Beyond the Risk Register –
Incorporating Risk into Asset Investment Decisions

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Word Count:  3,859 words, 9 figures and tables (6,109 total words, including figures & tables)
• Abstract -- 250
• Text – 3546 + 2250 for eight figures and one table (5,796 total)
• References – 63

Submitted -- July 30, 2015
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Abstract

MAP 21 requires that DOTs consider risk in their asset management decisions and agencies are already realizing that risk management can have significant benefits. However, while most DOTs can outline their risks in a general sense, they are struggling with how to include their assessments of risk into their overall investment strategies, and how to perform tradeoffs of risk-based versus performance-based investments. The reality is, various types of risks and their potential impacts have not been assigned to locations on the roadways.

The Colorado Department of Transportation has discovered a method for effectively identifying and prioritizing risk-based opportunities across their highway network. First, they developed a risk register including mitigation strategies, their benefits, and their costs. However, as valuable as the risk register was, it was not clear how to use it to make well-grounded investment decisions. The missing element was that risks needed to be tied to specific locations across the highway network in order to make comprehensive investment decisions.

CDOT now has a geographic representation of its various risk types across the state’s highways, including the types and magnitude of risks that correspond to each highway corridor. With this information, CDOT is now able to evaluate various risk mitigation strategies as part of their overall investment analysis, and make decisions regarding the allocation of investments across the network, including both performance and risk-based opportunities. This analysis will be combined with future work on incorporating corridor redundancy and criticality scores to derive a final geographic framework for decision making.
INTRODUCTION
In an era of constrained resources, effective management of transportation assets is becoming an increasingly important function of transportation agencies. The latest Federal transportation reauthorization, Moving Ahead for Progress in the 21st Century Act (MAP-21), is further institutionalizing asset management by requiring that all state departments of transportation (DOTs) develop a risk-based asset management plan for the National Highway System (NHS).

Even before the MAP-21 legislation was signed into law, the Colorado Department of Transportation (CDOT) had embraced asset management as an important business practice for maintaining its assets in a state of good repair over the long-term with the least investment of resources. For example, since 2011 CDOT’s asset managers have been working with their various management systems to develop budget scenarios and explore the relationships between funding and performance. CDOT has established risk-based asset management as the official approach for strategic preservation of the DOT’s assets and related investment decisions for those assets.

CDOT as well as other transportation agencies are discovering the importance of assessing risks and identifying mitigating strategies. In addition, the need to consider risk-based opportunities along with performance-based investments in asset management decisions is becoming accepted. Agencies are beginning to consider various levels of risk, including the corporate or “agency” level risks, as well as program and project level risks.

BACKGROUND
In early 2013, CDOT embarked on a project to formulate a transportation asset management plan, or TAMP. During that year, the first version of CDOT’s TAMP was drafted, refined, and published. At CDOT, asset classes beyond the MAP-21 requirements of Pavement and Bridges were covered in the TAMP, and these included Maintenance, Buildings, ITS, Fleet, Tunnels, Culverts and Geohazards.

As part of formulating the TAMP a gap assessment was performed, that explored the TAM-related capabilities that might need further development. This assessment spanned five dimensions in evaluating the agencies TAM capabilities, including:

1. Policy Guidance and Leadership
2. Planning and Programming
3. Program Delivery
4. Information and Analysis
5. Organizational

The result of this assessment indicated ten overall gaps for TAM, three of which are specifically related to risk (#2, #3, #4), as shown in the list below. Multiple others are strongly related to risk, such as #1, #5, #6, and #9.

1. Develop and document the current budget distribution, project selection and project tracking process
2. Integrate risk into planning and programming
3. Develop strategies to manage project and program delivery risks
4. Establish a risk framework to evaluate strategies
5. Analyze budget tradeoffs across programs
6. Improve project scoping and optimization
7. Incorporate life-cycle analysis into decision-making
8. Clarify the role of target setting
9. Implement a strategic management framework
10. Communicate benefits of TAM

Needless to say, the emphasis on risk was significant. A major effort was begun to establish how overall risk management would be approached at CDOT. A key part of this effort was to identify and characterize risks across the department, and for multiple levels, such as agency, program, and project-level risks. This effort began with an objective to draft a risk register that would be included in the original Risk-Based Asset Management Plan (RB AMP) that CDOT was planning to finalize in late 2013 (Reference 1).

