deloitte and Ernst & Young. Major information technology and services companies such as IBM, Oracle and others offer ERM services.

In short, ERM frameworks and processes are common throughout the corporate world.

Public Sector Risk Frameworks

An FHWA international scan report, *Linking Transportation Performance and Accountability,* (Braceras and Tally 2010) found consistent use of risk management among the agencies visited in Sweden, England, Australia and New Zealand. 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 New South Wales Asset Management Committee (2003) in its 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.

In 2011, another FHWA international scan examined risk management practices in detail. *Transportation Risk Management: International Practices for Program Development and Project Delivery* (Curtis and Daley, 2011) 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 objective of *Executive Strategies for Risk Management by State Departments of Transportation* (D’Ignazio, Hallowell and Molenaar, 2011) 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. 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 offers executives guidance on how to organize from the top-down an enterprise risk management process for the organization.

The NCHRP Report 706 (Halvardson and Cempel, 2010) 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 an 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 countermeasures 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.

British Public Sector ERM Frameworks

The British Government has produced several guides or frameworks for government agencies to implement and improve risk management practices.

The British Parliament's National Audit Office (NAO 2011) produced Managing Risks in Government, a good practice guide. It enumerates six principles which provide a framework for effective risk management. These include:

1. The tone at the top of the organization has an impact on the priority that management and staff give to risk management. The behavior and actions of the Board and the senior management team, particularly how they communicate with and challenge the business, reinforces the importance of risk management, and drives and encourages a consistent approach to safeguarding the business.
2. An overarching risk appetite for an organization in isolation is unlikely to be helpful in informing decision-making. By considering its appetite for risk in different areas of the business, such as its activities, functions and delivery bodies, and being clear about where it is prepared to tolerate more or less risk, those at the top can drive the right sort of behavior. Operational and investment decisions are more likely to be based on a clearer understanding of the organization's priorities. It can also highlight those areas of the business where controls are excessive and where there is potential for greater risk to be taken without significant impact on service delivery outcomes.
3. Responsibilities for identifying, communicating and addressing risk must be clearly defined and communicated so that each individual knows whether they can address the risk themselves (or make decisions on addressing the risk), or whether they need to escalate the risk to another individual (and, if so, to whom).
4. Risk management can only be as effective as the quality of the information used. Board members require clearly presented information which provides insight and explanation to inform discussions and support the decisions made. The Board should demand integrated risk, performance and financial information, linked clearly to the organization's objectives. Good quality information requires effective systems to be in place to capture data and the Board should challenge actively both the information and assumptions which support its decisions. The Board should also seek an appropriate level of assurance that risks are being properly considered and evaluated throughout the organization.
5. The management of risk is part of the discipline of ensuring the achievement of the organization's objectives within its available resources. Decisions on how to manage risk should be taken on the same basis as any other investment decision. This should include an evaluation both of the contribution to the achievement of strategic objectives and the cost of alternative options. The organization should start by quantifying the likelihood and potential impact arising from specific risks to achieving their objectives. This estimate can then be compared with the costs associated with options for mitigating action and the extent to which the risk, and the potential financial impact, is reduced.
6. Organizations should invest time in reflecting and learning lessons from their own and others' experience about how risks have been managed. The Board has a role to play in encouraging consideration of what has gone before and driving improvements in behavior in the future, including through challenging management to demonstrate how learning is driving improvements in the business.

The British Treasury (2004) produced several risk management guidance documents including The Orange Book, Management of Risk – Principles and Concepts. As do the other frameworks, it emphasizes that risk management must be an active process led by the senior leaders and cascading down through the organization from the strategic levels to the program and project and operational levels.

It includes a model framework that emphasizes that risk management is not a linear, but a circular, process. It depicts the risk process as occurring within larger circles of the external environment or context for the organization. Within the environment is the "Extended Enterprise" or all of the functions and responsibilities of the organization. Then, senior leadership cascades through the organization the:

- Identification of risks: Identification of risks to achievement of the organization's objectives occurs as an initial activity and then is continuously updated by the ongoing process. It categorizes risks as being external, operational or change related.
- Assessing risks: There are three key principles for assessing risks: 1) ensure there is a clear process; 2) record the assessment to facilitate monitoring and identification of priorities; 3) differentiate inherent, or unavoidable risks, and residual risk, the risk remaining after treatment.
- Addressing risks: This involves the decisions to tolerate, treat, transfer or terminate the risks, or take the opportunity provided by the risk.
- Reviewing and reporting risks: This is not a discrete step but rather a continuous process that evaluates the effectiveness of risk strategies and also identifies new risks, or changes to the risk environment.
- Communicating and learning: This also is not a discrete step but rather a continuous process that runs through the entire risk management process.

Australian Public Sector ERM Frameworks

The Australian Government's Better Practice Guide to Risk Management (2008) says that risk management has evolved into a well-recognized discipline that is a key governance and management tool in the public as well as the private sector. Managing risks underpins an agency's efforts to achieve its objectives. It notes that a 1997 Financial Management and Accountability Act require agencies to develop robust risk management programs. The Australian federal framework for its agencies says that sound risk management should be central to activities such as:

- determining policy direction and actions;
- considering spending proposals;
- considering issuing of an indemnity or entering into any other contingent liability as part of an agreement, arrangement or contract;
- meeting requirements under insurance policies;
- determining a suitable business continuity plan;
- issuing appropriate delegations and authorizations to officials; and
- ensuring correct payments are made to individuals or service providers.

The framework calls for managing risks to be as integral to an agency as strategic planning, management and decision making. Based upon ISO, it calls for a clear declaration of risk policy and the assignment of responsibilities. It includes a table listing the risk management roles that should be played by the board of directors, senior managers, audit and risk committees, managers and supervisors, the risk manager and individual staff members. It emphasizes that risk needs to be integrated into everyone's duties but at the same time it identifies the need for some specialty risk management skills. These include risk management specialists in the areas of finance, business continuity planning, fraud, occupational safety and health, purchasing and security.

Its framework calls for ensuring the function of four critical elements. These are:

1. Resourcing the risk management function to have the capability to function successfully;
2. Developing communication and training functions to build awareness and capacity;
3. Developing a sound risk assessment process;
4. Developing the ability to profile risks and report upon their nature, impact and management.

The Queensland (Australia) state government published A Guide to Risk Management 2011. It updated earlier guides that addressed financial risks to include all risks faced by an agency. It also was updated to emphasize how agencies can integrate risk management into their existing governance structures. The Queensland Guide closely follows the AS/NZS ISO 31000 framework. It uses the same basic risk management diagram as used in Figure 2 and it states many of the same benefits and rationale for adopting risk management.

The Guide focused upon government programs and their risks, and as such, emphasizes some areas not cited in other guides, such as ISO 31000. It says that agencies must not only manage their agency risks but they also need to manage risks that could affect other agencies, or the entire state government. An example may be if the transportation agency faces an environmental risk that also could affect the state's environmental agency or a major failure in a general fund agency could require resources that must be taken from other agencies. The Queensland risk guide emphasizes a whole-of-government responsibility among state agencies.

The Guide is similar to other frameworks or guides in describing the role, function and continuous nature of risk management. One additional feature is it includes checklists to measure the sophistication or maturity of each stage. The typical seven stages or steps are listed which are to establish the context, identify risks, analyze risks, evaluate risks, treat risks, communicate and monitor risks. Its framework includes numerous questions or tests to apply to an agency's practice of each of the seven steps. The degree to which the agency can successfully answer each question assesses the degree of maturity or sophistication of the agency's risk management process.

The New South Wales (Australia) Risk Management Toolkit for NSW Public Sector Agencies also closely follows the AS/NZS ISO 31000 framework. The toolkit and guide were developed to help NSW state agencies interpret the ISO 31000 guidelines and apply them their public sector programs.

The NSW tool kit enumerates the key principles that agencies should see in their risk management programs including:

- create and protect value to help your agency achieve its objectives;
- be an integral part of your agency's activities and processes, including planning, project and change management;
- be part of decision making as every decision you make has an element of risk. Effective risk management can help you make informed choices, prioritize actions and select between alternative options;
- deal explicitly with uncertainties inherent in all agency activities;
- be systematic, structured and timely to facilitate repeatable and reliable outcomes;
- be based on best available information with inputs to the risk management process drawing on objective data able to be independently verified wherever possible. Such inputs may include historical data, experience, feedback, observation, forecasts or expert judgment. Assumptions must be stated clearly;
- be tailored to your agency and consider its objectives, capabilities, the environment in which it operates and the risks it faces;
- take human and cultural factors into account by recognizing the perceptions of internal and external stakeholders, including staff members' capabilities and attitudes towards risk management;
- be transparent and inclusive about how risk is identified and assessed, how decisions are reached and how risks are treated. Senior management and relevant decision makers should be regularly consulted to ensure they can provide input into the criteria used to evaluate the effectiveness of the risk management process;
- be dynamic, iterative and responsive as the internal and external environments in which your agency operates change. You need to monitor these environments to determine which risks are still relevant and to identify any new and emerging risks. Your agency's risk management framework and processes need to be responsive to changes;
- facilitate your agency's continual improvement and enhancement, through regular reviews of and improvements to your risk management framework and processes.

The NSW guide provides steps for agency leaders to take to implement the ISO framework. The first of these is to define and endorse a risk management policy. The policy should clearly state the objectives for risk management and the agency's commitment to it. Next is to align the agency's culture and the risk management policy. Steps to align the culture include adopting a risk management vision statement, demonstrate management engagement, develop agency systems with which the management regularly engages, re-align the structure to emphasize risks, develop performance agreements with staff that includes risk efforts, and effectively communicate the risk commitment.

The guide also suggests steps to create the internal organizational architecture to support risk management. These can include creating an Audit and Risk Committee, appointing a chief risk officer, require managers to certify that they have an effective risk management program in place, identify risk owners and assign responsibility for individual risks to them, and require contractors to comply with the organization's risk framework. The guide also says that identifying the standing series of reports that

the agency requires for its risk process helps to standardize and focus departments upon their accountability for managing their risks.

The guide also provides suggested steps for measuring whether continuous improvement in the risk management process is occurring. These can include:

- Measuring changes to the consequences of known risks. If the impact of known risks has been diminished by the risk management process, then it can be a measure of the effectiveness of the risk management program.
- If the number of incidents of risks have been reduced;
- Whether the risk management process activities have been implemented.

The Victoria Government Risk Management Framework (Secretary Department of the Treasury 2011) also is based on the Australian/New Zealand ISO Standard. This framework represents another mature example of a state framework deployed in Australia, where risk management has been emphasized since the 1990s. The many provisions that are similar to ISO and the other Australian frameworks will not be repeated. An element particularly emphasized in the Victoria framework is the requirement for attestation. The boards and heads of agencies are required to provide an attestation in their annual reports stating that their agencies understand, manage and control key risk exposures and that a responsible body or audit committee verifies the review.

The Victoria guide also emphasizes the creation of a risk management culture. An important element of establishing a culture is the degree to which individuals understand the organization's policies and procedures. Culture also is enabled when the risk function is adequately staffed and provides resources for training and education.

Unlike U.S. public sector frameworks, the Victoria framework includes the provision for agencies to purchase insurance as a risk-management tool. The framework allows agencies to purchase insurance if it is available and it represents a reasonably priced risk-mitigation strategy. However, acquiring insurance brings obligations to the agency to exert the due diligence required by the insurer so as to not negate the policy.

The Victorian framework also includes an emergency response and preparedness expectation as part of a risk-management program. Individual agencies are to coordinate their emergency risk management programs with a central state program to manage major events that have statewide significance.

Canadian Public Sector ERM Frameworks

The Treasury Board of Canada Secretariat provides an enterprise risk management framework for Canadian cabinet agencies. (Treasury Board 2010) The guide intends to strengthen Canadian public sector risk management practices, which are considered to be one of the core competencies for cabinet agencies. The web-based guide does not specifically reference the Canadian ISO standard or other frameworks. It does, however, state key steps to be taken that reflect the ISO frameworks. It also states that Deputy Heads of agencies are responsible for ensuring their departments have robust risk management programs that support the agency's and national objectives.

The Province of British Columbia Risk Management Branch and Government Security Office (2012) published the Risk Management Guideline for the BC Public Sector. It is a companion guide to the CAN/CSA ISO 31000 standard, which is a replica of the international ISO 31000 standard. It follows the ISO seven-step framework but provides context for government agencies. It sets a vision for which the provincial public sector accepts risk as an integral part of doing business and manages those risks through optimal monitoring, treatment, transfer and consciously retaining residual risk at the appropriate level. It makes mandatory the establishment and application of risk management across the government. It states the objectives for the province's risk management are to:

- Ensure that senior strategic level decision making and planning are informed by accurate assessment or risks across the ministries through a cross-government ERM framework;
- Guide effective ministry decision making by the accurate assessment of risk across business areas;
- Adhere to risk management best practices and encouraging a culture that embraces innovation, opportunity and informed risk taking.

The BC risk management framework consists of the standards, policies, culture, responsibilities, governance and reporting structures applied to risk management. The CSA/ISO 31000 standard defines the risk management process adopted by the provincial government. As with many other frameworks, it defines risk management as operating on three levels, the Enterprise level, the ministry or operational level and at the program or service level. It establishes roles and responsibilities with the deputy ministers responsible for ensuring their agency's compliance for establishing a risk framework within their agency and integrating risk management into their practices. The Risk Management Branch serves as the Chief Risk Officer who provides central risk management programs, advice, and consultation. Each manager is responsible for integrating risk management into their business processes. Each employee is responsible for applying sound risk management within the scope of their duties and reporting to managers risks that are beyond their scope of responsibility.

U.S. Public Sector ERM Frameworks

The Minnesota Department of Transportation (2013) developed an Enterprise Risk Management Framework and Guidance. It establishes the standards, processes and accountability structure used to identify, assess, prioritize and manage key risk exposures across the agency. The framework enables leaders at all levels to systematically evaluate implications of decisions and actions to the agency's highest priority goals and objectives or "Key Results Areas" (KRA's) and effectively manage a broad array of risks in an informed and strategic manner to within an accepted tolerance level.

It includes an ISO-like series of steps that emphasize identifying and assessing risks to achieving the organization's priority business and multi-modal investment objectives, described as Key Results Areas. (KRAs) Agency senior management identifies performance targets, indicators and risk tolerances for outcomes associated with each KRA.

The framework applies to three levels of risk. Strategic risks impede the achievement of the department's mission, vision and key results. Business-line risks impede the agency's ability to deliver

products and services, meet performance targets or accomplish business objectives. Project-level risks threaten the scope, schedule, cost or quality of agency projects. Depending on the scope or complexity of the project risks, these risks can increase to create strategic or business-line risks.

The framework says that at the strategic level risk management is accomplished through annual risk assessments by senior leaders and by their identification of emerging risks. Business-line risks are assessed and managed by five groups who identify and manage risks for planning, pre-construction, construction, administration and operations. Project level risk management is the responsibility of project managers using a process that scales the depth of risk analysis to the complexity of the project.

The ERM work program illustrates a cascading series of events. After annual strategic risks are identified and assessed, they are incorporated into annual business plans, budgets, performance assessments and performance appraisals. The annual business-line risk identification and assessment flows down into business objectives and performance targets for business areas. Monthly reporting tracks the agency's progress and annual performance monitoring summarizes performance. The results influence annual employee planning and appraisals and the planning of Divisions, Districts, and Offices.

A risk register process compiles the risks while a risk management summary schedule spells out the annual and monthly responsibilities of employees from senior leaders, to management groups, divisions and offices, project managers and the risk office.

Managing Risks to Portfolios, Programs, Projects

Several of the frameworks depict risk management as operating at multiple levels as seen in Figure 4. Among the frameworks available are three from the Project Management Institute (2008) for managing risks to portfolios, programs and projects.

The Standard for Portfolio Management, Second Edition, (Project Management Institute) addresses the management of risk in a portfolio. 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

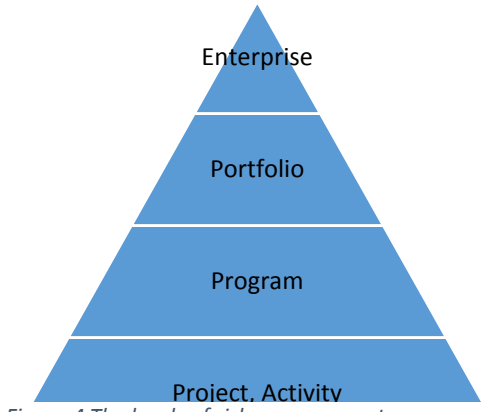

Figure 4 The levels of risk management.

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 harmful to the portfolio. It describes risks as threats to strategic success or as opportunities to enhance the chance of or degree of success.

The Project Management Institute's (2008a) Standard for Program Management 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 program 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.

The Project Management Institute (2008b) (PMI) includes a chapter on risk management in its project-management guide. 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.

Types of Transportation Program Risk Management

Building from the concept of managing risks at the enterprise, portfolio, program and project level, the literature review now examines managing risks to transportation portfolios, programs or projects. Risk management could also apply to activities, which would be on-going tasks to support enterprise,

portfolio, program or project objectives. A typical activity could be collecting statewide traffic count data, collecting pavement data, processing vehicle registration or license renewals or the conduct of purchasing and contracting. These typical activities also lend themselves to risk management approaches.

The following summarizes literature addressing managing risks to seven typical transportation portfolios or programs which are:

1. asset management;
2. highway safety;
3. increasing network resiliency by managing risks;
4. managing financial risks;
5. managing information or decision risks;
6. program and project risks;
7. business operational or reputational risk such as fraud, theft or malfeasance.

