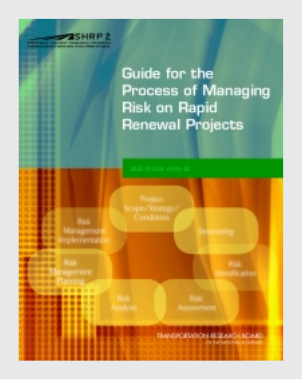

Guide for the Process of Managing Risk on Rapid Renewal Projects

DETAILS

0 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-43471-3 | DOI 10.17226/22665

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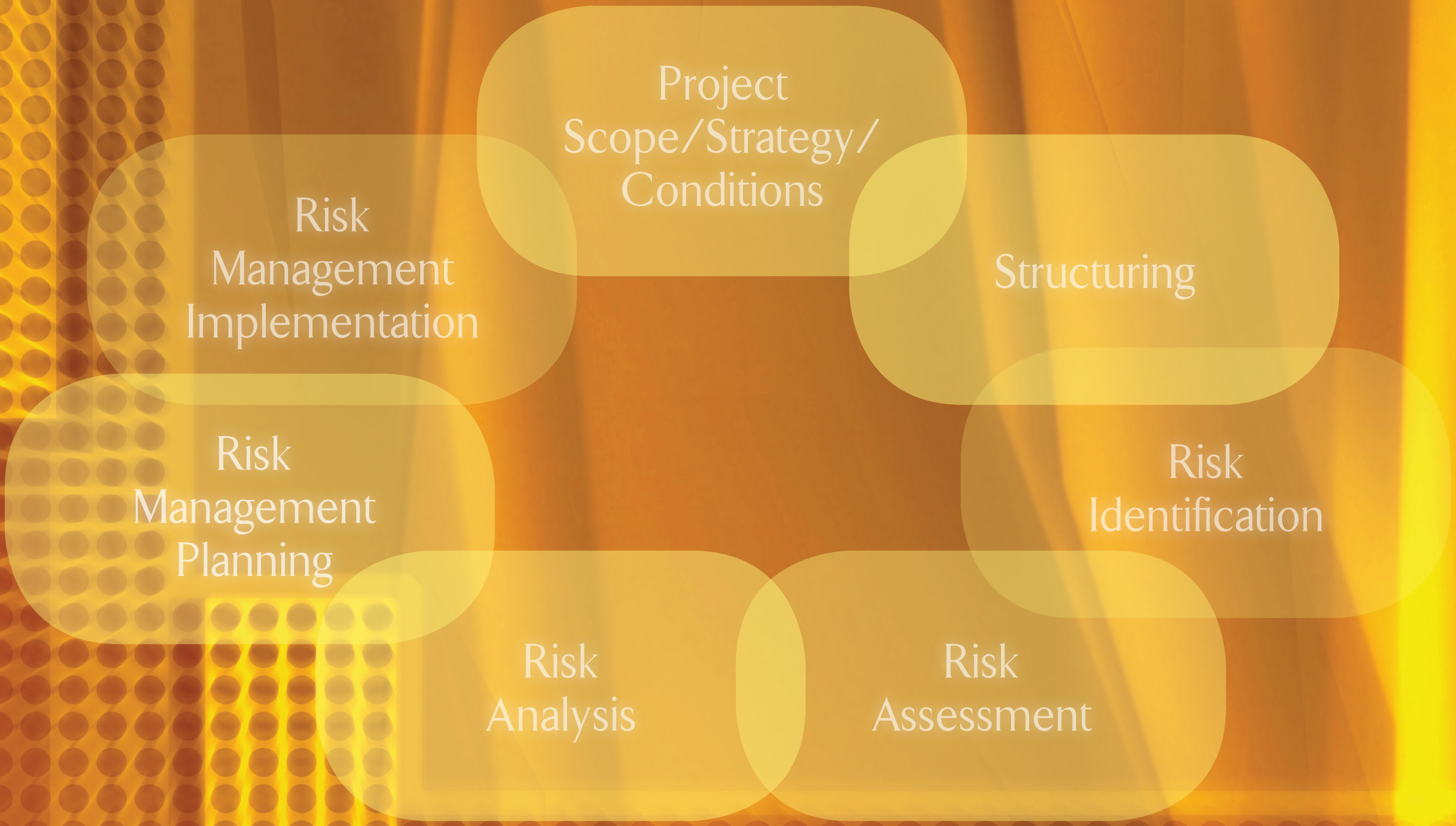
Golder Associates Inc.

SHRP 2
STRATEGIC HIGHWAY RESEARCH PROGRAM
Accelerating solutions for highway safety, renewal, reliability, and capacity

Guide for the Process of Managing Risk on Rapid Renewal Projects

S2-R09-RW-2



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THE SECOND STRATEGIC HIGHWAY RESEARCH PROGRAM

Guide for the Process of Managing Risk on Rapid Renewal Projects

SHRP 2 Report S2-R09-RW-2

Golder Associates Inc.
with
Keith Molenaar
Michael Loulakis
Ted Ferragut

TRANSPORTATION RESEARCH BOARD

Washington, D.C.
2014
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SUBJECT AREAS

Construction
Highways

THE SECOND STRATEGIC HIGHWAY RESEARCH PROGRAM

America's highway system is critical to meeting the mobility and economic needs of local communities, regions, and the nation. Developments in research and technology—such as advanced materials, communications technology, new data collection technologies, and human factors science—offer a new opportunity to improve the safety and reliability of this important national resource. Breakthrough resolution of significant transportation problems, however, requires concentrated resources over a short time frame. Reflecting this need, the second Strategic Highway Research Program (SHRP 2) has an intense, large-scale focus, integrates multiple fields of research and technology, and is fundamentally different from the broad, mission-oriented, discipline-based research programs that have been the mainstay of the highway research industry for half a century.

The need for SHRP 2 was identified in *TRB Special Report 260: Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life*, published in 2001 and based on a study sponsored by Congress through the Transportation Equity Act for the 21st Century (TEA-21). SHRP 2, modeled after the first Strategic Highway Research Program, is a focused, time-constrained, management-driven program designed to complement existing highway research programs. SHRP 2 focuses on applied research in four areas: Safety, to prevent or reduce the severity of highway crashes by understanding driver behavior; Renewal, to address the aging infrastructure through rapid design and construction methods that cause minimal disruptions and produce lasting facilities; Reliability, to reduce congestion through incident reduction, management, response, and mitigation; and Capacity, to integrate mobility, economic, environmental, and community needs in the planning and designing of new transportation capacity.

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SHRP 2 Report S2-R09-RW-02

ISBN: 978-0-309-27292-6

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ACKNOWLEDGMENTS

This work was sponsored by the Federal Highway Administration in cooperation with the American Association of State Highway and Transportation Officials. It was conducted in the second Strategic Highway Research Program (SHRP 2), which is administered by the Transportation Research Board of the National Academies. The project was managed by James Bryant, SHRP 2 Senior Program Officer, Renewal.

FOREWORD

James W. Bryant, Jr.
Ph.D., P.E., SHRP 2 Senior Program Officer, Renewal

In recent years, risk management has become an area of emphasis for transportation agencies. Project risks must be managed regardless of how they are allocated between the contractor and the transportation agency. Transportation agencies continue to seek a balanced approach to risk allocation because, generally speaking, increased risks to the contractor will be reflected in increased bid prices. The incorrect allocation of risks can also lead to project delays and increased costs.

Agencies are moving toward the use of innovative contracting approaches and accelerated construction techniques to complete projects more rapidly. Although guidance exists and is being developed for managing risks on transportation projects, this guidance has generally not included consideration of the unique features of rapid renewal projects, which are those projects that use accelerated project delivery.

Several state transportation agencies have been exposed to the formal risk management required by the Federal Highway Administration on infrastructure projects that exceed a total estimated cost of $500 million. Few transportation agencies use formalized risk assessment and management programs that are not associated with "major projects."

This guide and supporting products provide tools that transportation agencies can use to apply risk management principles systematically to their projects. They are specifically useful for those projects that are below the $500 million threshold for major projects.

The primary objectives of Renewal Project R09 were to address the general lack of understanding of risk and risk management associated with the unique aspects of rapid renewal projects and to develop practical guidance and materials for the application of risk management methods to the rapid renewal project development process in a manner consistent with state transportation agency business practices.

The products developed as part of this project include (1) a comprehensive guide, with extensive checklists and a comprehensive example project application, and (2) associated implementation materials for conducting risk management on relatively simple rapid renewal projects, including a presentation introducing the risk management process and a Microsoft Excel template (with user's guide) for both documenting the process and conducting the necessary analyses.

The guidelines and corresponding training materials provide the state of the practice for risk management on rapid renewal projects and also a detailed process of risk identification and mitigation strategies. The materials will be useful to state departments of transportation, municipal agencies, and consultants working on projects that involve some type of accelerated project delivery and will make the risk management process more accessible for use as a standard project solution.

CONTENTS

EXECUTIVE SUMMARY

In the past, many transportation projects have performed poorly (e.g., in terms of ultimate cost and schedule to completion), often because of unexpected problems. This might be amplified for rapid renewal projects, which are intended to accelerate schedule and minimize disruption through construction, without adversely affecting either costs through construction or postconstruction longevity. By definition, these rapid renewal methods typically are innovative, with little past experience from which to learn, and possibly more susceptible to poor performance.

This guide presents a formal risk management process (Figure ES.1) to better understand and to actually optimize project performance specifically for rapid renewal projects, especially by anticipating and planning for potential problems (risks) and potential improvements (opportunities). This process, which is a significant expansion of a previously developed risk management process for non–rapid renewal projects (for which the expanded process is also applicable), consists of a well-defined series of steps, each of which has been described in appropriate detail, including possible variations. Sufficient guidance is also provided to ensure compatibility and consistency among the various steps, and ultimately to ensure adequate accuracy and defensibility of results (where adequacy depends on how the results will be used), as efficiently as possible. The steps, which are sequential and in some cases iterative, include

Step 1. Structuring. Define the base project scenario (including the relevant project performance measures of cost, schedule, and disruption through construction, and postconstruction longevity, and trade-offs among them), against which risk and opportunity can be identified, assessed, and eventually managed.

Step 2. Risk Identification. Identify a comprehensive and nonoverlapping set of risks and opportunities (i.e., scenarios that might occur, changing the base project performance). In addition to brainstorming and then analysis of risks, to ensure completeness, check the lists of common risks that have been developed. Document the set of risks and opportunities to start the project *risk register.*

Step 3. Risk Assessment. Assess the severity of each of the risks and opportunities in the risk register, and then prioritize them on that basis. Generally, this is done by (a) subjectively assessing the relevant risk factors (i.e., impacts if the scenario occurs and the probability of the scenario occurring), either qualitatively (e.g., "high" versus "low" descriptors are quantitatively defined by ranges of values) or quantitatively (mean values or, for quantitative risk analysis, full probability distributions); and then (b) analytically combining the risk factors to determine changes in project performance measures and thereby severity. Document the risk-factor assessments in the project risk register.

Step 4. Risk Analysis. Analytically combine the base and risk factors to determine the project performance measures (e.g., ultimate project escalated cost) as well as changes in those measures (e.g., combined using trade-offs, as a measure of severity) associated with each risk. This can include quantification of the uncertainty in (and correlations among) those performance measures, as a function of subjectively assessed uncertainties in the base and risk factors. Note that appropriately conducting risk analysis requires specialized skills.

Step 5. Risk Management Planning. Identify and evaluate possible ways to proactively reduce risks, focusing on those that are most severe. Evaluate each possible action for its cost-effectiveness, considering changes in both base (e.g., additional cost) and risk (e.g., reduced probability) factors, and select those that are cost-effective. Consider reanalyzing the project performance measures for this risk reduction program, including quantification of uncertainty, based on which appropriate budgets and milestones can be established (e.g., to achieve a specified level of confidence). As part of these budgets and milestones, contingencies (in the form of additional funds and time, as well as recovery plans) and procedures to control their use would be established. Document this in the *risk management plan*.

Step 6. Risk Management Implementation. Implement the risk management plan as the project proceeds, including (a) monitoring the status of risk reduction activities and changes in risk (whether attributable to risk reduction or simply to changes in project development, conditions, and information) and (b) monitoring budget and milestones, especially with respect to contingencies. This might involve periodic updates (iterate Steps 1–5) at regular intervals or at major milestones or changes. For example, contingencies might be reduced as engineering reports or designs are completed and risks are avoided or reduced.

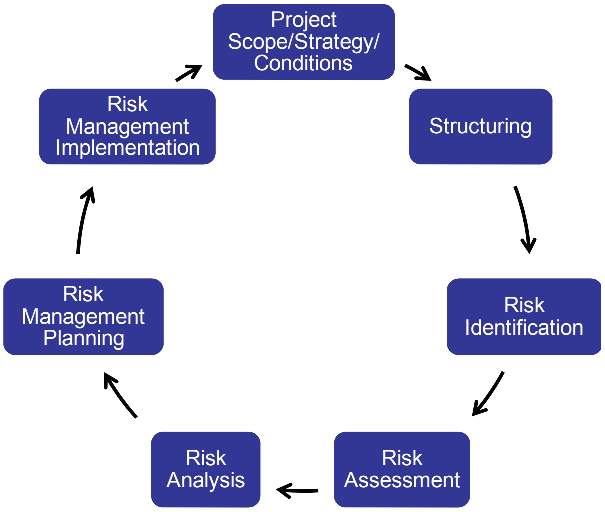


Figure ES.1. *Iterative risk management process.*

Adequate direction is also provided to help ensure successful implementation of the risk management process described herein, which requires adequate planning and resources, especially qualified facilitators and experts. A course also has been developed to train department of transportation (DOT) staff to successfully implement this guide, focusing on training DOT facilitators to (a) implement the risk management process directly on relatively simple rapid renewal (as well as non–rapid renewal) projects and (b) supervise the evaluation of more complex projects and perform quantitative risk analysis. To help these facilitators, in addition to this training course (which includes annotated PowerPoint slides and application to a hypothetical project), an overview presentation of the process and forms for documenting inputs (which are also available electronically in a Microsoft Excel workbook template that automates the necessary analyses) have been developed for relatively simple projects. The template and related training materials are available online at www.trb.org/Main/Blurbs.168369.aspx.

The primary benefits of the risk management process described in this guide include improved project performance as well as better understanding and clarity of the project and its range of possible performance. Moreover, it does this defensibly and efficiently. If performed correctly in accordance with the guide, the investment (e.g., in training, workshops, and documentation) should be small relative to the likely benefits of improved project performance, plus the more intangible benefits of better project understanding and the ability to defend significant project decisions.

1

INTRODUCTION

THE PROBLEM

The planning, design, construction, and subsequent operation of highway projects are complex and fraught with uncertainty. The result is that many highway projects have exceeded initial cost estimates and expected completion dates, as well as experienced other undesirable consequences, such as greater-than-expected disruption and poor longevity. As one example, the cost for the "Big Dig" (Central Artery/Tunnel Project in Boston) went from an estimate (for the environmental impact statement decision) of $2.6 billion in 1983 to $14.6 billion by 2001 (see Figure 1.1). Albeit extreme, the example of the Big Dig is not uncommon. A study of 167 roadway projects over the last 70 years shows that most such projects are initially underestimated by an average of about 20%. There is a wide range of such underestimates, with some even being significantly overestimated (see Figure 1.2). Such poor predictions of project performance can have various undesirable consequences; for example,

- Underestimating costs can result in having to find additional funds (which might come from other projects), reducing project scope (and thus project benefits), project delays while being resolved, or decisions to reduce quality (and thus longevity). Conversely, overestimating cost can lead to "starving" other worthwhile projects and to unnecessary work and features.
- Underestimating schedule can result in extended overheads and higher inflation (and thus additional costs), and might result in additional disruption as well as delay in realizing project benefits.
- Underestimating disruption can result in public dissatisfaction, which in turn can lead to project delays while being resolved and additional costs for mitigation.

- Underestimating longevity can result in additional costs for and disruption of operations and maintenance and for replacement, which might be needed sooner than planned.

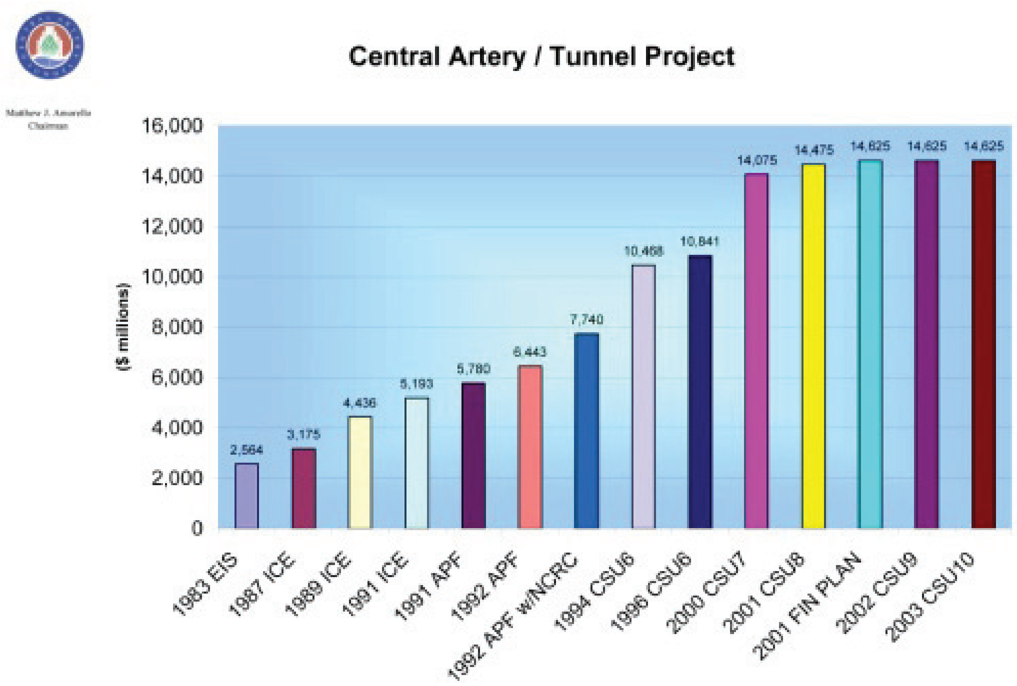


Figure 1.1. *History of "Big Dig" cost estimate (Edwards 2003).*

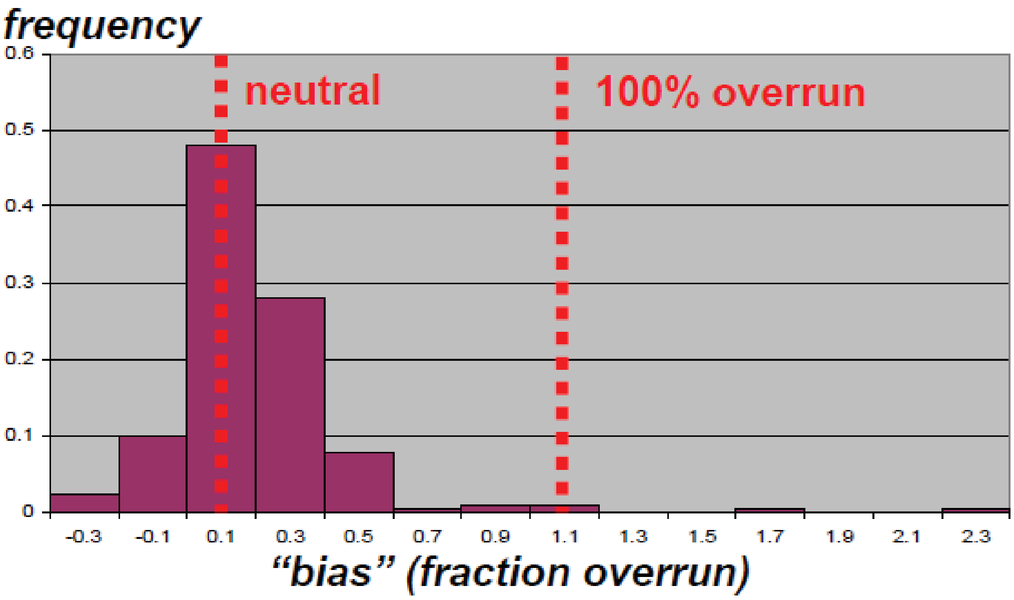


Figure 1.2. *Statistics of past cost underestimates for 167 road projects (Flyvbjerg et al. 2002).*

All of the above, in turn, can lead to poor project decisions and affect the department of transportation's (DOT's) credibility, especially with the public. The loss of credibility and public confidence can make it difficult to obtain approval and funding for future critical infrastructure projects.

Poor predictions of performance are attributable, at least in part, to the generally significant uncertainty in the factors that will determine project performance, especially unforeseen changes or problems that arise as the project develops. For example, many major scope and design decisions must be made during planning, which can significantly affect performance, and subsequent changes might be dictated by external stakeholders such as regulatory agencies and public groups. As another example, the conditions under which the project will be developed might change significantly over time (e.g., market pricing) or simply turn out to be different than expected (e.g., ground conditions). It is also conceivable that, in some cases, performance could even be intentionally underestimated to get project approval and commitment, after which it is difficult to stop a project, even though the underestimate eventually becomes obvious and the associated consequences noted above are realized.

The traditional approach to estimating project performance, which has often led to such poor predictions and subsequent problems, has generally consisted of a "deterministic" (single-value) approach, in which a particular scenario (scope, strategy, design, and conditions), with specific factor values and other assumptions that are intended to be appropriately conservative, is defined. Clearly, however, many other scenarios (with different factor values and thus different performance) are possible, but the likelihood of these other possible outcomes is not assessed and the actual level of conservatism in the deterministic approach is not evaluated. In some cases, the sensitivity of performance to the various project assumptions might be determined, but typically in an ad hoc way, either by judgment or by analysis, to guide further investigation and assessment of the important assumptions, as well as to guide project changes (e.g., via value engineering studies) and potential problem resolution (e.g., via risk management), with the general intent of optimizing project performance. However, because this typically is not done in a formal fashion and not quantified, such optimization cannot be ensured and, in fact, as shown in Figure 1.2, typically has not been successful.

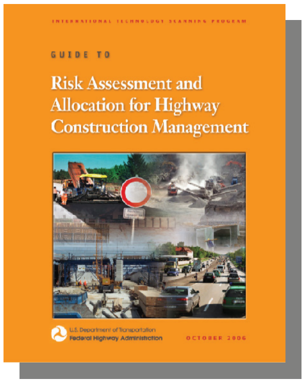
Rapid renewal projects, which by their nature tend to be innovative, create complexities above and beyond traditional projects (TRB 2009). Hence, the uncertainties in project assumptions and performance might be even greater for rapid renewal projects, possibly leading to even poorer predictions and suboptimization of their performance via the traditional approach. This guide focuses on rapid renewal projects. However, because non–rapid renewal projects are generally similar but less complex, this guide is generally applicable to non–rapid renewal projects as well.

Some project issues are programmatic (affecting all projects within a particular program of individual projects, for example, delays in program funding), agencywide (affecting all of the agency's projects, for example, agency resource limitations), or even nationwide (affecting all projects, for example, general inflation). These effects, and how they can best be managed, generally will vary as the number of affected projects increases. However, this guide focuses on individual project-level risks, which include the larger-scale risks as well.

THE SOLUTION

The best approach for effectively dealing with the problems identified above is an appropriate formal (as opposed to ad hoc) risk management process. Risk management processes are new to the rapid renewal context, but several associations (e.g., Project Management Institute and Association for the Advancement of Cost Engineering) and governmental agencies (e.g., U.S. Department of Energy, Federal Highway Administration, and Federal Transit Administration) have employed risk management processes on various projects and programs. A similar process has been developed for FHWA in the *Guide to Risk Assessment and Allocation for Highway Construction Management* (Molenaar et al. 2006). The *Risk Guidelines* (Figure 1.3) are implemented through training workshops developed by Golder Associates (2008a), although not specifically for rapid renewal projects. This existing and accepted process has simply been expanded in this guide and extended to rapid renewal projects.

An appropriate formal risk management approach is primarily intended to optimize project performance. However, it also needs to be efficient and defensible, as well as adequate (as opposed to perfect), in achieving this objective. It also must be compatible with the DOT organization and its projects. The process generally consists of the following two basic sequential and iterative steps: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GUIDE TO

Risk Assessment and Allocation for Highway Construction Management

U.S. Department of Transportation Federal Highway Administration

OCTOBER 2006

Figure 1.3. *Cover of the FHWA's risk guidelines document (Molenaar et al. 2006).*

Step 1: Diagnosis. Identify all significant potential problems and opportunities that could affect project performance, and adequately assess their current severity (either relative or absolute), in terms of their potential impacts and likelihood of occurrence. Such problems and opportunities are relative to an assumed base scenario, which must first be defined and then adequately documented in a project-specific risk register. This might include an analysis of ultimate project performance with quantification of uncertainty in that performance.

Step 2: Treatment. Identify feasible ways to manage those potential problems: (a) individually, with an adequate evaluation of their cost-effectiveness (in terms of reduction in severity, including more negative severity for opportunities); and (b) collectively, the appropriate contingencies (both cost and schedule allowances, as well as future project flexibility as needed). Adequately document such plans in a project-specific risk management plan, which must be successfully implemented, including monitoring, updates (rediagnosis), and decision making throughout project development and contract management.

Note that formal risk management is similar to value engineering (VE), in that the primary objective is to optimize project performance, although risk management focuses on reducing risks (both individually and collectively) whereas VE focuses on optimizing opportunities. Because of this similar objective and a reliance on expert judgment, risk management is sometimes combined with VE, so that the severe risks are first identified and then translated into the opportunities to be evaluated during the VE process.

Hence, a formal risk management process should optimize project performance through a plan to cost-effectively reduce risks, and in the process will help to develop better clarity and understanding of the project and its possible performance. In fact, the range in possible future project performance can actually be determined (through quantitative analysis), and effective strategies for dealing with that performance (e.g., budgeting at the 80% confidence level) can be developed early in the project to ensure project success.

The business case for including risk management as a standard project management component of major capital projects is unambiguous—the ability to better understand potential risks and how to manage them yields benefits far in excess of the costs of adopting risk management practices. This approach is widely considered to be state of the art. Perhaps the most compelling argument for pursuing risk management as a standard practice for rapid renewal projects is that the best agencies and organizations worldwide are doing it, and with great success. Golder Associates have previously developed a similar (but more limited) formal risk management process for FHWA and have also helped to develop parts of a similar (but again more limited) formal risk management process for the Washington DOT, which has successfully applied it to hundreds of their projects, as well as for the Florida DOT, Utah DOT, Nevada DOT, and Ontario (Canada) Ministry of Transportation. Various portions of the process also have been used successfully by Golder Associates on many other projects for various highway agencies [e.g., U.S. DOT/FHWA, California Department of Transportation (Caltrans), Colorado DOT, Virginia DOT, Wisconsin DOT, Kentucky DOT, Pennsylvania Turnpike Authority, King County (Washington) DOT, Seattle DOT, Hong Kong Highway Department] and rail/transit agencies [e.g., U.S. DOT/FTA, Metropolitan Transportation Authority (MTA, New York), Peninsula Corridor Joint Powers Board (Caltrain, San Francisco), Transbay (San Francisco), SunRail (Orlando), Washington Metropolitan Area Transit Authority (WMATA, Dulles), FasTracks (Denver), Evergreen Line (Vancouver, BC)], as well as for nontransportation projects. However, although basically similar processes (or parts of that process, albeit often greatly simplified) have been used in the industry to evaluate numerous other projects, the process has often been misused, producing misleading results and perhaps thereby leading to poor decisions.

THE GUIDE

The primary objective of this guide is to adequately but concisely describe an appropriate method for risk management on rapid renewal projects and provide adequate guidance on implementation. The method should result in optimizing project performance, achieving an appropriate balance of accuracy, defensibility, schedule of results, and resource utilization (allowing the DOT to do as much as it can independently), consistent with DOT and project conditions and requirements. Secondarily, for wider application, the method should be applicable to non–rapid renewal as well as to rapid renewal projects, and for easier acceptance, the method should be simply an extension of previously existing successful and accepted methods.