An excerpt of the Risk Register is shown in Table 1 below. Filling out the risk register began by identifying potential risk events, and then assembling a set of information regarding each risk. This included noting the level of risk, such as agency, program, or project level. In addition, the corresponding asset class was also noted. The scoring was done for all identified risk event types by estimating the probability of occurrence as well as the anticipated impact, should these events occur. Impacts were largely measured in terms of Safety, Mobility, Asset Damage, and Other Financial Impacts as listed here, and illustrated in this excerpt of the Risk Register. Other considerations were also included to finalize the scores as shown in this example.

- Mobility (impact on access for the traveling public, commerce, etc.)
- Safety (crashes, injuries, fatalities, property damage)
- Damage to the asset (maintenance and construction impacts)
- Other Financial Impacts (community, overall economy, etc.)
Lastly, risk management strategies were determined for each identified risk, including their benefits in terms of risk reduction, and their costs of implementation. Please note, however, that the context of the Risk Register was statewide, and the candidate risk management strategies listed in the Register were only general in nature and did not apply to specific situations. Hence the Risk Register was limited in its capabilities to support detailed decisions.

Following the initial draft of a risk register, and the release of the first RB AMP, it was decided to continue to further develop the register. A major part of this effort was to further refine the various types of risks that CDOT faces. The effort also included a refinement of the proposed management strategies for each risk event type, along with estimated costs and benefits. Part of this refinement was to consider more than one management strategy, if feasible, rather than just considering a single strategy for each risk.

The updated Risk Register considered over 100 risks, and the risk scores associated with these risks are shown in Figure 1. Note that the risk scores for the top 50 or so risks are where the majority of risk to CDOT resides. This information was very useful later on in the analysis approach that was chosen.

<table>
<thead>
<tr>
<th>Event / Occurrence</th>
<th>Likelihood</th>
<th>Safety</th>
<th>Mobility</th>
<th>Asset Damage</th>
<th>Other Financial Impact</th>
<th>Funding</th>
<th>Insurance</th>
<th>Reputation</th>
<th>Political</th>
<th>Social</th>
<th>Risk Score</th>
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<tbody>
<tr>
<td>Voted Priority</td>
<td>Level Risk ID</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Project 1b</td>
<td>Floodng (resulting in long term impacts – damage to assets, requiring replacement)</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Project 1a</td>
<td>Burn area - post fire debris flows, blocked culverts – loss of service</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>23.0</td>
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<td>Project 1l</td>
<td>Avalanche requiring maintenance but no or minimal delay</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>7.9</td>
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<tr>
<td>Project 2d</td>
<td>spotting required by contractors for safety related issues</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>16.1</td>
</tr>
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<td>Program 2a</td>
<td>Unfunded maintenance requirements – e.g. regulatory</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>15.8</td>
</tr>
<tr>
<td>Project 3e</td>
<td>Miscellaneous (need more of an event description) – spill, e.g. Hwy 6</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>15.8</td>
</tr>
<tr>
<td>Project 3l</td>
<td>Retaining walls (failing and impacting traffic)</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>15.0</td>
</tr>
<tr>
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<td>Crash with fire occurs inside a tunnel resulting in a loss of service</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>13.5</td>
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<tr>
<td>Project 3m</td>
<td>Overhead bridges are in danger of being hit - over height</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>12.4</td>
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<tr>
<td>Program 3l</td>
<td>Hit I-70 inaudible pull funding from other projects</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>11.0</td>
</tr>
<tr>
<td>Program 3b</td>
<td>Retirement of key people, loss or turn-over of staff, resulting in loss of knowledge</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>11.0</td>
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<tr>
<td>Program 3i</td>
<td>Data management that impacts ability of CDOT to document accomplishments</td>
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<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>11.0</td>
</tr>
<tr>
<td>Project 3k</td>
<td>ITS or traffic control failure – resulting in safety impact</td>
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<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>11.0</td>
</tr>
<tr>
<td>Project 3g</td>
<td>Avalanche causing delay</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>11.0</td>
</tr>
<tr>
<td>Agency 3a</td>
<td>Bridge failure – structural, other than hits, scour, resulting in loss of service</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>10.8</td>
</tr>
<tr>
<td>Agency 3d</td>
<td>Revenue variations/uncertainties – inability to predict/project total funds available</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>10.5</td>
</tr>
<tr>
<td>Project 3g</td>
<td>Avalanche requiring maintenance but no/minimal delay</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>9.6</td>
</tr>
<tr>
<td>Project 3d</td>
<td>Culverts less than 48 inch diameter (failing and closing road – not managed currently)</td>
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<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>9.5</td>
</tr>
<tr>
<td>Project 3e</td>
<td>Project delay due to environmental, utility, RR, or right-of-way issues, or landowner claims</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>8.5</td>
</tr>
<tr>
<td>Agency 3g</td>
<td>Return of commodity price volatility</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>7.5</td>
</tr>
<tr>
<td>Project 3a</td>
<td>Rockfall incident requiring maintenance, but no or minimal mobility impact</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Table 1: Risk Register Excerpt
Another result from the Risk Register was a breakout of risks by asset class, as shown in the bar chart in Figure 2. This type of information was very useful in the further analysis of risk. For example, one can see that several of these classes of risk have a geographic component to them. In addition, the collection of ”Agency” risks identified in the Risk Register needed to be further dissected, and the result was that these consisted of not only geographic-related risks, but also many risks that were related to the agency at the corporate level. These risks include:

- Revenue uncertainties
- Political risks
- Construction cost variability
- Organization-wide processes related to project delivery

These types of risks largely affect overall system performance and whether projects are delivered on time, as intended, and delivering the targeted performance. (Reference 2). But in general these risks do not have specific geographic elements to them.
Revision 1 of the Risk Register was then completed during the fall of 2014. This version of the register is a solid, complete collection of risks and their associated attributes. But again, the register by itself provided limited information and guidance regarding just how to allocate funds across regions, and specific highways. For example some risks are at the programmatic level or “agency” level and involve processes and events that affect an entire agency (Reference 2). However, a significant number of risks involve a geographic component, and understanding risks by location is important. Therefore, CDOT needed a method for using the information assembled in the Risk Register in order to assist in decisions that involved investment allocation across the highway network.

Figure 3 illustrates risk management capabilities that might be possible for an agency to develop over time. For example, some types of risk, such as Geohazards, are understood at a fairly mature level at CDOT, as shown at the upper right part of the diagram (Reference 3). Most other types of risks, however, were not understood at this level at CDOT. Therefore, in order to have a workable understanding of risks by location on the network, an approach was needed in order to achieve at least an “intermediate” level of understanding as illustrated in Figure 3.
STUDY OVERVIEW

Based upon the need to incorporate risk into CDOT’s investment decision making, a new capability needed to be developed. Using available information, and the requirements to be able to identify and manage risks across the highway network, a suitable approach was defined.

What did we develop?

- A method for understanding risk across the highway network
- Specifically, an approach to identifying where the risks are by corridor, not only in terms of total risk per highway segment, but in terms of specific risk event types, and the affected asset classes

Why is this important?

- To be able to include risk in asset management decisions
- In other words, CDOT needed ability to evaluate and prioritize risk-based opportunities in general
- Some risks are geographically distributed, so a means to analyze risks by location was needed, starting with corridor type
- Risks also needed to be examined by asset class, as well as by specific corridors
- CDOT needed the ability to consider “system risks”, such as the combined effects of risk event types that might affect multiple asset classes
The ability to consider various methods for packaging risk management strategies and solutions, such as site-specific solutions versus corridor-wide mitigation strategies was considered desirable.

Also desired was an ability to evaluate synergies and compromises between risk mitigation strategies.

It was desired to be able to consider risk mitigation strategies along with performance-related treatments and enhancements, and make tradeoffs between these investments.

In summary, CDOT needed the ability to include risk-based opportunities in overall asset management investment tradeoff analysis and project selection decisions.

Overall Requirement – This new capability should enable risks to be evaluated across the highway network, and strategies to be considered for managing or mitigating the risks. The capability that resulted now allows risk and performance-based opportunities to be considered together and prioritized.