These topics are not exhaustive, but rather representative of the most typical type of program risks that may be addressed within a transportation agency's ERM framework.

Section 2: Managing Risks to Assets

The following sources illustrates the application of risk management to the management of transportation assets.

Asset Management Manuals

The Institute of Local Government Engineering and the Institute of Public Works Engineering Australia (2006) in the International Infrastructure Management Manual (IIMM) provide 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.

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.

The International Infrastructure Management Manual says risk management should be 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 that is similar to ISO framework. 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.

The American Association of State Highway and Transportation Officials (AASHTO 2011) Transportation Asset Management Guide, A Focus on Implementation 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.

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 faulty materials, physical asset failures and operational 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. 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.

U.S. Studies

NCHRP Report 736 (Halvardson and Cempel 2009) 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. Cambridge Systematics (2009) in 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 countermeasures 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.

International Examples

One of the earliest FHWA documents (Geiger, Wells 2005) to discuss risk management in asset management was the 2005 FHWA international scan examining asset management practices in Australia, Canada, England and New Zealand. This report noted that as early as 2005, risk management was well established within the asset management practices of all of the agencies visited. The officials in those agencies viewed risk assessment as a way to educate and obtain support for asset management from elected officials.

In England in 2005, risk management was 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 as early as 2005, the national Asset Management Plan included an entire section on risk management. That plan was updated in 2011 and also includes an extensive risk discussion. (New Zealand Transit 2011) The New Zealand agency's risk process manual (2004) described 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.

In New South Wales, Australia, the Roads and Traffic Authority (now called Roads and Maritime Services) included risk as a basic component of its vision along with ensuring "value for money" and providing effective governance. The NSW Treasury (2002 and 2012) 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 their efforts to 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 incorporated 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 (Queensland Department of Transport 2004) 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.

The Queensland (Australia) Transport and Main Roads (2011) Guide to Risk Management 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. 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.

References to risk can be found integrated throughout asset-management related publications developed by the Queensland Department of Transport and Main Roads. For instance, the Skid Resistance Management Plan (Queensland Department of Transport 2006) 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 Queensland asset-management guidance. (Queensland Department of Transport and Main Roads, Part 4 Pavement Maintenance, 2002) 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 (Queensland Department of Transport and Main Roads, 2004) 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. The department also has an Audit and Risk Committee that addresses risk and liability throughout the department.

The New South Wales Division of Local Government (2013) audited the asset management plans of local governments throughout the state of New South Wales. It noted that asset management reduces risks by:

- Fully recognizing the resources required to maintain all infrastructure within the local governments;

- Providing comprehensive and consistent information concerning the condition of assets to assist with decisions on maintaining, renewing and replacing assets;
- Communicating to decision makers the assets they own, the services the assets provide, the lifecycle costs of the assets, the asset conditions and the plans for sustaining asset conditions;
- Highlighting the lifecycle cost obligations taken on when new assets are built;
- Identifying future funding liabilities;
- Documenting exposure to natural disasters;
- Indicating the risk of infrastructure loss through lack of adequate maintenance.

The Risk Management Process Manual for the New Zealand Transit Agency (New Zealand Transit 2004) discusses risk management in detail as interpreted and applied in New Zealand. The highway agency is referred to as "Transit" and is responsible for the national highway system. 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." 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."

The New Zealand State Highway Asset Management Plan 2011-2015 report (New Zealand Transit 2011) discusses the services provided by the New Zealand Transport Agency and states that these are based on statutory requirements and strategic direction from the government in particular the Government Policy Statement on transport funding-2012/12-2021/22. 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**.**

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 identify, 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.

The Case Studies and best-practices guideline for risk management on road-networks (Smith 2010) was aimed at establishing an integrated risk management framework designed for local New Zealand transportation agencies. 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."

It looked at risk management of road networks and its link to organizational risk management including other agency-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 New South Wales Risk Management Guideline (NSW Government Asset Management Committee, 2003) is a component of the New South Wales Total Asset Management Manual. It applies to all public works and not just to transportation assets. 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.

The Transport Scotland Road Asset Management Plan (Transport Scotland, 2007) 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. Transport Scotland uses many private contractors to perform maintenance. 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.

The VicRoads Risk Management Policy (VicRoads 2008) 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 (Coe 2006) examines how a risk-based bridge asset management program can serve as legal defense for liability claims in Australia. 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.

The England Highways Agency (2010) Risk Management Policy and Guidance document 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 the 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. 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 out when risks exceed acceptable thresholds. Eventually, they could be escalated to the governing board.

Proctor and Varma (2012, 2013) summarized the application of risk management to transportation asset management in a series of five short reports for the FHWA Office of Asset Management, Construction and Pavements. The first report, *Evaluating Threats, Capitalizing on Opportunities*, provides an overview of risk management and various ways it can be applied to the managing of assets. The second report, Examining Risk-Based Approaches to Transportation Asset Management, illustrated how risks can be managed at multiple levels, from the strategic down to the project or activity level. Report 3 dealt with Achieving Policy Objectives by Managing Risks. Report 4 was Managing Risks to Networks, Corridors and Critical Structures. Report five was entitled Managing External Threats to Risk-Based Asset Management.

U.S. Asset Management Plans

The New York State Department of Transportation (2014) identified its major risks to its transportation assets in its Asset Management Plan Draft v 05-02-14. Its plan says the agency followed the usual ISO seven step process to develop a risk register for its assets. It identified seven major risks which are:

A. If federal funding continues to be inadequate and further limited as to where it can be used on the highway network.
B. If climate change continues to impart a weather pattern with more intense storms and sea level rise.
C. If adequate resources are not dedicated to produce accurate, timely and complete data for all Federal-aid roads.
D. If NYSDOT does not provide staff support for the continued implementation of transportation asset management.
E. If NYSDOT is unable to properly balance investments across its programs, such as pavements, bridges, safety and others.
F. If trends continue for reduction in vehicle miles of travel, urban concentration, higher fuel efficiency vehicles and heavier freight loads.
G. If the NYSDOT does not begin to manage highway corridors and establish levels of service based on customer use (i.e. commuter/local, trade, intercity, emergency response, public evacuation and tourism/recreation.)

The Colorado Department of Transportation (2013) addressed several risks to its asset in its CDOT's Risk-Based Asset Management Plan. It followed the recognized processes of identifying risks at the agency, programmatic or project/asset levels. It convened a task force to identify, analyze and evaluate risks to the department's assets. It developed a color-coded risk rating scale of measuring risks from negligible to catastrophic. It also evaluated the likelihood and consequences of the various risks identified by the task force through a workshop.

It identified agency risks such as: Lacking funds to meet asset targets; inability to meet MAP-21 targets on NHS segments under local control; revenue unpredictability; politics and change in department leadership; negative public perception that inhibits ability to garner revenue; not communicating and getting buy-in within CDOT for asset management.

Risks identified at the program level include: unfunded maintenance requirements; a large I-70 project pulling funds from other projects; staff turnover and knowledge loss; data management; project delivery risks caused by organization or systematic issues; and construction cost variation.

At the project or asset level significant risks were identified by changing climate, increased rainfall and unstable geology in the mountainous state. Among the project or asset risks identified were: flooding impacts; rock falls, landslides; culvert failures and other issues. Additional risks were tunnel fires, ITS traffic control failures, failure of aging small culverts, scope growth in projects and project delays caused environmental, right-of-way or utility conflicts.

The Georgia Department of Transportation (2013) Transportation Asset Management Plan includes numerous references to managing risks to assets. It does not produce a risk register or quantified ranking of risks and their consequences but it does integrate the concept of risk-based decision making throughout the document. It also includes an asset management process improvement action plan that calls for the development of a robust risk management program. The plan discusses how risk elements are now inferred or implicit in many Georgia DOT investment decisions. Pavement treatment sections

are chosen in part based upon the risk caused by providing poor pavement to higher-volume roads than to lower-volume ones. Risks caused by missing or inadequate traffic control devices or risks caused by potential structure failures are considered in project-selection processes. The plan discusses risks at many levels and in many decisions at the department, but it does not include as formalized a risk approach as seen in later asset management plans.

Section 3: Managing Risks to Highway Safety

Highway safety is a well-established area of risk-based decision making and risk-based frameworks in the United States. What is less common in U.S. highway safety practices, however, is the use of the word "risk" and the terminology of managing risks as seen in ISO and other frameworks. Instead of referring to features or conditions such as rural two-lane roads at night as being of higher risk, U.S. practitioners tend to discuss such routes and conditions as having consistently higher crash rates. Based upon those rates, U.S. safety officials deploy countermeasures such as pavement safety edges, enhanced lighting, and improved lane delineation. In a risk-based framework, those routes would be high-risk routes and those countermeasures would be risk-treatment strategies. In most U.S. highway safety approaches, they are considered countermeasures.

In terms of contributing to a U.S. enterprise risk management guide, the U.S. highway safety literature is rich in examples. The application of these examples, however, may need to be recast in terms of risk and risk management to illustrate the degree to which U.S. highway safety programs are, and can be even more so, risk-based. In this section the literature review will compare and contrast the U.S. approaches to highway safety to some representative guidelines from Australia, Canada and Great Britain. The international examples explicitly emphasize a risk-based approach. The U.S. practices are similar to the international ones but they are less frequently cast in terms of risk and risk management.

To illustrate the different emphasis on risk management, the sections of U.S. Federal code relating to FHWA and the National Highway Traffic Safety Administration (NHTSA) highway-safety programs were reviewed. These include U.S.C. Title 23 sections 402, 403, 404, 405 and 412 and sec 148. In Sec. 402 that addresses the Highway Safety Programs, the word "risk" is not cited in statute but only appears in a footnote of a referenced policy about distracted driving. In Sec. 403, the safety research section of Federal code, again "risk" is only cited in relation to a footnote referencing a policy. Similarly, risk is not mentioned in Sections 404 on the National Highway Safety Advisory Committee, nor in Section 405 on occupant protection incentive grants, nor in Section 412 on agency accountability. In sec. 148, the High-Risk Rural Road Program represents the most explicit reference to risk-based highway safety programming. Sec. 148 makes numerous references to risk and risk-based decision making.

Although it is apparent that U.S. agencies use risk-based approaches in their highway safety programs, the approaches are less likely to be couched in risk management terms than in highway safety literature in Great Britain, Australia, New Zealand or Canada.

This section will first summarize representative international examples of how risk is a more explicitly used term in highway safety programs in those nations. Then, it will summarize several representative U.S. risk-based highway safety programs that may or may not explicitly depict crash programs in terms of managing crash risks, and which provide examples that will be useful in an enterprise risk management guide.

Australian, Canadian, British Frameworks

Austroads (2007) published the Guide to Road Safety Part 7: Network Crash Risk Assessment and Management which takes an ISO-centered approach to risk-based highway safety. The joint Australia and New Zealand Standard on risk management (AS/NZS 4360:2004) is used as the basis and structure for this framework for highway safety. The issues of communication and consultation, establishing the context, identifying risks, analyzing risks, evaluating risks, treating risks, and monitoring and review are discussed. Examples of risk in the road safety context are provided, including those relating to road trauma, legal risk, and risk from adverse public opinion. Case studies are provided to assist practitioners.

The document follows the seven steps of the AS/NZS framework and illustrates how each can provide the basis for an important highway safety countermeasures program. The report clearly links the ISO framework to a systematic approach to managing risks to highway traffic safety.

In the "Establish Context" step, the guide discusses how by establishing the context the agency gains an appreciation of all the factors that might influence the ability to meet the intended safety outcomes. These factors could include the external context, the stakeholders, the relevant strategies, regulatory issues and financial environment surrounding the safety program.

In the "Identify Risk" section, the guide describes how to capture and categorize the types of crashes involving vehicles and vulnerable users. It describes categorizing crashes by those involving only the roadway environment, the road users, the vehicle, the environment and combinations of those categories. It describes the Haddon Matrix that is a means for categorizing crashes by the factors of human, vehicle or road and identifying if the factor occurred before a crash, during a crash or after a crash. The guide provides examples of how the matrix and other tools can be used to identify the risks to highway safety.

In the "Analyzing Risk" section the guide describes how to determine whether to treat the risk, and if so, how. It describes weighing the causes of the risks that will lead later to determine if and how to treat its causes. It notes that often agencies need to take a qualitative approach to analyzing risks because they may not have definitive risk-causation factors upon which to depend, particularly for determining causation of crashes in small sample sizes. It describes reviewing sources of data including crash databases, insurance data, information from road maintenance inventories, enforcement data and public surveys to identify crash-causation factors. Where available, it encourages the use of crash causation-factors that may be applicable to statistically significant samples, such as crash causes across an entire network.

As in the ISO framework, the next step is to evaluate and prioritize the highway safety risks. This needs to occur within the reference of the internal and external context established in the first step, particularly in regards to the available funding. It says that "hot spot", or as they call it, "black spot," areas are among the easiest to prioritize whereas more systemic crashes that tend not to cluster at a given location are more difficult to prioritize. The prioritization occurs by balancing the available resources with expected reductions in crashes. The assumed effectiveness of a given treatment is compared to the cost of the treatment and benefit-cost comparisons are made between different

treatments at different locations. The prioritized list produces both a location-specific list of treatments as well as more systemic treatments that may address crash types such as roadway departure crashes that tend to be spread across a network.

The "Treating Risk" involves deploying the potential treatments that were identified in the preceding step. It notes that highway safety risks can be reduced by reducing exposure to the risk, by reducing the likelihood of a crash or reducing the severity by creating a more forgiving environment. Risk treatment is translated into highway safety treatment terms. For instance, risk treatment could involve removing hazards, such as trees or utility poles, requiring protective equipment such as air bags or helmets, or reconfiguring the roadway to reduce hazards of sight distance or curvature.

The ISO-based guide also emphasizes the need to monitor and review to ensure that the risk-treatment plan is as effective as hoped and that lessons learned are incorporated into future plans. It notes that some measures may have both a positive and a negative effect that must be captured and addressed.

In summary, the Austroads guide illustrates how the ISO framework could be applied systematically to highway safety programs.

Austroads (2014) provided the Australian National Risk Assessment Model (ANRAM) as a tool for risk-based improvement of highway safety. It is an Excel-based software that helps road agencies identify fatal and serious injury crash risk across all parts of the road network. ANRAM helps road agencies manage this risk through a mechanism for the identification, measurement and reporting of fatal and serious injury crash risk based on road infrastructure, speed and traffic flow, and on fatal and serious crash history. It then enables scoping and prioritizing of investment options to address the highest risk road sections on the Australian road network. Guidance is also provided for implementation of ANRAM by jurisdictions at strategic and practical levels.

The ANRAM system provides road agencies in Australia with a tool to implement a nationally consistent risk-based road assessment program to support the objectives of the country's National Road Safety Strategy. It allows jurisdictions to prioritize and develop targeted safety upgrade works for high-risk road sections, which reflect their local conditions and resources.

Austroads and its members pursued ANRAM after research indicated that "black spots" accounted for a declining number of high-risk locations. Others were widely dispersed across the network and required a more systematic, risk-based approach to designing new roads and modifying existing ones. That led to the Safe System approach to make all roads safer through systematic improvements.

Roper and Turner (2008) presented the results of investigations of Victorian and New Zealand crash data showing that only a third of fatal crashes occurred in locations classified as black spots. New Zealand data also revealed that more than half of fatal crashes occurred at locations where no other crashes had occurred in the previous five years. Scattering of severe (fatal and serious injury) crashes across the network suggests that if remedial attention is focused only on black spots, the opportunity to prevent a large proportion of crashes would be missed. Roper and Turner (2008) highlighted that the benefit-cost-ratios of black spot projects have also been declining in recent years.

Braceras and Tally (2010) reported that risk-based safety approaches were evident in Australia and New Zealand. The New South Wales (Australia) Road and Transport Authority (since reorganized as Transport for New South Wales) reported that it relied on risk-based analyses for many safety decisions such as requirements for graduated licensing of younger drivers, selecting locations for guardrail, and managing pavement friction. In driver licensing and vehicle inspection, the consideration of risk was highly evident. A Novice Driver Pilot Program was begun as an education program to reduce the number of young driver deaths on state roads. The trial was a joint effort by RTA, the Australian and Victorian governments, and the Federal Chamber of Automotive Industries. The training will provide young, provisional drivers with an understanding of their limitations and how they can reduce the risks they face on the road.

A vehicle selection matrix is used as a risk-based procedure for identifying and inspecting heavy vehicles. It improves the intercept rate of high-risk vehicles through a screening process to identify vehicles with historically poor compliance rates. It has been deployed at checking stations to reduce the intercepts of low-risk vehicles and to focus inspection activities on higher risk vehicles and operators.

They also reported upon the state of Victoria's "grey spot" program. In addition to "black spots" or high-risk locations, the state's transportation agency, VicRoads, focused on roadway sections with elevated crash risks even if the crashes were not clustered in specific "black spots" but spread across longer sections.

The Australian Transport Council (2011) references risk-based approaches repeatedly in its National Road Safety Strategy 2011-2020. The strategy was developed nationally and signed by the states' transport ministers. It weaves risk-based approaches throughout its strategies. Risk-based graduated driver licensing for young drivers was reported to be a continuing success at reducing the opportunity for young persons to drive under high-risk conditions, such as at night with multiple passengers. It also notes that despite other countermeasures, drivers still will make mistakes. Therefore, to further reduce the risk of injury or death, the states will continue to improve roadways to have fewer hazards to reduce the risk and severity of crashes that do occur. School zones and other high-pedestrian areas were identified as high risk and were treated with lower speed limits that appear to have led to a 23 percent reduction in pedestrian injuries. The strategy identifies high-risk user groups as including pedestrians, motorcyclists, bicyclists, young drivers and older drivers.