To achieve the above objectives, this guide focuses on the “why” and “what”; the “how” is covered in more detail in separate companion training and implementation materials. The guide is organized as follows:

- Chapter 2 (Risk Management Process) provides an overview of the process, including an iterative set of steps.
- Chapter 3 (Context for Rapid Renewal) describes the unique features of rapid renewal projects in that risk management process, supported by Appendix A (Inventory of Rapid Renewal Strategies and Methods) and Appendix D (Hypothetical Rapid Renewal Case Study).
- Chapters 4–9 provide details of each step in the risk management process, supported by an example application in Appendix D:
  - —Chapter 4 (Structuring a Project for Risk Management) describes how to construct the base scenario against which risks and opportunities can be identified, assessed, and eventually managed;
  - —Chapter 5 (Risk Identification) describes how to start a risk register and is supported by Appendix B (Rapid Renewal Risk Categories and Risk Management Action Categories);
  - —Chapter 6 (Risk Assessment) is about completing the risk register, including assessing risk severity and thereby prioritizing the risks;
  - —Chapter 7 (Risk Analysis) describes how to analytically combine the base and risk factors to predict project performance, which can be used to establish appropriate budgets and milestones (including contingencies), as well as to better guide subsequent risk management planning;
  - —Chapter 8 (Risk Management Planning) describes how to identify and evaluate possible ways to proactively reduce risks and is supported by Appendix B and Appendix E (Risk Management Plan);

Each technical section (Chapters 2–10) is subdivided into the following subsections:

1. *Introduction,* providing objectives and philosophy and concepts (plus insert for ”in a nutshell”);
2. *Process,* providing methods and guidance [plus, where applicable, inserts for input or analysis forms and template (Appendix C) and an illustrative example (Appendix D), which is carried throughout]; and
3. *Conclusions*

  - Chapter 9 (Implementing the Risk Management Plan) includes monitoring, updating, and decision making and is supported by Appendix E.

- Chapter 10 (Implementing This Guide) includes planning and resources, and is supported by Appendix C (Simplified Risk Management Overview, Forms, Template, and Template User's Guide) and the Simplified Risk Management Training designed specifically for DOT facilitators to evaluate (to a limited extent) relatively simple projects or supervise more complex evaluations or the evaluation of more complex projects.
- Chapter 11 (Conclusions) recaps the process and describes its limitations.
- Glossary and References follow.

CONCLUSIONS

In the past, many transportation projects have performed poorly, for example, in ultimate cost and schedule to completion, often because of unexpected problems. This might be amplified for rapid renewal projects, which are intended to accelerate schedule and minimize disruption through construction, without adversely affecting either costs through construction or postconstruction longevity. By definition, these rapid renewal methods typically are innovative with little past experience from which to learn and possibly more susceptible to poor performance.

A formal risk management process is needed to better understand and to actually optimize project performance specifically for rapid renewal projects, especially by anticipating and planning for potential problems (risks) and potential improvements (opportunities). This process, which is a significant expansion of a previously developed risk management process for non–rapid-renewal projects, consists of a well-defined series of steps, each of which is described in appropriate detail, including possible variations. Sufficient guidance is also provided herein to ensure compatibility and consistency among the various steps, and ultimately to ensure adequate accuracy and defensibility of results (where adequacy depends on how the results will be used), as efficiently as possible. This guidance includes a separate 2-day training course (with annotated slides), especially for DOT risk management facilitators, and an overview presentation of the process and forms for documenting inputs (which are also available electronically in a Microsoft Excel workbook template that automates the necessary analyses) for relatively simple rapid renewal (as well as non–rapid renewal) projects. The template and related training materials are available online at www.trb.org/Main/Blurbs.168369.aspx.

The primary benefits of the risk management process described in this guide include improved project performance as well as better understanding and clarity of the project and its range of possible performance. Moreover, it does this defensibly and efficiently. In fact, if performed according to the guidance presented herein, the investment (e.g., in training, workshops, and documentation) will be small relative to the benefits of improved project performance, plus the more intangible benefits of better project understanding and the ability to defend significant project decisions.

2

RISK MANAGEMENT PROCESS

INTRODUCTION

Objectives

The primary objective of the risk management process, whether at the individual project level or for a program of individual projects, is to optimize project performance (e.g., minimize cost, minimize disruption). As discussed in Chapter 1, problems can arise during a project that lead to undesirable performance. Anticipating the problems up front can lead to management strategies that minimize undesirable performance. For example, delays in property acquisition might delay a project, which in turn might increase project costs, whereas such delays might be avoided through early acquisition.

Similarly, opportunities to improve project performance (e.g., reduce cost) might arise during a project. Anticipating these opportunities up front can lead to management strategies that maximize such desirable performance. For example, reuse of excavated or demolished materials might reduce material and hauling costs but would have to be adequately investigated and approved beforehand. Such opportunities are often the focus of VE, which can be combined with risk management. Hence, the primary objective of the risk management process is to anticipate, evaluate, and plan for such potential problems and opportunities in order to optimize project performance.

Another objective of the risk management process is to complete the process efficiently while producing adequately accurate and defensible results. To achieve this efficiency, it is especially important that, among other aspects, the process be flexible (i.e., that the level of detail

Develop and implement a formal, structured, and iterative but flexible and efficient process to

- Anticipate and plan for potential project problems and opportunities.
- Better understand and control project outcomes.

The focus is on individual rapid renewal projects.

is appropriate and that reasonable approximations are made) and consistent with available information and expert judgment as well as with the needs of the project. Consensus among a broad group of experts helps ensure accuracy and defensibility. For example, such consensus on the process and on the inputs, and thereby on the outputs (results), can often be achieved through well-planned, facilitated workshops. Such workshops can also help achieve a common understanding, among the project team as well as possibly among other stakeholders, of the important elements of the project.

Although there are many approaches to risk management, it is important to establish a relatively formal, structured process, compatible with the overall project management approach. The process described is applicable to individual projects, including rapid renewal projects as well as non–rapid renewal (and even nontransportation) projects, and to programs composed of multiple individual projects. However, the focus in this guide is on individual rapid renewal projects.

Philosophy and Concepts

Project performance can be expressed in specific measures, such as the ultimate project cost or the substantial completion date. Such project performance measures, which are realized in the future, cannot be known with certainty beforehand. However, they can generally be predicted in advance for a specific set of assumptions (e.g., related to assumed quantities and unit costs for particular items), but these assumptions might not necessarily turn out to be true. Other conditions might in fact actually occur, resulting in different performance. In this guide, the following terms are used:

- *Base* describes the conditions and related performance associated with a particular set of assumptions about the planned project.
- *Risks and opportunities* describe the other possible conditions and unplanned events, and their related performance changes, depending on whether they degrade or improve performance, respectively.

Hence, total performance consists of a base component, which is related to a specific set of assumptions, and a complementary risk component, which is related to the differences associated with other possible assumptions. These two components can be estimated separately and then combined appropriately to determine the total. However, in many cases, the risk component will be a function of the base component, so that the base component must be estimated first. Although conceptually the total performance could be estimated directly, this would generally be difficult to do accurately because of lack of detail and, in any case, would not provide information on the likely sources of poor performance (i.e., risks) for subsequent management action.

Total = Base + Risk, combined appropriately

For example: Suppose that the base assumption for costing and scheduling a task is that suitable materials are on hand. However, there is a chance (e.g., 1 in 4) that suitable materials will not be there when needed, in which case it will cost extra and take extra time to obtain those materials—this is a risk.

Conversely, if the base assumption is that suitable materials are not on hand and must be obtained, then there is a chance (e.g., 3 in 4) that suitable materials are already on hand, in which case the time and cost to obtain those materials will have been saved—this is an opportunity.

Once the base assumptions are established for project performance, a comprehensive set of risks and opportunities (i.e., list) can be identified that might lead to changes in that performance. Ideally, to streamline the list and allow for meaningful analyses, the risks and opportunities should be comprehensive and nonoverlapping. Eventually, the items on the list will be prioritized by their severity. The severity of a particular risk (or opportunity) is a combination of two risk factors:

- Its set of possible performance impacts if the risk occurs (e.g., changes in project costs if the risk occurs), when the impacts are often uncertain and might be described in representative scenarios covering the range of possible outcomes; and
- The likelihood of those various scenarios actually occurring during various project phases.

These risk factors will evolve over time as conditions change and the project develops. Ultimately the risks will either occur with specific impacts or not occur (with no impacts). For example, a design risk will generally occur during the design phase, after which it can no longer occur so that, if it has not happened during design, its chance of occurrence drops to zero and it can be "retired" after design. As another example, a design risk might have occurred and been incorporated as a change in the base, in which case it too can no longer happen and it can be retired. The list of risks, including their relevant characteristics, forms the beginning of the project risk register, which the DOT should maintain throughout the project as the risks evolve.

Once recognized, the DOT can proactively manage some risks through various actions, aimed either at reducing their chance of occurrence (prevention) or at their impacts if they do occur (mitigation). For example, potential delays, which can result in additional costs, might be avoided by starting preliminary work early, even though that work might not eventually be needed. Presumably, this preliminary work should be done if its cost is less than the potential cost of delay considering its probability of occurring as well the other performance objectives (e.g., minimizing disruption). Such proactive risk management is similar to, and can be combined with, VE, in which opportunities to improve project performance are identified, evaluated, and recommended.

Even after such proactive risk management, there will be residual risks, which the DOT must accept and thus accommodate in the budget and schedule. Typically, DOTs do this by establishing and controlling contingencies for cost and for schedule, over and above the base cost and schedule. These contingencies can be established at various levels of conservatism or levels of confidence in their sufficiency—the higher the level of conservatism, the higher the chance that they will be sufficient, but also the more funds that must be committed to the project and not made available for other projects. The appropriate level of confidence should be a DOT policy rather than a technical issue, balancing the consequences of going over budget with those of going under budget. For example, many agencies choose an 80% confidence level, for which there is a 20% chance of exceeding budget (without cutting scope).

Adequate controls, in the form of procedures, are needed to ensure that the contingency does not simply become self-fulfilling, but remains adequate to cover remaining risks throughout the project and surplus contingency is released. However, because contingency is established at less than a 100% confidence level, there is a chance that it will not be adequate. In such cases, either additional funding must be found or the scope of work must be reduced in order to complete the project. These constitute contingency (or recovery) actions (as opposed to contingency funds or time) and should also be planned beforehand.

Hence, once the project risk register has been developed, the DOT should develop and subsequently implement a plan to effectively manage those risks, thereby optimizing project performance to the extent possible. This plan consists of management actions to proactively reduce specific high-priority risks, to establish and maintain adequate budget and schedule to accommodate remaining risks, and to modify the project as necessary if the established budget or schedule is inadequate despite proactive management actions. Moreover, this plan should establish the procedures and organization necessary to successfully carry out those actions. This plan is called the project risk management plan, which should also be maintained throughout the project as conditions and thus risks change.

PROCESS OF RISK MANAGEMENT

Although the risk management process can be (and in the past has been) done in a variety of ways with various degrees of success, the general process of successful risk management consists of a series of steps, which are applied at various times throughout a project. These steps, which are discussed individually in more detail in subsequent chapters specifically for individual rapid renewal project risk management, are shown in Figure 2.1 and consist of the following:

Step 1. Structuring. Before risks can even be identified, much less managed, the DOT must adequately define the base project. This base consists of the planned project scope, strategy, and key conditions, as well as a set of assumptions about those aspects that are not yet known for certain. Base project performance (e.g., project cost, schedule) is then determined as a function of these base project elements. Generally, this base project description is developed at a relatively broad level of detail simply via facilitated discussions with the project team. A template that identifies all relevant elements is often used to ensure that they are adequately described at the appropriate level of detail. This step, and the associated template, is subsequently discussed further in Chapter 4.

Step 2. Risk Identification. Once the base assumptions have been established and the project has been structured (Step 1), the DOT must adequately identify the risks and opportunities relative to that base. The intent is to identify a comprehensive and nonoverlapping set of risks and opportunities. To help accomplish this, the risks are often categorized; for example, in the context of the project phase in which they might occur. Generally, a combination of techniques, ranging from facilitated group brainstorming to risk checklists, is used, considering all readily available information. As the project develops and conditions change, additional risks might be identified, while some existing risks will be retired. The updated list of risks is maintained in the project risk register. This step is discussed further in Chapter 5.

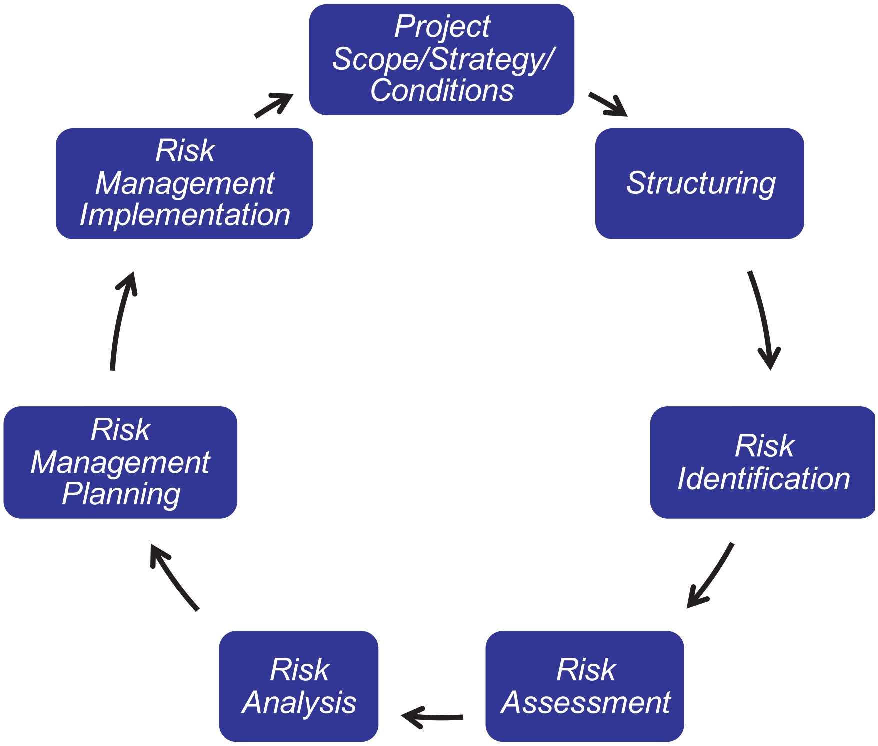


Figure 2.1. *Iterative risk management process.*

Step 3. Risk Assessment. Once the DOT has identified risks and opportunities (Step 2), the DOT should adequately assess the relative severity of the risks and opportunities so they can be prioritized for subsequent management (Step 5). If the DOT chooses to quantify uncertainty in project performance through risk analysis (Step 4), then the risk factors must also be adequately quantified, from which their severity and prioritization can be determined. The risk factors (i.e., the impacts if the event occurs and the probability of that event occurring) are assessed, either qualitatively or quantitatively, using a variety of techniques, ranging from statistical analysis to facilitated expert group opinion, considering all readily available information. As the project develops and conditions change, the risk factors for previously identified risks might change and need to be reassessed, while the factors for any new risks must be assessed. The updated assessments of factors describing the severity of each risk are maintained in the project risk register. This step is discussed further in Chapter 6.

Step 4. Risk Analysis. If the risk factors have been assessed quantitatively (Step 3), the DOT can use the risk factors in conjunction with the base performance to determine total project performance. For some performance measures that are additive, such as uninflated costs, this is a relatively simple analysis. However, for other performance measures that are not simply additive, such as schedule (and thus inflated costs), this is a relatively complex analysis. Typically, numerical models are developed to adequately calculate each performance measure as a function of various input factors (e.g., the base and risk). The overall mean value (i.e., probability-weighted average value) of the performance measure can then be approximated by using the mean value of each input factor, which for one risk would simply be its probability times its impact. The uncertainty (expressed by a probability distribution) in a performance measure can be approximated (e.g., typically by Monte Carlo simulation) by using the uncertainty for each input factor, appropriately considering any relationships (correlations) among those input factors. This can be done at various levels of detail and complexity, considering risks explicitly or implicitly; if risks are treated explicitly, their severity can be calculated and used to meaningfully prioritize the risks. As the project develops and the risks (and their factors) change, the project performance must be reanalyzed. This step is discussed in Chapter 7. Note that risk analysis requires specialized skills and experience.

Step 5. Risk Management Planning. Once the DOT has evaluated and prioritized the risks (Step 4 and possibly more definitively in Step 5), the DOT should identify and adequately evaluate proactive ways to manage those risks and select those that will be cost-effective, which is a process that is similar to (and possibly combined with) VE. The DOT should then develop adequate plans to accomplish those activities. Budgets and milestones that adequately account for the remaining residual risks must then be established (e.g., through use of contingency and float), based on agency policy on the appropriate level of conservatism. Adequate procedures must be established to control expenditure of that contingency, so that the project does not automatically consume the allocated contingency. Ways to meet budget or milestones if that contingency turns out to be insufficient (e.g., reduction in scope) at various milestones must be identified and adequately evaluated to select those that will be implemented if necessary. Adequate plans and decision criteria must be developed to accomplish those actions. As the project develops and the risks (and their factors) change, these plans must be reviewed and revised as necessary to optimize remaining project performance. The updated plans are maintained in the project risk management plan. This step is discussed further in Chapter 8.

Step 6. Risk Management Implementation. Once the DOT has developed the risk management plan (Step 5), it must be adequately implemented. This involves the following:

- Implementing and monitoring progress on proactive risk reduction activities;
- Monitoring risks and updating the risk register, partly in response to proactive risk reduction activities but also because of other changes in conditions (e.g., changes in the base);
- Periodically reanalyzing risks, especially at major milestones or major changes in conditions;
- Periodically reviewing and updating the risk management plan;
- Monitoring, controlling, and periodically revising contingency as necessary; and
- Deciding on whether to implement established contingency plans at various milestones.

Hence, as the project develops and the related risk management plan changes, the plan must continue to be effectively implemented. This step is discussed further in Chapter 9.

The appropriate details of the above process depend on each particular project's needs and conditions. Like most evaluations, the accuracy and defensibility can vary from very approximate with low defensibility, which can be achieved with relatively little detail, expertise, and thus effort (depending on project conditions), to very accurate with high defensibility, which requires significant detail, expertise, and thus effort (again depending on project conditions). The appropriate level of detail and expertise should be selected to achieve the needed level of accuracy and defensibility, considering the effort involved.

The actual "how to" details of implementing each of the above steps is covered in companion training materials, which are summarized in the Simplified Risk Management Training document and available online at www.trb.org/Main/Blurbs.168369.aspx.

The logistics of implementing the above set of steps (e.g., through facilitated workshops), as well as when they should be implemented during project development, are discussed in Chapter 10.

CONCLUSIONS ON THE RISK MANAGEMENT PROCESS

Historically, risks and opportunities have significantly affected projects and thereby program outcomes. This might be especially true in the future for innovative rapid renewal projects, for which there is a more dynamic environment and less experience. However, by adequately anticipating these risks and opportunities, and subsequently evaluating and planning for them, project performance can be improved.

Although risk management can be done in a variety of ways with various degrees of success, a formal, structured risk management process, as an integral part of project management, is needed to provide adequate accuracy and defensibility. Risk management can create a better understanding of possible outcomes and then help to manage those outcomes to the greatest extent possible. This risk management process consists of a series of well-defined steps, which are iterative and applied at various times during a project or program. The process must be flexible (especially in level of detail and expertise) for efficiency. Although this risk management process is generally applicable at the program or project level, and to non–rapid renewal and even nontransportation projects, the focus in this guide is on application to individual rapid renewal projects.

Example

A hypothetical case study by "QDOT" is used throughout this guide to illustrate the various steps of the risk management process. This case study is presented in Appendix D and includes a risk management plan (RMP) in Appendix E. The basic risk management process discussed in this chapter is used in that example, as summarized below.

QDOT is planning a significant highway reconstruction and expansion project. The objectives are to minimize cost, schedule, and disruption during construction and maximize longevity of the constructed facility after construction. Recognizing the uncertainty and risk inherent in this project, QDOT decided to conduct risk management planning, followed by implementation of the resulting RMP, to optimize satisfaction of these objectives (as described in general terms in this chapter and specifically for this application in Appendix E, RMP Section 1). However, it was decided not to conduct quantitative risk analysis (e.g., to objectively establish contingencies) at this time. To accomplish this (as described in Chapter 10 and specifically for this application in Appendix E, RMP Section 9), QDOT:

- Convened a group of project team staff and independent subject-matter experts from the key project disciplines, facilitated by a qualified risk elicitor and analyst, to conduct risk assessment and risk management planning (consistent with the principles, processes, and guidance described throughout the guide).
- Assigned a risk manager (with adequate authority and resources) to implement the resulting risk management plan.

3

CONTEXT FOR RAPID RENEWAL

INTRODUCTION

What Is Rapid Renewal?

Rapid renewal projects constitute a unique subset of highway projects. They have three primary objectives: (1) completing renewal of existing highways quickly; (2) doing so with minimal disruption to the community; and (3) producing facilities that are long-lasting At the core of rapid renewal projects are elements intended to realize optimal benefits for the project and public: a new way of managing collaborative relationships and decision making; better integration of management, planning, design, construction, and maintenance; and more synergistic use of technologies and methods.

The following are examples of rapid renewal projects:

- Reconstruct a busy rural highway quickly by using precast, posttensioned concrete panels in critical intersections to reduce lane closure times; and using high-early-strength concrete elsewhere to reduce curing times and achieve earlier opening. Ensure longevity by requiring a 10-year performance warranty.
- Accelerate delivery of a critical urban freeway reconstruction project by pursuing public–private partnership to secure funding and deliver the project many years earlier than possible with traditional funding and delivery methods.
- Replace an aging overpass bridge structure in an urban area by prefabricating a replacement bridge “offline,” and then moving the replacement bridge into place over a single weekend during a full road closure.

> Apply various management and/or technical techniques to reduce delivery time and disruption without adversely affecting project cost and longevity, although performance uncertainty and volatility might increase.

- Reconstruct a major urban freeway with a full closure or directional closures. In certain circumstances, full road closure can be less disruptive than attempting to maintain traffic through a construction area.
- Use contractor incentives to accelerate construction. Success with the use of contractor incentives on emergency projects (e.g., MacArthur Maze reconstruction in San Jose, California, after a tanker fire and the I-35W bridge reconstruction after the structural failure of the existing bridge) have led DOTs to use contractor incentives for nonemergency, rapid renewal projects.

These rapid renewal project examples clearly reflect more uncertainty (and risk) than traditional projects. Project acceleration makes schedules more volatile (e.g., any small delay can have significant impact on a highly compressed schedule). This uncertainty can affect the public's opinion of DOTs and ultimately the performance of their transportation network. Formal and consistent risk management is prudent on any project, but it is essential on rapid renewal projects to ensure that DOTs meet their performance objectives and promises to their stakeholders.

Background and Concepts of Rapid Renewal

The Federal Highway Administration (FHWA), American Association of State Highway Transportation Officials (AASHTO), and the Transportation Research Board (TRB) have been actively developing the concepts underlying rapid renewal. FHWA and AASHTO have been at the forefront of the effort through their work on the Accelerated Construction Technology Transfer (ACTT) Program. Although construction is in the ACTT title, the program addresses all phases of project delivery. Appendix A contains more information on ACTT.

Unfortunately, however, there is still no single definition of a rapid renewal project. Rather, rapid renewal is typically referred to by project characteristics or the techniques implemented to compress the project schedule. A recent publication by TRB (2009), *Special Report 296*, defines several rapid renewal strategies. These strategies reflect general categories of approaches for meeting rapid renewal objectives, including completing on-roadway construction activities that affect traffic flow and the communities and businesses that rely on the roadway for services.

- *Perform faster in situ construction* by using a compressed schedule, which might require extended overtime shifts, mobilizing additional workers, employing innovative technologies, full road closures with detour, and strategic design. This strategy also typically involves the use of design–build project delivery, flexible performance specifications, and nondestructive testing.
- *Minimize field fabrication* by establishing techniques that maximize prefabrication that can occur off-site. This can be achieved by prefabricating units of roadway or bridges, modular construction, and innovative installation strategies. Modular and prefabricated elements allow for accelerated schedules, improve quality control and longevity, and enhance the overall level of performance of the project.

- *Perform faster construction inspection and monitoring* by ensuring that renewal projects are inspected and accepted quickly (e.g., using nondestructive testing) so that they can be reopened to the public. This strategy may include intelligent compaction and the use of contractor quality assurance/quality control techniques.
- *Facilitate an innovative and equitable contracting environment* by making decisions and accepting them rapidly (e.g., streamlined environmental analyses and permitting processes, streamlined design approvals through colocation, privatized operations and maintenance, private financing, and alternative bonding). To effectively use this strategy, risk should be shared among project partners (e.g., DOTs, designers, private contractors, and partners), such as through incentives. Additionally, performance-based specifications can be used to provide the contractor with control over construction-related risks.
- *Improve customer relations* by recognizing the role that utilities and railroads play in the project development and execution. To prevent conflicts, institutional and procedural changes must be made and a proactive strategy for dealing with conflicts must be established in the early phases of project development. Similarly, right-of-way (ROW) acquisition can be advanced and joint development encouraged.
- *Design and construct low-maintenance facilities* so that the need for future rehabilitation is minimized. This may involve the use of innovative materials (e.g., composites) or construction in controlled environments (e.g., modularization and prefabrication).
- *Preserve facility life* by investing in facilities that are in good working condition to reduce the frequency of renewal.

These strategies, in turn, result in specific rapid renewal tactics or methods that can be employed for specific projects. Appendix A contains a rapid renewal inventory, or summary, of specific rapid renewal tactics and methods as identified through ACTT and TRB publications and interviews conducted with several state DOTs as part of the development of this guide. An example of a rapid renewal inventory is shown in Figure 3.1.

PROCESS OF RAPID RENEWAL

Objectives and Performance Measures for Rapid Renewal Projects

For the purpose of this guide, the four key project performance objectives (and related measures, or the bases for defining, assessing, and managing risks) for evaluating rapid renewal projects are as follows:

1. Minimize cost to complete project delivery (e.g., in terms of year of expenditure costs).
2. Minimize time to complete project delivery (e.g., in terms of completion date).
3. Minimize disruption during project delivery (e.g., in terms of hours lost by the public).

Construction	**Structures**	**Traffic Engineering/ Safety/ITS**	**Innovative Contracting/ Financing**	**Geotechnical Materials/ Advanced Testing**
• Closures • Preliminary Work/ Staging • Project Administration Streamlining • Construction Operations	• Prefabrication • Component Reuse • High-Performance Materials • Integral Designs • Standardized Design • Construction Placement • Temporary Structures • Long-Life Structural Design	• Advance Planning • Alternate Routes • Alternate Modes • Improved Physical Separation • Coordinated Emergency Response • Signage and Signalization • Closures • Work Zones	• Alternative Financing • Project Delivery • Procurement • Contract Payment • Warranties • Alternative Insurance • Advance Contract Packaging • Bonding/ Performance Securities	• Subsurface Exploration • Walls • Pavements • Alternative Materials • Intelligent Compaction • Material Testing
Public Relations	**Environment**	**Roadway/Geometric Design**	**Right-of-Way/ Utilities/Railroad Coordination**	**Long-Life Pavements/ Maintenance**
• Team Integration • Single-Point Communication • Additional Investment • Project Branding • Stakeholder Awareness • Performance Measurement	• Master Planning • Context-Sensitive Solutions • Comprehensive Scoping • Advance Permitting	• Alternate Access • Alternate Geometrics • Advance Roadwork	• Advance Right-of-Way Planning • Early Utility Location • Common Utility Crossings • Early Railroad Coordination	• Life-Cycle Design • Performance Indicators • Long-Life Materials • Maintenance Involvement

Note: ITS = Intelligent Transportation Systems.

Figure 3.1. *Rapid renewal inventory (Appendix A).*

4. Maximize longevity and minimize postconstruction problems:
   - —Minimize cost and disruption of operations and maintenance.
   - —Minimize cost and disruption for replacement and its frequency (e.g., ensure longevity in that the project meets or exceeds the design life according to the specifications and is designed for ease of maintenance and replacement).

Additional performance objectives or measures for rapid renewal projects could include the following, depending on project circumstances:

- Maximize the chance to secure adequate project funding (funding delays covered in schedule performance measure).Minimize environmental impacts throughout project life.
- Minimize safety impacts during construction and throughout project life.

- Maximize quality for operations (separate from operations and maintenance and replacement).
- Maximize stakeholder satisfaction with other project performance measures.
- Maximize revenue during operations, if applicable.

An overall project objective is to maximize satisfaction of the group of the above objectives, considering trade-offs among them. One logical way to accomplish this is to translate all objectives into common terms (e.g., equivalent cost) that can then be easily combined. For example, the value of changes in schedule, changes in disruption, and changes in longevity can be assessed in terms of how much the decision maker would be willing to pay (in dollars) to make desirable changes or to prevent undesirable changes [e.g., cost per month of schedule change, regardless of the magnitude of change (linear) and regardless of changes in other measures (independent)]. Once translated into equivalent cost terms, the various objectives can simply be summed to determine an overall value to be (in this case) minimized.

Different, expanded programmatic performance measures might also be defined for specific programs composed of individual projects (e.g., minimize overall program cost, optimize programmatic cash flow, minimize overall program schedule, minimize overall program disruption).

Rapid Renewal Project Phases

For the purposes of categorizing rapid renewal methods and their associated risks and risk management, it is convenient to characterize projects in terms of their various development phases" (or major activities, such as final design). In general terms, most projects progress through the phases presented in Table 3.1. The table also provides examples of rapid renewal strategies for each phase.