Study Approach – Corridor-based Risk Analysis

The following paragraphs provide the details of the steps that were followed in creating this new capability. The diagram shown in Figure 4 illustrates how information from the Risk Register was utilized to begin the process. Using the information from the Risk Register, and expert knowledge from various asset managers, the risk scores from the register were spread across corridor types for those risk types that had not previously been linked with location. In spreading the risk scores, the resulting information included details such as the asset classes associated with the risk scores for each corridor type. Ultimately, by cross-walking the scores for each corridor type to the actual corridors, on a per mile basis, the process was completed.
The first step was to begin with the statewide Risk Register. The top 50 risks that the agency faces were chosen as the focus of the study. The scores of these risks were noted, as well as the asset class involved. The objective was to spread these scores across the highway network, and associating risk to the type of corridor(s) was determined to be a realistic and efficient way to accomplish this.

Then, in order to do the spreading exercise, the next step was to characterize the highways within the network by type of corridor so that the identified risks could be associated with these types. To accomplish this, the task was to identify corridor types as a function of terrain, traffic level, interstate versus other NHS highways, urban versus rural, etc. There were a total of 17 combinations of these factors that were relevant to the objective of spreading risks to the highway network.

- Terrain type – Rolling, Plains, Mountainous
- Rural versus Urban
- Traffic Level – Low, Medium, High
- Interstate or Not
Once the corridor types were determined, it was necessary to devise a method for transferring the risk scores from the Risk Register to the corridor types, and then on to specific corridors. The method that provided the best balance between rigor and useful outcomes was to:

A. Meet with each asset class team and discuss how each of the risk event types would apply to the various corridor types

B. Splits of each risk score per corridor type were then discussed. For example, some risks were largely related to mountain corridors. This assignment of risks to corridor types was the enabler of distributing the risk scores across the highway network.

C. Some risks were assigned to combinations of corridor attributes. For example, a risk might be most prevalent in a corridor that was in the mountains AND was related to high traffic. There were several combinations of corridor attributes that appeared multiple times in terms of associating risks to the corridor types. Recognizing this made the calculations easier to model, and hence to achieve useful results efficiently.

D. After holding the sessions with the asset class owners, it became evident that a spreadsheet tool would be quite helpful in spreading risk scores to the corridor types and bookkeeping the results.

Hence, a tool was built to facilitate the spreading of risk scores across corridor types so that department personnel could analyze risks by corridor type, and eventually by individual corridors. The tool consists of columns for each of the corridor types, and rows for each of the risk event types from the Risk Register. The tool was constructed to spread the risks using Microsoft Excel.

Using the Risk Spreading Tool

At this point the team was ready to load the tool with the equations that would simulate the logic for spreading each risk score across corridor types. For instance, let’s examine a risk that was determined to be 80% applicable to mountainous terrain with high traffic. For this combination, the equations that were loaded into the tool accounted for 80% of that risk score by allocating it to the mountainous, high traffic corridors, and the remaining 20% of the risk score was allocated to the remaining corridor types.

The process was to input equations for each of the corridor types for each risk type, and let the tool calculate the portion of the risk score for that risk type for each corridor type. The Risk Register was utilized in this effort by choosing the top risks for each asset class. Specifically, risks with scores of greater than 10.0 were chosen to be used in this analysis. These risks were also the top 50 risks.

Once this was completed, the tool was then exercised, and risk scores were spread across corridor types. Since the scores were already identified as associated with a specific asset type, the risks per corridor types could be split out by asset class. Thus, the tool was very effective at bookkeeping the risk scores as well as spreading them across the corridor types.
As mentioned earlier, there were relatively few combinations of corridor attributes where the risks scores were prevalent. Therefore this made the usage of the tool fairly manageable, in terms of creating the score-spaying equations for allocating risk across the corridor types. The list of corridor attributes which served as a repeatable set of risk-spaying archetypes are listed here. These few combinations of corridor attributes significantly reduced the number of sets of equations needed to spread the risks across corridor types from needing sets for all combinations.

- Mountains
- Mountains, Rolling
- Interstates
- High Traffic
- Mountains, High Traffic
- Plains, Rural
- Urban

**RESULTS OF CORRIDOR-BASED RISK ANALYSIS**

After running the tool and spreading the risks across corridor types, the results were plotted up. Figure 5 shows the overall risk scores (total) per corridor type that resulted.