The Road Safety Strategy focuses upon strategies very similar to those pursued in the United States, they are only discussed more frequently in risk-based terms. The strategy identifies risks or crash propensities in four categories: Safe Roads; Safe Speeds; Safe Vehicles and Safe People. It then cites by risk level – or by frequency – the types of issues most likely to create risks or cause crashes in each of the four areas. Then, it applies strategies and risk treatments, such as using roundabouts, paved shoulders, better lane delineation, and fewer roadside hazards. The Safe System approach reduces risks by assuming three components: 1) people make mistakes and will crash; 2) humans are frail and need protection; 3) roads should be forgiving. These assumptions are applied to strategies that are intended to reduce risks not only to drivers and passengers but also to at-risk populations such as pedestrians, bicyclists, motorcyclists and the elderly or young. The strategy also advocates a process to upgrade "grey links" which are roadway sections with higher-than-average crashes or risks of crashes because of

the roadway type. Treatment strategies are very similar to FHWA's "Systematic Approach to Safety" in which systemic approaches – such as safety edges and rumble stripes and edges – are used across wide areas in which crashes are widely dispersed.

The Australian Automobile Association (2011) Road Assessment Program is a cooperative venture by various Australia insurance companies and highway safety advocacy groups. It produces periodic reports of high-risk routes and regions based upon crash rates. It reports risk in terms of what it calls "collective risk" and "individual risk" or high-crash rates. It defines collective risk as the density of crashes over a given section of road while the individual risk is the risk of a crash per vehicle. The routes are illustrated in a table very similar to a risk register in which the five-year crash ratings for 2000-2004 are compared to those for 2005-2009. The risks are rated as "low-medium" or "medium-high" and each section is color coded as would be risk levels in a "heat map" or risk register. The reports discuss the treatments that have been applied to the high-risk sections and illustrates the resulting benefit, or crash reduction. The report also identifies sections that have not seen reduced crash rates because of treatment and it continues to highlight them in red for "medium-high" risk or in black as "high" risk sections in the risk-register-like report card.

The Great Britain Department for Transport (2011) similarly makes frequent references to risk and risk assessment in its Strategic Framework for Road Safety. As with the approaches in the U.S. and other nations it prioritizes strategies based on crash history or propensity, which it casts as risks. It focuses on major categories of risks, such as pedestrians. Within the pedestrian group, it further analyzes the risks to sub-groups such as deprived children. It found substantially higher crash risks for young pedestrians in deprived areas because of greater densities, proximity to higher volume roads, lack of yards to play in and cultural factors. As such, this group is identified as high risk for pedestrian casualties and will be the focus of additional risk-reduction strategies. The Strategic Framework is not substantially different from the approaches seen in the U.S. except that it discusses crashes and injuries more frequently in terms of risk and risk-reduction than is common in the United States.

The Government of Canada's (2011) Road Safety in Canada report includes risk-based strategies that provide road safety professionals with approaches to promote road safety. The nation's Road Safety Strategy specifically targets high-risk groups such as young drivers between 16 and 24, medically at-risk drivers, vulnerable road users such as pedestrians, motor carriers, and high-risk drivers such as those who don't use seatbelts, speed or drive while impaired.

The focus on risk and risk management are frequent and explicit in the Canadian strategies. The report notes that young drivers comprise 30 percent of the driving population but account for 40 percent of fatalities and 45 percent of serious injuries, illustrating their higher-risk potential for crashes. Two-thirds of fatal collisions are on rural routes creating another higher-risk focus area. The report states that about 20 percent of fatal collisions involve driver fatigue which could be addressed with public education campaigns about higher risks when driving while tired. The strategy also emphasizes commercial drivers who it says have an even higher risk of fatigue-related crashes (30 percent) than does the general population. The strategy focuses on on-board recorders to monitor how long a vehicle is being driven and other fatigue-reducing measures.

The Canadian report also says that drivers over age 65 account for 17 percent of fatalities although they are 14 percent of the licensed drivers. Part of the greater risk for this population is their medical frailty. The report provides guidance for medical professionals for assessing and advising seniors of their risk factors. It also suggests that improved highway lighting could assist older drivers with less visual acuity. It also suggests vehicle features that could assist elders such as larger instrument displays and seatbelts and airbags less likely to injure older drivers.

The Organization for Economic Development and Cooperation (OECD 2013) also frequently references risk and risk-based approaches in approaching highway safety. Its 2013 report of international changes in highway safety includes a "heat map" of all 27 of its westernized, industrial members and illustrates their rate of change in fatalities in shades ranging from green to red. It tracks fatalities of bicyclists, motorcyclists, pedestrians and vehicle occupants and shows their rate of change from 2000 to 2011. The heat mapping complements other risk-based tools such suggesting which performance measures best capture risk to the public. The OECD report notes that many professionals are favoring the use of fatalities per 100,000 of population to allow the risk of death or injury by transport to be compared to other risk factors in the population.

U.S. Risk-Based Highway Safety Examples

The crash analysis practices and countermeasures described in the international examples are very similar to those in the United States with the exception of the risk-based terminology. The U.S. highway safety community has categorized crash trends and routinely reports upon what types of roadways, roadway sections, intersections, vehicles, drivers, and vulnerable roadway users that are most likely to be involved in crashes. Voluminous detail is provided on crash-modification factors and the effectiveness of countermeasures, which are risk-treatment strategies. Among the international examples reviewed for this literature review, the AASHTO Highway Safety Manual (2010) was the most detailed and comprehensive. Despite its more than 800 pages, its explicit references to risk are relatively limited in comparison to international counterparts. However, its inferred emphasis upon risks and managing risks is abundant. Most sections of the Highway Safety Manual could be recast as a risk-management manual for highway safety. Most of what would have to be changed is terminology.

The Highway Safety Manual brings statistical rigor to crash analysis and the application of countermeasures. It provides tools for developing and evaluating a roadway safety management program including the identification of hazardous site, diagnosing conditions, evaluation of potential treatments and the evaluation of the effectiveness of reducing crashes through programmed projects. These steps are readily identifiable in a risk-management framework such as ISO. Each would involve an ISO risk management step such as identifying a risk, analyzing its cause, evaluating treatment, treating the risk and monitoring and evaluating the effectiveness of the risk treatment. The Highway Safety Manual does not refer to ISO but it can be readily translated into an ISO framework.

The Highway Safety Manual also includes a predictive method to estimate crash frequency and severity. It also includes crash modification factors and complements the large list of crash modification factors available at http://www.cmfclearinghouse.org/ Again, while crash modification factors are not generally discussed in the U.S. in a risk-management framework, they are the corollary to risk-based highway

conditions. The Highway Safety Manual makes frequent references to the relationship to crash modification factors and risks. It notes that if a school is proximate to an intersection, the risk of pedestrian injuries increases. Similarly, the proximity of an establishment selling alcohol increases the risk of pedestrian crashes. Centerline rumble strips may reduce the risks of head-on collisions, opposite-direction sideswipe crashes and risky passing. The corollary being the absence of centerline rumble strips increases the risk of these crashes and behaviors. The crash risks of road sides and medians that are wide, flat and clear can be statistically compared to the higher crash risk of roadsides that are narrow, steep and containing hazards.

Although the Highway Safety Manual is not portrayed as an explicit highway safety risk management guide, it represents an example of a risk-based approach that is lacking in name only.

One of the more explicitly risk-based U.S. approaches is the FHWA Office of Safety's "Systematic Approach to Safety – Using Risk to Drive Action." (FHWA Office of Safety 2014) It is an approach to including explicit risk-based approaches to prioritizing countermeasures when obvious "hot spots" are not apparent but crash numbers are high across a network. The approach bears many similarities to Australia's Safe System strategy.

The systemic approach involves widely implemented improvements based on high-risk roadway features correlated with specific severe crash types. The program emphasizes roadway features that correlate to widely dispersed but frequent crashes, such as roadway departure crashes on two-lane, rural roads. The approach provides a more comprehensive method for safety planning and implementation that supplements and complements traditional site analysis. It helps agencies broaden their traffic safety efforts and consider risk as well as crash history when identifying where to make low cost safety improvements.

Rather than managing risk at certain locations, a systemic approach takes a broader view and looks at risk across an entire roadway system. A system-based approach acknowledges crashes alone are not always sufficient to determine what countermeasures to implement, particularly on low volume local and rural roadways where crash densities are lower, and in many urban areas particularly those where there are conflicts between vehicles and vulnerable road users (pedestrians, bicyclists, and motorcyclists).

The approach focuses on identifying risk factors that involve a number of crashes and then proactively improving the roadway features that correlate to the crashes. Potential risk factors can include lane widths, shoulder types and widths, median widths, horizontal curvature, lane delineation and advanced warning, differential speeds between tangents and horizontal curves, presence of lighting, left-turn phasing and several other factors.

FHWA advises that its systematic approach complements, and does not replace, traditional site-specific analysis. Both approaches rely on basic programming elements from the Highway Safety Improvement Program. The systematic approach does not identify the most appropriate approach for individual locations but rather it identifies low-cost, risk-reduction strategies to be applied across broad roadway sectors or across multiple intersections with similar characteristics.

Although the approach does not discuss ISO, it presents a six step process that is a cyclical, continuous improvement process similar to the ISO framework. The FHWA framework:

1. Begins with identifying the crash types and risk factors to be considered. This is based upon a prioritized and ranked list of most frequent crash factors, such as that young drivers account for 24 percent of all crashes, a disproportionately high number. Another factor could be that intersections account for 42 percent of crashes, at least within the example presented in the exercise. This step is similar to the "establish the context" step in ISO.
2. The second phase is to screen and prioritize the candidate locations. This is similar to the "identify and analyze" steps within ISO. In this step of the FHWA framework, the network elements that represent the locations with the highest crashes are identified. Then the risk factors are considered and locations, segments or roadway features are prioritized. A prioritized list of segments, horizontal curves and intersections are generated by the presence of the risk factors.
3. The third phase is to select countermeasures, which is similar to the ISO "evaluate risks" step. In this third step a list is identified of safety countermeasures associated with the targeted crash types. The countermeasures are evaluated and screened for effectiveness and cost. Then, countermeasures for the types of crashes to be addressed across the highway network are identified.
4. The fourth phase of the FHWA process combines elements of the ISO steps of evaluating risks and then treating risks. In the FHWA framework, a decision process is developed to consider multiple locations that share similar crash characteristics. Then, specific countermeasures for each candidate site is selected. The final step in this phase is to prioritize projects or treatments based upon funding, timing and other programming factors. The prioritized list of locations infers a particular order based on the risk factors for a given location or roadway element.
5. The fifth phase is similar to the ISO "treat the risk" phase. In this phase the countermeasures are implemented. This involves balancing the systematic strategies with the site-specific strategies and projects. It suggests a framework in which agencies can balance the two types of treatments based upon their frequency across the network. Urban areas may have more site-specific crash locations while rural areas may see risks more widely spread across the highway network. In this fifth phase, the projects and treatments are selected and applied.
6. The sixth phase involves evaluation, similar to ISO's steps of "monitor and review." In this phase the effects of the treatments are monitored by evaluating the change in crash frequency and severity over time. The evaluation allows for refinement and improvement of the countermeasures over time.

The FHWA Office of Safety says the risk-based approach allows an agency to address the high-frequency but widely dispersed crashes across rural highway networks. Similarly, it allows a risk-based approach in urban areas to crashes involving pedestrians, bicyclists and motorcyclists.

Another example where risk is specifically articulated in U.S. highway safety programs is in the High Risk Rural Road Program that was established in the SAFETEA-LU legislation and retained in MAP-21. (FHWA

2012) FHWA provides guidance for classifying routes as "high-risk rural roads" to quality for treatment under the MAP-21 provisions for such routes. Its guidance includes routes:

1. With a fatality rate that is higher than roadways of similar functional classifications in that State. For instance, a roadway with a fatality rate 10 percent higher than roads with a similar classification in that State. Alternatively, a State may use crash rates resulting in fatalities and serious injuries.
2. Use roadways with a crash frequency above a designated threshold, which eliminates the comparison calculation to other roadways.
3. Define high risk rural roadway characteristics that are correlated with specific severe crash types, such as cross-section width, lack of shoulders, substandard alignment, hazardous roadside, etc.
4. Use information gathered through means such as field reviews, safety assessments, road safety audits, and local knowledge and experience. Using information from observations in the field can identify high risk locations that may not be identified through data analysis or by identifying roadway characteristics.

Other risk-based U.S. highway safety tools include the Crash Modification Factors Clearinghouse (FHWA) that provides factors by which crash frequency may increase or decrease based upon factors. Hundreds of factors are considered from roadway geometry, to pavement surfaces, adjacent land uses, delineation, lighting, shoulder treatments and work zone conditions. Each represents strategy that could be applied in a risk-based highway safety framework.

Safety Analyst (AASHTOware) has similarities to Austroads' ANRAM software except it that it does not as explicitly emphasize risk. It does, however, appear to perform similar analyses that equate to risk-based assessment of highway safety. Safety Analyst is a set of software tools to identify and manage a systematic program of site-specific improvements to enhance highway safety. The software automates procedures to conduct six steps:

1. Network screening;
2. Diagnosis;
3. Countermeasure selection;
4. Economic appraisal;
5. Priority ranking;
6. Countermeasure evaluation.

Once again, the six steps could be cross-walked to an ISO-like process.

Safety Analyst's literature says it can be used to proactively identify sites that have a high potential for safety improvement, which is an inverse way of stating it identifies high-risk sections or locations.

FHWA's Interactive Highway Safety Design Model (FHWA 2014) provides another software tool U.S. agencies could use to assess highway risk-reduction strategies. The IHSDM is a suite of software analysis

tools to evaluate safety and operational effects of geometric design decisions. It estimates a highway design's expected safety and operational performance and checks existing or proposed designs against relevant policy values. It has a crash prediction module that can be used to estimate the crash reduction – or risk reduction – effect of different geometric designs.

FHWA's safety programs provide many examples of additional approaches that could be illustrated in a risk-management guide. The FHWA's Roadway Departure Strategic Plan (FHWA 2013) prioritizes strategies based upon their ability to reduce the most harmful events (MHEs) that contribute to roadway department crashes. Roadway departure crashes are selected for priority because they represent 51 percent of all fatalities and, as such, represent a high-risk factor. The primary focus areas are upon overturn crashes, opposite direction crashes and roadside trees and shrub crashes. Those three represent 73 percent of the MHE's in the roadway departure category.

Intersections are the location of another 21 percent of U.S. highway fatalities and represent another high-risk factor on the highway network. FHWA provides guidance on numerous strategies to reduce intersection crash risk including converting them to roundabouts, alternative designs such as the diverging diamond, improved pedestrian and bicyclist crossings, and red-light running cameras. Each strategy represents another risk-reduction tactic available to U.S. agencies.

To belabor this point no longer, the U.S. highway literature provides many examples that can be summarized to illustrate how a risk-based approach to highway safety can be adopted.

Section 4: Managing Risk from External Threats

An increasing body of literature is becoming available to agencies to assist them with a risk-based approach to dealing with external threats such as increased climatic and seismic events.

General Risk or Threat Assessments

The American Society of Mechanical Engineers Innovative Technologies Institute produced the Risk Analysis and Management for Critical Asset Protection Plus (RAMCAP) guide. (ASME ITI 2009) As its name implies, it's a process and series of procedures for assessing physical threats to physical assets. Sector-specific guidance (SSGs) has been developed for nuclear power plants, nuclear waste storage and transportation facilities, chemical manufacturing, petroleum refining, liquefied natural gas facilities, dams and locks and water and waste water facilities. However, the RAMCAP guidance is intentionally generalized so it can be applied to any sector.

The overall RAMCAP process will be described here using the sector-specific guidance for water and wastewater management systems. (ASME and AWWA 2010) The RAMCAP tool is described as a simple and efficient process to support consistent, quantitative risk analysis that allows for comparison of risks across different assets. The RAMCAP process can be applied to both human-induced threats such as terrorism or accidents as well as naturally occurring threats such as earthquakes and hurricanes. It does not address operational risk, or the risk of failure to achieve organizational objectives through process impediments.

The process describes seven steps that are similar to the ISO steps but differ in that all are appropriate only to tangible physical assets and not intangible ones such as the experience of staff. It includes the following seven steps which are:

1. Asset characterization
2. Threat characterization
3. Consequence analysis
4. Vulnerability analysis
5. Threat analysis
6. Risk/resilience analysis
7. Risk/resilience management.

The ASEM/AWWA framework holds relevance for managing threats to physical assets in that, as can be seen in the seven steps, it focuses upon characterizing the assets by their traits, or criticality, and by the threats they could face. It differs from ISO and other frameworks in that it does not seek to identify opportunities. It does evaluate threats and those which are low could be considered risks that are tolerated and not treated.

The RAMCAP framework does provides scales and values that could assist with objectively determining the benefits and costs of risk-reduction efforts. However, the user has to provide key inputs such as the assessment by law enforcement as to the level of terrorist threat in a given area. This step requires subjective assessments based upon the available expert guidance of the participating agencies.

The risk framework describes probability calculations that can be used to quantify risk through the equation of R = T x V x C. R represents risk, T threat probability, V is vulnerability and C is consequence. It walks the user through an example of determining the probability of a terrorist attack to a specific water facility in a given year. The number of terrorist threats nationally is reduced to a localized probability that after several calculations of multiplying fractions by fractions results in a value between 0.0003675 to 0.0001045 which is the range of probabilities of a threat to a given facility in a given year. When that probability is multiplied by the assumed effects of the consequences the benefits of a mitigation effort could be calculated. Then, the cost of the mitigation could be divided by the benefits to reach a benefit/cost ratio. The user provides key values such as the assumed economic costs of an attack on the water facility and upon the costs of various countermeasures.