The order in which these phases occur can depend on the project characteristics and the selected project delivery method. Two general (simplified) models for the sequencing of these project phases are shown in Figure 3.2. These models, although simplified, provide a framework for the risk management process and assist in developing risk-based cost and schedule models. Figure 3.2a shows traditional, linear design–bid–build project delivery; Figure 3.2b depicts innovative approaches such as design–build in which construction and final design are completed concurrently by the builder to shorten project delivery schedules. Although many variations are possible, these two models can accommodate a variety of delivery strategies at a level that is appropriate for risk management efforts.

Each box represents a phase, with the left side of the box representing the start and the right side representing the finish, and the top and bottom representing some point in between. Each arrow into a box represents a precedent requirement for that phase.

Subsequent chapters present a formal process for identifying, assessing, and managing rapid renewal–related risks. A key part of this process is identifying the major project activities and their sequence (e.g., as shown in Figure 3.2), which is in turn based on the project's scope, delivery strategy, conditions, and key assumptions.

TABLE 3.1. TYPICAL PROJECT PHASES AND EXAMPLES OF ACTIVITIES AND RENEWAL STRATEGIES

Project Phase	Typical Activity	Rapid Renewal Strategy
Planning	Determine purpose and need; consider environmental factors; facilitate public involvement and participation; consider interagency conditions.	Conduct accelerated programmatic or portfolio planning; conduct accelerated internal coordination; conduct accelerated external planning.
Scoping	Determine design criteria and parameters; make preliminary plans such as alternative selections; assign geometry, project delivery strategy, and programming; obtain funding authorization.	Conduct accelerated and comprehensive scoping; employ master planning and integrated project development process; use innovative project delivery (e.g., design–build, construction manager at risk).
Environmental	Conduct environmental analysis including discipline studies, National Environmental Policy Act of 1969 /State Environmental Policy Act, alternatives analysis, documentation, public hearings, permitting.	Accelerate the environmental documentation process; seek streamlined environmental approval process and approvals; streamline mitigation planning and implementation.
Design	Develop plans (preliminary and final), specifications, estimates, traffic control plans.	Accelerate design process; seek streamlined design approvals; hold early constructability reviews; use innovative and/or long-life designs.
Right-of-way, utilities, and railroad	Determine right-of-way impact; develop right-of-way approach; acquire right-of-way; determine utilities impacts; coordinate with utilities; develop railroad impact; coordinate with railroad.	Accelerate right-of-way planning; accelerate right-of-way acquisition; conduct early utility planning and coordination of agreements; accelerate utility relocation; conduct early railroad planning and coordination of agreements.
Procurement	Prepare contract documents, advertise for bids or proposals; hold a prebid conference; receive and analyze bids or proposals.	Use alternative contract packaging; employ advanced procurement.
Construction	Initiate contract; mobilize; conduct inspection and materials testing; administer contract; control traffic.	Use prefabricated materials and construction techniques; use modular construction techniques; use full road closures or other innovative traffic management techniques.
Operations	Operate facility; monitor performance; provide services for customers.	Consider privatized operations and maintenance.
Replacement (or decommissioning)	Plan for replacement; plan for design and construction or replacement; plan for decommissioning if appropriate.	Accelerate planning for replacement or decommissioning.

The project delivery selection process, as well as the accelerated construction method selection (and design in general) process, is beyond the scope of this guide, but there are various documents describing well-established processes for the selection of the project delivery method (e.g., by Canadian Provinces Ontario and British Columbia, as well as the UK Highways Agency's Gateway Process) that consider a range of factors in a collective, qualitative, and quantitative manner.

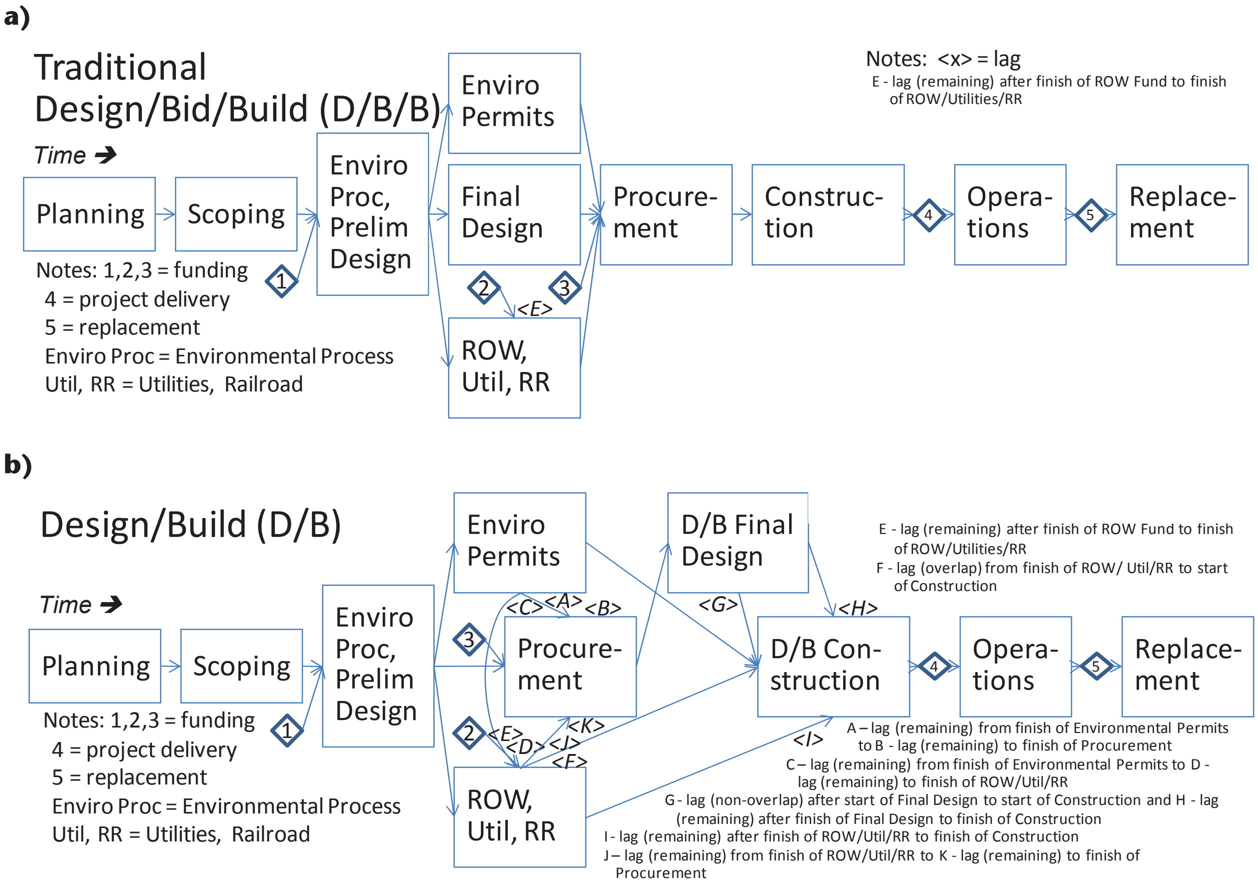


Figure 3.2. *Example sequencing of major project phases: (a) traditional design–bid–build (D-B-B) and (b) alternative design–build (D-B) delivery.*

The scope of this guide is to present an appropriate approach to comprehensively evaluating and managing the risks associated with any rapid renewal project, which might include innovative project delivery methods and accelerated construction methods—choices among project delivery methods and among accelerated construction methods can then be made, at least in part, on the basis of such evaluations of alternatives. Because the analysis of risks involves different models for different project delivery methods, and many of the risks themselves are different for the different project delivery methods, specific project delivery methods (i.e., D-B or D-B-B) must be evaluated separately and then compared. However, risks for each delivery method, in the context of rapid renewal, are discussed in depth in Appendix B, which will help DOTs understand the risks involved with each project delivery method.

CONCLUSIONS ON RAPID RENEWAL

With the increasing challenges posed by aging infrastructure and reduced funding, rapid renewal strategies and tactics will be increasingly required to deliver long-lasting projects quickly, cost-effectively, and with minimal disruption. However, such rapid renewal strategies and techniques are, in many cases, somewhat innovative and thus might perform in unexpected ways. This uncertainty, especially in high-visibility projects that serve as critical transportation links, can affect the public's opinion of our highway DOTs and ultimately the performance of our transportation network. Formal and consistent risk management, as presented in this guide, will be required to ensure that DOTs meet their objectives for rapid renewal projects.

Example

The hypothetical QDOT case study (see Appendix D), which is used throughout this guide to illustrate the various steps of the risk management process, and a risk management plan (RMP; Appendix E), consist of several rapid renewal elements as discussed in this chapter and summarized below.

QDOT is planning to reconstruct and expand segments of two existing (intersecting) highways, US-555 and SH-111, through a rapidly developing suburban area. The existing highways are nearly 40 years old, have increasingly inadequate capacity, and are expensive to maintain. These facilities are the only viable east-west (US-555) and north-south (SH-111) routes for commercial traffic for several miles in either direction. Therefore, it is imperative that the necessary improvements be made quickly and with minimal disruption. QDOT would also like to minimize construction costs and future repair cycles and maintenance requirements, as well as eventual replacement issues. To help achieve these objectives, QDOT plans to encourage contractor innovation through the use of performance-based specifications and incentives, and to procure with an innovative project delivery method (i.e., design–build). It is expected that accelerated bridge construction techniques, minimally disruptive maintenance of traffic (e.g., detour or realignment or full temporary closure), and innovative pavement design, among other rapid renewal elements (as described in Appendix A), will be considered for this project. As described in this chapter, it is important that the project be adequately understood (and documented) before starting the risk management process. The project is described in Appendix E, RMP Section 2.

4

STRUCTURING A PROJECT FOR RISK MANAGEMENT

INTRODUCTION

As described in Chapter 2, the first step in the risk management process is to describe the base project to facilitate the rest of the process.

Objectives

The primary objective of structuring a project for risk management is to adequately define the base project, relative to which risks can be identified, assessed, and eventually managed. As discussed in Chapter 2, the base project consists of a set of project assumptions about how the planned project will perform with respect to the project's performance measures (e.g., in terms of actual ultimate cost, schedule). The base project excludes other possibilities, which are generally described as risks or opportunities. It should not include any cost or schedule contingencies, or other conservatisms, that are intended to cover those risks (i.e., only planned or known items of work should be included). If done appropriately, such structuring facilitates risk identification (Chapter 5) and risk assessment (Chapter 6) and forms the basis for risk analysis if needed (Chapter 7) and risk management planning (Chapter 8).

> Adequately but efficiently define the base project scenario, against which risk and opportunity can be identified, assessed, and eventually managed.

A secondary objective of structuring a project for risk management is to develop a clear and common understanding of that project, including the project scope and strategy, and the key project conditions and assumptions. Although this is not strictly within the purview of risk management, many project managers find it to be a valuable side benefit because it allows for an evaluation of the consistency of project cost, schedule, and other performance estimates with the project scope and strategy, considering the key project conditions and assumptions.

Another objective is to complete this step in the overall risk management process efficiently, producing accurate and defensible results that are compatible with the other steps of the process (which in turn is compatible with the project management approach). To achieve this efficiency, it is especially important that the level of detail be appropriate. This guide includes examples and forms to assist in defining the appropriate level of detail for risk management. Facilitated consensus among a broad group of project-team and independent subject-matter experts is key to successful structuring.

Philosophy and Concepts

As discussed in Chapter 3, the relevant project performance objectives for evaluating rapid renewal projects include minimizing project cost, schedule, and disruption during construction and maximizing longevity. Also as discussed above (and in Chapter 2), each such performance measure consists of a base component (based on a particular set of assumptions or scenario) and a complementary risk component that covers all other possible outcomes. The base component must be clearly defined before the risk component can be defined.

The DOT must develop cost and schedule estimates for a project to establish budgets and schedule milestones. These cost and schedule estimates are necessarily established on a large set of assumptions about planned project scope, strategy, and conditions. In deterministic estimates, some of these assumptions are explicitly stated, but most are implicit and incorporate various degrees of unstated bias or conservatism. Cost contingencies (as a percentage of base costs) typically are used to cover the cost risks. Schedule contingencies (time in addition to the base schedule) are sometimes used to cover schedule risk.

However, the DOT can develop these cost and schedule estimates in various ways and at different levels of detail, based on the types of information (e.g., ranging from past experience to direct contractor quotes). Generally, for costs, the DOT identifies a set of cost items, then estimates quantities and unit costs (uninflated) for each item, and then sums and inflates (based on an assumed schedule) the resulting costs. Similarly, for schedule, the DOT identifies a set of schedule activities, characterizes their sequence and precedence requirements (including external milestone dates), estimates the duration for each item (e.g., by estimating the quantities and progress or production rates), and then evaluates the critical path through the schedule.

The set of items used for cost analysis and for schedule analysis needs to be comprehensive but nonoverlapping (i.e., does not double-count anything). Typically, but not always, the cost and schedule are estimated separately, in which case they might be based on different assumptions and therefore be inconsistent with each other. Clearly, it is important that these estimates be consistent with the specified project scope and strategy, as well as the known project conditions, and with each other. It is also helpful if all other significant assumptions are clearly stated.

In establishing the base project cost and schedule for the risk management process, the DOT needs to remove from the estimates any conservatisms and contingencies that are intended to cover these risks. Conservatisms and contingencies will be accounted for in a formalized and structured manner in later steps of the risk management process. The risk management process will be used to replace these traditional estimate items with a more individually defined set of risks and a conscious policy decision on the appropriate level of confidence (reliability) in planning.

It is also often useful to "abstract" detailed cost and schedule estimates to a common, relatively broad level of detail, which the DOT can explicitly link to establish a base cost-loaded schedule, which in turn can be used to more accurately determine inflation and cash flow. Such an explicit link can be provided, for example, by a simple matrix that allocates each portion of each item in the cost estimate to each schedule activity.

Similarly, the project scope and strategy, in combination with the actual project conditions, will also determine the actual disruption and longevity of the project. For consistency with the base cost and schedule estimate, the DOT should estimate the base disruption and longevity on the same set of assumptions. For example, as discussed in Chapter 3:

- Disruption might be determined by estimating the number of users affected during each project phase (e.g., average number of people affected per day times the number of days) and their average delay.
- Similarly, longevity might be determined by the net present value (NPV) of operations and maintenance (O&M) cost and replacement cost, appropriately considering the duration of operations, the cost and disruption of O&M (e.g., average per year) and of replacement, and a net discount rate.

Similar to base cost and schedule, the base disruption and longevity, to which the risks will subsequently be added, should be stripped of any conservatisms and contingencies.

Note that, even before considering risks, there typically will be significant uncertainty in what the various base factors (e.g., unit cost, quantities) actually will be. Such base uncertainties are usually covered by conservatisms in the estimate, as well as by contingencies. The intent is to assess the mean value for each uncertain base factor (before considering risks). Base uncertainties can be then treated as a risk (see Chapter 6) or, if quantitative risk analysis is being conducted, treated separately and explicitly (see Chapter 7).

PROCESS OF STRUCTURING

This section provides an overview of methods and some guidance for successfully structuring a project for risk management, but details on how to conduct this process are not included here. Refer instead to the Simplified Risk Management Training course. As discussed briefly in Chapter 10, this process of structuring is usually finalized in a facilitated workshop, although much of it can be done offline beforehand. The key elements of structuring, which the DOT should adequately document, include project scope, planned delivery strategy, key conditions and assumptions, and base project performance (cost, schedule, disruption and longevity), which are described individually below in more detail.

Project Scope

The *scope* of the project outlines what the project will construct, what it will remove or demolish, and, perhaps, what the project will not construct. This description determines, for example, the types and quantities of cost items, and consists of broad items such as the project limits, vertical and horizontal alignment, capacity, access, disruption requirements, and longevity (O&M and design life) requirements. In more detail, the scope includes, for example, the type, size, and location of new or rehabilitated lanes, interchanges, and intersections; structures (and their foundations); cut and fill retaining walls; type of pavement; and the type and extent of mitigation required.

Sometimes the DOT will want to consider alternative scopes, such as different alignments or different types of structures. Because the different scopes might have some different risks, they might be evaluated separately and their performance compared to facilitate a decision between them. In this case, it is often useful to identify one scope as the basis for comparison and simply identify just the differences for any other scopes.

Often, it is useful in developing a common understanding and as a communication tool to develop a simple project schematic that adequately depicts the key scope elements (e.g., for each alternative, if more than one).

Planned Delivery Strategy

The *strategy* for delivering the project scope, which determines the project schedule as well as affecting project cost, disruption, and longevity, consists of a series of project activities to accomplish each phase of project development. As discussed in Chapter 3, the project phases primarily include preconstruction, construction, O&M, and replacement, all of which require adequate DOT funding. Traditionally, all preconstruction activities (e.g., design, funding) must be completed before going to procurement and then to construction. However, this could be done through multiple procurements (or contracts), which are phased to allow some construction to start before other parts are ready, or by having the builder complete the preconstruction activities and start construction in overlapping phases (design–build). Also, funding required for the project might be provided in phases or by the builder (instead of by the DOT), which might have to be paid back with interest or in exchange for some or all operating revenues. Hence, the delivery strategy consists of contract packaging (number and size of contracts), type of contract (design–bid–build versus design–build), and funding source (DOT versus private, and phases), as well as more detailed elements (e.g., approach to environmental process, approach to public involvement, construction phasing).

Often, it is useful for the DOT to develop a simple project flowchart to help gain consensus on a reasonable and accurate project delivery and schedule logic, as well as to provide common understanding and a communication tool. This flowchart, which also serves as the basis for integrated cost and schedule analysis (Chapter 7), depicts the major project activities and their sequence and precedence requirements. As discussed later, the project schedule can subsequently be determined from this flowchart by assessing activity durations, lags, and external milestone dates.

Key Conditions and Assumptions

The key *conditions* under which the DOT will achieve the specified project scope via the specified strategy, which in turn will determine project performance, include items such as

- Requirements and constraints, including
    - Political commitments;
    - Design standards and specifications;
    - Environmental standards and process (e.g., documentation, approvals);
    - Mitigation requirements; and
    - Procurement.
- Technical conditions, including
    - Existing infrastructure and potential interfaces (transportation, utilities);
    - Environmental conditions (wetlands, streams, parks, historic areas);
    - Real estate (land use, development pressure); and
    - Subsurface conditions (geotechnical, groundwater).
- Political or other external conditions, including
    - Stakeholders;
    - Owner policies;
    - Funding; and
    - Market conditions.

Some of these conditions will be known as fact, whereas others will be uncertain and must instead be assumed. When such assumptions must be made, they should be reasonable as well as documented and recognized as only assumptions, not fact. Even though reasonable, some assumptions might turn out otherwise, which constitutes risk (see Chapter 5).

Often, it is useful in developing a common understanding and as a communication tool to add these key conditions and assumptions to the simple project schematic (e.g., a one-page diagram) and simple project flowchart previously discussed. For example, it might be assumed that funding, which is a prerequisite for particular schedule activities, will be available by a particular date—this can easily be shown on the project flowchart.

Base Project Performance

Base project performance includes the base project schedule, cost, disruption, and longevity. All bias, conservatisms, and explicit contingencies should be removed from the base performance measures; these will be added in the later risk assessment and risk analysis, as discussed in Chapters 5 through 7. The performance models and unbiased assessments of the model inputs should be confirmed by facilitated consensus among a broad group of project-team and independent subject-matter experts. If mean input values are used, then the approximate mean output value is produced by the model.

Schedule

After developing the project flowchart and assessing the base duration, lags, and external milestones consistent with the base project scope, strategy, and conditions (including any assumptions), the DOT can determine the base project schedule via critical path analysis. Various software packages (e.g., Microsoft Project or Primavera Project Planner) are commercially available to accomplish this type of analysis. For the purpose of risk management (as opposed to project controls), the level of detail can be relatively broad (e.g., typically several tens of activities). In fact, simple standard flowcharts have been developed for two primary project delivery approaches, which are traditional design–bid–build and design–build (see Figure 3.2), and the base schedule analysis for each has been programmed in Microsoft Excel (see Appendix C).

Cost

The base project *cost* consists of the sum of the base costs of all the project activities, inflated to future [year-of-expenditure (YOE)] dollars depending on when they will occur and the appropriate inflation rate for that type of cost and time frame. Typically, however, the cost through construction is considered separately from postconstruction cost, which will instead be considered under longevity. The base cost of each project activity (e.g., for engineering, for real estate acquisition, for construction) in turn must be adequately assessed (e.g., as the product of assessed quantities and unit costs) consistent with the project scope, strategy, and conditions, including any assumptions. However, as for schedule, for the purpose of risk management (as opposed to project controls), the level of detail can be relatively broad (e.g., several tens of key cost items, including miscellaneous items to collectively capture all smaller items). These cost items can then be allocated to the project activities to determine a simple cost-loaded schedule, which allows relatively accurate determination of inflation and cash flow (if desired). Regarding a schedule, if one of the simple standard flowcharts (Figure 3.2) is used, the uninflated costs for each flowchart activity can be estimated and then readily analyzed because the base cost analysis for each has been programmed in Microsoft Excel (see Appendix C).

Disruption

The base project *disruption* consists of the sum of the base disruptions associated with all project activities, typically expressed (as previously discussed) as cumulative users' lost time. Typically, however, as for cost, disruption through construction is considered separately from postconstruction disruption, which will instead be considered under longevity. The base disruption for each activity in turn must be adequately assessed. For example, base disruption during construction could be calculated as the product of these assessed values:

- Number of days when delays will occur (e.g., as a fraction of that activity's duration);
- Average number of users affected each of those days; and
- Average delay for an individual user.

These factors must be assessed consistently with the project scope, strategy, and conditions, including any assumptions. As for cost and schedule, if one of the simple standard flowcharts (Figure 3.2) is used, the disruption for each flowchart activity can be estimated (as described above) and then readily analyzed because the base disruption analysis for each has been programmed in Microsoft Excel (see Appendix C).

For example: If disruption occurs during about 10% of the construction period, which is 1,000 days long, and an average of 10,000 people per day are affected, losing an average of 1 hour each, then the disruption is 1 million hours.

Longevity

The base project *longevity* consists of the combination of costs and disruption after construction, during O&M and replacement, discounted to NPV depending on when they will occur (e.g., schedule of replacement), the value of disruption, and the appropriate discount rate. The base cost and base disruption for O&M and for replacement must be adequately assessed, and the value of disruption and net discount rate specified. For example,

- Replacement base disruption (million hours, Mh) could be translated to equivalent cost ($/h), and then added to direct cost ($), and the NPV of this combined cost can be determined as a function of design life (years) and net discount rate (%/year);
- O&M base disruption (Mh/year) could be translated to equivalent cost ($/h), and then added to direct cost ($/year), and the NPV of this combined annual cost can be determined as a function of design life (years) and net discount rate (%/year); and
- The NPVs of O&M and replacement can be summed as a reasonable measure of longevity.

For example: If

- disruption averages 0.1 Mh/year during O&M and 1 Mh during replacement,
- the value of disruption is $10/h,
- direct cost averages $1 million/year during O&M and $10 million during replacement,
- replacement is in 50 years, and
- the net discount rate is 5%/year, then the NPV of postconstruction cost and disruption (longevity) is
- O&M: $1 million/year + 0.1 Mh/year × $10/h = $2 million/year, which over 50 years at 5%/year has an NPV of $36.5 million.
- Replacement: $10 million + 0.1 Mh/year × $10/h = $20 million, which over 50 years at 5%/year has an NPV of $1.8 million.
- Longevity: $36.5 million + $1.8 million = $38.3 million.

As for cost, schedule, and disruption, if one of the simple standard flowcharts (Figure 3.2) is used, then the cost and disruption for each postconstruction flowchart activity can be estimated (as described above) and then (with values for disruption and net discount rate) readily analyzed because the base longevity analysis for each has been preprogrammed in Microsoft Excel (see Appendix C).

Combined Performance (for Evaluating Severity of Risks)

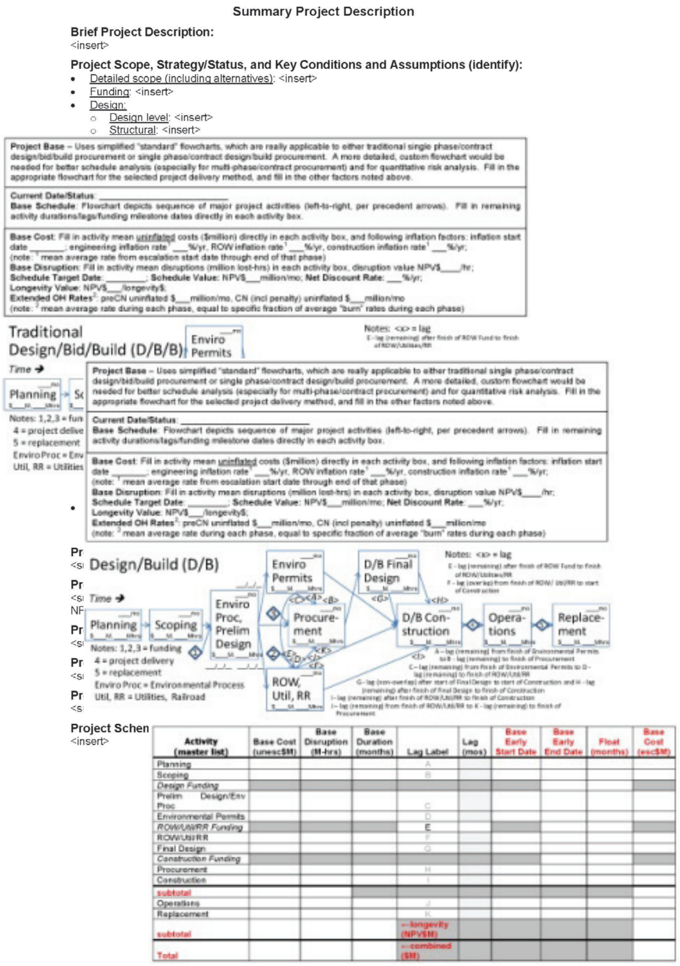
An overall measure that appropriately combines all of the more detailed project performance measures (i.e., cost, schedule, disruption, and longevity) is needed to express the *severity* of risks (in terms of change in combined performance associated with that risk), as well as to compare alternatives. This is done by defining trade-offs among those more detailed project performance measures, so that they can be expressed in common terms and meaningfully combined. For example, if trade-offs are approximately linear and independent of each other,

- Base project schedule (i.e., completion date) could be translated to equivalent cost (YOE$/month) based on the amount the decision maker would be willing to pay to change that schedule.
- Base project disruption during construction (Mh/year) could be translated to equivalent cost (YOE$/h) based on average user costs.
- Base project longevity (NPV$) could be translated to equivalent cost (YOE$) based on the amount the decision maker would be willing to pay to change longevity.
- The above three translated measures could be summed with escalated base project cost (YOE$) as a reasonable measure of combined performance.

As for cost, schedule, disruption, and longevity, if one of the simple standard flowcharts (Figure 3.2) is used, then trade-offs for schedule, disruption, and longevity can be specified and readily analyzed because the base combined performance analysis has been programmed in Microsoft Excel (see Appendix C).

Documentation

It is important for the DOT to adequately document the base project scenario to provide the basis for subsequent risk management steps. As previously stated, risk management is an iterative process that is repeated at various key milestones and project phases. Documentation at each stage is a key to efficient and successful risk management. Similar to a basis for cost estimate, the base documentation for risk management also helps to qualify the results of the process so that if the base changes (e.g., a major change in scope), it becomes clear that the old results might not be applicable any longer and should be updated. Such documentation can be done at a broad level of detail, suitable for qualitative risk assessment, using the forms provided in Appendix C (see also form examples in Figure 4.1). As described in Chapter 7 on quantitative risk



Summary Project Description

Brief Project Description:
<insert>

Project Scope, Strategy/Status, and Key Conditions and Assumptions (identify):

- Detailed scope (including alternatives): <insert>
- Funding: <insert>
- Design:
    - Design level: <insert>
    - Structural: <insert>

Project Base – Uses simplified "standard" flowcharts, which are really applicable to either traditional single phase/contract design/bid/build procurement or single phase/contract design/build procurement. A more detailed, custom flowchart would be needed for better schedule analysis (especially for multi-phase/contract procurement) and for quantitative risk analysis. Fill in the appropriate flowchart for the selected project delivery method, and fill in the other factors noted above.

Current Date/Status: ____________________
Base Schedule: Flowchart depicts sequence of major project activities (left-to-right, per precedent arrows). Fill in remaining activity durations/lags/funding milestone dates directly in each activity box.