**FIGURE 5  Total Risk Scores by Corridor Type**

These results were explored further by separating out the risk scores by asset class, per each corridor type. These results are shown here in Figure 6.
These sets of information are very useful as is, but the information needed to be distributed across specific corridors for each corridor type. For example, a corridor “type” might have a total of 2,000 miles of actual centerline miles. Therefore the risk scores for that corridor type now needed to be distributed across those 2,000 miles, in order to get an actual risk score per mile for every corridor of that type in the network. Hence, the effort was to cross-walk risk scores (both total and for each asset class) to individual corridors using GIS analytics, from the risk scores for corridor types. The information for each corridor, i.e. total risk scores and scores by asset class, are in the form of risk score per mile. Hence, with the risk scores mapped from the corridor types to specific corridors/segments, the agency was able to map and query the scores by road segment as shown in the Figure 7 below.
FIGURE 7  Total Risk Scores by Corridor

Similarly, risk scores are now available to be portrayed by each asset class, for each corridor in the highway network. An example is shown in Figure 8 for bridge-related risks.

FIGURE 8  Risk Scores for Each Asset Class, by Corridor
GIS-based analysis, on an ad hoc basis and/or perhaps for a set of canned reports, will now be possible for exploring and portraying where each type of risk is on the network. Initially the display was as simple as color-coding the risk level/score (with a legend of course), for both the total risk score per mile as well as for any asset class risk score (also per mile). Now, any combination of asset class risk scores is viewable as well. Therefore the power of GIS-based analytics, for appropriate layers of information, should provide regional decision makers with valuable information to formulate and evaluate projects.

Supporting TAM Decision Making with Corridor-based Risk Analysis

Program-to-Program Investment Allocation

The capability described above enables a user to query total risk score by corridor, or region, or any other geospatially defined area. In addition, the analysis also allows the query of risk score by any geographical area by individual asset class as well. Finally, the usage of GIS analytics will facilitate the examination of combinations of asset classes. This information can be used to support investment analysis of how to best allocate risk-related funding.

Part of this analysis would include the use of a “Criticality Index” for weighting the corridors that have more importance than others. For instance, a corridor may have high traffic in general as well as a heavy freight and commerce component. In addition, this corridor may have few alternative routes to rely upon. Therefore, this may be termed as a “critical corridor”. This consideration may be used as a multiplier on the risk scores from the corridor risk analysis in prioritizing and allocating funding.

Project Formulation and Scoping

Using the results of this corridor-based risk analysis can also be valuable in formulating and scoping projects. The economics of a candidate risk management solution will ultimately be a major consideration in putting a good project together. But in narrowing down the locations within a region for potential risk-based investments, the risk scores by location as well as by asset class and location should prove useful. For example, if a corridor has a high overall risk score, and the asset-based risk information can provide additional insight into the types of risks involved, then the decision maker can begin to identify potential risk-based opportunities for investment.

As the agency develops more and more capabilities in identifying risks, assigning them to geographic location, or location along each corridor, the ability to create and utilize “bottoms up information” will evolve. The Geohazards set of risks is a good example of how a risk management plan for a category of risks can be geospatially enabled, and used to perform a variety of analyses. But until those capabilities are in hand for most asset classes and categories of risk, the corridor-based information developed in this approach will provide a useful “top down” capability as described here.
For example, once a regional decision maker has identified potential risk-based investments within a corridor with a high overall risk score, the benefits and costs of specific candidate investments can then be calculated. This economic information, together with the knowledge of anticipated performance-based treatments in the same stretch of road, will support the formulation of coherent projects that contain both risk and performance-based considerations.

**SUMMARY**

CDOT now has a basic method for making investment decisions that includes the consideration of risk. This approach allows the decision maker to examine risk event types and asset class impacts regarding each corridor in the network. Additional information to support project formulation will now be available, for evaluating both risk and performance-based opportunities. The approach also will enable decision makers to include packaging considerations regarding risk management strategies, and whether a solution should be site-specific, corridor-based, regional, or network-wide.

The evolution ahead will involve estimating the benefits and costs of specific, proposed risk management strategies, for a given location, along with the redundancy and resiliency of specific corridors. Eventually decision makers will be able to consider synergies and compromises between risk mitigation strategies. In other words, strategies may reinforce each other in terms of benefits of their implementation; however some strategies may “cancel each other out” and result in a waste of invested dollars. The end result will be a fully mature means of examining risk across the highway network, and making risk and performance-based investments with greater confidence.

**REFERENCES:**