Threats from earthquakes, floods and other natural disasters can be estimated in the framework. It provides generalized probability tables such as the likelihood of tornadoes or hurricanes at a given location in a given year. These can then be used to start calculating probabilities that can be multiplied by the consequences to determine risks to given assets. However, the risks are based on very broad categories across entire regions of the country.

Climate Change Risks

Meyer et al (2014) provide a practitioner's guide to dealing with climate change in transportation that includes a chapter on assessing the risk and vulnerability to assets. They report that performing climate change risk assessments helps transportation agencies understand the consequences of climate change on infrastructure and supports decision making regarding prioritization and adaptation. They note that climate-change risk analyses help agencies assess the uncertainty that climate change poses to their assets. The analysis can lead to improved short-term and long-term decision making, such as identifying which assets to harden first, how to incorporate long-term adaptation into the scoping of future projects, and for identifying risk-mitigation strategies for both existing and planned assets. It presents examples of incorporating climate change risks into agencies' processes, such as a California DOT (CalTrans) policy for evaluating new facilities during the design process for future sea level rise impacts. The report also captures a City of Toronto environmental assessment tool that was used in a public process to assess climate risks.

FHWA's (2012) Climate Change and Extreme Weather Vulnerability Assessment Framework is a guide for transportation agencies interested in assessing their vulnerability. It gives an overview of key steps for conducting vulnerability assessments and uses in-practice examples to demonstrate a variety of ways to gather and process information. The framework is comprised of three key steps: defining study objectives and scope; assessing vulnerability; incorporating results into decision making.

The framework says climate change and extreme weather vulnerability are a function of a transportation asset's or system's sensitivity to climate effects, exposure to climate effects, and adaptive capacity. Tasks in the vulnerability assessment include: gathering and integrating data and information on asset location, characteristics, and climate sensitivities; gathering and obtaining information on historical weather events and projected climate; combining the asset and climate information to identify vulnerabilities; and potentially, assigning a level of risk of the climate impacts on the assets. The vulnerability assessment work is an iterative process; information gathered on assets may inform climate information needs and vice versa.

The framework includes risk assessment that considers the severity of a climatic impact with its probability. To consider its consequence upon an asset or segment of the transportation network, the agency considers the risks which are measured in terms of the assets' degree of redundancy, the value of the asset, the effect of its closure and other factors. Each of these help assess the degree of consequence to an asset which, in turn, affects the degree to which the agency may tolerate, treat or terminate the risk to the asset.

The framework includes a risk-register-like heat map of the consequence and probability of risks upon assets or network segments. These risks are ranked upon the degree of probability multiplied by the consequence to create a traditional risk matrix.

Although not an ISO framework, the framework parallels the ISO steps. Its early stages include establishing the context of what assets exist and what climatic variables may create risks. The framework then moves through identifying which assets are at risk and analyzing what creates the risk. Then treatment options are assessed and treatment steps identified, if possible. If risks cannot be treated, they are tolerated and monitored. Finally, communication with stakeholders and review and evaluation of changing risks occur on an ongoing basis.

The Federal Emergency Management Agency (2011) advocates what has been called an "all hazards" approach that suggests that planning for one kind of hazard or threat can increase an agency's or a community's ability to deal with others. The generic framework for agencies preparing for a wide variety of risks has been dubbed the "Three R's" or redundancy, robustness and resiliency.

Redundancy can be defined as duplicative or excess capacity that can be used in times of emergency. Although adding redundant highway capacity generally falls outside the practice of risk management, it can be a risk-treatment strategy. An example may be strengthening a bridge on a route parallel to an interstate highway to provide additional detour options if a risk threatens the interstate highway.

Robustness can be defined as the capacity to cope with stress or uncertainty. Well-maintained assets generally are better able to withstand the stresses of storm events and other disasters than weakened and poorly maintained ones.

Resiliency has been defined by the National Research Council's (2012) Committee on Increasing National Resiliency to Hazards and Disasters as the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events. Enhanced resilience allows better anticipation of disasters, better planning to reduce disaster losses and recovery times after an event.

Proctor and Varma (2013) report that asset management and risk management serve as complementary tools for managing external threats. Asset management can make assets more robust and able to withstand events while risk management can lead to scenario planning that makes an agency more resilient in responding to events after they occur. Risk management can help identify, quantify and mitigate the threats to physical assets. Likewise, a sound asset management program increases infrastructure resiliency and robustness that reduces impacts caused by storms, floods or seismic events.

When an agency is competent in the tools of risk management, it can logically recalculate its priorities after an event. A risk-based disaster preparedness plan for highway assets is likely to include at least:

- An assessment of the greatest threats based on a probability and impact assessment;
- Ongoing mitigation programs for the greatest threats such as seismic retrofit programs, stream monitoring systems, hurricane evacuation and preparedness programs, redundant communication systems and recovery protocols;
- Business continuity plans;
- A rank order of priority for restoring asset functionality;
- Emergency-response contracts for rapid mobilization;
- Existing prioritization protocols for making tradeoffs as to which new level of asset condition to accept after events.

Schwartz et al (2008) for the Committee on Climate Change and U.S. Transportation of the Transportation Research Board says that integrating the extreme variability caused by climate-change-driven weather events requires a new risk-based perspective from transportation planners and engineers. They typically extrapolate from historical trends to forecast future needs and conditions that influence their investment choices and operating plans. It warns that U.S. agencies may not be able to simply extrapolate from past weather patterns to predict the climatic risks they face in the future. It notes that floods are likely to be more severe, wind events more extreme and droughts more common.

Schwartz notes that planning for the risks of extreme weather variability is not a future need, but a current one. The flooding caused by Hurricane Irene and Super Storm Sandy are likely to be repeated and represent one of the more common risks to be faced as a result of climate change. It recommends as a risk-management strategy the need to inventory at-risk assets so that they can be prioritized for treatment. The great cost of hardening these assets prompts the need for a risk-based approach to investment. Agencies will need enhanced skills in assessing risk to be able to make tradeoffs between the large number of assets that need to be hardened to withstand climate change.

The extreme events that in past years were considered to be outliers may become more common. The bell curve of weather events may well flatten with much more deviation from the traditional mean of events. As such, the asset and risk managers need to establish as a basic goal for their programs considerations of extreme weather variability.

Field et al (2012) with the Intergovernmental Panel on Climate Change notes that climate-change impact approaches are shifting from a disaster-response-focused approach to a risk-management approach.

Risk-based approaches seek to build resistance to climate-induced impacts through making systems more robust and more resilient. Risk management and climate adaption become linked as risk-based strategies to increase infrastructure's resilience also serve to mitigate the effect of severe climate events.

The IPCC says that an idealized risk-based approach to protecting assets from climate change threats would be probabilistic. It would create common denominators between possible actions by multiplying the probability of an event by its consequences. A wide number of possible events could be calculated and compared for prioritizing risk-mitigation actions. This type of standard calculation is seen in most risk registers.

However, the ability to produce a purely probabilistic analysis is greatly complicated by the wide variability in calculating a threat to a given asset within a given time period. Although a flood is likely to occur over a 100-year period at a given location, an agency with a 20-year planning horizon may not be able to justify the higher cost to protect against such an event. Also, reliable estimates of the cost of an event is speculative and may not be firm enough to withstand a benefit/cost analysis with a short time horizon. A simple approach would be to design every facility for a 500-year storm event, but the costs are prohibitive and unrealistic.

The difficulty in prioritizing all risk-response actions based on probabilities leads the IPCC to recommend that agencies consider a set of "no regrets" mitigation steps to address climate change threats. These are steps or expenditures likely to produce both climate- change-mitigation benefits and other benefits, thereby warranting their investment even if severe events don't occur by a given planning horizon. For infrastructure, "no regrets" investments could include:

- Updated design standards or design inputs that take greater storm frequency and severity into consideration;
- Improved event forecasting systems such as stream gauges and hydrological forecasting tools to better predict hydrological events and understand their effects upon assets;
- Increased inspection protocols to more promptly identify the effects of events upon at-risk assets;
- Coordination with land use agencies to discourage development in vulnerable areas where impacts could exacerbate at-risk infrastructure;
- Improved "downscaling" or the localizing of climate change projections to better understand the likelihood of extreme events;
- Improved asset inventory data including more accurate elevations to understand more precisely the potential effects of flooding or storm surges;
- The identification of at-risk slopes, routes, structures and other assets;
- Qualitative and simple probabilistic analyses to identify and prioritize storm event risks to assets.

The IPCC notes these types of risk-mitigation strategies are more incremental and lower cost than hardening or expanding all assets to withstand the most severe climate event possible.

The lessons of Superstorm Sandy led the State of New York's NYS 2100 Commission (2013) to conclude

that the state needs to develop a risk assessment of the state's infrastructure. It says it needs to identify those assets that are vulnerable to extreme weather events, storm surge, sea level rise and seismic events, and to prioritize future investment through the use of a lifeline network that defines critical facilities, corridors, systems, or routes that must remain functional during a crisis or be restored most rapidly.

It called for four general strategies to prepare for what it calls the "new normal" of more frequent extreme events. They are:

- Develop a risk assessment of the state's infrastructure to identify those assets that are vulnerable to extreme weather.
- Strengthen existing networks by improving the existing infrastructure with an emphasis on key bridges, roads, tunnels, transit, rail and marine facilities.
- Strategically expand the transportation network to create redundancies.
- Built for a resilient future with enhanced guidelines, policies and strategies so that new assets are built with more robustness or are built outside of vulnerable areas.

The Washington State Department of Transportation (Maurer et al 2011) provides a case study of an agency's risk-based assessment of its climate change impact. It used FHWA's climate change risk assessment tool to evaluate the type of more extreme weather events it is likely to experience and then analyzed that weather's effect upon vulnerable infrastructure. It noted that it did not consider its exercise to be a risk assessment because it used scenarios and did not assign probabilities to its impacts. However, the result of the analysis allows the agency to identify where its greatest vulnerabilities occur.

It says that like other risks it plans for such as retrofitting bridges against seismic risks, the agency plans to update its planning and design policies to protect its infrastructure from climate change. It says this risk-based planning is sensible asset management. The agency builds highways and bridges to last decades so it must make them more resilient to have long service lives in an era of extreme weather.

The assessment included a "down scaling" exercise by university climatologists who took IPCC models and used them to predict the type of climate change extremes that could affect the state's climatically and geographically diverse regions. Then with these higher levels of precipitation, higher temperatures and rising sea levels, the department conducted workshops with staff to identify vulnerable assets. The agency made a point of including frontline maintenance personnel who have first-hand knowledge of vulnerable assets, such as aging culverts. The workshops involved quantitative and qualitative assessments to identify through the experience of staff the agency's most vulnerable assets.

The NYS2100 report and the Washington State analysis note that risks were difficult to assess for sea level rise because of a lack of accurate asset elevations. The third dimension of elevation in addition to latitude and longitude was needed to assess the "bath tub effect" of where assets would be under water. These observations led to them noting that better asset data, including elevations, becomes a risk-assessment need.

The diverse terrain and climate of Washington led to different risk assessments across the state. Eastern Washington is hot and dry and will get hotter and drier. That leads to greater fire threat which can not only directly threaten assets but lead to erosion or slips if denuded slopes become saturated.

In coastal Washington, the analysis concluded that most roads were high enough to withstand projections of a two-foot sea level rise. However, more roadway flooding in the mountains was expected because of increased precipitation and increased glacial melt. In urbanized areas, many culverts will be undersized for the increased events and roads at the toe of slopes could experience more closures because of slides.

The analysis resulted in a listing of vulnerable assets by district and the generalized assessment that the most vulnerable assets were those in the mountains, above or below steep slopes, in low-lying areas, along rivers that are affected by glacial melt and low-lying coastal areas affected by sea level rise. Once identified, the department's normal maintenance and planning program could consider whether to address the assets' vulnerability when the assets are next scheduled for maintenance or repair.

Rock Fall Hazard Programs

Rock fall hazard programs represent one of the most explicitly risk-based approaches to managing transportation assets. The steps in a rock fall rating and treatment program fairly closely parallel the steps in a risk management process, and an asset management process.

Most of the rock fall hazard programs derive from the Oregon Rockfall Hazard Rating System (Pierce 1991) that was begun in 1984 and was further refined in 1991. It still serves as a model for rock fall hazard systems and as a model for other types of risk-based analyses of risks to assets.

It includes six main features:

1. A uniform inventory of slopes;
2. A preliminary rating of the slopes;
3. A detailed rating of the hazardous slopes;
4. A preliminary design and cost estimate for the most serious sections;
5. Project identification and development;
6. Annual review and evaluation.

The first two steps result in all slopes categorized into an A, B, or C rating. Slopes in the A category are prioritized for further analysis, the B's analyzed as resources permit and the C slopes are deemed to be of low risk and not included in the data base or subject to further analysis.

An objective, risk assessment is then conducted on the A slopes. The B slopes are analyzed as resources permit. The objective assessment categorizes the slopes by risk factors including:

- Slope height;

- Ditch effectiveness which assesses its ability to prevent a falling rock from traversing the ditch and reaching the roadway;
- Average vehicle risk which is a measure of the percentage of time that vehicles are present in the rock fall zone;
- The percent sight distance determines the length of roadway a driver has to avoid a sudden hazard;
- The roadway width which is a function of the maneuvering room a driver has;
- The geologic character of the slope reflects its proclivity to fail or produce falling rocks;
- Block or rock size prone to falling;
- Presence of water or other climatic factors;
- Rock fall history.

The points assigned to each factor range from a low of three to a high of 81, which leads to substantial risk-assessment differences between the lowest-and-highest-risk sites.

The 1991 Oregon process has been refined and updated by Oregon and adapted by other states using additional criteria and data-collection methods. However, the original risk-assessment process is cited here to make the point that analogs for risk-based programs are long-established, their concepts can be adapted to other assets and their utility has been repeatedly validated. For instance, with the six steps cited above, the word "slopes" could be replaced with "culvert," or "bridge" or "lifeline route" and the six steps would still be useful for a basic risk-based asset analysis.

In the early 1990's, the Washington State DOT (Huang et al 2009) developed a risk-based programming application that includes a numerical rating system that relies upon easily measured and quantifiable factors to evaluate risk of an unstable slope impacting the highway facility. This numerical rating system assigns points to eleven risk categories using an exponential scoring system that quickly distinguishes increasing hazard and risk potential. The rating system addresses the type and severity of a slope hazard in only one rating category, while the remaining categories are dedicated to establishing risk factors to the highway facility. Generally, the higher the total point value for an individual slope, the higher the overall risk to the highway facility. In addition to numerically rating the slopes, a cost-benefit analysis is conducted on potential projects that considers the anticipated cost of traffic impacts resulting from a slope failure with the annual maintenance costs over 20 years versus the cost of mitigating the slope hazard. To select slopes for programming, WSDOT initially concentrated on slopes along high volume corridors with higher ratings, positive cost-benefit ratios, and higher average daily traffic values (ADT). It has more recently moved on to slopes with lower ratings, positive cost-benefit ratios, and lower ADT. Since 1995, WSDOT has mitigated approximately 250 (8%) of its known (≈3000) unstable slopes and about 35% of its highest risk slopes for an approximate cost of $180 million.

Seismic Risk Assessment Approaches

Land et al (2013) track the history of the bridge seismic retrofit program in California that somewhat tracks the evolution of risk-based approaches.

Table 1 Seismic risk rating system

Category/Characteristic	Characteristic Weight
Site Hazard	
Soil Conditions	33%
Peak rock acceleration	38%
Duration	29%
Structure Vulnerability	
Year Designed	25%
Outriggers or shared columns	22%
Abutment type	8%
Skewness	12%
Drop type failure	16.5%
Bent redundancy	16.5
System Impact	
Average Daily Traffic	28%
Lease air space residential	15%
Leased air space parking, storage	7%
ADT over/under structure	12%
Facility crossed	7%
Route type on bridge	7%
Detour length	14%
Critical utility	10%

They noted that 65 years passed between the great 1906 San Francisco earthquake and the 1971 San Fernando quake, the first major quake of the recent era. During those decades, little was done to protect bridges from seismic damage. As noted by Lam (2003) and others, as the consequences of failure increased in society, so did the emphasis upon managing that failure. Land noted that the 1971 event did not precipitate a major statewide retrofit program but subsequent quakes in 1987 and 1989 convinced policy makers of the need for an aggressive bridge retrofit program. In an example of how a risk can create opportunity, the 1987 Whittier earthquake did not create extensive damage but it provided the department valuable lessons regarding bridge vulnerabilities and further convinced the public of the need for a retrofit program. Then, the damaging 1989 Loma Prieta earthquake accelerated the legislative support for an aggressive retrofit program.

Caltrans engineers developed a risk-based process for prioritizing the state's 24,000 bridges. The objective was to prevent loss of life not the more expensive objective of preventing all damage to bridges. The department engineers developed a risk-based algorithm for three categories: site hazard, structure vulnerability and system impact as seen in Table 1. By applying the algorithm to all bridges, a risk-based prioritization was possible.