Base Cost: Fill in activity mean uninflated costs ($million) directly in each activity box, and following inflation factors: inflation start date ________; engineering inflation rate¹ ___%/yr, ROW inflation rate¹ ___%/yr, construction inflation rate¹ ___%/yr;
(note: ¹ mean average rate from escalation start date through end of that phase)
Base Disruption: Fill in activity mean disruptions (million lost-hrs) in each activity box, disruption value NPV$____/hr;
Schedule Target Date: _________; **Schedule Value**: NPV$___million/mo; **Net Discount Rate**: ___%/yr;
Longevity Value: NPV$___/longevity$;
Extended OH Rates²: preCN uninflated $___million/mo, CN (incl penalty) uninflated $___million/mo
(note: ² mean average rate during each phase, equal to specific fraction of average "burn" rates during each phase)

Project Base – Uses simplified "standard" flowcharts, which are really applicable to either traditional single phase/contract design/bid/build procurement or single phase/contract design/build procurement. A more detailed, custom flowchart would be needed for better schedule analysis (especially for multi-phase/contract procurement) and for quantitative risk analysis. Fill in the appropriate flowchart for the selected project delivery method, and fill in the other factors noted above.

Current Date/Status: ____________________
Base Schedule: Flowchart depicts sequence of major project activities (left-to-right, per precedent arrows). Fill in remaining activity durations/lags/funding milestone dates directly in each activity box.

Base Cost: Fill in activity mean uninflated costs ($million) directly in each activity box, and following inflation factors: inflation start date ________; engineering inflation rate¹ ___%/yr, ROW inflation rate¹ ___%/yr, construction inflation rate¹ ___%/yr;
(note: ¹ mean average rate from escalation start date through end of that phase)
Base Disruption: Fill in activity mean disruptions (million lost-hrs) in each activity box, disruption value NPV$____/hr;
Schedule Target Date: _________; **Schedule Value**: NPV$___million/mo; **Net Discount Rate**: ___%/yr;
Longevity Value: NPV$___/longevity$;
Extended OH Rates²: preCN uninflated $___million/mo, CN (incl penalty) uninflated $___million/mo
(note: ² mean average rate during each phase, equal to specific fraction of average "burn" rates during each phase)

Project Schen
<insert>

Activity (master list)	Base Cost (unesc$M)	Base Disruption (M-hrs)	Base Duration (months)	Lag Label	Lag (mos)	Base Early Start Date	Base Early End Date	Float (months)	Base Cost (esc$M)
Planning				A					
Scoping				B					
Design Funding									
Prelim Design/Env Proc				C					
Environmental Permits				D					
ROW/Util/RR Funding				E					
ROW/Util/RR				F					
Final Design				G					
Construction Funding									
Procurement				H					
Construction				I					
subtotal									
Operations				J					
Replacement				K					
subtotal				←longevity (NPV$M)					
Total				←combined ($M)					

Figure 4.1. *Examples of forms (Appendix C).*

analysis, however, more detail might be appropriate, including (a) a custom project flowchart with an explicit allocation of the various cost items and risks to those more detailed project activities; and (b) explicit uncertainties in (and correlations among) the base factors (e.g., various unit costs), separate from risks.

CONCLUSIONS ON STRUCTURING

Structuring a rapid renewal project for risk management is a necessary and valuable first step in the risk management process. It provides the base for identifying risks and opportunities, assessing them, and eventually managing them; it also documents the current state for future reference. If done appropriately, structuring facilitates subsequent risk identification and assessment as well as clarifies the important elements of the project, providing a common understanding and a communication tool. For relatively simple projects, the DOT can accomplish this efficiently (and compatibly with the other steps of risk management) through the use of the forms provided in Appendix C, which can be filled out before (to the extent possible), and then finalized during, a facilitated workshop. For more complex projects and for quantitative risk analysis, more detail typically is required.

Example

The hypothetical QDOT case study (see Appendix D), which is used to illustrate the various steps of an adequate risk management process and a risk management plan (RMP; see Appendix E), was structured following the principles outlined in this chapter, as documented in RMP Section 2, and as summarized below:

1. QDOT presented the project's scope, strategy, status, key conditions and assumptions, and the associated cost, schedule, and disruption estimates to the combined group of key project-team staff and independent subject-matter experts.
2. Facilitated by a base lead, the group reviewed, "de-biased" (i.e., removed any over- or underestimates), and validated the cost, schedule, and disruption estimates for the stated assumptions. The results were base cost, schedule, and disruption estimates, exclusive of risk and opportunity. Note: Subsequently, a quantitative risk analysis was conducted, for which uncertainties in and correlations among the base costs, schedule, and disruption estimates were assessed; see RMP Addendum X. Facilitated by a risk lead, the group adopted a design–build (D-B) standard simplified flowchart describing the sequence of major project activities (see RMP Figure E.1), and the cost, schedule, and disruption estimates

(continued)

were allocated to those flowchart activities. This simplified flowchart serves as the basis for subsequent risk identification and assessment, and then proactive individual risk reduction identification and evaluation. Note: Subsequently, a quantitative risk analysis was conducted, for which a more detailed flowchart was developed; see RMP Addendum X

3. Mean (i.e., probability-weighted average) base project performance (i.e., schedule, uninflated and inflated cost, and disruption total both for the project and by project activity) was then approximated using an appropriate risk model (a Microsoft Excel workbook template). For subsequent risk and risk management evaluations, QDOT established trade-off values (which are policy rather than technical issues) that allowed the various project performance measures to be combined, for example, (a) combining postconstruction schedule, cost, and disruption into longevity; and (b) combining schedule, cost, and disruption through construction with longevity into severity.

5

RISK IDENTIFICATION

INTRODUCTION

As described in Chapter 4, the base project describes the planned project scope, strategy, conditions, and assumptions. However, projects do not always go as planned, particularly when projects involve new or innovative methods like rapid renewal projects do. The DOT should identify what events *might* occur and thus change the project relative to the base assumptions and thereby affect the project's performance objectives of minimizing project cost, schedule, and disruption through construction, and maximizing longevity of the constructed facility. The risks and opportunities are listed in the risk register for later risk management activities. As described previously, events that might occur and change the project outcomes can be risks (potential problems that degrade project performance) or opportunities (potential improvements that enhance project performance).

> Adequately but efficiently identify, categorize, and document (in a risk register) a comprehensive, nonoverlapping set of risks (potential problems) and opportunities (potential improvements), which are events outside the base set of assumptions that might occur and change base project performance.

Objectives

The objectives of risk identification are to

- Identify, categorize, and document all risks and opportunities that could significantly affect the project's base performance measures.
- Start a risk register, which is a comprehensive set of nonoverlapping risks and opportunities.

- Set the stage for subsequent steps in the risk management process, which include
  - —Risk assessment (Chapter 6);
  - —Risk analysis, if needed (Chapter 7); and
  - —Risk management planning (Chapter 8).

Another objective is to complete this step in the overall risk management process efficiently, producing accurate and defensible results that are compatible with the other steps of the process (which in turn is compatible with the project management approach). Facilitated consensus among a broad group of both project-team and independent subject-matter experts is key to successful risk identification.

Philosophy and Concepts

Risk identification is a relatively straightforward process, but DOTs should still follow a basic set of principles to ensure that risk identification is conducted appropriately. Key principles of risk identification are outlined below. Guidance for following these principles is provided later in this chapter.

- *Risk identification is just that—identification*. To mitigate bias, it does not involve discussion of severity, screening, or prioritization. Similarly, risk identification does not involve redesigning the project to fix problems or identifying risk management actions.
- *Risk identification should be comprehensive*. Be careful not to miss or exclude risks or opportunities. Do not assume that risks will be avoided through later engineering efforts. Consider all project phases, elements, and components. However, it is inevitable that some risks will be missed, and hence, to be comprehensive, there should be a miscellaneous risk to cover those unidentified risks.
- *Seek out both risks and opportunities.*
  - —Do not focus solely on potential problems (risks).
  - —Opportunities generally do not include potential risk management actions. Risk management actions are deliberately planned and implemented specifically to manage risk or exploit genuine opportunities.
- *Risks and opportunities should be defined relative to the base.*
- *Risks and opportunities should be identified at an appropriate level of detail.*
- *Risks should be characterized and documented adequately (in a risk register)*, to provide enough basis for understanding the issue and subsequent assessment:
  - —What is the nature of the risk? (What is the fundamental issue of concern?)
  - —Who is affected by the risk? (Does the risk primarily affect the DOT?)
  - —When could the risk occur? (Can it occur once during the project, or multiple times?)
  - —Where could the risk occur? (What element of the project could it affect? Can it occur in more than one location or affect more than one element of the project?)

- —What could cause the risk to occur? (What are the causes or triggers, and how would they be recognized?)
- —How likely are these triggers to occur during various phases of the project?
- —What are the potential impacts if it occurs? (How would this affect the project's performance measures if it occurred?)
- —What are the potential relationships (correlations, dependencies) with other risks?

Example Risk Documentation (This is not *the hypothetical case study)*

Additional Wetland Impacts Result from Changes to Project Design

Wetland impacts have been delineated and permitted for the planned sign gantry foundations. However, the contractor might need to change one or more sign locations. If so, that might introduce additional wetland impacts, which are likely to be small (e.g., under several thousand square feet). In any case, the contractor would have to get approval for any temporary impacts to the wetlands and develop and obtain permits for mitigation for any unavoidable permanent impacts, where permitting might involve the U.S. Army Corps of Engineers. This problem could affect the DOT's project schedule (e.g., delaying permits, which is a precursor to other activities) and cost (in the form of a claim from the design–builder for additional mitigation and extended overheads).

- *Risks change* as the base project evolves, as conditions change, and new information becomes available. Eventually, each risk happens (and becomes part of the base) or does not happen (and can be "retired"). Generally, specific types of risk can only happen during specific project phases, after which they cannot occur.

PROCESS OF RISK IDENTIFICATION

There is not just one way to conduct risk identification. Risk identification can range from an informal, back-of-the-envelope, individual "thought exercise" to a very structured, very formal, and facilitated process. For DOTs attempting to identify risks for rapid renewal projects, a facilitated yet semiformal group exercise, commonly known as the Delphi approach, is often the most efficient and effective approach to adequate risk identification. The following are key elements of a group process, which should be efficient, minimize bias, and maximize discovery and identification of risks:

1. *Include both project-team members and independent subject-matter experts in the risk identification exercise*. Ideally, these experts will be the same group that developed the project base (described in Chapter 4).

2. *Circulate base information to the participants beforehand*. Ensuring that the participants in the risk identification are already familiar with the project scope, strategy, conditions, and assumptions will promote more effective discussion during the risk identification exercise.
3. *Before the actual risk identification exercise, ask each expert to document his or her issues of concern*. This helps to ensure participant buy-in and subsequent consensus.
4. *In a facilitated meeting or workshop environment with the experts, have a qualified facilitator lead the identification of risks, minimizing bias*. This is generally done
    a. First through group brainstorming (e.g., existing concerns of project team and reviewers, issues identified during structuring, and judgment or experience from other similar projects);
    b. Then through analysis (e.g., evaluation of scope, key assumptions and conditions, and project strategy or project phase); and
    c. Finally through comparison with risk checklists (see below).
5. *After the risks have been identified, have the facilitator categorize the risks to help establish a proper risk register*:
    - —A risk register is a comprehensive, nonoverlapping set of risks and opportunities. In a risk register, risks are often organized or categorized in some convenient fashion and should be described at the appropriate level of detail (i.e., typically dozens of significant risks). The risk register is a dynamic document "owned" by the project team.
    - —Categorization can be by type of risk, by project component, or by project phase (which captures both the type of risk and the time element). For the purposes of this guide, the recommended categorization is by project phase because the authors' experience is that people often organize their thinking about the project by the type of project activity and when the activity occurs. In fact, it is recommended that risks be categorized by the phase in which they are most likely to occur (which is not necessarily when the impacts would occur) and after which they can be retired, which subsequently helps in developing contingency drawdown and risk monitoring plans (see Chapter 8). However, it is not important for the categories to be rigidly defined. In fact, many risks could easily be categorized into more than one category because of their impacts across many facets of the project.
    - —Categorization serves to
        - ▪ Organize the list of risks at an appropriate level of detail.
        - ▪ Combine highly correlated or dependent risks, which means that the remaining risks are often largely independent.
        - ▪ Eliminate duplicate risks.
        - ▪ Identify missing risks within each category.

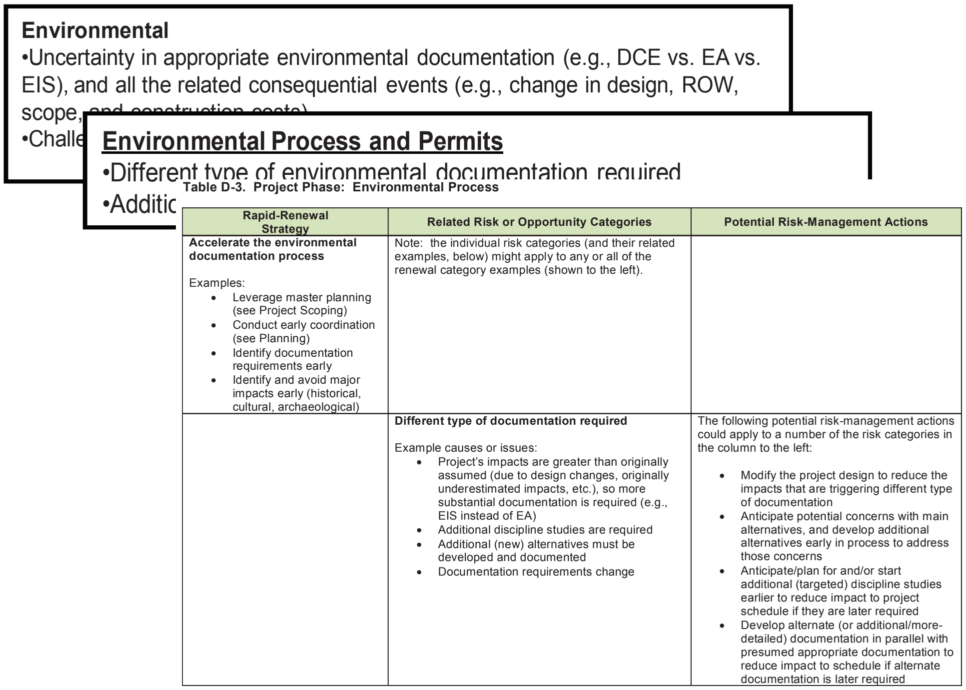
To ensure a smooth and effective risk identification exercise, consider the following guidance (which parallels some of the previously identified principles):

- *Document all credible possibilities* outside the base set of assumptions to develop a comprehensive set of risks and opportunities (separate from potential risk management actions). However, recognize that regardless of how thorough the identification process is, there will still be risks that have not been identified, although they should not be major ones. A miscellaneous risk can capture all of these unidentified risks ("unknown unknowns").
- *Do not debate the severity of issues* (i.e., the likelihood of occurrence or the magnitude of the impacts from occurrence) or *prematurely screen out minor issues*—this comes later during risk assessment.
- *Do not try to "fix" the problem*—this comes later during risk management.
- *Think broadly*. Individuals should consider other projects they have worked on, and reflect on how much those projects changed from original concept to completion. They should also consider both obvious and implied risks (e.g., as hinted in base project documentation by words such as might, maybe, could, assumes, or likely). Ideally, the group could, at the completion of the project, look back and say, "We identified as a possibility every significant change that ultimately occurred."
- *If at all possible, do not intentionally exclude any significant issues* from the risk identification and subsequent risk assessment.
    - —Excluding major uncertainties, risks, and opportunities is the quickest way to misleading or erroneous risk assessment results.
    - —If a DOT must exclude something from the risk assessment (for whatever reason), document the exclusion explicitly. Remember that results will be conditional on the assumption that the excluded issues do not occur (which might be a big assumption), and results might be misleading if these exclusions are not clearly conveyed to those who use the results.

As mentioned earlier, to supplement the brainstorming and analysis by project-team and independent subject-matter experts, the facilitator should attempt to identify any missing risks through use of risk *checklists* (Figure 5.1). These checklists are not intended to be proper risk registers per se, because they are often not comprehensive and contain items that might partially overlap one another. However, their purpose is to serve as memory prompts or shopping lists of issues that have been observed on other projects.

The facilitator can peruse these lists to identify types of risks that might be applicable to the current project but that were not identified through brainstorming and analysis. Note that risk checklists should only be used after the brainstorming and analysis to avoid prepopulating a risk register and therefore stifling creativity and jeopardizing buy-in.

Although various risk checklists are available in several risk assessment references, most lists are substantially incomplete for various reasons (Golder Associates 2008b). As a result, a significant focus for the research effort that led to this guide was to



Environmental

•Uncertainty in appropriate environmental documentation (e.g., DCE vs. EA vs. EIS), and all the related consequential events (e.g., change in design, ROW, scope,

•Challe

Environmental Process and Permits

•Different type of environmental documentation required

•Additi

Table D-3. Project Phase: Environmental Process

Rapid-Renewal Strategy	Related Risk or Opportunity Categories	Potential Risk-Management Actions
Accelerate the environmental documentation process Examples: • Leverage master planning (see Project Scoping) • Conduct early coordination (see Planning) • Identify documentation requirements early • Identify and avoid major impacts early (historical, cultural, archaeological)	Note: the individual risk categories (and their related examples, below) might apply to any or all of the renewal category examples (shown to the left).	
	Different type of documentation required Example causes or issues: • Project's impacts are greater than originally assumed (due to design changes, originally underestimated impacts, etc.), so more substantial documentation is required (e.g., EIS instead of EA) • Additional discipline studies are required • Additional (new) alternatives must be developed and documented • Documentation requirements change	The following potential risk-management actions could apply to a number of the risk categories in the column to the left: • Modify the project design to reduce the impacts that are triggering different type of documentation • Anticipate potential concerns with main alternatives, and develop additional alternatives early in process to address those concerns • Anticipate/plan for and/or start additional (targeted) discipline studies earlier to reduce impact to project schedule if they are later required • Develop alternate (or additional/more-detailed) documentation in parallel with presumed appropriate documentation to reduce impact to schedule if alternate documentation is later required

Figure 5.1. *Checklists (Appendix B).*

develop a more comprehensive, yet still usable, checklist of risk categories, or types of risks, that could occur for rapid renewal projects. This checklist of rapid renewal risk categories is presented in Appendix B:

- *The Risk Checklist for Traditional Transportation Projects section provides a summary of types or categories of risks for traditional (non–rapid renewal) transportation projects, by project phase*. This is presented because, DOTs with rapid renewal projects should, for comprehensiveness, address risks and opportunities for the entire project, not just for the project's rapid renewal elements.
- *The Summary Risk Checklist for Rapid Renewal Projects section provides a summary of risk categories specifically for rapid renewal projects, by project phase*. This section is intended to serve as a risk checklist for rapid renewal projects, but only in terms of generic types of risks. It is up to the DOT to extrapolate from the risk checklist and identify specific risks related to specific rapid renewal strategies and methods employed in the DOT's particular project.
- *The Rapid Renewal Risk Categories and Potential Risk Management Actions by Project Phase section provides more detail than the Summary Risk Checklist for Rapid Renewal Projects section*. Each table in this section corresponds to one of the various project phases defined in Chapter 3:

  —Table B.1. Planning

  —Table B.2. Project Scoping

—Table B.3. Environmental Process and Permits

—Table B.4. General Principles of Design and Construction

—Table B.5. Structures

—Table B.6. Geotechnical and Earthworks

—Table B.7. Drainage and Stormwater Management

—Table B.8. Roadway, Geometrics, and Intelligent Transportation Systems

—Table B.9. Pavement

—Table B.10. Maintenance of Traffic

—Table B.11. Right-of-Way

—Table B.12. Utilities

—Table B.13. Railroads

—Table B.14. Procurement and Contracting Strategy

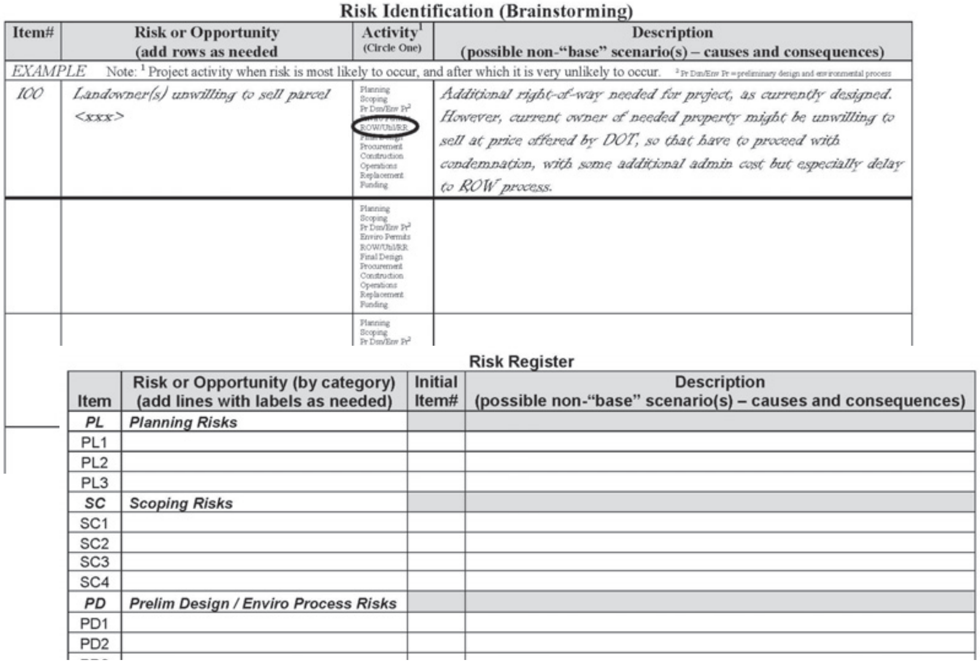
—Table B.15. Operations and Maintenance

—Table B.16. Replacement

Tables B.1 through B.16 provide insight into the summary checklist provided in the Summary Risk Checklist for Rapid Renewal Projects section. Within each table, the relevant major rapid renewal strategies and tactics or methods (distilled from Appendix A) are listed for that project phase. For each rapid renewal strategy in a given table, the general types of risks (risk categories) that could occur from using that renewal strategy are identified. And for each rapid renewal strategy, potential proactive risk management actions are also identified to manage the corresponding risks, as discussed in Chapter 8.

When considered together, the Risk Checklist for Traditional Transportation Projects section and the Summary Risk Checklist for Rapid Renewal Projects section (which is expanded in the Rapid Renewal Risk Categories and Potential Risk Management Actions by Project Phase section) constitute a relatively complete set of risk categories (types of risks) that could occur for projects with both traditional and rapid renewal elements. Remember that these risk checklists are not intended to be proper risk registers—they are only "brain ticklers."

To help the facilitator document and categorize risks during brainstorming, and to then add risks from analysis as well as from checklists and then edit risks to eliminate duplication, specific forms and a Microsoft Excel workbook template have been developed (see Figure 5.2 and Appendix C). These forms and template use the basic project phases shown in Chapter 3 for categorizing risks. The template automatically sorts risks (by category) from brainstorming and assigns each one a unique label. This set of risks can then be supplemented by other risks identified in each category by analysis and then by comparing with risk checklists, and then can be edited to eliminate duplication. This complete set of edited risks becomes the basis of the risk register.



Risk Identification (Brainstorming)

Item#	Risk or Opportunity (add rows as needed	Activity[1] (Circle One)	Description (possible non-"base" scenario(s) – causes and consequences)
EXAMPLE	Note: [1] Project activity when risk is most likely to occur, and after which it is very unlikely to occur. [2] Pr Dsn/Env Pr = preliminary design and environmental process		
100	*Landowner(s) unwilling to sell parcel <xxx>*	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding	*Additional right-of-way needed for project, as currently designed. However, current owner of needed property might be unwilling to sell at price offered by DOT, so that have to proceed with condemnation, with some additional admin cost but especially delay to ROW process.*
		Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding	
		Planning Scoping Pr Dsn/Env Pr[2]	

Risk Register

Item	Risk or Opportunity (by category) (add lines with labels as needed)	Initial Item#	Description (possible non-"base" scenario(s) – causes and consequences)
PL	***Planning Risks***		
PL1			
PL2			
PL3			
SC	***Scoping Risks***		
SC1			
SC2			
SC3			
SC4			
PD	***Prelim Design / Enviro Process Risks***		
PD1			
PD2			

Figure 5.2. *Forms (Appendix C).*

The actual how to details of implementing each of the above steps is covered in companion training materials. The logistics of implementing the above set of steps (e.g., through facilitated workshops), as well as when they should be implemented during project development, are discussed in Chapter 10.

CONCLUSIONS ON RISK IDENTIFICATION

Risk identification is an important step in the risk management process. It involves identifying, categorizing, describing, consolidating and editing, and documenting all potentially significant risks and opportunities to the project's base performance measures. No screening or excluding is done at this time because the significance of the various risks will be determined later, at which point those that are not significant will be identified as such and there will be a record of this determination. Similarly, no changes to the project to fix these problems are made (or assumed) at this time because this will also be done at a later step after the risks have been prioritized. Risk identification forms the basis for a project risk register, risk assessment, risk analysis (if needed), and risk management planning. Therefore, a qualified elicitor should facilitate identification (via brainstorming and then analysis) of a comprehensive and nonoverlapping set of risks from the project team and an appropriate group of project-independent subject-matter experts, efficiently achieving consensus among them, based on available information and expertise. A suitable risk checklist can then be used to ensure completeness.

Example

The hypothetical QDOT case study (see Appendix D) and associated risk management plan (RMP; see Appendix E), which are used throughout the guide to illustrate the various steps of the risk management process, was examined following the principles and process outlined in this chapter and documented in RMP Section 3, and is summarized below.

The facilitated combined group of key project-team staff and independent subject-matter experts identified, categorized, and documented in the project risk register nearly 60 current risks and opportunities (relative to the base) with potential cost, schedule, and disruption impacts (see the table below for several examples). The risks and opportunities (hereafter collectively termed risks) spanned all remaining phases of the project and were categorized by the project phase in which they were most likely to occur (and after which they could be retired), for example, 4 planning risks, 7 scoping risks, 16 preliminary design or environmental process risks, 2 environmental permitting risks, 10 right-of-way or utility risks, 8 procurement risks, and 12 construction risks. At this point in the risk assessment, the group did not discuss the likelihood or severity for any of the risks.

Initially, risks were simply brainstormed by the group and then categorized. Once the initial list of risks was categorized, the group added risks to complete each category, finally referring to the checklists (Appendix B), and then edited the risks to eliminate any overlap.

Select Rapid Renewal Risks for QDOT US-555 and SH-111 Project

Project Phase	Risk ID	Title of Risk or Opportunity No.
Preliminary design or environmental process	PD13	Change in environmental documentation
Right-of-way, utilities, and railroad	RU3	Unwilling sellers
Procurement	CP2	Uncertain design–build contracting market conditions at time of bid
Construction	CN3	Problems with planned accelerated bridge construction technique

Source: Appendix E, RMP Section 3.

6

RISK ASSESSMENT

INTRODUCTION

After identifying risks and opportunities as described in Chapter 5, the next step is to understand the importance that each risk and opportunity has on the project's performance measures. Assessing the severity of each risk and opportunity allows the DOT to better plan risk management actions and make better project decisions.

Objectives

The primary objective of risk assessment is to adequately determine the significance of each risk and opportunity, to determine those risks and opportunities that should be refined further (e.g., by gathering additional information) or reduced (if possible) through proactive risk management actions (Chapter 8).

Secondarily, when considered collectively over the complete set of risks and opportunities, this significance can provide some insight into ultimate project performance. A more quantitative determination of ultimate project performance is discussed in Chapter 7 and plans for managing that performance (including establishing and managing contingencies) are discussed in Chapter 8.

Adequately but efficiently assess the *severity* (combination of likelihood and various consequences), and therefore significance, of each of the risks (including opportunities) in the risk register.

Another objective of risk assessment is to complete this step in the overall risk management process efficiently, producing accurate and defensible results that are compatible with the other steps of the process. How this information will be used in later steps of the process will determine its requirements. In all cases, facilitated consensus among a broad group of project-team and project-independent experts is key to successful risk assessment.

Philosophy and Concepts

There are several important concepts regarding risk assessment that affect the accuracy and defensibility of the results, as well as the effort, including

- Implicit versus explicit rankings;
- Qualitative versus quantitative assessments;
- Subjective versus objective assessments; and
- Level of detail.

Implicit Versus Explicit Rankings

The significance of a risk or opportunity is defined in terms of its severity, or likely effect on project performance. This significance can be determined by ranking the various risks and opportunities in one of two basic ways:

- Implicitly assessing each risk's likelihood of occurring and its impacts on project performance if it occurs (e.g., Risk A is more significant than Risk B), both with respect to individual performance measures and to a combined measure. However, because of the many complexities involved (i.e., the difficulty in implicitly combining and adequately accounting for so many factors), this is difficult to do accurately and defensibly.
- Explicitly assessing and then appropriately combining the risk factors that characterize each risk, including
    - —Likelihood that the risk occurs (e.g., 25% chance); and
    - —Magnitude of the consequences (impacts) to each performance measure if the risk occurs (e.g., $2 million cost increase and 6-month delay to construction).