In 2003, a state seismic advisory board issued a report that recommended that the comprehensive, risk-based process continue with continuous-improvement and continuous-monitoring processes incorporated. The recommended steps included:

- The state should adopt as official policy Caltrans' policy of building, maintaining and rehabilitating bridges to provide an acceptable level of earthquake safety;
- Caltrans should maintain its construction standards to provide safety and functionality of lifeline bridges and continue its current practice of independent reviews to ensure compliance with those design standards;
- Caltrans should regularly reassess seismic performance to ensure that the design standards are adequate as additional seismic events and research provide new information;
- Caltrans should continue its commitment to seismic research;
- Caltrans should maintain its rapid response capability to evaluate, repair and restore damaged bridges.

Although the advisory board did not refer to the concept of "resiliency," its recommendations incorporate the elements of a risk-based, continuously improving resiliency program for seismic retrofit of bridges.

The Washington State DOT (Washington DOT 2014) likewise developed an objective, risk-based program for prioritizing its seismic retrofit program. The risk elements include the structural redundancy of a bridge, the seismicity of its location, the route recovery time and the average daily traffic. The structural redundancy focused upon each bridge's number of columns, as non-redundant one-column bridges are at higher risk than structures with multiple columns. The seismicity was based upon U.S. Geological Service maps which rate the 1000 year seismic risks of sites. State routes were given higher priority than non-state routes, and priority was given for structures carrying higher traffic volumes. With this criteria, the department could prioritize for retrofit its bridges facing the highest risks.

Bridge Scour Risks

A recent NCHRP report provides guidance for estimating threats to bridges caused by scouring. NCHRP Report 761 (Lagasse and Ghosn 2013) is a Reference Guide for Applying Risk and Reliability-Based Approaches for Bridge Scour Protection. This report presents a reference guide to identify and evaluate the uncertainties associated with bridge scour prediction including hydrologic, hydraulic, and model/equation uncertainty. Tables of probability values to estimate scour depth when a bridge meets certain criteria for hydrologic uncertainty, bridge size, and pier size are included in the reference guide. For complex foundation systems and channel conditions, a step-by-step procedure is presented to provide scour factors for site-specific conditions. The reference guide also includes a set of detailed illustrative examples to demonstrate the full range of applicability of the procedures.

Section 5: Managing Risks to Financial Resources

An internet search of the terms “risk management” or “asset management” would turn up thousands of references to managing risks to financial resources or assets, and far fewer references to managing risks to transportation assets or organizations. This imbalance reflects the much longer history and more robust frameworks for managing risk in the private financial sector. In fact, for a majority of individuals who practice “risk management” they view the discipline as managing risks to financial returns. (Lam 2003), (Van Deventer 2013) (Hull 2012). Each of these authors produced detailed textbooks of hundreds of pages of algorithms to measure risks. The risks they refer to are risks that investments may suffer because of stock market volatility, commodity price changes, currency exchange rates, inflation or political volatility affecting global markets. The financial world’s management of risk reveals a rich, diverse and highly quantified set of evaluation tools to measure risks to individual assets and across an entire portfolio.

These risk management tools reflect investment-fund managers’ need to manage the risk to the investment objectives of their portfolios. A tracking service such as Morningstar (2014) tracks thousands of stocks and mutual funds and calculates the volatility or risk for each. It uses measures such as the Beta measure that is a reflection of how likely a stock or mutual fund is to be influenced by market risk, or the abrupt downtown of the overall stock market. Some stocks rise and fall with the market, whiles others are less likely to do so. For instance, investments in gold or consumer goods such as soap are less influenced by short-term downward market swings but also are less likely to rise because of short-term market increases. They would have a lower Beta than a stock for a speculative high-tech company. The R-squared value measures the difference between a given portfolio and a benchmark, such as a model portfolio. The alpha measures differences in a fund’s actual returns and its expected returns, or its risk of failure to perform as predicted. Taken together, these three values allow a knowledgeable investor to understand if a mutual fund has above-or-below levels of risk and volatility. These factors, then, can influence the degree of risk that an investor is willing to take. High risks over the long term correlate with higher returns but also correlate to greater chances of losses in the short term. The aggregation of the risk metrics to an entire portfolio allows an investor or fund manager to understand the total, quantified risk and volatility of the entire portfolio. This level can be compared to an established, quantified risk appetite to stay within acceptable risk levels.

McGrath (2012) says it is financial reliability and consistency, not just high returns, that investors value most. This is akin to performance reliability. The investor wants to know that he or she can invest in a low-return, low-risk security and get the predicted return and security. Equally, the investor is willing to accept higher risk if the long-term higher returns are commensurate. In short, says McGrath, it is consistency in achieving financial targets – even if the targets are modest – that is valued by investors who need a diversified portfolio with credible risk levels.

Fone and Young (2005) relate this precedent for managing risks in the financial sectors to the template that has spread to expectations for the public sector as well. Now, the expectation is that the same diligence used by investment fund managers be applied to managing the risks to government

investments and operations. Both investment portfolios and performance-based government programs are expected to be managed so that risks to performance are minimized.

An example of how the financial trading industry's asset-risk management has translated to the public sector lies in the 10-year financial metrics included in Australian local government asset management financial plans. (Proctor 2014) The local governments in the Australian states of Queensland, New South Wales, South Australia and Victoria produce 10-year asset management plans that are accompanied by financial plans. The financial plans include metrics forecasting the degree of financial adequacy, or financial risk, that the governments face. The risks would be primarily that the value of their transportation assets will decline in the future because the agency is under investing or has such high debt levels that it will not be able to sustain infrastructure investments. These metrics were relatively simple compared to those produced on Wall Street. They would include long-term debt ratios, and forms of the Asset Sustainability Ratio which is a measure of whether the agency is investing as much in asset renewal as it experiences in asset depreciation. These examples allow an agency to illustrate the degree of financial risk it is accepting in terms of its long-term ability to invest enough to sustain asset conditions. The sustainability ratios measure the degree of long-term risk and the degree to which the agency is meeting its "intergenerational equity" commitments. The "asset portfolio" that the local governments are managing are the highway and other infrastructure assets that are reported on its financial statements. The agencies are expected to sustain or grow their asset values over time so that they leave future users with a healthy and robust infrastructure network.

Although these measures represent a relatively new innovation in quantifying financial risks for transportation agencies, they appear quite simple compared to the typical Wall Street risk analyses that occur daily. Hull (2013) describes the "Greeks" or the various risk tests conducted on an investment portfolio. In contrast to the 10-year Australian financial risk analyses conducted annually, a Wall Street investment house would track the changing "Greeks" based on every day's trades. In addition to the ones used by Morningstar, other metrics include delta which is the sensitivity of an investment to small price changes in its underlying assets. The gamma would measure the sensitivity of larger price changes, while the vega is the sensitivity to the rate of change in the value of the portfolio over time. The Rho is the sensitivity of the portfolio to interest rate changes. These and other measures allow a fund manager to understand how risky or volatile an investment portfolio could be based upon traders' daily activities.

Another example in which overall risk levels are aggregated and reported is reflected in the U.S. Comptroller of the Currency's Semiannual Risk Perspective. (U.S. Comptroller 2014) The June 25, 2014, report says that in aggregate, U.S. banks are taking on more credit risks after being more conservative following the 2008 financial crisis. The comptroller tracks the risk performance measures of U.S. banks and issued a caution that banks were easing credit standards and making risker loans as a result of tightening competition. The report said banks were raising their risk appetite because of a sluggish economy and low interest rates. This caused the Comptroller to warn that banks were assuming greater risk and exposure to potential future losses. The Comptroller report said the agency will focus on the banks' risk-management practices to ensure they are not taking on inordinate risks that could threaten the economy.

These examples illustrate a maturation of risk measurement from focusing upon a single function or asset to an aggregated, system-level measurement of risks. The portfolio manager can assess across the entire portfolio whether risk levels are changing, are acceptable or whether investments need adjusted to stay within the fund's risk appetite. Similarly, the Australian local government's financial risk metrics allow the agency's decision makers to make strategic investment changes in asset classes by each of the upcoming 10 years to keep financial risk to an acceptable level. The Comptroller of the Currency can use risk-based financial performance measures to assess the overall degree of risk in the entire national banking system.

The state planning agencies in the Australian states used the individual local sustainability metrics to make comprehensive, system-wide assessments of the overall financial risks to all local government assets. (New South Wales Government, 2013) This statewide assessment has some similarities to the U.S. Comptroller of the Currency's assessment of banks' loan portfolio. The annual state audit summaries produced tables, pie charts and trend lines illustrating how financial and infrastructure management risks were changing year-by-year for local governments' assets. Like a portfolio manager on Wall Street, the state and local decision makers could understand if their financial risk levels were changing as a result of their investment decisions.

The MAP-21 requirement to develop financial plans to support transportation asset management plans may lead to more comprehensive financial analysis of the risk facing transportation agencies in terms of sustaining asset condition and performance. These plans are to include reports of the Asset Sustainability Index which is a ratio of the long-term budget for asset investment divided by need. For instance, if an agency needs $100 million a year to sustain pavements but only expects to have $80 million per year the ratio would be $80 million/ $100, or .8. The lower the ratio, the greater the unmet need and the greater the financial risk the agency faces.

Currently, the Federal highway trust fund is on the verge of insolvency creating substantial risk and uncertainty for agencies dependent upon Federal-aid assistance. Predicting income risks is likely to become an increasing activity for state agency risk managers.

An example of how one state forecast its long-term financial uncertainty is the Vermont Agency of Transportation's Sec. 40 report (2013) to its legislature. The report name refers to the state legislation section that required the report.

The report notes that Vermont faces three major long-term income risks. State fuel tax revenues are declining because of greater vehicular fuel efficiency, fewer miles travelled and more reliance on other modes. Second, its forecasts the Federal highway trust fund to be level-funded at best, if not providing declining receipts. Third, it expects construction inflation to outpace income and lead to a reduction in real purchasing power of the revenue it does receive. These trends are further exacerbated by increasing investment needs created by aging infrastructure that has not been maintained as needed because of inadequate income. For the period of 2014-2018, the agency needs $698 million to meet its basic preservation and operations needs but has only $457 million. That leads to an approximate sustainability index of about .65 percent for the period. The department did not forecast need beyond 2018 but it did forecast the erosion of some revenue streams out to 2033. It forecasted that traditional

state fuel tax receipts will fall from $60 million in 2013 to $39.3 million by 2033 if declines in fuel consumption continue. That is offset with some new fees and assessments which will cause income to rise slightly in inflation-adjusted terms until 2021 but then start declining in real terms because of inflation. It shows that in inflation-adjusted dollars it will have a total budget in 2033 of about the same size as today. In other words, based on its best forecast it will remain with only two-thirds of its needed revenue for the next 20 years. This creates substantial risk of declines in asset condition and performance.

The New York State Department of Transportation produced a similar forecast in its Transportation Asset Management Plan (2014). It says its greatest overall risk is the uncertainty of Federal-aid funding which comprises 70 percent of its construction program. The existing degree of underfunding and forecasted flat or declining overall revenue causes the department to calculate an Asset Sustainability Index of .3 for pavements and bridges for the next decade. In other words, it forecasts to have only 30 percent of the needed funding to achieve and sustain its targeted bridge and pavement conditions. The Federal uncertainty and overall low funding levels are significant risks for the agency.

The MAP-21 requirements to develop transportation asset management plans will lead more states to generate fiscal forecasts and compare them to needed levels of investment to sustain asset conditions. This requirement in MAP-21 mirrors in several ways the Australian requirements to estimate the degree of adequacy and risk in long-term fiscal forecasts for infrastructure. The requirement also could lead to the ability to estimate overall levels of financial risk facing entire states, regions or even the nation as a whole. These developments appear to mirror an evolution in U.S. transportation agencies of managing financial portfolio risk somewhat similar to the managing of portfolio risk by investment fund managers.

Braceras and Tally (2010) reported how in a somewhat similar fashion the then New South Wales Road and Transport authority used a network-level bridge risk assessment process. It would report on the changing level of risk to all of its bridge inventory assets by prioritizing bridge investments by the historical failure rates for specific elements of bridges and bridge designs. The pre-1948 bridges were not built to modern standards and result in greater risk. Similarly, timber bridges create greater risks as they age. The department aggregated the risk to its bridge inventory and tracked how the maintenance and replacement investments changed the level of network bridge risk over time. The perspective allowed the department to track whether its investments in bridge repair and replacement allowed it to offset the continuous increase in risk among aging bridges in the inventory, or bridge portfolio.

	Mar -03	Jun -03	Sep -03	Dec -03	Mar -04	Jun -04	Sep -04	Dec -04	Mar -05	Jun -05	Sep -05	Dec -05	Mar -06	Jun -06	Sep -06	Dec -06	Mar -07	Jun -07	Sep -07	Dec -07	Mar -08	Jun -08	Sep -08	Dec -08	Mar -09	Jun -09	Sep -09	Dec -09	Mar -10	Jun -10	Sep -10	Dec -10	Mar -11
Price Index	1	1	1	1	1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.3	1.4	1.3	1.2	1.1	1.1	1	1.1	1.1	1.1	1.1	1.1

Inflation Risk Management

The FHWA National Highway Construction Cost Index (FHWA 2011) includes the following data of national construction

price changes from 2003 to 2011. The data illustrate the significant change and uncertainty that U.S. transportation agencies faced between 2005 and 2009 as prices rose because of a growing international building boom and then fell sharply after the recession of 2008.

This volatility represents a significant risk for transportation agencies as they develop long-term programs, such as 10-year transportation asset management plans. As seen in Figure 6, the future buying power of an agency could be affected dramatically over time depending upon the long-term effects of inflation.

Figure 5 National construction price trends

Lam (2003a) and others refer to volatility as market risk. It is the risk that prices, interest rates, currency exchange rates or other factors will substantially affect prices. Companies generally pursue several strategies to control market risks, in addition to trying to accurately forecast it. One strategy is hedging, or the buying of long-term options to buy a commodity at a fixed price. An example would be an airline buying options to purchase aviation fuel at a set ceiling to hedge against fuel price increases. This hedging agreement provides the airline an upper limit or risk for the important cost input of fuel.

Hedging is common in some transportation agencies functions. Agencies may write contracts to buy road salt a fixed price for a year. This manages their risk both of running out of salt and facing higher prices during a harsh winter when supplies may be scarce. Transportation agencies also sometime join pools to buy fuel in bulk at a fixed price contract, which again is another hedging strategy. In fact, any sort of pooled purchasing program represents a type of hedging. Another hedging or risk-transfer strategy is requiring contractors to have performance bonds. These protect the transportation agency against some of the risk of a contractor failing to complete a construction project.

The Managed Funds Association, a trade group of hedge fund managers (2009) says hedging works like an economic risk absorber. It helps to set upper and lower limits for prices by selling risk-based options to investors. It also allows the spreading of market risk among more investors and allows investors to see the economic cost of managing risks. That cost is the price of the risk-hedging product, such as a slightly higher cost for fuel in the short term to manage the risk of higher fuel costs in the future.

It is not possible, however, to hedge against all construction price inputs. Rising costs for diesel fuel, asphalt binder, cement and aggregates are greatly affected by international markets as well as localized markets where commodities may not be plentiful. Van Deventer (2013) notes that the private sector offers many options for hedging against commodity prices such as “puts” and “calls” which allow someone to buy or sell a commodity at a given price in the future. These are not risk free, in that they come with a cost and may not be needed. However, they do provide a form of insurance, such that a company could buy cement at a given price in six months, regardless if the market price of cement rises higher than the “call” price.

Without hedging opportunities for major construction cost components, transportation agencies are left with the risk-mitigation strategy of trying to forecast the degree of volatility they may experience in

long-term construction prices. Then, they can illustrate that volatility as a risk in their asset management plans. They may have to tolerate the risk because they have few options to treat it.

Bonding Risks

State and local transportation agencies regularly issue debt to finance major transportation projects. Although most agencies have excellent credit ratings and can borrow money at attractive rates, managing interest rate risks is a concern with long-term financial plans. Decisions when to best issue debt creates financial risks. If rates are currently low, it may be attractive to borrow but borrowing early could lead to needless interest payments if the full amount of the proceeds are not immediately needed to pay construction costs. Waiting too long to issue debt, could risk higher future interest rates.

Abelson (2012) addresses several economic theory issues regarding the equity of issuing public debt for transportation, noting that it can violate some basic economic fairness principles if all taxpayers are retiring the debt but the debt benefits few because it is focused on building a specific project. However, he notes there is little overall risk to general obligation debt because of the government's ability to pool repayment across many taxpayers and because of government's ability to raise taxes to repay debt as a last resort.

However, he notes the greater risk – although perhaps greater fairness – when debt is issued for special projects and is to be repaid through tolls or land assessments generated by the project. These could be bonds issued to be repaid by tolls generated by a project or through tax-increment financing where the increased property values generated by a transportation investment – such as a new interchange – will be dedicated to repay the debt.

The New South Wales Treasury (2002) notes that integrating design, construction, operation and maintenance over the life of an asset within a single project finance package can encourage maximum innovation from the private sector to improve the design and performance of the infrastructure and to reduce the whole of life costs. It encouraged public private partnerships and design-build-operate-and finance projects as a means to reduce the risk of higher costs and less efficient major projects.

However, Grad (2013) notes that several of the high-profile Australian public private partnerships failed because traffic revenues did not generate enough to retire the debt leading to default. That left investors, many of whom were local citizens, with substantial losses. He noted that recriminations and class action lawsuits resulted.

Ableson notes that these high-profile failures illustrate the substantial traffic-projection risks, income risks and financing risks that can come with issuing debt for transportation projects.