Assessing the individual risk factors is generally less complex, more tractable, generally more accurate and defensible, as well as more informative—if done appropriately—than implicit assessment. Generally this approach also allows for both identifying and accurately evaluating potential risk management actions (Chapter 8), as well as providing a foundation for risk analysis (Chapter 7), if needed.

This guide focuses on the explicit approach.

Qualitative Versus Quantitative Assessments

Qualitative assessment involves characterizing the likelihood and consequences in terms of nonquantitative ratings. A risk might be assessed to have a High (*H*) likelihood of occurrence and a corresponding Medium (*M*) cost impact and Low (*L*) schedule impact if it occurs. Another approach is to use numerical ratings (e.g., 1 through 5) instead of *H*, *M*, and *L* ratings. In both cases, these ratings typically are not defined with respect to quantitative values. On the benefit side, qualitative assessments may be relatively quick to conduct and provide a simple visual rating (depending on the method used).

Drawbacks of qualitative assessments can include the following:

- Ratings can be vague, if qualitative ratings are not tied to specific values (e.g., what does a "High" likelihood of occurrence really mean?). As a result, different people can interpret qualitative ratings in different ways, which might lead to inaccuracies or problems in developing consensus.

- If the ratings (e.g., for likelihood and consequence) are not combined, then no overall measure of the risk is possible, which means that the register of risks cannot be ranked or prioritized.
- If the ratings are combined, the resulting risk rankings are generally ambiguous, relative (not absolute), and can even be misleading. To rank a risk based on assessed risk factors, the risk factors must generally be combined in some fashion. The most logical approach is to first determine the combined consequence rating from the various consequence types and then to determine the rank as the product of the likelihood rating and the combined consequence rating. However, qualitative ratings cannot actually be added or multiplied and, because the risk-factor ratings are often vague, the resulting risk ranking is ambiguous. For example, suppose a risk has been assessed to have a High (H) likelihood and a Low (L) combined consequence [which in turn was based on a Low (L) cost consequence and a Low (L) schedule consequence]. Is the ranking for this risk $H \times L = M$? And does this risk have the same ranking as another risk with $M \times M = M$? And is this the same ranking as $L \times H = M$?

Quantitative assessment generally involves characterizing the risk factors in one of two ways:

- *Ratings*. In terms of ratings that are defined by appropriate numerical scales (e.g., a High likelihood of occurrence might be defined as a probability of occurrence between 40% and 70%). An example of this type of semiquantitative assessment is presented later in this chapter.
- *Numerically*. Directly in terms of numerical values, which avoids ratings altogether. For example, a risk might be assessed to have a 25% probability of occurring, and if it occurs, would result in a mean value of $1 million additional cost and 2-month project delay during construction. An example of this type of quantitative assessment is also presented later in this chapter.

However, to adequately quantify the uncertainty in project performance, it is generally necessary to assess the uncertainties in (and the correlations among) the various "conditional" consequences of the most significant risks, as well as in the base cost and schedule factors (see Chapter 4). This can be done in terms of likely ranges (continuous probability distributions) or scenarios (discrete probability distributions), as discussed further in Chapter 7.

- *Mean value* is the probability-weighted average value.
- *Conditional value* is the value if the risk occurs (ignoring the probability of that risk occurring).
- *Unconditional mean value* is the mean value considering (that is, accounting for) the probability of that risk occurring.

The benefits of quantitative assessments can include the following:

- There is no ambiguity in values.
- Risk-factor assessments can be meaningfully combined (analytically rather than subjectively):
    - Risk likelihood and consequence can be combined. For example, the “unconditional” mean value of additional cost associated with a particular risk simply equals the product of the conditional mean value of additional cost if the risk occurs and the probability that it will occur.
    - The change in the various project performance measures (i.e., sensitivity) associated with each risk can be determined. For example, for additive project performance measures (such as uninflated cost), either (a) the conditional impacts can be used to determine the conditional change in the performance measure, which is then weighted by its probability of occurrence; or (b) the unconditional impacts can be used directly. However, for nonadditive performance measures (e.g., schedule), these two approaches might give different results, and so conditional impacts should be used.
    - Changes in various individual project performance measures associated with each risk can be combined to create a *single performance measure* for that risk, as a measure of risk severity. For example, the value (in terms of equivalent cost, in dollars) of schedule, disruption, and longevity can be determined and then combined with capital or direct cost, to determine a single combined performance measure in monetary terms. A method for determining the equivalent monetary value for nonmonetary performance measures is described later in this chapter.
    - If the set of risks is comprehensive and nonoverlapping, then the changes in project performance measures associated with that set of risks can be determined. For example, the mean value of the change in uninflated project cost associated with all the risks is the sum over all risks of the unconditional mean value of additional uninflated cost associated with each risk.
- Risks can be ranked meaningfully and appropriately based on their unconditional mean values by consequence type (e.g., uninflated cost increase, schedule impact) or more completely by combined consequence (severity).
- The basis for quantitative risk analysis (Chapter 7) and for quantitative evaluation of possible risk reduction actions is formed, as part of risk management planning (Chapter 8).

- *Performance measure:* For example, cost in monetary terms versus schedule in nonmonetary terms.
- *Combined performance measure:* Nonmonetary performance measures translated into equivalent monetary terms via trade-off value (i.e., willingness to pay to change) and then combined.
- *Severity:* Change in combined performance measure.

For example: If schedule delay is 2 months and the value of such delay has been established at $1 million/month (for deferred operations), then the delay's equivalent cost is $2 million, plus any other time-related delay (increased overheads and escalation). The delay's equivalent cost can be compared directly to capital cost.

The drawbacks of quantitative assessments can include the following:

- Additional effort is required to adequately
  - —Assess the risk factors more precisely and achieve consensus among a broad group of experts. This is especially true if full uncertainty in conditional consequences of risks, as well as in base cost and schedule factors, is assessed, in which case correlations and dependencies must also be considered. This is discussed further in Chapter 7.
  - —Determine (by analysis) the change in project performance measures associated with the assessed risk factors, especially for nonadditive performance measures. This can be done to various degrees of approximation and can become very complicated and prone to error (especially for full uncertainty). This is discussed further in Chapter 7.
  - —Assess the trade-off values to determine equivalent costs of nonmonetary performance measures so that a single combined performance measure can be developed. This is typically a policy (rather than a technical) issue, which should be addressed by DOT management.
- If computing total project risks (i.e., combining the set of risks), a nonoverlapping and comprehensive set of risks is required to avoid double-counting and missing any items, respectively. A suitable allowance (e.g., loosely based on an 80:20 rule that suggests 80% of the total is associated with 20% of the items) is generally used for unidentified risks to make the set comprehensive. For example, a 50% chance of an extra 50% of identified risks, or a 100% chance of an extra 0% to 50% of identified risk, might be used for this allowance.

Subjective Versus Objective Assessment

When an adequate database of information related to a particular risk is available, an objective, or statistical, approach can be used to assess the risk factors. However, this is rarely the case in transportation construction projects and, in particular, for innovative rapid renewal projects. Similarly, when appropriate analytical methods are available to calculate changes in performance measures as a function of the risk factors, then this objective approach can be used, as opposed to assessing those changes in performance measures directly; for example, it is better to assess the change in an activity duration and then analyze the change in project completion date (considering critical path) than to assess the change in project completion date directly.

However, when statistical information or appropriate analytical methods are not available, the opinion of subject-matter experts, based on all available information, can be elicited, de-biased, and quantified in the form of subjective assessments. Because most transportation projects—and particularly rapid renewal projects—are relatively unique, adequate data generally are not available, and properly obtained subjective assessments usually are required to develop risk-factor assessments. Subjective assessments, when properly developed and documented, and especially if they represent a consensus among a wide group of experts, are widely accepted in risk assessment practice. However, subjective assessments are subject to bias, which must be identified and mitigated. Guidance on how to mitigate bias is provided later in this chapter.

Level of Detail

The level of detail, and therefore effort, put into risk assessment should be consistent with the level of information available on the project's cost and schedule, the size and complexity of the project, and the objectives for the risk assessment. For example, if the objective for the risk assessment is

- Simply to roughly identify the top risks, then less detail and precision (in terms of approximation, as opposed to the number of digits) is required.
- To be able to quantify the benefits of proposed risk management actions, then higher-quality and more-detailed assessments and analysis are required.
- To quantify the uncertainty in project performance, then full uncertainty in (and correlation among) the various factors and more-detailed probabilistic analysis are needed, as discussed further in Chapter 7.

PROCESS OF RISK ASSESSMENT

Methods

As mentioned previously, various methods exist to conduct risk assessment via risk factors (as well as implicitly). Several of the more common methods for assessing and combining risk factors include, in increasing level of complexity,

- Qualitative:
  - —*Red/Yellow/Green*. This method uses qualitative ratings for risk factors, which generally are not defined and are combined subjectively.
  - —*Rating Scale*. This method uses numerical ratings, which generally are neither appropriately defined nor appropriately combined.

- Quantitative:
  - —*Mean-Value Ratings*. This method is an extension of the qualitative methods mentioned above, with mean-value ratings based on defined numerical scales and combined appropriately (analytically), resulting in mean risk severity ratings.
  - —*Mean Values*. As its name implies, this method bypasses ratings altogether, instead quantifying risk factors directly in terms of mean values (e.g., dollars,

time), which are combined appropriately (analytically), and results in mean risk severity values (dollars) and mean performance values (e.g., dollars, time).

— *Full Uncertainty.* This method involves quantifying the uncertainties in (and correlations among) the risk factors, as well as the base factors, and then appropriately combining all of the uncertainties (analytically), as discussed in Chapter 7, and results in probability distributions for project performance and contributions to specific target percentiles of project performance.

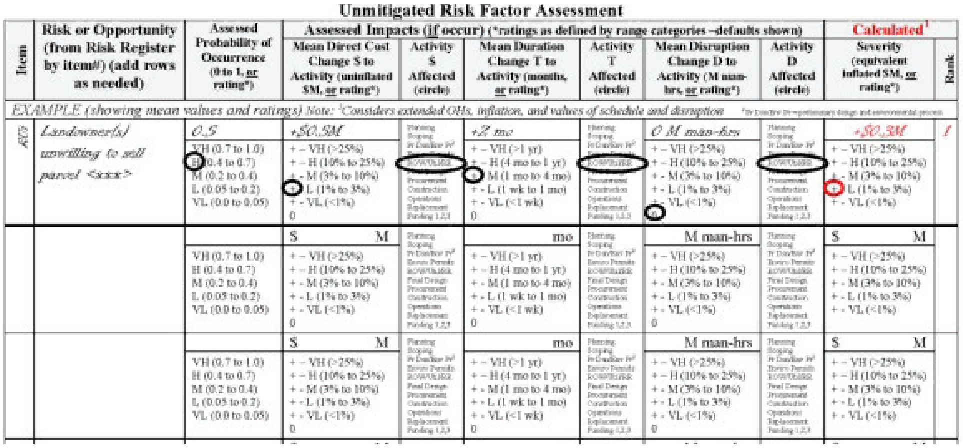
Quantitative Mean-Value Method

The mean-value method characterizes individual risk factors directly in terms of mean values in the corresponding units or dimensions (e.g., probabilities in percent, consequences in dollars and time). Ideally, as discussed later, consensus among a broad group of experts is achieved on these mean values, appropriately considering (either statistically or subjectively) all available information. These mean values of the various risk factors (i.e., probability and conditional consequence by type to specific activities) are then appropriately combined (e.g., by analysis) to determine a mean change in each performance measure, as well as a mean change in a combined performance measure (severity), in terms of equivalent inflated project cost (see next box).

Equivalent inflated project cost is one possible combined performance measure (as described previously). The change in equivalent inflated project cost resulting from a risk reflects the following: (a) the indirect cost of delays in the form of additional overhead or staffing costs, (b) the time-value equivalent cost of schedule delay in terms of additional monetary inflation, (c) the time-value equivalent cost of schedule, disruptions, and longevity in terms of value; and (d) the direct-cost consequence in uninflated monetary terms. If the set of risks is comprehensive and nonoverlapping, then mean total (i.e., base + risk) performance can also be approximated by appropriately combining the base and individual risks, from which the mean collective risk can be determined. However, because this is approximate, it must be done carefully to avoid misleading results. In any case, because it ignores uncertainty in performance, the results should not be used for budgeting (see Chapter 7).

This is the most straightforward method discussed in this chapter because it avoids the ambiguities of intermediate risk-factor ratings and their combination. This method's results can be the least ambiguous and perhaps the most useful, assuming that the DOT wants to use risk assessment results in some quantitative way, providing absolute measures of risk severity and a basis for quantitative risk analysis if needed (Chapter 7). The only drawback is that significant effort might be required to adequately assess the mean values for each risk factor of each risk, and to adequately conduct the analyses to convert the mean values of the risk factors into the mean value of severity. An example of this type of assessment, including an example calculation of the mean value of severity (in equivalent cost terms) and of the collective risk, is shown here. Automating this analysis clearly is the key.

The companion Simplified Risk Management Training course addresses this method in more detail. It includes a form (Figure 6.1) and a Microsoft Excel workbook template (see Appendix C) for conducting this type of risk assessment (including



Unmitigated Risk Factor Assessment

Item	Risk or Opportunity (from Risk Register by item#) (add rows as needed)	Assessed Probability of Occurrence (0 to 1, or rating*)	Assessed Impacts (if occur) (*ratings as defined by range categories –defaults shown)						Calculated[1]	
			Mean Direct Cost Change $ to Activity (uninflated $M, or rating*)	Activity $ Affected (circle)	Mean Duration Change T to Activity (months, or rating*)	Activity T Affected (circle)	Mean Disruption Change D to Activity (M man-hrs, or rating*)	Activity D Affected (circle)	Severity (equivalent inflated $M, or rating*)	Rank
EXAMPLE (showing mean values and ratings) Note: [1]Considers extended OHs, inflation, and values of schedule and disruption								[2]Pr Dsn/Env Pr = preliminary design and environmental process		
R05	Landowner(s) unwilling to sell parcel <xxx>	0.5 VH (0.7 to 1.0) [✓ H] (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	+$0.5M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) [✓ +] - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding 1,2,3	+2 mo + – VH (>1 yr) + – H (4 mo to 1 yr) [✓ +] - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding 1,2,3	0 M man-hrs + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) [✓ 0]	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding 1,2,3	+$0.3M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) [✓ +] - L (1% to 3%) + - VL (<1%)	1
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	mo + – VH (>1 yr) + – H (4 mo to 1 yr) + - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	M man-hrs + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%)	
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	mo + – VH (>1 yr) + – H (4 mo to 1 yr) + - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	M man-hrs + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%)	

Figure 6.1. *Form (Appendix C).*

automatic analyses of risk severity and mean base + risk performance), appropriately considering risks and opportunities, as well as the performance measures and activities for rapid renewal, especially for simple projects. The risks are defined as impacts (by activity) to the base, with values specified (in equivalent monetary terms) for the various performance measures to determine longevity and severity (see Chapter 4).

Quantitative Mean-Value Rating Method

In this method, rating scales are used instead of actual mean values. These scales are predefined so that each rating (e.g., *H*) corresponds to a specific range of values. Ultimately, for calculations, a mean value is assumed for each category and used in the same way as for the quantitative mean-value method. For example, if a probability rating of *M* was defined to represent a range from 40% to 70%, for calculations, a mean value of 55% would be used. This approach therefore involves more approximation, which is the method's main disadvantage compared with the mean-value method.

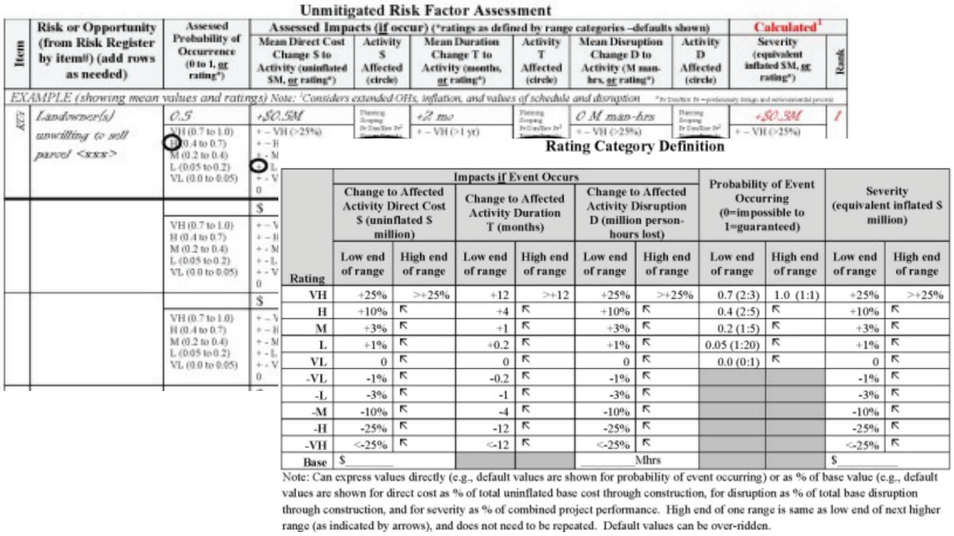
An example of the mean-value rating assessment is shown below. In this simple example (using only three categories), a High cost consequence rating corresponds to a range of cost change between $100,000 and $1 million, whereas a High probability rating corresponds to a range of probabilities between 50% and 100%. For visualization, the assessments can be color-coded (e.g., red for High, yellow for Medium, and green for Low), as shown.

After the risk factors and risk-factor ratings have been defined, the risk factors (i.e., likelihood and various consequence types) for each risk are assessed using the defined scales. Again, ideally the facilitator will achieve consensus among a broad group of experts. These assessments typically can be done very quickly by comparing the predefined rating scales, which is the main advantage of this method over the mean-value method. These risk-factor ratings are then combined to get an equivalent combined mean severity rating, via either

1. An approach that first converts the individual ratings into their equivalent mean values (e.g., middle of the range), then analytically combines those mean values into individual mean performance measures and then a mean combined performance measure in the same way as the mean-value method does, and finally converts the combined value back into an equivalent combined mean severity rating (i.e., an overall mean severity rating for the risk, considering all consequence types or performance measures). Because the combined value is determined before being translated into a rating, risks can be approximately ranked even within each consequence type.
2. An approach that prespecifies the severity rating as a function of the risk factor ratings (e.g., by matrices), which in turn can be determined beforehand either
   - —Analytically, determining the risk severity rating for each possible combination of risk-factor ratings in the same way as discussed above; or
   - —Subjectively, based on consensus among a wide group of experts, which is difficult to do accurately and defensibly, but relatively easy to do analytically.

   However, in this method, risks cannot be ranked within a category (e.g., all Highs are equal).
3. Pure direct subjective assessment, implicitly considering how the various risk factors combine. However, as discussed above, this can be difficult to do accurately and defensibly, but may be relatively easy to do analytically and can be very inefficient to do individually for each risk (e.g., in a workshop).

The companion Simplified Risk Management Training course also addresses Method 1 in more detail, including the same form (Figure 6.2) and spreadsheet template (see Appendix C) as used for the mean-value method (in which mean values and ratings can be mixed). Five (rather than three) ratings (*VL*, *L*, *M*, *H*, *VH*) are used, including negative values for opportunities. This is applicable for relatively simple projects.



Unmitigated Risk Factor Assessment

Item	Risk or Opportunity (from Risk Register by item#) (add rows as needed)	Assessed Probability of Occurrence (0 to 1, or rating*)	Assessed Impacts (if occur) (*ratings as defined by range categories –defaults shown)						Calculated¹	
			Mean Direct Cost Change $ to Activity (uninflated $M, or rating*)	Activity $ Affected (circle)	Mean Duration Change T to Activity (months, or rating*)	Activity T Affected (circle)	Mean Disruption Change D to Activity (M man-hrs, or rating*)	Activity D Affected (circle)	Severity (equivalent inflated $M, or rating*)	Rank
EXAMPLE (showing mean values and ratings) Note: ¹Considers extended OHs, inflation, and values of schedule and disruption										
XXX	*Landowner(s) unwilling to sell parcel <xxx>*	*0.5* VH (0.7 to 1.0) [✓ H] (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	*+$0.5M* + – VH (>25%) + – H + - M [✓ +] - L + - V 0		*+2 mo* + – VH (>1 yr)		*0 M man-hrs* + – VH (>25%)		*+$0.3M* + – VH (>25%)	*1*
			$							
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	+ – V + – H + - M + - L + - V 0							
			$							
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	+ – V + – H + - M + - L + - V 0							

Rating Category Definition

	Impacts if Event Occurs						Probability of Event Occurring (0=impossible to 1=guaranteed)		Severity (equivalent inflated $ million)	
	Change to Affected Activity Direct Cost $ (uninflated $ million)		Change to Affected Activity Duration T (months)		Change to Affected Activity Disruption D (million person-hours lost)					
Rating	Low end of range	High end of range	Low end of range	High end of range	Low end of range	High end of range	Low end of range	High end of range	Low end of range	High end of range
VH	+25%	>+25%	+12	>+12	+25%	>+25%	0.7 (2:3)	1.0 (1:1)	+25%	>+25%
H	+10%	↖	+4	↖	+10%	↖	0.4 (2:5)	↖	+10%	↖
M	+3%	↖	+1	↖	+3%	↖	0.2 (1:5)	↖	+3%	↖
L	+1%	↖	+0.2	↖	+1%	↖	0.05 (1:20)	↖	+1%	↖
VL	0	↖	0	↖	0	↖	0.0 (0:1)	↖	0	↖
-VL	-1%	↖	-0.2	↖	-1%	↖			-1%	↖
-L	-3%	↖	-1	↖	-3%	↖			-3%	↖
-M	-10%	↖	-4	↖	-10%	↖			-10%	↖
-H	-25%	↖	-12	↖	-25%	↖			-25%	↖
-VH	<-25%	↖	<-12	↖	<-25%	↖			<-25%	↖
Base	$________				________Mhrs				$________	

Note: Can express values directly (e.g., default values are shown for probability of event occurring) or as % of base value (e.g., default values are shown for direct cost as % of total uninflated base cost through construction, for disruption as % of total base disruption through construction, and for severity as % of combined project performance. High end of one range is same as low end of next higher range (as indicated by arrows), and does not need to be repeated. Default values can be over-ridden.

Figure 6.2. *Forms (Appendix C)*

Example of a Quantitative Mean-Value Assessment (this is not the hypothetical case study)

For a project, the base performance has been established and a set of risks (relative to that base) has been identified and their factors (mean value of impacts of various types by activity and likelihood of occurrence) have been assessed quantitatively. For each risk, severity is calculated as follows:

- Calculate the mean-value change in each performance measure as a function of the mean value of unconditional consequences.
- Combine those mean-value changes in each performance measure into a mean-value change in the combined performance measure.

If the set of risks is comprehensive and nonoverlapping, then the mean value of the performance measure can be approximately determined by simply combining the changes associated with each risk. For example:

- Unconditional schedule-change consequence: Schedule critical path change is determined, and related extended overheads (OHs) are added to direct cost:
  - — for Risk R1: (6-month delay to ROW – 0 base float for ROW) × 15% probability = 0.9 month (mean-value change to schedule performance measure)
  - — for Risk B1: (2 months to procurement – 0 base float for procurement) × 40% probability = 0.8 month (mean-value change to schedule performance measure)
  - — for Risks R1 *and* B1: 0.9 month + 0.8 month = 1.7 months
- Unconditional cost-change consequence: Direct-cost change must be inflated to account for: (1) schedule delay and the associated additional OH costs (at $0.1M/month for preconstruction), and (2) additional inflation of total cost due to schedule delay:
  - — for Risk R1: {[$0.5M direct uninflated cost to ROW + (6-month delay to ROW – 0 base float or ROW) × $0.1M/month (extended OH for ROW)] × 1.10 (inflation factor for additional direct cost, including delay, for ROW) + $100M (remaining cost after ROW) × 0.02 (increase in inflation in remaining cost after ROW due to 6-month delay in ROW)} × 15% probability = $0.48M (YOE)
  - — for Risk B1: {[$2.0M direct uninflated cost to construction + (2-month delay to procurement – 0 float for procurement) × $0.1M/month (extended OH for procurement)] × 1.20 (inflation factor for additional direct cost, including delay, for construction) + $90M (remaining cost after procurement) × 0.01 (increase in inflation in remaining cost after procurement due to 2-month delay in procurement)} × 40% probability = $1.42M (YOE)
  - — for Risks R1 *and* B1: $0.48M (YOE) + $1.42M (YOE) = $1.90M (YOE)
- Unconditional disruption consequence change is determined as follows:
  - — For Risk R1: 0 person-hours × 15% probability = 0 person-hours
  - — For Risk B1: 0 person-hours × 40% probability = 0 person-hours
  - — For R1 *and* B1: 0 person-hours + 0 person-hours = 0 person-hours

(continued)

- Longevity change is determined (see Chapter 4) based on changes in cost and disruption associated with operations and maintenance and replacement, as well as schedule of replacement, and various trade-offs, but is zero in this case and not shown.
- Overall severity for a risk, in terms of a combined performance measure, is then determined (see Chapter 4) from changes in individual performance measures and separately assessed trade-offs among the performance measures:
  - For Risk R1: 0.9 month × $0.5M/month (delay value, separate from extended OHs and inflation) + $0.48M + 0 person-hours × $10/person-hour (disruption value) = $0.93M
  - For Risk B1: 0.8 month × $0.5M/month (delay value, separate from extended OHs and inflation) + $1.42M + 0 person-hours × $10/person-hour (disruption value) = $1.82M
  - For R1 and B1: $0.93M + $1.82M = $2.75M

Note: M = million.

The above example of a quantitative mean-value assessment (both inputs and outputs) has been summarized in the table below.

Risk	Scenario for Conditional Consequence to each Performance Measure[a]			Scenario Probability	Risk Severity (equiv $)
	Direct-Cost Change (uninflated $)	Schedule Change (months)	Disruption Change (h)		
…	…	…	…	…	…
R1. Landowner unwilling to sell key property	$0.5M to ROW	6 to ROW	0	15% through ROW	$0.93M
…	…	…	…	…	…
B1. Poor bidding climate for general contractor	$2M to construction	2 to procurement	0	40% through procurement	$1.82M
…	…	…	…	…	…
Total Unconditional Consequence	$1.90M	1.7	0		$2.75M

Note: M = million, ROW = right-of-way, YOE = year-of-expenditure (i.e., inflated).

[a] If risk occurs.

Example of Quantitative Mean-Value Rating Assessment (this is not the hypothetical case study)

Similar to the previous example, the base performance for a project has been established and a set of risks (relative to that base) has been identified and their factors (mean value of impacts of various types by activity and likelihood of occurrence) have been assessed qualitatively (i.e., *L*, *M*, *H* in this example). These risk-factor ratings are defined below. The risk-factor ratings are converted into approximate mean values, and then risk severity is calculated by first calculating the mean-value change in each performance measure as a function of the mean value of unconditional consequences, and then combining those mean-value changes in each performance measure into a mean-value change in the combined performance measure in the same way as for the mean-value method (see previous example), which is then translated back into a rating (as also defined below). For example, to determine the effect of Risk R1 on project completion date

- *H* (>3 months) assessed change to duration of ROW translates to about 6 months
- *L* (<20%) assessed probability of occurrence translates to about 10%
- Mean change in critical path can be determined to be (6-month delay to ROW – 0-month base float for ROW) × 10% probability = 0.6 month (which translates back to *L* schedule change). Note that the mean-value ratings result in slightly different mean values than the mean value (see previous example) because of approximation associated with ranges.

Rating definitions are as follows:

Rating	**Consequence**			**Probability**	**Severity**[d]
	Cost Change[a]	**Schedule Change**[b]	**Disruption Change**[c]		
L	<$100,000	<1	<10,000	<0.2	<$200,000
M	$100,000–$1,000,000	1–3	10,000–100,000	0.2–0.5	$200,000–$2,000,000
H	>$1,000,000	>3	>100,000	>0.5	>$2,000,000

[a] Cost change in direct uninflated dollars (to specific activity).

[b] Schedule change in months of delay to specific activity (regardless of critical path).

[c] Disruption change in equivalent person-hours (to specific activity).

[d] Severity in equivalent inflated dollars.

(continued)

The above example of quantitative mean-value rating assessment (both inputs and outputs) has been summarized in the table below.

Risk	Scenario for Conditional Consequence to each Performance Measure[a]			Scenario Probability	→	Risk Severity
	Cost Change	**Schedule Change**	**Disruption Change**			
…	…	…	…	…		…
R1. Landowner unwilling to sell key property	*M* to ROW	*H* to ROW	*L*	*L*		M
…	…	…	…	…		…
B1. Poor bidding climate for general contractor	*H* to construction	*M* to procurement	*L*	*M*		M
…	…	…	…	…		…
↓						↓
Total unconditional consequence	H	M	L		→	H

[a] If risk occurs.

Other Methods

The qualitative red/yellow/green method is essentially the same as the quantitative mean-value rating method, except that

- The ratings involve only three categories (*H*, *M*, *L*), which are quick and color-coded (and thus visual). However, the ratings are generally undefined and thus ambiguous (How much is "High"? What is the relationship between the risk consequence and the performance measure?).
- The risk factors are usually combined in a purely subjective (rather than in an analytical) way to assess risk severity. If not assessed directly (i.e., implicitly considering the various risk-factor ratings), this combination is sometimes done through predefined matrices showing which combinations of likelihood and various consequences result in various categories of risk, although, generally, there still would not be any mathematical basis for the matrix (only judgment). Conceivably, these matrices could be developed beforehand through analysis, similar to what would be done for the mean-value rating method.

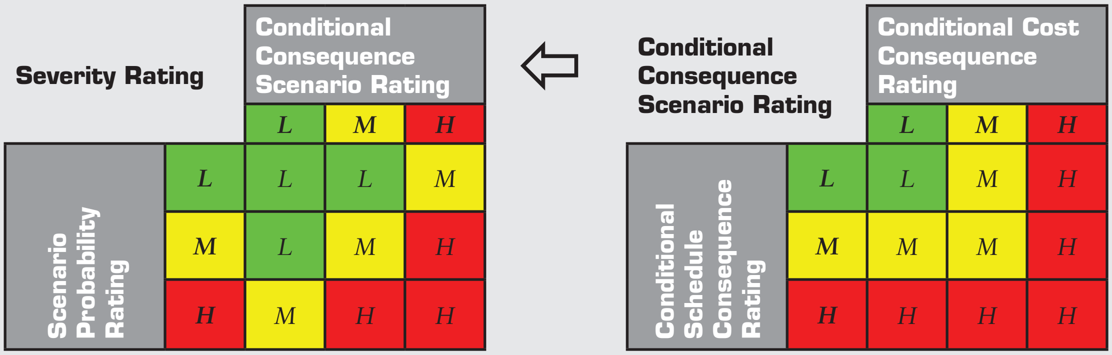
- Risks are only roughly categorized (e.g., as High) without any ranking within categories.
- Except by judgment, total risks cannot be determined (e.g., $M + M =?$).

There is no significant advantage to this method compared with the quantitative mean-value rating method, except that it does not require analysis to determine risk severity as a function of the risk-factor rating. However, this generally results in much less accuracy (and often even errors) in the subsequent severity ratings, with little increase of efficiency because the analysis can be done relatively easily. Hence, this method is not generally recommended.

The qualitative rating-scale method is basically an extension of the red/yellow/green method, and attempts to improve how the risk factors are combined to determine risk severity. This method is very similar to the mean-value method, except that dimensionless, numerical rating scales (rather than mean values for the mean-value method, or just *L*, *M*, *H* for the red/yellow/green method) are generally used for the risk factors. For example, 1 = "rare" to 5 = "certain" for likelihood, and 1 = "low" to 5 = "catastrophic" for consequences. These numerical ratings are then combined in essentially the same mathematical way as for the mean-value method, to determine unconditional consequences and then severity for each risk. For example, the numerical ratings for likelihood (e.g., $P = 1$) and combined consequences (e.g., $C = 3$), which in turn are either assessed directly or determined from the various types of consequences (e.g., as the maximum rating among them), are simply multiplied to determine the severity for each risk (e.g., severity = $1 \times 3 = 3$). The set of risks (i.e., all risks in the risk register) can then be categorized and ranked on the basis of the severity of each individual risk. This is intended to address a few of the problems associated with the red/yellow/green method (i.e., combining risk factors and ranking risks within categories), while still being quick.

However, this rating scale approach to combining likelihood and consequence ratings is only mathematically correct if the rating scales have been appropriately defined and the factors appropriately assessed (e.g., consequences in terms of changes in performance measures). This means that if ratings are being multiplied (as described above), then the individual rating scales should be linear, so that, for example, a consequence of 2 is twice as bad as a consequence of 1, and a likelihood of 4 is twice as high as a likelihood of 2. Otherwise, if the scales are not appropriately defined, the combination of individual likelihood and consequence ratings will produce severity ratings that might scale nonlinearly or even be noncomparable (e.g., does $1 \times 3 = 3 \times 1$?). Conceivably, like the mean-value rating method, these numerical ratings (if adequately defined) can be translated into mean values and then used, in which case it is essentially the same as the mean-value rating method. However, even if done properly, this method provides only a relative measure of risk (i.e., in terms of the nondimensional rating scales, such as 1–5), and not an absolute measure (e.g., in terms of dollars or months), which would be needed to evaluate cost–benefit of possible risk reduction actions (see Chapter 8). Hence, there is no advantage to this method over the mean-value method, and hence it is generally not recommended.

Example of a Qualitative "Red/Yellow/Green" Assessment



Severity Rating		Conditional Consequence Scenario Rating		
		L	M	H
Scenario Probability Rating	L	L	L	M
	M	L	M	H
	H	M	H	H

Conditional Consequence Scenario Rating		Conditional Cost Consequence Rating		
		L	M	H
Conditional Schedule Consequence Rating	L	L	M	H
	M	M	M	H
	H	H	H	H

Note: Risk severity either is assessed directly (implicitly considering conditional consequence scenario and scenario probability ratings) or is based on predefined matrices (e.g., as shown above), which must be carefully developed to avoid errors.

Guidance

This chapter has introduced a number of concepts and methods related to risk assessment. Although this guide is not meant to be a how-to document (the companion Simplified Risk Management Training course materials address implementation), it is worthwhile here to provide some key guidance related to the previously introduced concepts and methods.

Risks (including opportunities) are uncertain events that might or might not happen, and if they happen, could result in uncertain (i.e., difficult-to-predict) consequences to the project's performance measures. Risk assessment attempts to "wrap its arms around" each risk, and characterize and quantify (or qualify) it. This can be difficult, considering variability in conditions under which the project will be planned and constructed, and uncertainty in (i.e., our lack of knowledge or ignorance about) those conditions and what problems and opportunities exist, and what their impacts might be if they occur. Therefore, a few key points are notable when conducting risk assessment to ensure that the assessment reasonably, accurately, and defensibly quantifies (or qualifies) the risks and opportunities:

- *Consequences Must Be Consistent with Likelihoods.* The assessed consequences reflect the anticipated magnitude of a risk's impacts. The magnitude of the impacts implies a particular likelihood of occurrence. For example, catastrophic impacts are usually less likely than are minor impacts (but not always, depending on whether thresholds are defined). A number of realistic or feasible scenarios or outcomes could be defined for a particular risk. Therefore, the authors recommend defining a realistic risk scenario that pairs consistent likelihood and consequence values. Note that from a mean-value perspective, it is the combination of risk-factor values (i.e., the mean risk) that matters, assuming realistic scenarios. Hence, for example, a risk with a 25% probability of occurrence and a $4 million cost impact is equivalent to a risk with a 50% probability of a $2 million cost impact, because both have a mean risk of $1 million. Having said this, however, extreme scenarios (i.e., very low likelihoods of catastrophic consequences) are not usually selected as the basis for mean-value assessments if other, more average scenarios are possible.

- *Bias Must Be Identified and mitigated*. The goal of risk-factor assessment is to obtain accurate, defensible assessments. As mentioned previously, subjective assessments are usually required to assess risk factors but are subject to bias. Bias essentially comes in two forms (Roberds 1990):
  - "Motivational bias" occurs when someone says something that contradicts what they believe. This bias can be difficult to detect and counter, but is often present when participants have a stake in a project's continued survival or other conflict of interest. It can also occur when experts intentionally inject some conservatism into their assessments or intentionally exclude some scenarios. The various types of motivational biases include
    - *Management*—telling them what they want to hear;
    - *Expert*—wanting to appear knowledgeable;
    - *Conflict*—being self-serving;
    - *Conservative*—erring on the "safe" side; and
    - *Peer pressure*—going with the crowd.
  - "Cognitive bias" occurs when someone believes something that is inconsistent with the facts. Most people will overestimate what they know about a particular topic, which leads to overoptimism and to underestimating uncertainty. The various types of cognitive biases include
    - *Anchoring*—focusing on the starting point (e.g., neglecting extremes);
    - *Overconfidence*—ignoring unlikely possibilities;
    - *Coherence/Conjunctive Distortions*—ignoring combination of component parts (e.g., if Event x requires a set of y independent events, then $P[x] = \prod_y P[y]$);
    - *Availability*—focusing on easily recalled info;
    - *Base Rate*—focusing on the most specific information (neglecting data-based frequency of occurrence); and
    - *Representativeness*—ignoring relevance of different types of information (treating all information equally).

  These biases can often be effectively countered by a qualified facilitator and use of project-independent subject-matter experts. However, simply being aware of these potential biases is the first step toward mitigating them. In addition, avoiding these other common pitfalls (which a qualified facilitator should also help with) can mitigate bias:

  - — Poor problem structure (e.g., ambiguous definition of what is to be assessed, such as an average value or a random value);
  - — Adverse group interactions (e.g., dominance by one person);
  - — Ignoring important relationships among factors; and/or
  - — Failing to consider all possibilities and all available information appropriately.

- *Experiment with Methods for Assessing Risk Factors*. A few methods are covered in the companion Simplified Risk Management Training course, but DOTs should be aware that numerous approaches are available to help ensure reasonable risk-factor assessments. A particular approach or tool might resonate better with one group than another, and so the DOT can experiment with each group to determine which works best for that group. Example methods include
  - — Ranges, which use thresholds;
  - — Comparative probabilities, which compare the likelihood of the risk being assessed against the likelihood of common events (e.g., coin toss or roll of a die) with known probabilities, bracketing and converging on the risk;
  - — Ranking and relative difference, which first ranks possible outcomes by pairwise comparison, then assesses relative likelihoods (in terms of ratios) by pairwise comparison, then uses the ratios from the comparisons to determine individual probabilities;
  - — Probability wheel, which uses a wheel with a rotating wheel segment to visually cue for probability, or converging confidence intervals by pairwise comparison;
  - — Decomposition, which is the process of graphically breaking down a risk into its component causes or sequence of events or outcomes. Decomposition can be accomplished using well-established graphical tools:
    - ▪ "Event trees" (also known as "probability trees") are useful for graphically defining scenarios of outcomes and the corresponding probabilities and consequences that might result from a triggering risk event.
    - ▪ "Fault trees" can be used to evaluate the probability that a risk ("failure event") occurs, by building up the various combinations of events that are required to trigger the risk's occurrence.
  - — Full probability distributions (see Chapter 7).
- *Use Appropriate Methods for Combining Risk Factors*. As described previously, a variety of methods are available for combining risk-factor assessments into a measure of risk severity, ranging from implicit subjective assessment to explicit mean-value assessment and analysis to detailed probabilistic analysis (as discussed in Chapter 7). Applying these methods involves different levels of skill and effort, and they result in different levels of accuracy and defensibility. The appropriateness of any particular method depends on how the information will be used, as well as

the nature of the risk-factor assessments. Within this context, the analysis of severity should adequately consider (a) all relevant performance objectives and tradeoffs among them, (b) the uncertainties in meeting those performance objectives, and (c) how each risk or opportunity affects meeting those objectives, including the relationship between the risk consequence factors (e.g., uninflated direct cost, schedule delay, disruption), as assessed, and the performance objectives (e.g., inflated total cost, overall project schedule). As previously noted, for relatively simple projects, a Microsoft Excel workbook template has been developed to document the assessments and automatically calculate risk severity and mean performance.

CONCLUSIONS ON RISK ASSESSMENT

The objective of risk assessment is to adequately describe the severity of project risks, to rank the risks for subsequent risk reduction planning, and if done quantitatively, forms a basis for probabilistic risk analysis, if needed (e.g., to objectively establish budgets or contingencies). Various methods are available for conducting risk assessment, and each has its strengths and weaknesses:

- Qualitative methods are quick but prone to inaccuracy with limited usefulness.
- Quantitative methods involve more effort but are more accurate and useful, although a statistical basis has limited applicability whereas a subjective basis is prone to bias (requiring mitigation by facilitator).

Two of the methods (mean-value ratings and mean values), which are appropriate for relatively simple projects, have been incorporated in specific forms and in a Microsoft Excel workbook template, available online at www.trb.org/Main/Blurbs.168369.aspx.

The DOT should select an appropriate method depending on its objectives for the risk assessment. Regardless of the chosen method, the DOT should take steps to ensure that risks are assessed defensibly, accurately, and efficiently, and documented appropriately (in the risk register). A qualified risk facilitator who guides the assessment process (at the appropriate level of detail, considering the model and factors involved), mitigates bias, and develops consensus among a broad group of project-team and independent experts is key.

Example

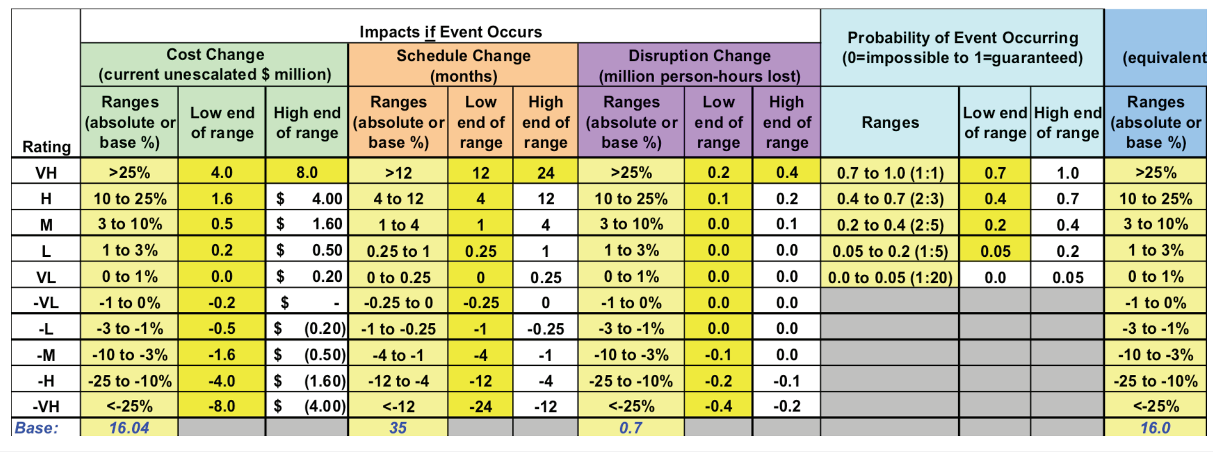
The hypothetical QDOT case study (see Appendix D), which is used throughout the guide to adequately illustrate the various steps of the risk management process and includes a risk management plan (RMP), involves assessments of each of the risks in the risk register (using the methods and guidance described in this chapter), as documented in Appendix D and Appendix E, RMP, Chapter 3, summarized below.

(continued)

QDOT initially decided that assessing the current risks in terms of mean-value ratings (e.g., *L*, *M*, and *H*) would be sufficient for its intended use of the risk assessment results (i.e., prioritizing the risks for proactive individual risk reduction). Hence, the group first defined mean-value rating scales for the various risk factors:

- Each of the three types (cost, schedule, and disruption) of impacts of occurrence (e.g., a Medium (*M*) cost impact was defined to correspond to a value between 3% and 10% of the base project cost, in uninflated dollars);
- The probability of occurrence (e.g., *M* probability corresponded to a probability of occurrence between 0.2 and 0.4); and
- The severity of combined impacts (considering the probability of occurrence and trade-offs) (e.g., *M* severity was defined to correspond to a value between 3% and 10% of the base combined performance, in equivalent inflated dollars).

Risk Factor Rating Scale Definitions for QDOT US-555 and SR-111 Project



Rating	Impacts if Event Occurs									Probability of Event Occurring (0=impossible to 1=guaranteed)			(equivalent
	Cost Change (current unescalated $ million)			Schedule Change (months)			Disruption Change (million person-hours lost)						
	Ranges (absolute or base %)	Low end of range	High end of range	Ranges (absolute or base %)	Low end of range	High end of range	Ranges (absolute or base %)	Low end of range	High end of range	Ranges	Low end of range	High end of range	Ranges (absolute or base %)
VH	>25%	4.0	8.0	>12	12	24	>25%	0.2	0.4	0.7 to 1.0 (1:1)	0.7	1.0	>25%
H	10 to 25%	1.6	$ 4.00	4 to 12	4	12	10 to 25%	0.1	0.2	0.4 to 0.7 (2:3)	0.4	0.7	10 to 25%
M	3 to 10%	0.5	$ 1.60	1 to 4	1	4	3 to 10%	0.0	0.1	0.2 to 0.4 (2:5)	0.2	0.4	3 to 10%
L	1 to 3%	0.2	$ 0.50	0.25 to 1	0.25	1	1 to 3%	0.0	0.0	0.05 to 0.2 (1:5)	0.05	0.2	1 to 3%
VL	0 to 1%	0.0	$ 0.20	0 to 0.25	0	0.25	0 to 1%	0.0	0.0	0.0 to 0.05 (1:20)	0.0	0.05	0 to 1%
-VL	-1 to 0%	-0.2	$ -	-0.25 to 0	-0.25	0	-1 to 0%	0.0	0.0				-1 to 0%
-L	-3 to -1%	-0.5	$ (0.20)	-1 to -0.25	-1	-0.25	-3 to -1%	0.0	0.0				-3 to -1%
-M	-10 to -3%	-1.6	$ (0.50)	-4 to -1	-4	-1	-10 to -3%	-0.1	0.0				-10 to -3%
-H	-25 to -10%	-4.0	$ (1.60)	-12 to -4	-12	-4	-25 to -10%	-0.2	-0.1				-25 to -10%
-VH	<-25%	-8.0	$ (4.00)	<-12	-24	-12	<-25%	-0.4	-0.2				<-25%
Base:	*16.04*			*35*			*0.7*						*16.0*

The group then discussed each of the identified risks in the risk register and quantified (by consensus) each of them in terms of mean-value ratings (or sometimes directly in terms of mean values) for the following, before any additional mitigation: (a) the cost, schedule, and disruption impacts (and the affected activity) if the risk occurs; and (b) the probability that the risk (as defined by its impacts) will occur (during the particular project phase under which it is categorized). Subsequently, a quantitative risk analysis was conducted, for which these unmitigated assessments were refined; see Appendix E, Addendum X.

QDOT then used these assessments to determine (using an appropriate risk model, for example, the Microsoft Excel workbook template that incorporates the algorithms presented in this chapter: (a) the approximate unmitigated mean-value contribution of each risk to the project objectives of cost, schedule, and disruption; and (b) by combining with QDOT's established value trade-offs among the objectives, an unmitigated mean-value longevity

(continued)

and then severity for each risk, based on which the risks were ranked. Subsequently, a quantitative risk analysis was conducted, for which the contribution of each risk and other uncertainty to the potential budget, before any additional mitigation, was determined more accurately; see Appendix E, RMP, Addendum X.

Unmitigated Risk Factor Assessments for Select Rapid Renewal Risks for QDOT US-555/SR-111

Project Phase	Example Risk or Opportunity	Probability of Occurrence	Mean-Value or Ratings to Affected Activity		
			Mean Cost Change if Occurs	Mean Duration Change if Occurs	Mean Disruption Change if Occurs
Preliminary design/ environmental process	PD13. Change in environmental documentation	*L*	+*M* to preliminary design / environmental process	+*H* to preliminary design / environmental process	0
Right-of-way, utilities, and railroad	RU3. Unwilling sellers	*H*	+*M* to ROW/ Util/RR	0	0
Procurement	CP2. Uncertain D-B contracting market conditions at time of bid	25%	+10% of base (i.e., +$1.2M) to D-B construction	+1 month to procurement	0
Construction	CN3. Problems with planned accelerated bridge construction technique	*H*	+*L* to D-B construction	+*L* to D-B construction	+*L* to D-B construction

Unmitigated Risk Severity Determination and Ranking for Select Rapid Renewal Risks for QDOT US-555/SR-111 Project

Project Phase	Example Risk or Opportunity	Mean Severity (equiv YOE $M or Rating scale definition above) Fine.	Rank
Preliminary design/ environmental process	PD13. Change in environmental documentation	*L*	11
Right-of-way, utilities, and railroad	RU3. Unwilling sellers	*M*	4
Procurement	CP2. Uncertain D-B contracting market conditions at time of bid	0.38	9
Construction	CN3. Problems with planned accelerated bridge construction (technology, procurement, and implementation)	*L*	12

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7

RISK ANALYSIS

INTRODUCTION

The tasks of identifying, assessing, and managing risk for rapid renewal projects can produce results useful to project risk managers, in helping to understand and optimize project performance. However, there is another very valuable process within the sphere of risk management, *risk analysis*, which can provide additional valuable information to project managers when projects are more complex or the information required for decisions must be more precise.

Objectives

Risk analysis starts with the results from structuring, risk identification, and risk assessment, as described in the previous chapters. Risk analysis then expands on those elements and combines them to quantify the key project performance measures, such as project cost and schedule, considering risk as well as base. This can be done in terms of mean values (as discussed in Chapter 6) or more completely in terms of full uncertainty (e.g., Figure 7.1). Results from risk analysis can then be used to help make important project decisions because they contain more detail and information than do risk assessments.

> Adequately but efficiently (a) quantify uncertainties in (and correlations among) inputs (including risks and opportunities); (b) propagate those uncertainties through to outputs (e.g., project cost and schedule); and (c) quantify sensitivity.

Hence, the primary objectives for risk analysis are to

- Adequately quantify uncertainty in the project performance measures, such as project inflated year-of-construction cost and completion date, appropriately considering risks as well as the base uncertainties;

- Adequately (a) quantify the likelihood for achieving existing budgets and milestones or (b) establish budgets and milestones (including contingencies) for a desired reliability or confidence level (e.g., 80% chance for success); and
- Adequately quantify the sensitivity of those project performance measures to the individual risks and base uncertainties, which provides additional information for risk management planning.

Ideally, this would be done not only from a current perspective but also projected to various milestones to determine remaining costs and schedule to finish (e.g., to establish defensible contingency drawdown requirements).

Another goal is to complete this step efficiently, producing defensible as well as accurate results that are compatible with the other steps of the process. How this information will be used will determine the requirements and the level of effort (which can be significant) for this step. However, adequate quantification of the significant uncertainties in the various base and risk factors and development of an appropriate risk model that can be easily updated are keys to successfully completing this step.

Philosophy and Concepts

Performance measures can generally be adequately estimated as a function of specific factors. For example, total project cost is simply the sum of all of the various costs, both base and realized risks. As another example, the project completion date can be determined by critical path analysis, based on activity durations (both base and realized risks) and precedence requirements (including lags and external milestone dates). Typically, however, there is significant uncertainty in what those factors will be (especially risks, which might or might not occur), which in turn results in significant uncertainty in what the performance measures will be. Generally (as discussed in Chapter 6), mean values of the performance measures can be adequately approximated as a function of the mean values of those various factors. However, the determination of the full uncertainty in performance measures requires more sophisticated analysis, which can be done in various ways with different levels of accuracy and defensibility, and thus effort. The types of results produced by risk analysis are illustrated later in this chapter by example.

The various important concepts associated with risk analysis include

- Qualitative versus quantitative assessment;
- Uncertainty description;
- Performance measures;
- Deterministic versus probabilistic analysis;
- Risk-based versus non–risk-based analysis;
- Time-variable versus time-independent analysis;
- Decoupled versus integrated analysis;
- Initial versus updated analysis; and
- Levels of detail, accuracy, defensibility, and effort.

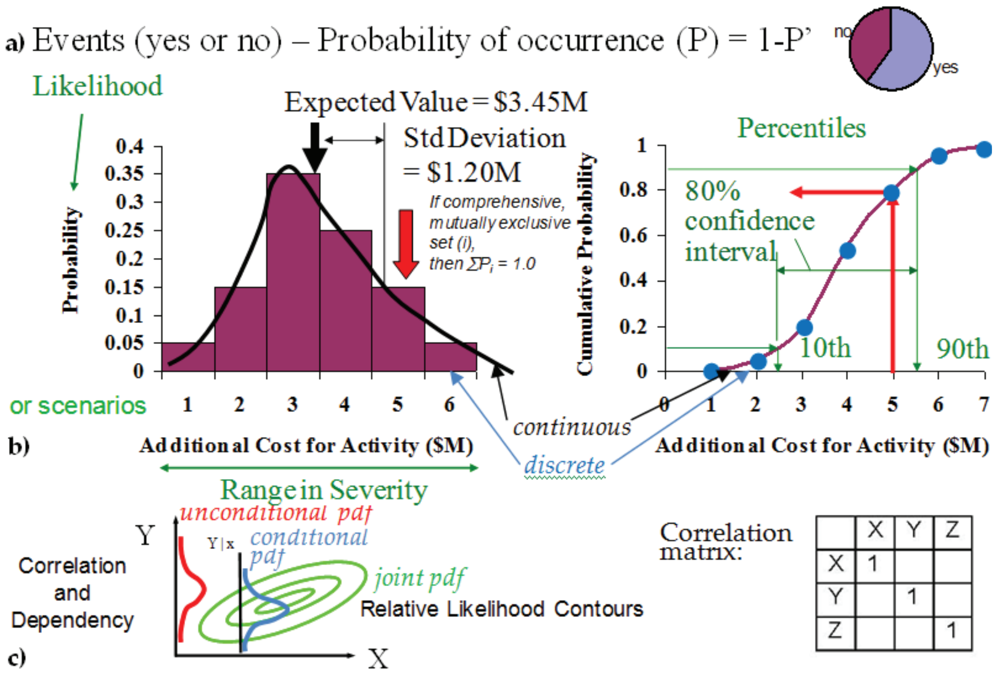
Qualitative Versus Quantitative Assessment

This was addressed in Chapter 6 with respect to risk assessment. For risk analysis as described in this chapter, quantitative assessment is required, generally including explicit quantification of significant uncertainties (in terms of probability distributions) and correlations for input variables. The discussion in Chapter 6 focused on mean-value assessments, which are appropriate for some applications but ignore uncertainties and correlations.

Uncertainty Description

Uncertainties can be described in terms of "probability distributions," which express the relative likelihood of any one particular value for a factor that has a set of possible values. The uncertainty in the value of a particular factor can be expressed in different ways, depending on the nature of that factor (Figure 7.1):

- Two possible values (e.g., yes or no)—probability (Figure 7.1a);
- Discrete set of possible values (e.g., several ranges of values, or scenarios)—discrete distribution (Figure 7.1b), which in turn can be combined into two states (e.g., either more or less than a particular value, or either one or the other subset of scenarios); and
- Infinite set of possible values (e.g., cost)—continuous distribution (Figure 7.1b), which can be "binned" into a discrete distribution or even two states (e.g., either more or less than a particular value).



	X	Y	Z
X	1		
Y		1	
Z			1

Figure 7.1. *Probability distributions.*

Probabilities are defined on a range from 0.0 (impossible) to 1.0 (guaranteed), so that the sum of probabilities of a comprehensive and mutually exclusive set of values must equal 1.0. For continuous distributions, the relative likelihood value is defined so that it integrates to 1.0.

Uncertainties in combinations of factors are generally described by the probability distribution of each factor, in combination with a correlation coefficient, or by “conditional” distributions (Figure 7.1c).

Performance Measures

As discussed in Chapter 3, several key performance measures are of interest for rapid renewal projects: schedule, cost, and disruption through construction, longevity after construction, and combined performance.

- *Schedule*. Key milestone dates (e.g., start of operations) or durations (e.g., time to replacement) typically are of interest. The entire schedule can be modeled via critical path analysis, in which (1) a complete and nonoverlapping set of project activities is identified; (2) their sequence (in terms of precedence requirements) is identified (e.g., visually in a flowchart); (3) activity durations, lags, and/or external milestone dates are assessed; and (4) early start and end dates are determined for each activity, which defines the critical path (and float for non–critical path) activities and critical milestones and durations of interest.
- *Cost*. Inflated costs through specific milestones (e.g., through construction) typically are of interest. Costs can be modeled as follows: (1) a complete and nonoverlapping set of project cost items is identified; (2) quantities and uninflated unit costs (including appropriate markups) are assessed for each item, consistent with the schedule (e.g., for overheads); (3) uninflated costs are determined for each item by multiplying the quantities and uninflated unit costs; and (4) inflated costs are then determined depending on when the various cost items occur (schedule of project activities and their relationship to the cost items) and on relevant inflation rates. The various cost items can be allocated to the project activities (e.g., 60% to Activity *x* and 40% to Activity *y*) to generate a cost-loaded schedule, and variable inflation rates for specific activities can be used.
- *Disruption*. This is defined in terms of equivalent lost user person-hours, which includes traffic delays and detours, as well as business and other socioeconomic impacts. Disruption is assumed to be approximately additive, and thus can be modeled as follows (as discussed in Chapter 4): (1) a complete and nonoverlapping set of disruptive activities is identified; (2) the average disruption rate and duration for each activity are assessed, where the disruption rate might be determined on the basis of assessments of the average delay per person and average number of people affected per day; (3) the disruption is then determined for each activity by multiplying the average delay per person for that activity, the average number of people affected per day during that activity, and the duration of that activity; and

(4) the schedule of disruption can then be determined (if desired) by identifying when the disruptive activities will occur (e.g., according to the schedule activities).