Predicting future interest rates is a major risk management activity for banks (Croughy, Galai 2006) because mortgages can comprise up to 28 percent of banks' assets. If they charge too little for long-term mortgages and rates rise in the future, the banks will have to borrow money at higher rates than they are earning from their outstanding mortgages. It also would dampen the re-sale of the mortgages to other investors, which is a common practice for banks. However, for the public sector which is not

dependent upon future interest rates as a significant part of its income stream, the risk of interest rate fluctuation is less severe to its income forecasts.

Section 6: Managing Information and Decision Risks

Risks to information and decision making come in many forms. A key risk is created by a lack of information, such as when a transportation agency lacks information about key assets such as drainage structures or curb ramps. If a major water-quality regulation is enacted the agency may not know its risks for bringing drainage structures into compliance. Similarly, a lack of data about where curb ramps are needed creates risks that it does not know the cost to comply with accessibility requirements.

Other risks relate to the quality of forecasts from models, such as pavement, bridge or maintenance management models. Inventory data may be inaccurate or outdated which leads to problems with the models but also with understanding asset conditions, treatment needs or even location.

Security of information systems is a major risk. Hacking, phishing and other threats can expose sensitive personal or medical information, or threaten the integrity of financial management systems. Information risks, therefore, cover a broad area that can degrade decision making, the quality of investments or the privacy and security of sensitive information and transactions.

General Information System Risks

Information risks discussed in this section take two general forms. First, are risks relating to security and protecting data from malicious acts or degradation through poor processes, such as a lack of regular data updates. The second, relates to data and information that does not meet users' needs, such as a lack of quality data for making performance-based decision.

The British National Technical Authority for Information Assurance (2008) says information is the currency of today's society so government needs to identify and mitigate risks to good information. It notes that information risk includes risk to information technology (IT) systems but is broader and can include risks to all information that supports decision making. Stressing the British approach that risk management is about balancing opportunities and threats, it notes that not providing information can create risks. Therefore, information risk management is about reducing threats while creating opportunities to improve decision making for more stakeholders by providing data in secure and accurate ways. The guide stresses that both processes and culture matter to managing information risks. Security firewalls and processes need to be in place but also management at all levels needs to be engaged to ensure that data and information is readily available to all decision makers at all levels, and outside of the organization.

It provides a checklist 24 key questions nested within six general areas that are:

- Have we assessed the importance of information to our business?
- Have we assessed our information risks?
- Do we have a plan for managing these risks?
- Do all staff understand their roles and responsibilities in managing these risks?

- Does my organization have the right skills and technical capabilities to manage these risks?
- Is management information embedded in my business processes?

The U.S. Government Accountability Office (1998, 1999) provides two guides to help federal managers implement ongoing information security risk assessment processes. It portrays data protection as a risk-management process. Computerized systems provide invaluable information opportunity and process streamlining that is enhanced through the interoperability of systems. However, the very scope and interoperability of the systems increases their risks. Hacking into one system can allow access into others, creating vulnerabilities from many sources. The GAO guides provide a framework for managing information system risks and also provides case studies of best practices.

The GAO identifies critical success factors as including:

- Securing management support to ensure that risk assessments are taken seriously by lower levels of the organization;
- Designating groups or individuals to be responsible to oversee and guide the risk-assessment process;
- Documenting procedures for conducting risk assessments and developing tools to standardize the process;
- Calling upon business and technical experts from a range of sources to better understand the criticality and sensitivity of data operations;
- Holding business units and individuals accountable to emphasize the importance of the data risk-assessment and reduction efforts;
- Documenting results so that decision makers could be held accountable and progress recorded.

The Queensland, Australia, government (2014) produces an information technology risk check list. It identifies risks to information and information systems coming in the form of:

- hardware and software failures;
- malware;
- “phishing” threats in which harmless looking email messages are sent to users which when accessed infect the system with malware or hijack computers;
- human errors in processing or using data;
- catastrophic threats such as fires or hurricanes that can knock out a data center.

It recommends a standardized three step process to reduce information or data risks. This includes steps for prevention, preparedness for risks, and recovery plans for when risks strike. Prevention includes the use of firewalls, required passwords, data backups and thorough training of both IT staff and general users. The use of SSL, or secure socket layer, technology to encrypt transaction data is another common security tool. It recommends having a risk management and business continuity plan to formalize the agency’s steps to protect data and to restore it after an emergency. It provides an 18-point checklist of steps that executives should require to reduce risks to IT systems.

The Data Governance Institute (2014) provides a web portal of voluminous information on data governance, or the best practices in acquiring, managing, securing and providing data. It categorizes sound data governance in six general areas including:

- Data governance policies give weight to other data-risk-management steps such as the development of procedures for ensuring data quality, data security and data access to decision makers;
- Data quality policies or procedures includes checks and balances to ensure that data are accurate, frequently updated, and meet the users' needs;
- Privacy, compliance and security guidelines are another risk-reduction component. They typically come from senior management mandate and usually include policies and procedures but also specialized software and technologies to protect data and identify threats;
- Data architecture and integration practices include steps such as requiring consistent data definitions, efficient architectures for storing and sharing data, cross-functional attention to integration, identifying stakeholders and their data needs;
- Data warehousing and business intelligence rules and procedures for the provision of data in easy-to-access ways that also reduce the risk from malicious attacks or degradation of the data quality or accuracy;
- The final area for reducing risks is on data management alignment. This involves realizing and documenting the different needs of different stakeholders. One group that collects data for one specific purpose may not recognize the needs of another group to use the data in different ways. Management alignment seeks to maximize the use of the data and systems by all stakeholders.

Hall (2006) identified numerous data integrity challenges for a performance-based transportation program in the United States. A survey of state respondents indicated that there were major concerns about data quality, data collection efficiency, data access and data sharing. The respondents also expressed the need for improved analytic and modeling tools. Presenters at a workshop for the report reported numerous problems with accessing data for optimized decision making. They discussed how data were isolated in different management system silos and that thwarted efforts to synthesize information and optimize decisions. One presenter described how different systems produced different answers to the same query which undermined executive confidence in the agency and its decisions. Several presenters described how different units collected and used data that were optimized for their function without regard for how the data could benefit other divisions.

Halvorson and Cempel (2011) in NCHRP Report 736 describes methods that managers can use for providing data for risk-based performance management. It says that transportation agencies at all levels of government are embracing performance measurement to improve agency efficiency and accountability. Setting performance targets, a crucial step in the management process, generally entails balancing among competing objectives and dealing with political implications. Unless the basis for setting those targets are sound and defensible, the effectiveness of performance-based management is likely to be compromised. This report presents a framework and specific guidance for risk-based target-setting and for ensuring that appropriate data are available to support performance management.

It provides a framework for data management, somewhat similar to that recommended by the Data Governance Institute. It includes establishing the need for data governance, establishing goals for it, assessing current data programs, establishing data governance programs, acquiring technology for data management and linking data for planning, performance management and target-setting processes.

Secrest and Schneweis (2011) provide a transportation data self-assessment guide to help agencies determine the degree to which their data processes may be at risk. The unofficial guide was produced for AASHTO and was a first step that led to an ongoing process to develop an official data self-assessment guide that is yet unpublished. They say the components of data management include a focus on quality data, alignment with strategic goals, clear definitions, the ability to aggregate or separate data spatially, regular audits of data, adaptable data management plans, clear organizational roles, and mechanisms for security and privacy.

One of the standards for data government and maturity is the copyrighted Capability Maturity Model originally developed by Carnegie-Mellon University and since spun off to the CMMI Institute. A white paper on the institute's services notes that it helps agencies assess their data maturity on a five-level scale from basic performance to a sophisticated, optimized level 5.

Since the Capability Maturity Model publication in the 1980s, many other organizations and associations have developed similar ones. The IBM Data Governance Council (2007) is a group incorporating 52 corporations or associations. It builds from the original framework by describing the five phases of data governance maturity as identified originally in the capability maturity model.

Level 1 is an environment where processes are ad hoc and the environment unstable. Success relies on the competence of individuals, rather than proven processes. At level 2, successes are repeatable but processes may not be. Yet, there still is risk of failure because of a lack of ingrained processes. At level three, the organization adopts a set of standards and processes. At level four, organizations set quantitative quality goals for processes and maintenance. At level five, the quantitative process-improvement objectives are firmly established and are continually revised to reflect changing business objectives.

The IBM council enhances the original five-level model into 11 categories of maturity for assessing the maturity of an IT organization to reduce its risks to the quality, security and usability of data. The categories of maturity include:

1. The maturity of the organizational data owners' awareness of their responsibilities to support the business decisions of the organization;
2. The maturity of the stewardship or quality control discipline for data asset enhancement, risk mitigation and control;
3. The maturity of policies to articulate the desired organizational behavior;
4. The maturity of processes to create value with data by supporting good decisions;
5. The maturity of data risk management and compliance to identify, qualify, quantify, avoid, mitigate or transfer data risks;
6. The maturity of the security and privacy processes to mitigate risks and protect data assets;

7. The maturity of the data architecture or design and structure of the systems and applications to serve appropriate users;
8. The maturity of the data quality management to measure and improve the provision of quality data;
9. The maturity of classification and metadata, which are the terms for identifying and classifying categories of data;
10. The maturity of the information lifecycle management for the collection, use and eventual deletion of data, and:
11. The maturity of audit and reporting functions to monitor and measure the value of data, risks and effectiveness of governance.

The Minnesota Department of Transportation's Data Business Plan (2008) represents an effort to formalize the vision, objectives and processes for managing data. The report does not address managing information risk because it preceded the department's embrace of risk management. However, its conclusions document the plan's intention to reduce information and decision risks by:

1. The infrastructure preservation recommendations set the stage for implementing an organizational approach to asset management and for addressing critical transportation infrastructure data gaps and needs.

2. Traveler safety recommendations cite the need for better data on local road characteristics and more enhanced safety data analysis tools.

3. The mobility recommendations identify the need for research and resources to collect potentially new data to address increasing interest in multimodal accessibility, reliability and person throughput questions.

4. The financial data recommendations address the need for enhanced information on life-cycle costs, return on investments and data for evaluating service delivery options.

5. Business intelligence recommendations highlight the value of department-wide solutions for improving data availability, integration and analytical capabilities.

6. Enterprise architecture recommendations provide an opportunity to strategically look at how all information systems might fit together to reduce data redundancies and create operational efficiencies.

7. The data governance recommendations lay out a comprehensive series of steps for clarifying data roles and responsibilities and for setting standards and policies to reduce redundancies and promote data quality and reliability. They recommend developing a data catalogue and a thorough assessment of department-wide information system architecture to identify opportunities for integration to reduce redundancies and promote efficiencies.

8. The GIS recommendations set the stage for business process, data governance and organizational changes to fully achieve desired objectives.

The Colorado Department of Transportation (2011) Data Business Performance Plan likewise does not use an explicit information-risk-reduction terminology but it does reference the need to improve the department's data and processes to support enhanced decision making. The objective of the project was to support enhanced decision making around nine key performance areas which are the number of fatalities, bridge conditions, pavement conditions, roadside conditions, snow and ice control, roadway congestion, on-time construction, on-budget construction and strategic action implementation. The plan addresses data management methodologies to support the department's ability to make informed decisions on how best to achieve the targets for each measure.

Managing risks to models

Crouhy et al (2006a) identify as a major concern in the modern organization the risks to models and decision-support systems. They compare the modern manager to a pilot who flies by instruments. If the computers and other navigational aids fail, the chance of catastrophe increases. Although models and technology can be risk-reducing tools, they also can create complacency so that a model failure combined with a significant unplanned event creates a higher risk of failure if the manager or pilot is overly reliant on the model.

They cite examples of the criticality of the accuracy of financial-risk-and-return models that are analogous to pavement-design risks discussed by Haas and Hudson (1994) who note that a common reason for premature pavement failures is the underestimation of truck loadings. Crouhy et al emphasize that data and models are a major source of focus for modern risk managers who are responsible for capital assets. Although Croughy discusses model risk in terms of financial assets, the concept applies equally to models addressing assets such as pavements and bridges.

No best practice guides were found for the calibration of transportation models to reduce the risk of sub-optimized investment decisions based on model error. However, the literature does include many references to metropolitan planning organizations routinely calibrating their travel demand models. They generally do this by comparing the model outputs to base year observed traffic counts to validate the model is at least accurately replicating current conditions. The literature also provides some published research about agencies calibrating their pavement models to improve their treatment recommendations and condition forecasts. It would seem that a gap exists in providing guidance to update pavement and bridge models to reduce decision risk caused by model errors.

Lewis et al (2013) describe an effort to calibrate the Oklahoma Department of Transportation's pavement management models based upon 16 years of pavement performance. They discuss how the department wanted for a number of years to test and validate the accuracy of its model based upon observed pavement conditions. Inputs that were important to the model's forecasts were the embedded models on deterioration curves, pavement families, and the effectiveness of various treatments. They reported some skepticism about the cost and upkeep of the model within the department. The model relied on deterioration curves based on regression conducted in 2001 upon a limited number of data points. The effectiveness of various treatments relied upon the engineering judgment and experience of pavement management engineers. These major input models were in use without active validation using actual pavement assessment condition data. The calibration effort

resulted in 630 new deterioration curves that would be used to predict appropriate pavement indexes for eight different pavement families. The curves and new treatment effectiveness indexes were compiled into a spreadsheet tool to update the pavement model.

Austroads (2010) provides a chapter on the calibration of pavement performance models to reduce information risks in its Guide to Asset Management. Its chapter five includes guidance on the selection, formulation and calibration of pavement performance models. The modelling considered is intended to facilitate reporting of current conditions and life-cycle predictions of future pavement performance. The modelling considered extends from static models for the derivation of composite indicators (such as key performance indicators, KPIs) from a range of individual measures, through to future prediction using comprehensive dynamic pavement performance modelling of functional, structural, and treatment effects.

Henning and Costello (2006) describe an effort by Land Transport New Zealand, then the name of the national highway agency, to calibrate its pavement model to more accurately forecast conditions and identify treatments based upon enhanced cracking and rutting data.

Section 7: Managing Risks to Business Operations

This section will discuss risks to internal "back shop" business functions such as purchasing, contracting, inventory control and employee health and safety. Twenty years ago in a traditional corporation, these would have been the functions upon which risk management largely focused. Then, risk management was largely concerned with reducing insurance costs and business losses. Still today in retailing, risk management is largely synonymous with reducing loss through theft. Although these areas are no longer the primary focus of enterprise risk management, they remain business areas which can be improved with a risk-management approach.

Traditional Risk Management

The State of North Dakota's Risk Management Manual reflects a traditional approach to managing risks to the state by managing insurance costs, insurance claims, reported losses through accidents or injuries, loss to vehicles, property or equipment, contracts and worker's compensation claims. It says it enacted the risk management program after a state supreme court decision that eliminated the state's sovereign immunity. The court said the state, like individuals, could be held responsible for negligence of its agents and employees. Its mission statement says the intent is to protect the state's assets - which are its people, property and financial resources – so it can meet its obligations to its citizens. Its guide says it will evaluate risk treatment strategies to decide if it tolerates, terminates, transfers or reduces risks. Strategies to tolerate risk include not buying insurance if risks are low, or accepting some deductibles to retain some risk. Where it can transfer risk it will buy insurance, join insurance pools or transfer risks to third parties such as contractors or suppliers.

Risks from Theft, Fraud, Malfeasance

Semiannually, the Office of the Inspector General of the U.S. Department of Transportation issues a report to Congress on its activities. The report for April to September of 2013 comprises 122 pages on investigations into fraud, waste and abuse or recommendations for process improvements and efficiencies. The report catalogs examples of process failures, fraud and abuse that represent risks to U.S. transportation agencies and ultimately the taxpayers.

One example cited in the report was of a paving contractor who was charged with disadvantaged business enterprise fraud on $87 million in federal funded paving contracts. An indictment alleged that for more than a decade the contractor fraudulently obtained contacts by falsely certifying that a DBE was actually performing the work. In another case included in that report, a contractor was convicted of filing false tax returns, conspiracy and wire fraud in relation to the DBE program. Another example was a state right of way employee convicted of accepting a $30,000 bribe in relation to allowing a fraudulent claim for relocation assistance by a land owner affected by a highway widening. Another company agreed to pay a $2.8 million settlement to resolve allegations it defrauded the DBE program. A 2009 report by the U.S. DOT inspector general said that in the preceding five years there had been 278 indictments, 235 convictions, 191 years of jail time and $737 million in fines and restitution related to

fraud in DOT programs. These examples illustrate the rationale behind risk-management practices to control contracting fraud and abuse.

Barnett and Russell (2009) reported that fraud is more common than many agencies suspect. Common types of fraud involve bid rigging where companies conspire to raise prices on bids, to product substitution, to bribery, kickbacks and filing false claims.

The GAO (2006) issued guidance on the elements of a well-designed fraud prevention system. It was intended for disaster-relief programs but is applicable to other Federal programs as well. It says to reduce the risk of fraud requires three essential elements: 1) Upfront preventive controls; 2) detection and monitoring; 3) investigations and prosecutions. The GAO said upfront preventive controls can screen out the majority of fraud and are the most effective and efficient means to minimize fraud waste and abuse. The audit confirmed that upfront controls work most effectively when they require validation of eligibility for payment. Training personnel in fraud prevention and awareness also is an integral component of preventive controls. Detection and monitoring can occur with data mining for suspicious patterns and the setting up of fraud hotlines and other means for reporting. Program integrity is enhanced by investigating cases of fraud. However, the cost of prosecution is so high that it strengthens the benefits of upfront controls to prevent fraud in the first place.

The Chartered Institute of Management Accountants (2008) produced a Fraud Risk Management Guide to Good Practice. It reports that although no system can eliminate all fraud, a formal process built upon proven techniques can be an effective risk management process. The guide discusses the key components of an anti-fraud strategy. It says that fraud risk ought to be a regular component of an organization's operational risk management. A fraud review considers whether other operational errors or events could be the result of fraud, such as overpayment to contractors or unaccounted for inventory. Risks such as false accounting or theft ought to be assumed as a possible operational risk in any organization. The guide also says that overall responsibility for internal controls should be at the highest levels of the organization. Although the senior management should have strong teams of auditors and analysts devoted to detecting fraud or abuse, it should be up to corporate leadership to create a climate of ethical behavior, put controls in place and actively pursue reported fraud or abuse. Whistle blower programs and hotlines can be an effective means to augment formal auditing processes.

The guide also calls for a comprehensive system of internal controls and policies. These often include the division of responsibilities and checks and balances to reduce risk. In such a system, an originator of a request for a good, service or payment, would be segregated from the unit that negotiates price and quality of the purchase of the good or service. Best value processes would be in place and handled by other parties to ensure arm's length, best-value transactions. Purchases or payments are clearly documented and the accounting arm ensures that costs and payments are in line with budgets and standards. Training, monitoring and regular reviews of purchases and processes would be routine. Other techniques include pre-employment screening of employees who will be in fiduciary positions, regular audits and data mining of transactions to look for suspicious patterns.

A risk management tool for construction bidding is the collusion-detection module within the AASHTOWare Project BAMS/DSS software. It compiles years of bid tab data and includes collusion-

analysis modules. These look for patterns in bidding that could indicate collusion between contractors in terms of bidding, subcontracting and provision of construction materials.

The British Treasury's Good Practice Guide to Tackling External Fraud (2008) focuses upon preventing fraud from third parties seeking payment or benefits to which they are not entitled. It says that all British departments have a responsibility to develop anti-fraud policies and to demonstrate effective prevention practices. It advises as to the many different types of fraud risk that agencies should address. These can include acquiring benefits to which persons are not eligible, organizations claiming exemptions or special status when they are ineligible, people who evade taxes or payments, companies or individuals colluding to rig bids, those who substitute inferior products or services, and those guilty of theft of money or other assets.

The guide asks agencies to take a strategic and systematic approach to identifying the types of fraud to which they may have risk and to comprehensively take steps to prevent, monitor and prosecute if it occurs. Responsibility for tackling fraud starts at the top of the organization and should be seen as an enterprise risk managed by senior leadership. As do other guides, the Treasury guide says that prevention is more effective and economical than prosecution. Therefore, emphasis should be placed on developing controls that signal criminals that fraud should not be attempted because of the high risk of detection. Creating a culture that does not tolerate fraud nor accept it as unavoidable is another senior management imperative. Training and awareness programs are an essential component of an effective fraud-prevention effort. Senior leadership should regularly evaluate the strength of internal controls to ensure that complacency or routine have not eroded their effectiveness. An internal fraud-investigation unit is essential, as are procedures to seek outside investigatory help. Evidence that investigations are common and effective serves as an effective fraud deterrent. Along with investigations, the imposition of effective sanctions also reinforces perceptions of effective fraud controls.

Similar to the British guide, the Australian National Audit Office (2011) produces a Better Practice Guide for Fraud Control in Australian Government Entities. It depicts effective fraud risk control as a multi-layered and continuous system. It begins with strong leadership enacting sound policies and procedures. It then enacts continuous prevention, detection and response processes that are continually monitored for improvement.

The Australian Guide complements an enterprise risk management approach. It parallels ERM's stratified but coordinated approach of addressing fraud at the enterprise, program, project and activity level. At the top are clearly stated policies, procedures and commitment by the leadership. At every level of the organization, managers are expected to implement the fraud-prevention and detection processes. Central to the effective practice are key strategies for fraud prevention and detection. These strategies can include:

- Rigorous and transparent bidding and procurement processes;
- Screening of potential suppliers;
- Segregation of duties throughout the planning, scoping, selection and negotiation phases;
- Regular reviews of suppliers' products or services;

- Data mining of bidding and payment events;
- Internal and external reporting mechanisms such as hotlines;
- Internal audits of processes;
- Audits of final payments to ensure compliance with bid or purchase specifications.

Again, it emphasizes that fraud prevention is the first and most effective line of defense. Employees at all levels must be trained, empowered and responsible for implementing their responsibilities for fraud control. Feedback loops are needed so that employees understand the actions taken when fraud is reported, including when it results in no action.

For high-risk activities, the guide says agencies should consider rotating personnel through processes to ensure no group can consistently hide malfeasance or fraud, high level screening may be required for staff, regular reviews or audits can be enacted and independent confirmation required for the proper delivery of services or products.

The guide depicts fraud prevention and detection as a key corporate responsibility in an enterprise risk framework. It equates it in importance to managing security risks, business risks and other enterprise risks. The guidelines require agencies to undergo a fraud risk management assessment at least every two years. The risk assessment is to be conducted in accordance with the AS 8001-2008 Fraud and Corruption Control standards, which are the Australian versions of the ISO standards.

Controlling Risks to Inventory

The GAO (2002) also provides an inventory control guide for government agencies. It is based on the GAO's analysis of seven private sector companies who were leaders in inventory control. The GAO said managing the acquisition, production, storage, and distribution of inventory is critical to controlling costs, operational efficiency, and mission readiness. Proper inventory accountability requires that detailed records of produced or acquired inventory be maintained, and that this inventory be properly reported in the entity's financial management records and reports. For example, detailed asset records are necessary to help provide for the physical accountability of inventory and the efficiency and effectiveness of operations. Additionally, the cost of inventory items should be charged to operations during the period in which they are used. Physical controls and accountability reduce the risk of (1) undetected theft and loss, (2) unexpected shortages of critical items, and (3) unnecessary purchases of items already on hand. These controls improve visibility and accountability over the inventory which reduces risks to the continuation of operations, productivity, improper storage, or excess or obsolete stock.

The GAO found repeatedly that agencies lacked complete and reliable information for inventory, property and equipment. Agencies could not account for all their assets, verify the existence of inventory, or substantiate the reported inventory and property. Failing to know where assets are increases the risks of theft, misuse, unnecessary storage costs or inaccurate estimates of program costs.

It identified 12 key factors for achieving consistent and accurate control over physical inventory including:

1. Established accountability
2. Written policies
3. A formal inventory control approach
4. Frequent counts
5. Segregated duties for control
6. Knowledgeable staff
7. Adequate supervision
8. Periodic spot counts
9. Ensuring the completeness of counts
10. Investigate discrepancies between counts of assets and inventory records
11. Evaluate the results of physical counts and determine their effectiveness.

Employee Safety and Workers' Compensation Management

In the private sector, a company's managing of its employees' health care claims can reduce the health care premiums that a company and its employees pay. Therefore, managing health care costs is a standard risk management activity in the private sector. State agencies generally can't individually control their health care costs because premiums are negotiated statewide. One exception is workers' compensation costs which often are agency specific. A transportation agency that puts employees into a highway environment generally has higher premiums for workers' compensation than would an agency that only has office employees. This fact provides transportation agencies an opportunity to manage their workers' compensation risks. If an agency reduces its workers' compensation claims history, its future premiums can be reduced.

Efforts to reduce workplace injuries and lower insurance costs lend themselves to an ISO-like risk management approach. The effort begins with acknowledging the workplace environment, identifying risks to worker safety, analyzing and then treating those risks. Constant ongoing monitoring and communication are necessary to stay abreast with changing conditions in the workplace and to communicate regularly with workers about safety practices.

Workplace risks and their associated premiums generally are treated in two ways: preventing injuries from occurring through sound workplace safety programs and training, and speeding the workers' recovery from injuries to get them back on the job. Unlike standard health care costs, the cost of medical treatment is often not the highest part of the workers' compensation claim. Lost wages can be a significant, if not majority, cost of a claim, particularly if a worker is off for months or even years. Therefore, the more effectively an organization gets an injured worker treated, rehabilitated and back on the job the lower the long-term workers' compensation costs will be.

The American Occupational Therapy Association, Inc. (2014) recommends an effective transitional return to work strategy for its multiple benefits. To the agency, it lowers long-term lost work costs. However, to the employee it provides physical and important psychological benefits. The worker's therapy can be managed by an occupational therapist who compares the worker's physical capabilities with the job duties. The therapist can suggest reduced or amended duties that complement the worker's condition and therapy. More importantly, the worker again sees himself or herself as a

competent, able individual who is on a path to return to a full lifestyle. Normal routines and habits are regained. The return to work and contributing to the workplace reduces feelings of permanent disability and resignation to diminished capabilities. The benefits are recognized as being so significant the workers' compensation insurers will either pay for the transitional therapy or give the company premium reductions.

The North Dakota Risk Management Guide says that statistics show that employees who are away more than six months have only a 50 percent chance of ever returning to their jobs. If the lost time extends to one year, there is only a 10 percent chance. Such claims create major expenses for agency's workers' compensation premiums for many years.

The North Dakota worker's compensation risk management program also includes many industry-standard recommendations. These include having an effective safety policy and program to identify workplace risks and to take steps to reduce them. Annual inspections of facilities for safety equipment and safe working conditions are required. Training programs are essential to train workers about job safety.

Active management of workers' claims is another key component. The agency strives to assist workers navigate the medical and claims process so they get prompt treatment and do not face paperwork or approval delays. This assistance can speed treatment and therapy and prevent lingering injuries from increasing long-term disability. The active management also helps get the worker healthy to return to transitional work faster.

The Queensland Department of Transport and Main Roads (2011) reports on an aggressive program to reduce worker injuries, particularly in construction zones. These not only reduce insurance costs, but importantly protect the health and safety of its and contractors' employees. The steps include appointing champions to ensure that compliance with safety procedures takes place and to guide the development and implementation of appropriate policies. In work zones, it has experimented with a robotic mannequin to remind motorists if they are speeding in a work zones, paging units inform workers if equipment has breached a pre-determined work area, reversing cameras are on heavy equipment to improve operators' rear vision, vehicle-activated variable speed message signs inform motorists if they are speeding in work zones. The department also tracks workplace injuries as a core performance measure. Its reports injuries and lost time of employees as a key performance measure in its annual report.

The Public Entity Risk Institute (2014) lists several key strategies for managing workers' compensation risks. First is to reduce injuries. Injury reduction is the "holy grail" of public sector workers' compensation programs. Next is increasing the efficiency of the claims process by streamlining and automating processes. This also speeds the workers' receipt of treatment. Transitional return-to-work programs are emphasized. It is cheaper to have a worker performing part-time work at full-time pay than to have higher insurance premiums for many years. Reducing litigation by working cooperatively with injured workers can dramatically reduce costs. The PERI estimates that in some states up to 50 percent of all benefit claims are litigated. Another strategy is to improve the quality of care for injured

workers and ensure they see specialists and therapist as soon as possible. This speeds their recovery, improves their attitude toward their employer and assists with their return to work.

Section 8: Managing Risks to Programs and Projects

Project and program management are among the most mature and extensively documented areas of risk management in the U.S. transportation sector. This extensive body of literature reflects the large number of projects pursued by transportation agencies and their experiences with the negative consequences of risks to project cost, scope, schedule and quality. This section examines several examples of risk management resources relating to program and project management. Three of the most comprehensive program and project management frameworks were already mentioned in Section 1. Those were the PMI standards for portfolio, program and project management. The following sources illustrate guides related to project management. When the project management is aggregated, it becomes a form of program management.

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. (Molenaar et al 2010) 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.

Caltrans Project Risk Management Handbook

"Threats and opportunities" is the subtitle of this handbook by Caltrans. (Caltrans 2013) 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 2013 guidance from the Washington State Department of Transportation provides a comprehensive framework for deploying risk-management strategies for construction projects. (Gabel 2013) Although focused only on construction projects, the guide easily could be modified to address risks of almost any type. 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. 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.

Guide for Managing Risk on Rapid Renewal Projects

The second Strategic Highway Research Program (SHRP2) produced a guide for Managing Risks on Rapid Renewal Projects. (Golder 2014) It notes that traditional risk assessment activities often lack rigor and formality in project planning, design and delivery. This can be a particularly serious shortcoming with rapid renewal projects that emphasize a "get in, get out and stay out" approach. These rapid renewal projects pursue accelerated schedules that increase the risk that unforeseen issues can create delays that lead to missed milestones, disputes over acceleration incentives and disappointment by the public when construction dates are missed. The guide helps managers quantify risks and provides guidance on the level of risk management needed. It provides a formal risk management process that addresses the accelerated schedule issues that confront rapid renewal projects. It provides performance measures, project delivery methods and construction methods that complement rapid renewal projects. The guide provides a risk analysis process that allows a user to factor in issues such as project scope, strategy and conditions to identify, analyze, treat and monitor risks. The project also provides spreadsheets and a two-day training course.

Managing Risks on Complex Projects

This SHRP2 Guide addresses managing risks on complex projects. (Shane et al 2012) It identifies a five-dimension framework intended to manage complex projects including their risks. Although not specifically a risk management guide, it is a project-management guide that emphasizes project controls that, in effect, manage risks. It says that complex projects are characterized by a degree of disarray, instability, evolving decision making, non-linear processes, dynamic processes with a high degree of uncertainty. The guide says that most project-management frameworks address three components, cost, schedule and quality. This guide adds context and financing as additional sources of risk or uncertainty. The context risks are those that include risks caused by stakeholder expectations, local issues, environmental issues, or unexpected occurrences. Financing risks can be caused by uncertain public finances, bonding risks, tolling or other revenue risks, public-private finance risks such as occur with tax-increment financing or franchising projects. The guide provides a process to identify and then map the risks or issues. It does not follow an ISO framework but is similar in its risk-identification and analysis steps. The guide describes the steps of assembling a risk-identification team, brainstorming risks, developing ranking and mitigation for the risks, assigning resources to mitigate the risks and then integrating the risk-mitigation decision into the cost estimates, schedules, designs and monitoring plans. It cites the example of a New Mississippi Bridge between St. Louis and East St. Louis in which the risk management plan was reviewed weekly by the project team to keep abreast of issues.

Managing Risks in the Environmental Process

Several project-management risk guides note that the risk of decisions that could eventually affect cost, scope or schedule often are greatest early in the project-development process. Then, the project team has fewer details and makes more assumptions that later could result in risks to project costs and schedules. Wood et al (2011) produced a report, Guidance for Managing NEPA-Related and Other Risks in Project Delivery Process, that address risk to projects in the environmental planning stage. The project effort involved assembling a group of practitioners to validate a draft set of typical risks faced in the environmental planning stage and strategies to mitigate them. The project identified more than 50 different risks that could occur ranging from unrealistic community expectations, vague purpose and need statements, lack of decision-making staff by resource agencies and late identification of impacts. The guide recommends an ISO-like process of identifying risks early in the environmental planning stage, then mitigating and monitoring them throughout the project-development process.

References

AASHTOware, Safety Analyst accessed at http://www.safetyanalyst.org/index.htm on June 30, 2014.

American Society of Mechanical Engineers Innovative Technologies Institute, All Hazards Risk and Resilience, Prioritizing Critical Infrastructure Using the RAMCAP Plus Approach, Washington, D.C. 2009

American Society of Mechanical Engineers Innovative Technologies Institute and the American Water Works Association, Risk and Resilience Management of Water and Wastewater Systems, 2009

Ableson, P, 2012, Financing transport infrastructure: Public Finance Issues, Macquarie University, Sydney, NSW, access at http://www.appliedeconomics.com.au/pubs/papers/pa03_trans.htm July 1, 2014

American Association of State Highway and Transportation Officials (2011) Transportation Asset Management Guide – A Focus on Implementation, pp. 5-50-5-56

AASHTO 2010 Highway Safety Manual, AASHTO 444 N. Capitol St. Washington, DC

American Occupational Therapy Association Inc. 2014 accessed at http://www.aota.org/en/About-Occupational-Therapy/Professionals/WI/Transitional.aspx June 30, 2014

AS/NZS ISO 31000:2009 Risk Management – Principles and guidelines, Standards Australia, Sydney, Australia.

Association of Local Government Engineering New Zealand (INGENIUM) and the Institute of Public Works Engineering of Australia (IPWEA), 2006, International Infrastructure Management Manual, Version 3.0, INGENIUM, New Zealand, pp. 3.53-3.76

Austroads 2007, Guide to Road Safety, Part 7: Road Network Crash Risk Assessment and Management, Austroads, Inc., Level 9 Robell House, 287 Elizabeth Street, Sydney, Australia.

Austroads, 2010, Guide to Asset Management Part 5H: Performance Modeling., Austroads, Inc., Level 9 Robell House, 287 Elizabeth Street, Sydney, Australia.