- *Longevity.* This is defined (see also Chapter 4) as the net present value (NPV) of costs and disruption (translated to equivalent cost) for operations and maintenance (O&M) and replacement, considering schedule (time to replacement) and using an appropriate net discount rate (which is a DOT policy issue rather than a technical one). The objective is to minimize this NPV. In this way, difficult (expensive or disruptive) O&M or replacement, or a short time to replacement, will be appropriately "penalized." Hence, longevity can be modeled as follows (as previously discussed in Chapter 4): (1) the average uninflated cost and disruption associated with O&M (e.g., on an annual basis) and with replacement, and the duration of O&M to replacement, are assessed; (2) the net discount rate and trade-off value (cost equivalence) of disruption are established; and (3) the NPV of cost and disruption is determined by translating annual O&M and replacement disruption into equivalent cost terms and then adding them to annual O&M and replacement cost, respectively, and then discounting annual and replacement equivalent cost to NPV and adding them together.
- *Combined*. Severity is defined as a change in the combination of the above performance measures, considering trade-offs among them. Severity can be modeled as follows: (1) the change in each of the performance measures is determined, as discussed above; (2) the trade-off value of schedule (advancing the operations date), of disruption (decreasing lost person-hours), and of longevity (decreasing the NPV of O&M and replacement cost and disruption) is established; and (3) the change in equivalent cost is determined by summing (a) change in inflated cost, (b) product of change in operations date and value of schedule change, (c) product of change in disruption and value of disruption change, and (d) product of change in longevity and value of longevity change.

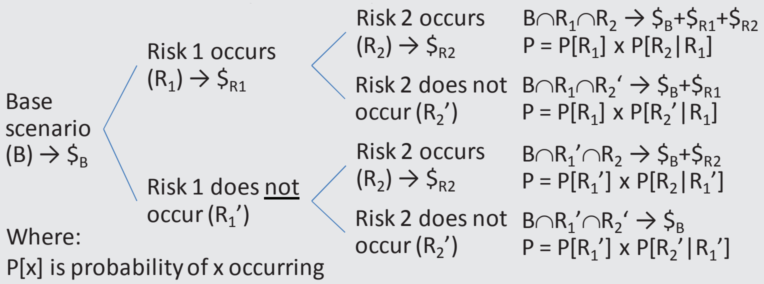
Deterministic Versus Probabilistic Analysis

Deterministic (or traditional) analysis calculates one set of outcome values for one set of input values. It typically ignores the uncertainty in those inputs and the resulting uncertainty in the outcomes. Probabilistic analysis, on the other hand, calculates probability distributions for the outputs as a function of correlated probability distributions for the inputs (see Figure 7.1). This is done in one of two ways: analytical solutions or Monte Carlo simulation.

- *Analytical solutions* can be done in several ways:
  - A discrete probability distribution can be determined, as shown in this simple example for cost, for a set of representative scenarios. However, in most cases, there are too many scenarios to tractably represent all possible combinations in such a combinatorial "tree."

Example of Analytical Solution for Discrete Distribution

Base and two risks (R1 and R2), each with cost impact



Where:
P[x] is probability of x occurring
P[x'] is probability of x <u>not</u> occurring = 1 – P[x]
P[x|y] is probability of x occurring <u>if</u> y occurs
$\$_x$ is cost impact if x occurs

—The mean value and standard deviation of the outputs can be determined approximately as a function of the mean and standard deviation of each input (in conjunction with the correlation coefficients between each pair of inputs), for example, via first-order second-moment and related point-estimate methods. Although such approximate solutions are relatively simple for the mean (i.e., the mean value of an output is simply the deterministic function of the mean values of the inputs), it becomes more difficult and even impractical for the standard deviation (especially when inputs are correlated and for nonlinear models, such as for schedule). Also, except for some special cases in which the form of the probability distribution can be assumed (e.g., the sum of a large number of independent variables is a Gaussian distribution, and similarly the product of a large number of independent variables is a lognormal distribution), the entire probability distribution is not developed. Only its mean and standard deviation are developed, so specific percentiles cannot be determined without further assuming a distribution form for the output.

- Monte Carlo simulation can approximate the entire probability distribution of each performance measure, as well as the sensitivity of each performance measure to the various inputs, as follows:

  1. A large number of possible sets of inputs (each set with a known probability of occurring) are developed by sampling (either randomly or more focused) the various input probability distributions (appropriately considering their correlations).

2. A set of outputs is developed for each set of inputs, using the deterministic model. Each set of outputs has the same probability of occurring as its set of inputs.
3. The large number of possible outcomes for each performance measure, where each outcome has a known probability, is statistically analyzed to determine the probability distribution of that performance measure. This sampled population of outcomes is inferred to adequately represent the actual population of possible outcomes.
4. Correlations among the performance measures, as well as between each performance measure and each input, can also be determined statistically.

Non–Risk-Based Versus Risk-Based Analysis

Risk analysis can be conducted with or without identifying and quantifying individual risks, which might or might not occur.

- In a *non–risk-based* approach, project uncertainties are "lumped" or "rolled up" into allowances (or contingencies) that are applied at high levels within the analysis:
  - —For deterministic analysis, these allowances are intended to reasonably cover the various uncertainties. For example, a contingency of 20% of the base construction cost might be considered appropriate (based on published guidance) at a particular point in project development.
  - —For probabilistic analysis, uncertainties in specific items are assessed, implicitly combining base uncertainties and risks. For example, a factor can be applied to a base cost item to express the range of that item, from the base cost item at the 10th percentile to the factor times the base cost item at the 90th percentile. Such a factor can be assessed on the basis of judgment (which is very difficult to do accurately and defensibly at such a lumped level) or, if enough data are available for that base cost item (which is very unlikely), based on statistics, essentially averaging all of the projects included in the database ("one size fits all").
- On the other hand, risk-based approaches explicitly address individual risks that can affect particular project elements. Risk-based approaches allow for more detailed uncertainty analysis, considering the uniqueness of each project, and facilitate formal risk management planning, and are the focus of this guide.

Time-Variable Versus Time-Independent Analysis

For processes that vary significantly with time, the element of time should be considered in the risk analysis. For many applications, a "pseudo–time-based" modeling approach (e.g., through use of a project cost-loaded schedule model) can adequately capture the key time-dependent features of projects without explicitly modeling the passage of time. For example, seasonal delays, inflation, and extended overheads can all be adequately incorporated in the model, and cash flow (or, in reverse, contingency drawdown) can be calculated.

Subjective Versus Objective Assessment of Input Information

As discussed in Chapter 6, when an adequate database of information related to a particular variable is available, an objective, or statistical, approach can be used to develop inputs to the risk analysis. However, when statistical information is not available, the opinion of experts can be elicited, de-biased (as discussed in Chapter 6), and quantified in the form of subjective assessments. Because most transportation projects—and particularly rapid renewal projects—are relatively unique, adequate statistical information is generally not available, and properly obtained subjective assessments are required to conduct risk analysis. Facilitated consensus among a broad group of experts helps to enhance accuracy and defensibility of such assessments.

Decoupled Versus Integrated Analysis

It is possible to conduct risk analysis on various project performance measures (e.g., cost, schedule) separately from one another. However, typically such decoupled analyses either ignore important relationships between these measures or treat relationships in an ad hoc manner. Integrated analyses explicitly identify, quantify, and model relationships (correlations and dependencies) between input variables and output performance measures. For example, an integrated cost and schedule analysis explicitly models the various relationships between inflated project cost and schedule.

Initial Versus Updated Analysis

Risks as well as the base generally evolve over time as the project develops and status, conditions, and plans change and new information becomes available. Once significant changes have occurred, the previous analysis (and its results) becomes outdated and should be updated to stay relevant. For example, a risk analysis ("diagnosis") is typically performed before risk management planning ("treatment") to identify targets for risk management. Plans will then change, based on risk management planning, and the risk analysis should be updated to consider those new plans.

Levels of Detail, Accuracy, Defensibility, and Effort

The *level of detail* can vary from simple algorithms with few but independent inputs to complicated algorithms with many correlated inputs. Although too little detail generally involves too much approximation, too much detail can introduce errors, as well as unnecessary effort.

The *level of accuracy* is a function of the method of analysis and level of detail chosen, as well as the accuracy of the inputs.

The *level of defensibility* is a function of (a) the level of consensus achieved on inputs and the credibility of those involved; (b) the method of analysis chosen, especially its logic and transparency; and (c) documentation of how the assessments were elicited or derived and how the analysis was conducted.

The *level of effort* is a function primarily of the method of analysis and level of detail chosen, and of the accuracy, documentation, and level of consensus achieved and experts involved. Hence, the requirements for the levels of accuracy and defensibility must be balanced with the level of effort required to achieve those requirements.

PROCESS OF RISK ANALYSIS

The risk analysis process is relatively straightforward, consisting of the following eight steps, which are subsequently described in more detail:

Step 1. Identify the desired outputs or types of results from the risk analysis.

Step 2. Select an appropriate method or approach for conducting the risk analysis.

Step 3. Define a model of the system (i.e., project development), which also defines the inputs and relates the inputs to the outputs.

Step 4. Define a project base (exclusive of risks).

Step 5. Identify risks and opportunities relative to that base.

Step 6. Quantify the risk analysis inputs (both base and risk factors), including their uncertainties and correlations.

Step 7. Implement the model with uncertain (and correlated) inputs to determine uncertainty in the desired outputs and the sensitivity of the outputs to the inputs.

Step 8. Document, check, and update (as needed).

These eight steps are discussed in more detail.

Step 1. Identify the desired outputs or types of results from the risk analysis.

It is important to identify and adequately but efficiently answer the right questions. A risk analysis that does not address the DOT's key questions is of limited use. As previously discussed generally in Chapter 2, the desired outputs typically involve specific aspects of the project's performance measures, including

- The project's total inflated cost, key schedule milestones, and cash flow through construction, and especially for rapid renewal projects, disruption through construction and longevity. Specific aspects of these broad performance measures might also be of interest, for example, construction contract cost and duration. This might include uncertainty in those performance measures, to help determine appropriate budgets, milestones, and contingencies.
- Sensitivity of specific performance measures (e.g., a combined performance measure) to each of the inputs, especially risks, to help develop risk management plans and proper allocation of the risks in the contract.

These desired outputs should not be constrained by "canned" software outputs, because methods are available that can produce virtually any type of output. The accuracy and defensibility requirements for the results should be established, appropriately considering the level of effort required to achieve them.

The following guidance regarding the project scope and the evaluation strategy applies:

- *Evaluate the entire project.* Consider all project phases and elements, including maintenance and operation where applicable, as described in previous chapters.

Be careful not to focus project risk assessments too narrowly on construction. This is a mistake because many of a project's largest risks and other uncertainties can occur early in a project's development.

- *Evaluate all relevant performance objectives*. For rapid renewal projects, consider disruption during construction and longevity (i.e., postconstruction cost and disruptions as well as postconstruction schedule) along with cost and schedule through construction.
- *Identify all possibilities, but stay focused on the key issues*. Make sure to consider all possible outcomes, but do not get bogged down on insignificant items. Do not artificially exclude any significant uncertainties (including risks and opportunities) from the analysis, because ignoring or otherwise excluding significant uncertainties, risks, and correlations will yield results that underestimate the true uncertainties, and provide misleading or even incorrect results that will not stand the test of time. However, if the DOT wants conditional analysis of various scenarios to help them evaluate internal decisions (e.g., regarding procurement method), then the results should be clearly "qualified."

Step 2. Select an appropriate method or approach for conducting the risk analysis.

An appropriate method must be selected to provide the desired types of results, as identified in Step 1. Also as discussed generally in Chapter 2, the appropriate method depends on the desired outputs. For example, for DOTs who want to establish project budgets and schedules with a quantified confidence level (e.g., 80% probability of success), as well as conduct risk management, a viable approach is probabilistic, risk-based, integrated cost and schedule modeling. However, if the DOT is only interested in quantifying project cost in current (uninflated) dollars, then there is no need to model project schedule (although there might be extended overheads). Similarly, if the DOT is only interested in project schedule, there is no need to model project cost. Typically, however, DOTs are interested in predicting both cost and schedule. Because inflated cost and schedule are functionally linked, DOTs should in this case conduct integrated (or joint) cost and schedule modeling. Furthermore, DOTs are often interested in evaluating the likelihood that their existing budgets will be met or establishing a budget (or contingency) with a reasonable likelihood for success. When this is the case, probabilistic modeling (i.e., appropriately considering uncertainties, correlations, and probabilities) is appropriate. Moreover, if contingency drawdown is desired, then an integrated cost and schedule model (which models cash flow) is needed.

As will subsequently be discussed, risk-based models are needed for determining sensitivity of performance measures to risk and opportunities. However, if the DOT wants to determine the sensitivity of the target percentile of a performance measure (e.g., escalated cost) to the various risks and opportunities and other uncertainties, then special analyses are required, although still based on the results of a probabilistic, risk-based, integrated cost and schedule model (Figure 7.2).

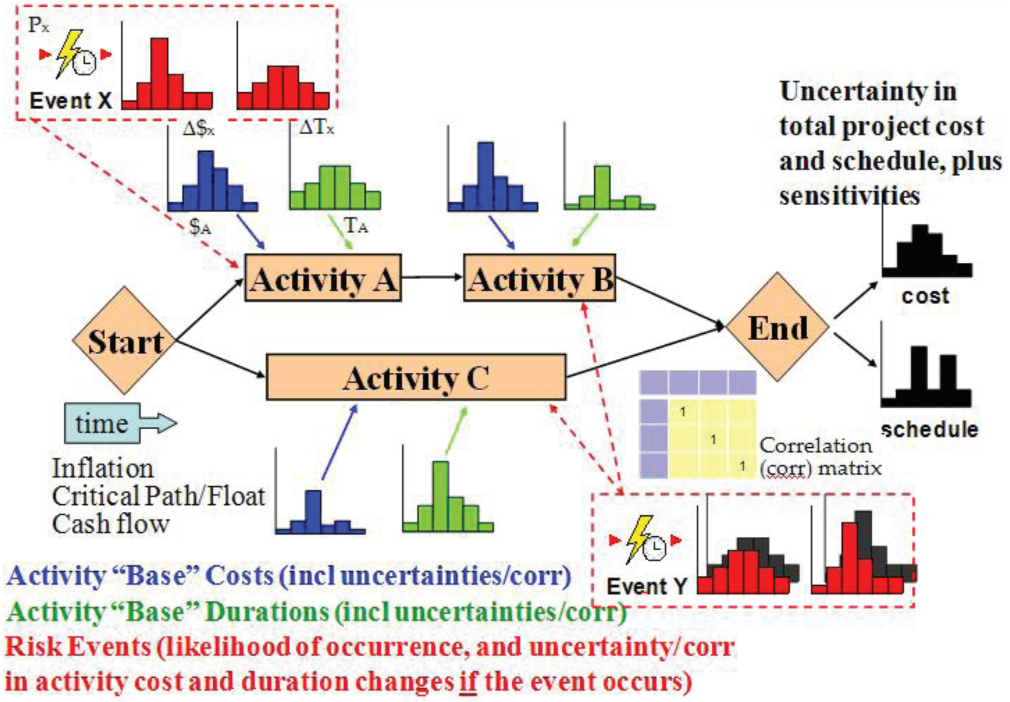


Figure 7.2. *Probabilistic risk-based integrated cost and schedule model.*

Assuming a qualified modeler, DOTs can choose from several commercially available software packages to perform probabilistic, risk-based, integrated cost and schedule modeling. A few canned packages also conduct risk-based analysis. Otherwise, a Microsoft Excel workbook, with a commercially available add-in to do Monte Carlo simulation, can be used.

Step 3. Define a model of the system (i.e., project development), which also defines the inputs and relates the inputs to the outputs.

For project risk analysis, a numerical model of the project's cost and/or schedule must typically be developed to adequately but efficiently combine and transform specific inputs into the desired outputs, consistent with Steps 1 and 2. For example, cost-loadable scheduling software or a suitably structured spreadsheet is typically used as a model to calculate the project's ultimate inflated cost and schedule. Such a spreadsheet can be expanded to include other performance measures (disruption and longevity), whereas scheduling software is generally not as flexible. Above all else, however, the numerical model must adequately represent the system (i.e., project development in this case) being modeled to avoid introducing significant model error that could produce misleading results.

For rapid renewal, the model should generally consist of the following linked elements (as previously described):

- *Schedule.* Calculate (via critical path analysis) early start and end dates, as well as float, of each flowchart activity based on either its precedence logic (including lags) and duration or, if no precedence requirement, its milestone date. Durations can be base-only (which might be uncertain) or base plus realized risks, which in turn assume partial overlap of delays if multiple risks are realized in a particular activity.

- *Cost.* Calculate total unescalated cost by simply summing the costs of a comprehensive and nonoverlapping set of cost items (i.e., the cost estimate). Calculate total escalated cost by allocating the cost items to the various flowchart activities (via a matrix), creating a simple cost-loaded schedule, and then escalating the cost of each activity based on its midpoint (from the calculated schedule) and its assessed escalation rate, which might vary among activities and from year to year. Typically, calculate total cost only through construction with postconstruction cost considered under longevity. Each cost item can be a base cost (which in turn can be calculated from an average unit cost and a quantity, either or both of which might be uncertain) or a realized risk cost (some of which might be triggered by a schedule delay). Both kinds of costs are assumed to be additive in a particular activity. Escalation rates might also be uncertain.
- *Disruption.* Calculate total disruption by summing the disruption associated with each flowchart activity. Typically, calculate total disruption only through construction with postconstruction disruption considered under longevity. The disruption associated with each flowchart activity can be a base value (which in turn can be calculated as the product of the duration of disruption, the average number of people affected by disruption per day, and the average delay per affected person, any of which might be uncertain) or base plus a realized risk value (which might be triggered by a schedule delay). Both kinds of value are assumed to be additive in a particular activity.
- *Longevity.* Calculate the net present value (NPV) of postconstruction cost and disruption, based on the unescalated cost and disruption associated with O&M and replacement, the calculated schedule of O&M and replacement, and the established net discount rate and value of disruption (see Chapter 4). The unescalated costs and disruption for each activity can be base-only (which might be uncertain) or base plus realized risks (as discussed above).
- *Combined.* Calculate the total equivalent escalated cost of the project, by translating (via trade-offs) disruption through construction, construction completion date, and longevity into equivalent escalated cost and summing with the total escalated cost through construction (see Chapter 4). These can be base-only (which might be uncertain) or base plus realized risks.

Step 4. Define a project base (exclusive of risks).

The project base must be defined consistent with Steps 1–3, as described generally in Chapter 4. As noted in Step 1, this might include alternative scenarios (e.g., representing internal decisions) for which conditional analyses are conducted to help make those decisions.

Step 5. Identify risks and opportunities relative to that base.

A comprehensive and nonoverlapping set of project risks and opportunities must be identified consistent with Steps 1–4, as described generally in Chapter 5. These risks and opportunities are relative to the base (Step 4).

Step 6. Quantify the risk analysis inputs (both base and risk factors), including their uncertainties and correlations.

The various risk analysis inputs must be adequately but efficiently assessed consistent with Steps 1–5, and as described generally in Chapter 6. These risk analysis inputs include

- Base factors, including the base uninflated direct cost of each activity (or more detailed factors such as quantities and unit costs of various items, and their allocation to activities), activity base duration, lags, milestone dates, activity base disruption, and base escalation rates for each type of activity;
- Each impact scenario (in terms of quantitative changes in uninflated direct cost, duration, and disruption by activity) and its probability of occurring; and
- Other policy factors, including postconstruction discount rates, value of disruption, value of schedule, and value of longevity.

If quantification of uncertainty in performance measures is desired, then the uncertainties in (and correlations among) these risk analysis inputs must be assessed.

Among all the steps in risk analysis, quantifying uncertain inputs is perhaps the most problematic, because unqualified personnel can easily miss or improperly assess uncertainties and correlations. Therefore, DOTs should ensure that only qualified staff (with formal probabilistic training and relevant experience) attempt to quantify probabilistic inputs. As stated previously, only limited guidance on how to conduct quantitative risk analysis is provided in this guide because the topic is so expansive and several good references are available for probability theory and probabilistic and uncertainty analysis (see References section). However, some key guidance for quantifying uncertainty, which typically is not highlighted in common references, is provided here:

- *Variable definition.* The variable being assessed should be clearly defined, so that everyone has a common understanding. Errors in input assessments, or their subsequent misuse, and difficulties in achieving consensus on such input assessments often arise from such misunderstandings. For example, the uncertainty in a value on any particular day, where that value changes significantly from day to day ("variability"), is very different from the uncertainty in the average value over all the days of interest ("ignorance"), which might be the intent and how the value is actually used in the analysis. In other words, there is a significant difference between variability and ignorance, which should be recognized: uncertainty due to ignorance can be reduced by additional information, whereas variability cannot. Hence, the model will define the variable, and whether variability or ignorance is the main source of uncertainty.

- *Distribution.* For significant factors (i.e., those that can greatly affect the outputs), the full range of possibilities and their relative likelihoods should be assessed:
  - —When the range of possibilities is continuous (e.g., a cost change of anywhere from $1 million to $2 million), a continuous probability distribution (as illustrated in Figure 7.1) should be used. To develop this distribution, reasonable lower and upper limits (bounds) should be identified first, and then intermediate values and their relative likelihoods should be addressed. The most likely or mean values should not be focused on first, because this will tend to lead to underestimation of the actual bounds and, therefore, of uncertainty. If low values are preferable (e.g., costs), then the reasonable lower bound represents a very optimistic value and the reasonable upper bound represents a very pessimistic value; conversely, if high values are preferable (e.g., benefits), then vice versa. The level of conservatism associated with these bounds should be clearly established beforehand; for example, it is typically specified (based on research) that the reasonable lower bound corresponds to the 10th percentile (for which there is a 10% chance that the actual value will be less than that and a 90% chance that the actual value will be greater than that) and the reasonable upper bound corresponds to the 90th percentile (for which there is a 90% chance that the actual value will be less than that and a 10% chance that the actual value will be greater than that), so that there is an 80% (4:5) chance of being within this range. Some training of the assessors might be required to ensure that they understand what 10% chance means (e.g., by identifying common events that have a 10% chance of occurrence for comparison). A common probability distribution form (e.g., a normal or Gaussian distribution) is then fitted to the range and other percentiles, based on judgment regarding the shape of the distribution (e.g., symmetry, tails). However, there should not be a constraint of using only particular probability distributions (e.g., because they are convenient). Uncertain inputs should be quantified with reasonable representations of the relative likelihood for the various outcomes, and in particular should reflect the uncertainty as envisioned by the experts making the assessments.
  - —When the range of possibilities is discrete (e.g., the risk either occurs or does not) or based on outcomes from potential scenarios (e.g., the DOT builds either a bridge crossing, or a tunnel crossing, or an at-grade crossing), consider using a discrete probability distribution (as illustrated in Figure 7.1) or an event tree (as illustrated in a previous example) to appropriately structure and quantify the risk. In the case of a comprehensive and mutually exclusive discrete set of possibilities, it is useful to first rank the possibilities (*x* is more likely than *y*) and then assess their relative differences (*x* is twice as likely as *y*) to determine their probabilities (recognizing that the probabilities must sum to 1.0).

Conversely, for relatively insignificant factors, only the mean value (instead of the full range of possibilities) is generally needed. Assessing their full range of possible values would not significantly affect the results, but would take significant effort, and would thus not be cost-effective.

- *Correlations and dependencies.* As previously discussed, a probability distribution expresses the uncertainty in the value of a particular factor (either input or output). However, the uncertainty in the complete set of factors (especially input factors) is generally needed. Some factors might be related (e.g., because of a common underlying factor), such that if one factor x is on the high end of its range, the related factor y would also tend to be on the high end of its range (positive correlation) or on the low end of its range (negative correlation). Some factors might be a function of ("conditional on") other factors (e.g., the probability of Event B occurring might be different if Event A happens or not). Such relationships can be expressed in terms of a correlation coefficient for continuous or discrete distributions, or in terms of independent and dependent variables, in which the dependent variable has a conditional probability distribution that is a function of the value of the independent variable. These relationships among uncertain input factors should be adequately assessed and subsequently incorporated in the analysis. Otherwise, the uncertainties in the outputs will not be correctly determined, typically being underestimated if such relationships are ignored (as subsequently discussed). However, correlations among factors that are described only by their mean value (as opposed to a distribution) do not need to be assessed. Also, dependencies among events (as described by conditional probabilities) can often be avoided by combining these related events into a *set* of scenarios, each of which has a probability of occurrence (e.g., probability of Event A *and* Event B occurring). Note that probability distributions for outputs are conditional on the probability distributions used for the inputs, which in turn are conditional on various assumptions (including exclusions). If these assumptions turn out to be invalid, then the probability distributions for the inputs and thus the outputs might not be correct and could be misleading.
- *Subjective assessment.* For factors that must be subjectively assessed (because a statistically valid data set is not available), judgment biases (both management and cognitive, as discussed in Chapter 6) on the part of the assessors can result in errors. However, such biases can and should be countered to the extent possible by qualified facilitators and by achieving consensus among a broad group of experts, including those that are independent of the project. The assessments should be consistent with all available information, which will generally support some values as being more likely than others, and might even preclude some values. As discussed in Chapter 8, some key input uncertainties can generally be reduced by obtaining specific new information that reduces the degree of ignorance.

Step 7a. Implement the model with uncertain or correlated inputs to determine uncertainty in the desired outputs.

The model must be adequately but efficiently implemented consistent with Steps 1–6. For project risk analysis, this involves translating the various inputs (base factors and risk factors) into all the outputs of interest (project performance measures, such as cost, schedule, disruption and longevity), as previously discussed, but also includes

For example: To determine the total unescalated project cost ($\$_T$) from the unescalated costs ($\$_{T_i}$) of a comprehensive and nonoverlapping set of cost items (i):

$$\$_T = \sum_{\text{all } i} \$_{T_i}$$

The mean of $\$_T$:

$$m\left[\$_T\right] \approx \sum_{\text{all } i} m\left[\$_{T_i}\right]$$

The variance of $\$_T$:

- iff $\$_{T_i}$ are all *independent*, $p[\$_T]$ is approximately "Gaussian"

  (normal bell-shaped curve) with:

  $$v\left[\$_T\right] \approx \sum_{\text{all } i} v\left[\$_{T_i}\right]$$

  $$\%\left[\$_T\right] \approx m\left[\$_T\right] + \phi_{\%} * \sqrt{v\left[\$_T\right]}$$

- iff $\$_{T_i}$ are all perfectly positively *correlated*:

  $$\%\left[\$_T\right] \approx \sum_{\text{all } i} \%\left[\$_{T_i}\right]$$

- otherwise

  $$v\left[\$_T\right] \approx \sum_{\text{all } i} v\left[\$_{T_i}\right] + 2 \sum_{i = 1 \text{ to } n} \; \sum_{j = i+1 \text{ to } n} \operatorname{cov}\left[\$_{T_i}, \$_{T_j}\right]$$

where

$p\left[x\right]$ is probability distribution of x

$m\left[x\right]$ is mean value of x

$v\left[x\right]$ is variance of x

$\%\left[x\right]$ is specific percentile value of x

$\phi_{\%}$ is standard normal probability function for specific percentile (%), where, for example, $\phi_{80\%} = 0.842$

$\operatorname{cov}\left[\$_{T_i}, \$_{T_j}\right]$ is covariance between $\$_{T_i}$

and $\$_{T_j} = \left[\$_{T_i}, \$_{T_j}\right]\sqrt{v\left[\$_{T_i}\right]}\sqrt{v\left[\$_{T_j}\right]}$

$\rho\left[\$_{T_i}, \$_{T_j}\right]$ is a correlation coefficient between $\$_{T_i}$ and $\$_{T_j}$

translating uncertainties in the inputs into uncertainties in the outputs. Several good, although technical, references are available on propagating uncertainty (see References section). However, as previously discussed, for project risk analysis, there are essentially two general ways to propagate input uncertainties through a model: analytical approaches and numerical approaches (such as Monte Carlo simulation). A simple example of an analytical solution is shown for unescalated cost, which is a simple linear model. Although such analytical solutions are often not tractable for other performance measures, especially those that are more complex and nonlinear, they do provide some insight. The results in the example at the end of this chapter, on the other hand, are based on Monte Carlo simulation. If performed properly, simulation is a convenient and appropriate way to propagate uncertainty (even for nonlinear models) and to conduct project risk analysis. Simulation capability is available for most popular project cost and scheduling software packages, as well as for many modeling platforms (e.g., Microsoft Excel).