Austroads 2014, Australian National Risk Assessment Model, Austroads Ltd., 287 Elizabeth Street, Sydney

Australian National Audit Office, 2011, Fraud Control in Australian Government Entities

Australian Automobile Association Road Assessment Program, 2014 accessed at https://www.racq.com.au/__data/assets/pdf_file/0003/82578/AusRAP_-_Rating-Australias-National-Network-for-Risk_-_Benchmarking-the-performance-of-Australias-roads-in-the-Decade-of-Action.pdf on June 29, 2014

Bank of England, 2005, The Report Into the Collapse of Barings Bank, accessed at http://www.numa.com/ref/barings/bar00.htm June 2014

Barnett, B., M. Russell, 2009, Maximizing Transportation Investments: Collaborate Fraud Prevention and Outreach, Public Roads, Vol. 72, No. 5

Bazovsky, Igor, 2004, Reliability Theory and Practice, Dover Publications, Inc., Mineola, N.Y., p.286

Beattie, A., 2010, The History of Insurance, accessed at http://www.investopedia.com/articles/08/history-of-insurance.asp

Bernstein, P., 1996, Against the Gods: The Remarkable Story of Risk, John Wiley & Sons, New York

Braceras. C. and R. Tally et al, 2010, Linking Transportation Performance and Accountability, a report of the FHWA International Technology Scanning Program, accessed at http://www.international.fhwa.dot.gov/pubs/pl10011/ pp 2, 37-38, 44

British Treasury, 2004, The Orange Book Management of Risk – Principles and Concepts, 1 Horse Guards Road, London

British Treasury, 2008, Tackling External Fraud Good Practice Guide, the National Audit Office

British Treasury, 2009) Risk Management assessment framework: a tool for departments, 1 Horse Guards Road, London

Buehler, Kevin, Andrew Freeman, Ron Hulme, 2008, The Risk Revolution, No. 1, working paper by McKinsey and Co. accessed at http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0CCsQFjAB&url=http%3A%2F%2Fwww.mckinsey.com%2F~%2Fmedia%2Fmckinsey%2Fdotcom%2Fclient_service%2FRisk%2FWorking%2520papers%2F1_The_Risk_Revolution.ashx&ei=1c2RU6SsNMOXqAbq_4FI&usg=AFQjCNHuMrjAUTexsG8zSy5VHS3og2nVmg&sig2=Xedi14BxBxQztNz4XivSig June 2014.

Cambridge Systematics, 2009, NCHRP Report 632 An Asset-Management Framework for the Interstate Highway System, Transportation Research Board

Coates, J. IV, 2009, The Goals and Promise of the Sarbanes-Oxley Act, The Journal of Economic Perspectives, Volume 21, Number 1, Winter 2007 Pages 91-116

Coe, D., 2006, Risk Based Bridge Asset Management, conference paper Melbourne, Australia,

Coleman, T., 2011, A Practical Guide to Risk Management, The Research Foundation of the CFA Institute

Colorado Department of Transportation, 2011 *CDOT Performance Data Business Plan, Final Report*

COSO 2004 Enterprise Risk Framework Executive Summary, Committee of Sponsoring Organizations of the Treadway Commission, 2004.

Croughy, M. and D. Galai, R. Mark, 2006 The Essentials of Risk Management, McGraw-Hill, New York, pp 156-126, 397

Curtis, J., J. Dailey, 2012, Transportation Risk Management: International Practices for Program Development and Project Delivery, FHWA Office of International Programs,

Data Governance Institute portal accessed at http://www.datagovernance.com/ July 1, 2014

D'Ignazio, J., M. Hallowell and K. Molenaar, 2011, Executive Strategies for Risk Management by State Departments of Transportation, NCHRP 20-24 (74) Transportation Research Board

Doney, D., The Effect of SOX on Internal Control, Risk Management, and Corporate Governance Best Practice, from QFinance accessed at http://www.qfinance.com/regulation-best-practice/the-effect-of-sox-on-internal-control-risk-management-and-corporate-governance-best-practice?page=1 June 2014

England Highways Agency, 2010. Risk Management Policy and Guidance

Federal Emergency Management Agency, May 25, 2011, Fundamentals of Emergency Management, Independent Study p 230

Field, C., et al, 2012, Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, U.K., and New York, N.Y., USA

FHWA 2011 National Highway Construction Cost Index accessed at http://www.fhwa.dot.gov/policyinformation/nhcci/pt1.cfm on July 1, 2014.

FHWA 2012, Highway Safety Improvement Program, MAP-21 High Risk Rural Roads Guidance, Issued December 27, 2012, FHWA Office of Safety at, https://www.fhwa.dot.gov/map21/guidance/guidehrrr.cfm

FHWA 2014, A Systematic Approach to Safety – Using Risk to Drive Action, accessed at http://safety.fhwa.dot.gov/systemic/ June 30, 2014

Fone. M and P. Young, Managing Risks in Public Organizations, 2005, published by Palgrave McMillian 175 Fifth Ave. New York pp 8, 89-93

Geiger, D., P. Wells et al, 2005, Transportation Asset Management in Australia, Canada, England and New Zealand, US DOT, FHWA Office of International Programs, Nov. 2005., pp. xii, xiii, 5, 11, 13, 20, 27, 37-39, 42, 46, 52-53, 56, 59, 63, 83, 88.

Golder Associates, Guide for the Process of Managing Risk on Rapid Renewal Projects, second Strategic Highway Research Program, project R09, 2014.

Government of Canada, 2011, Road Safety in Canada, Road Safety Canada.

Grad, P. Tunnel Talk, July 2013 accessed at http://www.tunneltalk.com/Discussion-Forum-16Jul13-Australia-PPP-toll-tunnel-crisis.php

Gunter, R., 2012, Strategy & Competition, How the Growth Outliers Do It, Harvard Business Review, Jan.-Feb. 2012, p154

Hall, J. July 8, 2006, Challenges of Data for Performance Measures, A Workshop, Transportation Research Board Circular E-C115

Halvorson, R., E. Cempel et al, 2011, Cambridge Systematics, Uses of Risk Management and Data Management to Support Target-Setting for Performance-Based Resource Allocation by Transportation Agencies, NCHRP Report 736

Henning, T., S. Costello, T. Watson, 2006, A Review of HDM/dTIMS pavement models based on calibration site data, Land Transport Research Report 303

Haas, Ralph, W. Ronald, Hudson, John Zaniewski, 1994 Modern Pavement Management, Kreiger Publishing Company, Malabar, Fla., p.295

British Treasury, 2004, The Orange Book, Management of Risk – Principles and Concepts, HM Treasury, 1 Horse Guards Road, London, 2004.

Huang, S., M. Darrow and P. Calvin, August 2009, Unstable Slope Management Program, Background Research and Program Inception, for the Alaska Department of Transportation and Public Facilities, pp. 15-17

Hull, K, 2012, Risk Management and Financial Institutions, Third Edition John Wiley and Sons, Inc., Hoboken, N.Y., pp 3, 137-157

IBM Data Governance Council Maturity Model, October 2007, accessed at http://www-935.ibm.com/services/us/cio/pdf/leverage_wp_data_gov_council_maturity_model.pdf July 2, 2014

International Organization for Standardization (ISO), 2009, Risk management - Principles and guidelines, Switzerland

International Risk Governance Council, 2008, Chemin de Balexert 9, Geneva, Switzerland

The International Risk Management Institute, 2006, accessed at http://www.irmi.com/online/insurance-glossary/terms/r/risk.aspx

Kaplan, Robert, et al, Oct. 2009, Managing Risk in the New World, Harvard Business Review, pp. 69-75

Knight, F. 2012, Risk, Uncertainty and Profit, accessed at http://www.econlib.org/library/Knight/knRUP6.html#Pt.III,Ch.VII

Lagace, M. 2008, Strategy Execution and the Balanced Scorecard, Harvard Business Review, Aug. 11, 2008

Lagasse, P, Michel Ghosn, Peggy Johnson et al, 2013, NCHRP Report 761 Reference Guide for Applying Risk and Reliability-Based Approaches for Bridge Scour Protection

Lam, J. Emerging Best Practices in Developing Key Risk Indicators and ERM Reporting, an executive white paper accessed at http://www1.gsm.pku.edu.cn/stat/public_html/ifirm/reports/ERM%20Dashboard_KRI%20White%20Paper_October%202006%28james%27s%20paper2%29.pdf

Lam. J., 2003,Enterprise Risk Management from Incentives to Control, John Wiley & Sons, Inc., pp 4, 83-89.

Lamb, K., 2012, Measuring and Managing Risk, accessed at http://www.investopedia.com/articles/08/risk.asp#ixzz1jNd6LkN1

Land, R. and K. Thompson, 2013, *The Challenge of Achieving Seismic Safety* accessed at http://people.ce.gatech.edu/rd72/italy/papers/S6-5_US-Italy%20Seismic%20Bridge%20Workshop_RLand%20Paper.pdf on June 30, 2014.

Lewis, P, D. Jeong, H. Khaleghian, July 31, 2013, Calibration of Controlling Input Models for Pavement Management System, Final Report, Oklahoma Transportation Center

Managed Funds Association, 2009 Sound Practices for Hedge Fund Managers, 2009 Edition

Maurer, Mark, and Carol Lee Roalkvam, Sandra Salisbury, et al, 2011, Washington State Department of Transportation Climate Impacts Vulnerability Assessment Report

McGrath, R., 2012 *How the Growth Outliers Do It*, Harvard Business Review, January-February 2012.

Meyer, M., M. Flood, J. Keller, J. Lennon et al, 2013, Strategic Issues Facing Transportation: Volume 2: Climate Change, Extreme Weather Events and the Highway System: Practitioner's Guide and Research Report, NCHRP Report 750, Transportation Research Board, pp 56-68

Minnesota Department of Transportation, 2008, Data Business Plan, 2008.

Minnesota Department of Transportation, 2013, Enterprise Risk Management Framework and Guidance, 2013, accessed at http://www.dot.state.mn.us/riskmanagement/pdf/erm_framework.pdf June 11, 2014

Molenaar, K., S. Anderson, C. Schexnayder, Guidebook on Risk Analysis Tools and Management Practices to Control Transportation Project Costs, NCHRP Report 658, 2010

Monda, B., M. Giorgino, 2013, An Enterprise Risk Management Maturity Model, Munich Person RePEc Archive, MPRA Paper No. 45421 at http://mpra.ub.uni-meunchen.de/45421/

Morningstar website accessed at http://www.morningstar.com/invglossary/beta.aspx June 30,2014

National Audit Office of the United Kingdom, June 2011, 157-197 Buckingham Palace Road, London

The National Technical Authority for Information Assurance, 2008, Managing Information Risk, A Guide for Accounting Officers, Board Members and Senior Information Risk Owners, prepared by the National Archives.

National Research Council. Building Community *Disaster Resilience Through Private-Public Collaboration*. Washington, DC: The National Academies Press, 2011. p 16.

National Research Council, 2012, *Disaster Resilience: A National Imperative*. Washington, DC: The National Academies Press

New South Wales, 2003, Total Asset Management Guide, NSW Government Asset Management Committee, Sydney, Australia.

New South Wales Treasury, 2012, Risk Management Toolkit for NSW Public Sector Agencies, Volume 1, Guidance for Agencies

New South Wales Treasury, 2002, Private Provision of Public Infrastructure and Services, TRP 02-03.

New South Wales Government, June 2013, Local Government Infrastructure Audit, Division of Local Government, pp. 64-69, 109-112

New South Wales Government Asset Management Committee, 2003, Total Asset Management Manual

New York State Department of Transportation, 2014, Asset Management Plan Draft v 05-02-14, pp 6-1 to 6-16, Table 6.2 and Appendix C

New Zealand Transit, 2011, State Highway Asset Management Plan -2012-2015

New Zealand Transit, 2004, Risk management process manual 0-478-105560-6 Version 3

Oppel, R., A. Ross Sorkin, Nov. Nov. 29, 2001, Enron's Collapse: The Overview; Enron Collapses as Suitor Cancels Plans for Merger, The New York Times

Organization for Economic Develop and Cooperation, 2013) Road Safety Annual Report, International Traffic Safety Data and Analysis Group, Paris, France

Palermo, T., 2011, Integrating risk and performance in management reporting, Research executive summary series, Volum7, Issue 5, The London School of Economics and Political Science, for the Chartered Institute of Management Accountants, pp 1-12

Pierce, L., Nov. 1991, The Rockfall Hazard Rating System, accessed at http://library.state.or.us/repository/2008/200811050838383/index.pdf Feb. 27, 2013

Proctor, G. and S. Varma 2013, Risk Based Transportation Asset Management: Building Resilience into Transportation Assets, Report 5, accessed at http://www.fhwa.dot.gov/asset/pubs/hif13018.pdf

Project Management Institute, Inc., 2008, The Standard for Portfolio Management, Second Edition, Newtown Square, Penn., pp.140

Project Management Institute, Inc., 2008a, A Guide to the Project Management Body of Knowledge, Third Edition, pp. 380

Project Management Institute, Inc., 2008b, The Standard for Program Management, Second Edition, Newtown Square Penn., pp. 312

Province of British Columbia Risk Management Branch and Government Security Office, 2012 Risk Management Guidelines for the BC Public Sector

Public Entity Risk Institute 2014 accessed at http://www.riskinstitute.org/peri/component/option,com_bookmarks/Itemid,44/catid,35/navstart,0/task,detail/mode,0/id,753/search,*/ July 2, 2014.

Queensland Department of Transport and Main Roads, 2006, Skid Resistance Management Plan, Road Asset Management Branch

Queensland Department of Transport and Main Roads, 2002, Part 4 Pavement Maintenance manual

Queensland Department of Transport and Main Roads, 2004, Bridge Inspection Manual, Bridge Asset Management Structures Division

Queensland Financial Accountability Act of 2009 Part 4, Sec. 61.

Queensland Government 2014 Information technology risk management website visited at http://www.business.qld.gov.au/business/running/risk-management/information-technology-risk-management July 1, 2014

RandMark, 2010 A Brief History of Insurance, accessed at http://www.randmark40.com/index.php?option=com_content&view=article&id=33&Itemid=56

Risk Management Society, 2014 What is ERM? Accessed at http://www.rims.org/resources/ERM/Pages/RiskMaturityModelFAQ.aspx

Risk Management Association 2012 Enterprise Risk Management Framework, the Risk Management Association, 1801 Market Street, Suite 300 Philadelphia, PA 19103-1628

Risk Management Institute, 2006, accessed June 30, 2014 at http://www.rims.org/resources/ERM/Pages/RiskMaturityModelFAQ.aspx

Rittenberg, L, 2012, White Paper: COSO 2012 – Updated, Principles-Based, and More Guidance, The American Institute of Certified Public Accountants.

Road Safety Canada Consulting, 2011, Road Safety in Canada, the Government of Canada.

Romero, S., R. Atlas, 2002, WorldCom's Collapse: The Overview: WorldCom Files for Bankruptcy: Largest U.S. Case, The New York Times

Roper, P. and B. Turner, 2008, Why Do We Need to Take a Risk Assessment-Based Approach in Road Safety?, ARRB Group, 2008.

Schwartz, H. et al, Committee on Climate Change and U.S. Transportation, Potential Impacts of Climate Change on U.S. Transportation, Transportation Research Board Special Report 290 p. 133

Scott D., 2003, Wall Street Words: An A to Z Guide to Investment Terms for Today's Investor, Houghton Mifflin Company.

Secretary Department of Treasury and Finance, March, 2011, Victorian Government Risk Management Framework, Melbourne, Australia. pp 37.

Shewart, W., 1931, Economic Control of the Quality of Manufactured Product, reprinted by ASQ Quality Press, Milwaukee, Wis.

Shane, J. K. Strong, D. Gransberg, Project Management Strategies for Complex Projects, Second Strategic Highway Research Program, 2012.

Smith, B. K. Dever-Tod, 2010 Case Studies and best-practices guideline for risk management on road-networks, September Hill GHD Limited, Auckland, TFP Henning, University of Auckland, and National Asset Management Steering (NAMS) Group, Wellington.

State of Queensland, 2011, Department of Transport and Main Roads, Risk Management Guide

Transit New Zealand, 2004, Risk Management Process Manual, 2004, Assurance and Compliance Manager

Transport Scotland, 2007, Road Asset Management Plan

Treasury Board of Canada Secretariat 2010, Guide to Integrated Risk Management, web document accessed at http://www.tbs-sct.gc.ca/tbs-sct/rm-gr/guides/girm-ggirtb-eng.asp on June 11, 2014.

Treishman, J., R. Hoyt., D. Summer, 2005, Risk Management and Insurance, South-Western, Mason, Ohio

U.S. Federal Aviation Administration, 2009, Risk Management Handbook, pp. 1-2,1-5

U.S. Government Accountability Office, 2002, Executive Guide Best Practices in Achieving Consistent, Accurate Physical Counts of Inventory and Related Property.

U.S. Government Accountability Office, 1998, Executive Guide Information Security Management Learning from Leading Organizations

U.S. Government Accountability Office Information Security Risk Assessment Practices of Leading Organizations, 1999.

United States Comptroller of the Currency, OCC Report Examines Risks Facing National Banks and Federal Savings Associations, accessed at http://www.occ.gov/news-issuances/news-releases/2014/nr-occ-2014-91.html July 1, 2014.

United States Securities and Exchange Commission, 2009, Study of the Sarbanes-Oxley Act of 2002 Section 404 Internal Controls over Financial Reporting Requirements, Office of Economic Analysis.

Van Deventer, D, K. Imai, M. Mesler, 2013, Advanced Financial Risk Management, Second Edition, John Wiley and Sons, 2013, Singapore and p 251

Vermont Agency of Transportation, 2013, Vermont Transportation Funding Options, Section 40 Act 153 (2012) Final Report

VicRoads 2008, Risk Management Policy, adopted 2008.

Walton, M., 1986, The Deming Management Method, Perigree Books, p.257

Wood, H, et al, Guidance for Managing NEPA-Related and Other Risks in Project Delivery, Volume 1, Parsons-Brinkerhoff for the National Cooperative Highway Research Program, Web-Document 183, 2011.

Gabel, M. Project Risk Management Guidance for WSDOT Projects, 2013

Washington State Department of Transportation, 2014, Seismic Retrofit Program accessed at http://www.wsdot.wa.gov/Bridge/Reporting/SeismicRetrofitProgram.htm on June 30, 2014.

World Road Association, 2010, Towards Development of a Risk Management Approach, PIARC Technical Committee 3.2. p.196