Regardless of the modeling method used, it is important to adequately incorporate the correlations in inputs. As shown in the simple example, there are typically two extreme (bounding) cases for correlations: total independence and “perfect” positive correlation. The results, especially in the tails of the distribution, can be very different for these two extreme cases, with the variance and higher percentiles much greater for perfect positive correlation. Generally, for appropriate correlations, the distribution will be between these two extreme cases, with the total independent case underestimating (sometimes significantly) the uncertainty and the perfect positive correlation case overestimating (sometimes significantly) the uncertainty. Analytical approaches can incorporate correlations among the input factors through more complicated equations. Monte Carlo simulation can appropriately incorporate correlations among the input factors during the process of sampling those input factors, so that appropriate combinations of input factors are generated and used to determine the output populations.

Because model inputs can be correlated and because model outputs can be functionally related in the model (e.g., because of common inputs), the various outputs might be correlated. For example, a risk that has a cost and a schedule impact will affect both cost and schedule, so that these two outputs would be correlated because of this common factor. On a bigger scale, escalated cost is affected by schedule (i.e., the escalated cost increases with schedule increase), so that these two outputs will obviously be correlated. These correlations in outputs are important if the outputs will be combined (e.g., into an overall measure of performance), as has been suggested here, for the same reasons as discussed above (i.e., the uncertainty in that combined measure would be underestimated if such correlations are ignored). There are two primary ways to deal with this correlation: (a) determine the outputs separately, assess (e.g., subjectively) the correlation among those outputs, and incorporate those correlations in any analysis in which those outputs are combined; or (b) determine all outputs jointly and combine them appropriately using an integrated model during Monte Carlo simulation (see Figure 7.2). Approach (b) is recommended.

Step 7b. Determine the sensitivity of the outputs to the inputs.

The results must be adequately but efficiently analyzed to determine the sensitivity of those results to the various input factors (e.g., to subsequently guide risk management, as discussed in Chapter 8). The traditional way of determining sensitivity is to change each input by a specific amount (e.g., zero out a risk) and to then recalculate the outputs and measure their change (e.g., in the target percentile). However, this becomes quickly unmanageable, especially if the model involves Monte Carlo simulation. Fortunately, other approximate methods are available to do this more efficiently. For the previous example shown here, the sensitivity of various aspects (e.g., mean, variance, specific percentile) of an output (e.g., total unescalated project cost) to the various inputs (e.g., unescalated cost of each item) can be determined analytically for simple linear models, especially with independent inputs. For base factors, the contribution of their uncertainty to specific ("target") percentile values can be determined by assuming that their variance goes to zero (i.e., $\Delta v[\$_{T_i}] = -v[\$_{T_i}]$ in the simple example), with no change in the mean value. For risks, their contribution can be determined by assuming that both their mean value and their variance go to zero (i.e., $\Delta m[\$_{T_i}] = -m[\$_{T_i}]$ and $\Delta v[\$_{T_i}] = -v[\$_{T_i}]$ in the simple example), where

- The mean value of a risk equals its probability of occurrence times its mean value if it occurs; and
- The variance of a risk equals the sum of
  - —Its probability of occurrence times the square of the difference between (a) its mean value if it occurs and (b) its mean value; and
  - —One minus its probability of occurrence, times the square of its mean value.

For example (see previous example):

To determine the *sensitivity* of $\$_T$ to *each* $\$_{T_i}$ (one at a time)

$$\Delta\$_T = \Delta\$_{T_i}$$

$$\Delta m[\$_T] = \Delta m[\$_{T_i}]$$

- iff $\$_{T_i}$ are all *independent*, $p[\$_T]$ is approximately "Gaussian" with:

$$\Delta v[\$_T] = \Delta v[\$_{T_i}]$$

so that

$$\Delta\%[\$_T] \approx \Delta m[\$_T] + \phi_{\%} * \Delta\sqrt{v[\$_T]} \approx \Delta m[\$_{T_i}] + \phi_{\%} * \Delta\sqrt{v[\$_{T_i}]}$$

- iff $\$_{T_i}$ are all perfectly positively *correlated*:

$$\Delta\%[\$_T] \approx \Delta\%[\$_{T_i}]$$

For more complex nonlinear models, approximate linear models can be developed that use weights (actually first derivatives) for each input factor, where the weights are derived by regression analysis from the many results produced during Monte Carlo simulation. Then the sensitivity can be determined in the same way as described above. This is how the example at the end of this chapter was developed, in which the contribution of each of the many uncertain factors to the target percentile (80%) of total escalated cost was determined, with one particular risk identified as being most important on that basis. The sum of the changes in mean value associated with each risk will equal the change in the mean value associated with all the risks collectively, whereas the sum of the changes in a specific percentile (e.g., 80th) associated with each risk generally will not equal the change in that percentile value associated with all the risks collectively.

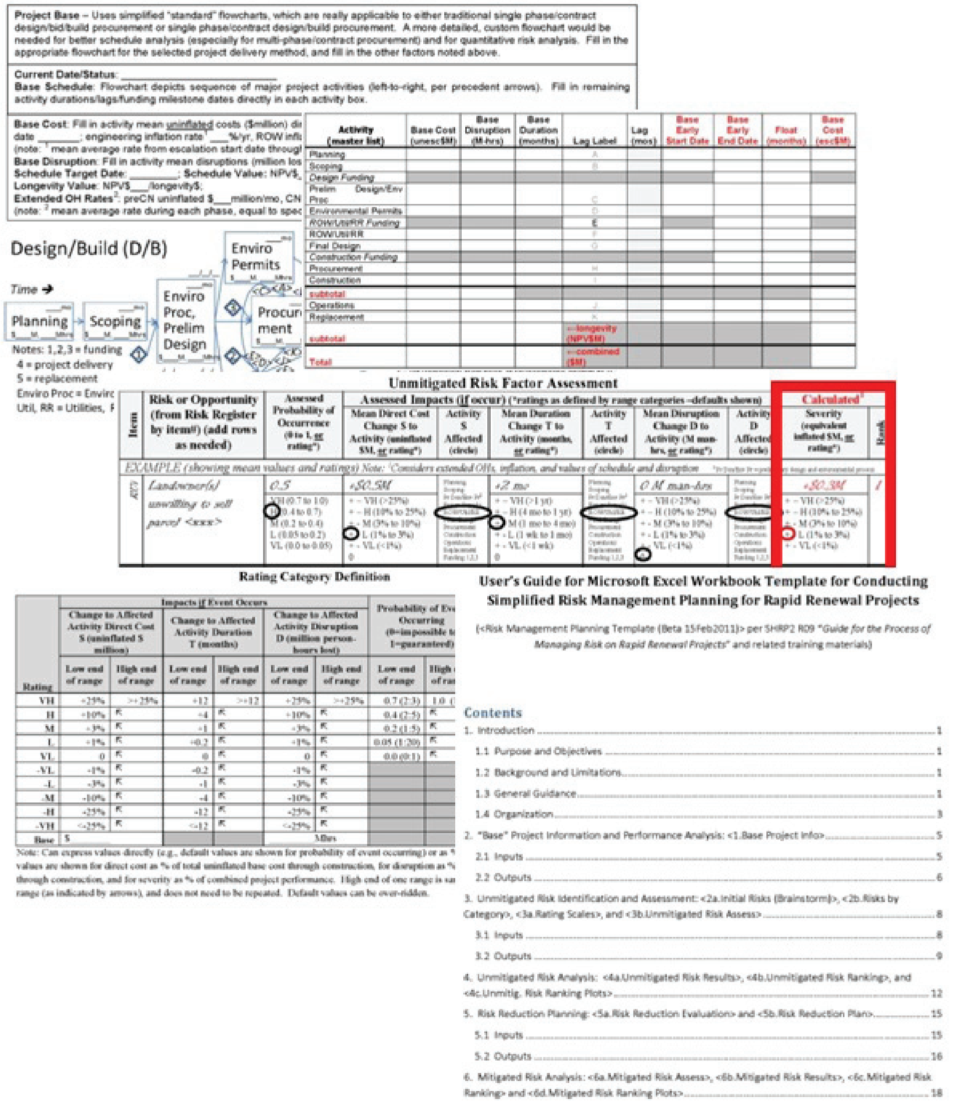
Step 8. Document, check, and update (as needed).

Each step in the above process should be adequately but efficiently documented, reviewed, and checked. In particular, another qualified person should review the model logic, inputs, and results to ensure that the results are accurate and appropriate. Subsequently, as inputs change, their assessments, and the analysis, should be updated.

This process is often iterative, especially updating Steps 4–8 as a project evolves over time and the risks, as well as the base (especially uncertainty), change with changing status, plans, conditions, and information. For example, after an initial analysis has been conducted to identify the key risks, risk management planning is conducted to proactively reduce those risks, albeit often at some cost (see Chapter 8). Hence, for a particular risk management plan, the risks as well as the base will have changed, so that the risk analysis should be updated, presumably (if the risk management plan is cost-effective) resulting in better predicted performance and lower contingency requirements.

The forms (Figure 7.3) and Microsoft Excel workbook template (template and related training materials are available online at www.trb.org/Main/Blurbs.168369.aspx) that were previously referenced for structuring in Chapter 4 and for risk assessment in Chapter 6 have been developed to facilitate limited risk analysis for relatively simple projects (see Appendix C). The template incorporates appropriate models to automatically and adequately determine

- The relevant mean base project performance measures as a function of specific mean base factors, as input on the project structure form;
- The mean changes in project performance measures, and thereby change in the mean combined performance measure (severity) for each risk, as a function of specific mean risk factors, as input on the risk assessment form; and
- The relevant mean base + risk project performance measures as a function of specific mean base and risk factors, as input on the project structure and risk assessment forms, respectively.



Project Base – Uses simplified "standard" flowcharts, which are really applicable to either traditional single phase/contract design/bid/build procurement or single phase/contract design/build procurement. A more detailed, custom flowchart would be needed for better schedule analysis (especially for multi-phase/contract procurement) and for quantitative risk analysis. Fill in the appropriate flowchart for the selected project delivery method, and fill in the other factors noted above.

Current Date/Status: ______________________

Base Schedule: Flowchart depicts sequence of major project activities (left-to-right, per precedent arrows). Fill in remaining activity durations/lags/funding milestone dates directly in each activity box.

Base Cost: Fill in activity mean uninflated costs ($million) di

date ________; engineering inflation rate ___%/yr, ROW infl

(note: mean average rate from escalation start date througl

Base Disruption: Fill in activity mean disruptions (million los

Schedule Target Date: ________; **Schedule Value**: NPV$_

Longevity Value: NPV$___/longevity$;

Extended OH Rates: preCN uninflated $___million/mo, CN

(note: mean average rate during each phase, equal to spec

Activity (master list)	Base Cost (unesc$M)	Base Disruption (M-hrs)	Base Duration (months)	Lag Label	Lag (mos)	Base Early Start Date	Base Early End Date	Float (months)	Base Cost (esc$M)
Planning				A					
Scoping				B					
Design Funding									
Prelim Design/Env Proc				C					
Environmental Permits				D					
ROW/Util/RR Funding				E					
ROW/Util/RR				F					
Final Design				G					
Construction Funding									
Procurement				H					
Construction				I					
subtotal									
Operations				J					
Replacement				K					
subtotal				←longevity (NPV$M)					
Total				←combined ($M)					

Unmitigated Risk Factor Assessment

Item	Risk or Opportunity (from Risk Register by item#) (add rows as needed)	Assessed Probability of Occurrence (0 to 1, or rating*)	Assessed Impacts (if occur) (*ratings as defined by range categories –defaults shown): Mean Direct Cost Change S to Activity (uninflated $M, or rating*)	Activity S Affected (circle)	Mean Duration Change T to Activity (months, or rating*)	Activity T Affected (circle)	Mean Disruption Change D to Activity (M man-hrs, or rating*)	Activity D Affected (circle)	Calculated¹ Severity (equivalent inflated $M, or rating*)	Rank
EXAMPLE (showing mean values and ratings) Note: ¹Considers extended OHs, inflation, and values of schedule and disruption										
R??	Landowner(s) unwilling to sell parcel <xxx>	0.5 VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	+$0.5M + – VH (>25%) + – H (10% to 25%) + – M (3% to 10%) + – L (1% to 3%) + – VL (<1%) 0		+2 mo + – VH (>1 yr) + – H (4 mo to 1 yr) + – M (1 mo to 4 mo) + – L (1 wk to 1 mo) + – VL (<1 wk) 0		0 M man-hrs + – VH (>25%) + – H (10% to 25%) + – M (3% to 10%) + – L (1% to 3%) + – VL (<1%) 0		+$0.3M + – VH (>25%) + – H (10% to 25%) + – M (3% to 10%) + – L (1% to 3%) + – VL (<1%)	1

Rating Category Definition

Rating	Impacts if Event Occurs: Change to Affected Activity Direct Cost S (uninflated $ million)		Change to Affected Activity Duration T (months)		Change to Affected Activity Disruption D (million person-hours lost)		Probability of Eve Occurring (0=impossible t 1=guaranteed)	
	Low end of range	High end of range	Low end of range	High end of range	Low end of range	High end of range	Low end of range	High (of ran
VH	+25%	>+25%	+12	>+12	+25%	>+25%	0.7 (2:3)	1.0 (
H	+10%	↖	+4	↖	+10%	↖	0.4 (2:5)	↖
M	+3%	↖	+1	↖	+3%	↖	0.2 (1:5)	↖
L	+1%	↖	+0.2	↖	+1%	↖	0.05 (1:20)	↖
VL	0	↖	0	↖	0	↖	0.0 (0:1)	↖
-VL	-1%	↖	-0.2	↖	-1%	↖		
-L	-3%	↖	-1	↖	-3%	↖		
-M	-10%	↖	-4	↖	-10%	↖		
-H	-25%	↖	-12	↖	-25%	↖		
-VH	<-25%	↖	<-12	↖	<-25%	↖		
Base	$				Mhrs			

Note: Can express values directly (e.g., default values are shown for probability of event occurring) or as % values are shown for direct cost as % of total uninflated base cost through construction, for disruption as % through construction, and for severity as % of combined project performance. High end of one range is sa range (as indicated by arrows), and does not need to be repeated. Default values can be over-ridden.

User's Guide for Microsoft Excel Workbook Template for Conducting Simplified Risk Management Planning for Rapid Renewal Projects

(<Risk Management Planning Template (Beta 15Feb2011)> per SHRP2 R09 "*Guide for the Process of Managing Risk on Rapid Renewal Projects*" and related training materials)

Contents

Figure 7.3. *Forms and template (see Appendix C).*

Although these models are deterministic, if mean values are used for inputs, then the models produce reasonable approximations of the mean values of the outputs. More sophisticated analyses, typically using Monte Carlo simulation in conjunction with these (or more complicated) deterministic models and uncertain model inputs, are required to determine full uncertainty in the performance measures.

CONCLUSIONS ON RISK ANALYSIS

Risk analysis is a valuable (but not absolutely necessary) element of the overall risk management process. The primary objective of risk analysis is to quantify a project's performance measures, including its uncertainty. Quantifying a project's performance measures enables project decision makers to make better decisions among project alternatives or for the selected alternative, to establish (or determine confidence in pre-established) budgets and milestones, as well as to quantitatively determine the severity of each risk with respect to that set of project performance objectives, which allows for better risk management planning.

If the DOT plans to conduct risk analysis, which involves quantitatively assessing the inputs (and their uncertainties, including correlations) and developing a model to calculate the outputs (and their uncertainties, including correlations), it should select the best method for its particular application, and then be sure to have adequately trained personnel conduct the analysis to avoid common pitfalls. If conducted and interpreted properly, the results can provide the DOT with valuable insight into potential future project performance. However, if not conducted or interpreted properly, the results can be misleading.

Example

The hypothetical QDOT case study (see Appendix D), which is used to illustrate the various steps of the risk management process and includes a risk management plan (RMP; see Appendix E), involved using the principles and process outlined in this chapter, as documented in RMP Addendum X (Appendix E) and summarized below.

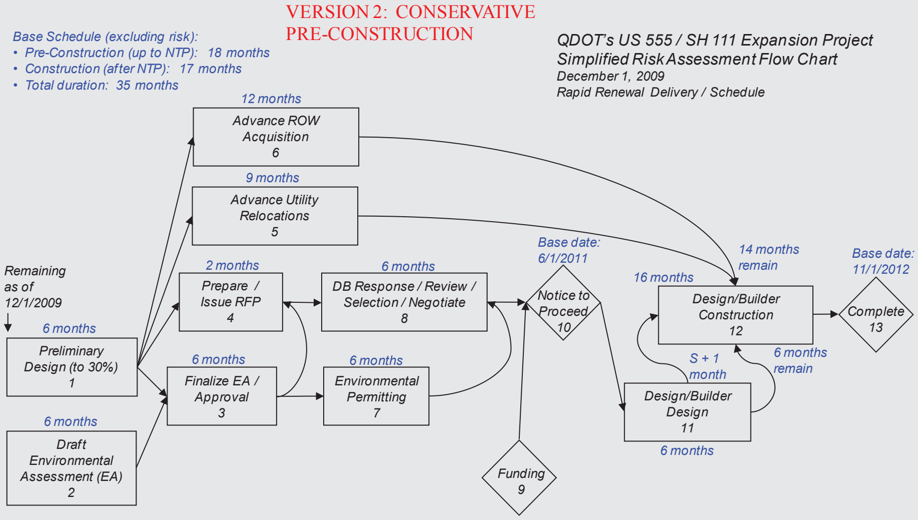
QDOT used the mean base and unmitigated risk assessments to determine (using the Microsoft Excel workbook template) the approximate mean unmitigated project performance (i.e., schedule, uninflated and inflated cost, and disruption, both total for the project and by project activity) in the same way as for base project performance. Although these results were very approximate (because of simplifications in the analysis), it provided insight into the collective effect of the risks, before any additional mitigation. This information and these tools were also used to determine the mean severity of each risk, in terms of how much the combined performance measure is affected by that risk.

Subsequently, a quantitative risk analysis was conducted (see Appendix E, RMP, Addendum X for inputs and results), for which:

- A more detailed flowchart was developed (by consensus) by the facilitated group (see below).
- Uncertainties in the unmitigated base cost estimate and schedule were assessed (by consensus) by the facilitated group; for example, bridge structure cost ranges (10th to 90th percentile) from –20% to +20%, and is moderately correlated (coefficient of 0.75) with other construction cost items.
- Unmitigated risk factor assessments were refined (by consensus) by the facilitated group (see below).
- A more sophisticated probabilistic (via Monte Carlo simulation) integrated cost and schedule model was developed to represent the more detailed flowchart and implemented with the more refined unmitigated base and risk assessments.
- Uncertainties in unmitigated project performance (i.e., project completion date and cost through construction, both unescalated and escalated) were determined (see below).
- Contributions of each risk and base uncertainty toward the target (80th percentile) escalated cost through construction and project completion date were determined (see below); for example, EP2 contributes $0.2 million to 80th percentile of escalated project cost, and ranks 13th.

As will be discussed, the uncertainties in project performance can be used to determine appropriate budget, milestone, and contingency, and the sensitivity of the budget (not just the mean cost) to the various risks can be used to better guide risk management.

(continued)

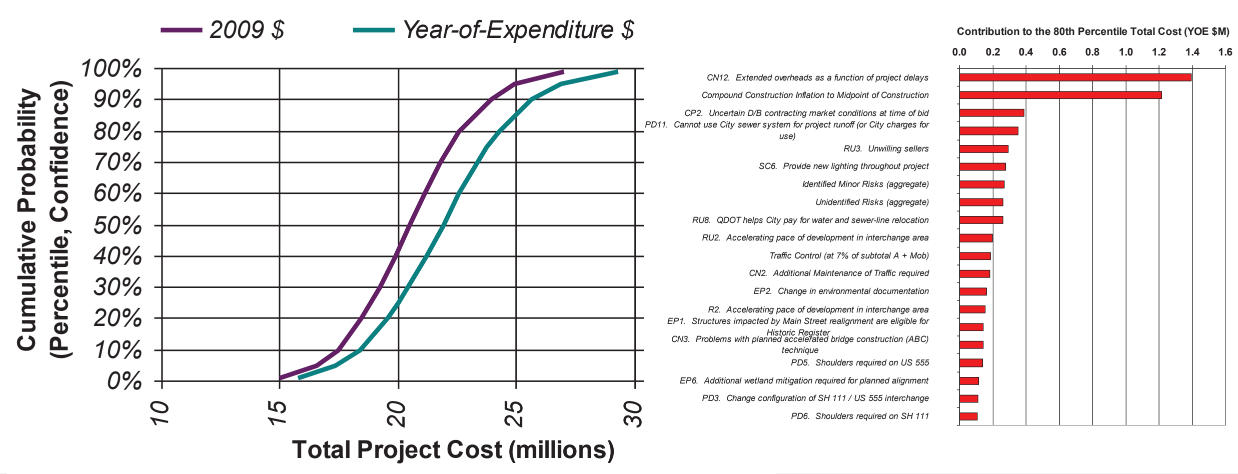


Notes:
1. Single Design/Build contract.
2. Advance Right-of-Way (ROW) Acquisition includes appraisals, offers, acquisition, relocation, and demolition for parcels that QDOT anticipates will be critical to early construction by the Design/Builder.
3. Advance Utility Relocations includes coordination, approvals, and relocations of utilities that QDOT anticipates will be critical to early construction by the Design/Builder. Additional relocations that might be required will be the responsibility of the Design/Builder during construction. Assumes minimal new ROW required for utility relocations.
4. QDOT will complete the Environmental Assessment (EA) and obtain all environmental permits before Notice to Proceed (NTP).
5. Construction duration includes typical winter shut-down period from November 15th through March 15th.
6. Construction includes construction permits, remaining utility relocations, and all construction-related effort. Remaining ROW acquisition by QDOT also occurs during this timeframe.

QRA flowchart for QDOT US-555 and SH-111 Project

Risk or Opportunity	Probability of Occurrence (%)	Cost Change if Occurs (2009 millions of $)	Duration Change if Occurs (months)
PD13 Change in environmental documentation	Mutually exclusive scenarios: A. 50 (base) B. 40 C. 8 D. 2	A. 0 (base) B. +0.1 to Activity 2 C. +0.5 to Activity 2 D. +0.5 to Activity 2 and +1.0 to Activity 12	A. 0 (base) B. +1 to Activity 2 C. +6 to Activity 2 D. +6 to Activity 2

Quantitative Assessment for a Select Rapid Renewal Risk for QDOT US-555 and SR-111 Project



Unmitigated project performance (cost) uncertainty and sensitivity of 80th percentile of escalated cost for QDOT US-555 and SH-111 Project

8

RISK MANAGEMENT PLANNING

INTRODUCTION

Objectives

The primary objective of risk management planning is to optimize future project performance, specifically with respect to risks. Value engineering has a similar objective of optimizing project performance, but generally focuses on improving the base rather than reducing risks (e.g., through changing project design, project delivery strategy, and construction means or methods). Risks and opportunities from the risk identification process, with risk-factor assessments from the risk assessment or risk analysis, and the base factors from structuring, are necessary input for risk management planning. The risk management planning process develops specific actions and assigns responsibilities to cost-effectively deal with individual risks and capitalize on opportunities, and to then deal with the remaining risks collectively through contingency (both reserve and recovery plans). The *risk management plan* (RMP) is the output of that process.

Develop and commit to implementing an adequate but efficient *Risk Management Plan* to address project risks, both proactively and individually, and then reactively and collectively, to optimize project performance.

The RMP documents specific actionable items to deal with risks and opportunities. These actionable items require resources. The RMP provides a consistent format for assigning and documenting these resources. It answers the essential questions about risk management: *Who* will manage the risk? *What* will be done? *When* will it be done? *How* will they do it? What *resources* are likely to be required? What are the likely *benefits*?

The RMP should be accurate and defensible, as well as cost-effective. Following a rigorous process (of risk identification, assessment, and possibly analysis before risk management planning) will help to ensure accuracy and defensibility. Documentation of each step in the process is essential for effective planning efforts. Decisions on the investment of resources in risk management alternatives should ultimately be made through a cost–benefit analysis. Following the steps of the risk management process will allow the team to use prior risk assessment outputs and weigh the benefits of risk management alternatives against the costs of implementation.

Ultimately, the RMP should fit within the context and culture of the DOT. Risk management (i.e., anticipating and addressing potential problems and improvements) is an essential element of project management, and should integrate into the project team's approach to cost, schedule, scope, and quality management, and into the DOT's goals for program delivery.

For example, one particular risk (of many) on a project consists of a 50% chance of an extra $1M (unescalated) and a 1-month delay, both during construction. However, one action for addressing this risk, which would cost $100K, would reduce the chance of that risk happening by half (to 25% chance). The combined impact of the risk *if* it happened (considering the effect on the critical path, escalation of the cost impact and increased escalation of remaining costs, and the value of project completion delays) is $2M (equivalent YOE). Hence, the reduction in the probability of occurrence (from 50% to 25%) is worth $500K (equivalent YOE). Since this risk reduction exceeds its cost of implementation by $400K or 4:1, the action is cost-effective and should be adopted.

Philosophy and Concepts

At any point in time, future project performance is uncertain because of many factors, as previously discussed. However, this uncertainty generally decreases with time as the project develops, and various issues are resolved, although it cannot be predicted whether the mean value (or even the high or low ends of the range) will increase or decrease. Project teams can affect some aspects of future performance through proactive individual risk reduction. Ultimately, however, a risk eventually either happens or it does not. Effective risk management planning establishes budgets and schedule milestones with contingencies (both reserves and recovery plans) for risks to adequately cover the uncertainty that remains—even after the best planning efforts.

A project team would ideally avoid all risks and capitalize on all opportunities through an investment of minimal resources, but this is not realistic in practice. *Risk reduction*—the proactive reduction of risk probabilities and impacts—is the next option when risk avoidance is not viable. The mean impact value of a risk is the probability of its occurrence multiplied by the impact if it does occur. Comparing the reduction in the severity of the risks with the cost of individual mitigation actions, or a suite of actions, helps the project team to decide if the mitigation effort is cost-effective. Ultimately, however, the effectiveness of risk mitigation is only realized at implementation. Therefore, the assignment of a risk owner with adequate resources is necessary to ensure that the process is complete (see Chapter 9).

Residual risks are those future risks that the team cannot avoid or completely eliminate. Risk reduction, by definition, does not completely eliminate the risk, and in fact, new risks may surface during the reduction efforts. Contingency amounts and recovery plans are the tools to deal with residual risks. Effective risk management processes budget for contingency and plan for recovery on the basis of the residual risks to ensure that the project will meet budget and schedule milestones. Because risks are resolved as the project evolves (i.e., if they occur, they are covered by contingency, if available; but if they do not occur during their phase, they are retired), the residual risks tend to decrease as the project evolves, regardless of what happens up to that point.

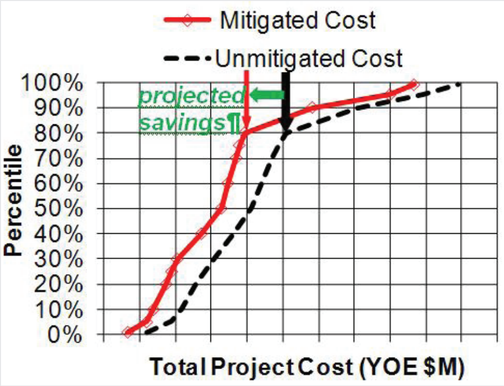
Some risks will remain when the project is let for a contract. Rapid renewal projects often involve the allocation of risks to the designer or construction through alternative project delivery methods such as design–build. The residual risks are allocated at this point in project development through the provisions of the contract. Such transfer of risk comes at a price (in the contractor's bid) and might not be as effective as expected.

With these objectives and philosophies in mind, the rest of this chapter discusses the risk management planning process.

PROCESS OF RISK MANAGEMENT PLANNING

The process of risk management planning generally involves addressing risks (a) individually and proactively through risk reduction (including risk allocation) and (b) collectively and reactively through contingency management and recovery plans. *Risk reduction* is a proactive process of employing cost-effective actions to reduce risks (e.g., through avoidance or transfer, including risk allocation, which involves contractually assigning the residual risks to a party in the contract). *Contingency management* involves the maintenance of adequate resources in the case that residual risks occur. Recovery plans involve ways to continue the project (possibly changed) if the contingency is exceeded. The RMP essentially documents these plans. This section briefly describes the risk management process.

Example benefits of risk management in terms of "mitigated" cost (can also evaluate other project performance measures)



Risk Reduction

The goal of risk reduction is to proactively and cost-effectively reduce (mitigate) individual risks. The risk identification process (Chapter 5) will identify many risks, even for the least complex projects. Because the list of risks can be extensive, teams should start with the most significant risks as identified through the risk assessment process (see probability and impact rating techniques in Chapter 6) or a more rigorous risk analysis process (see sensitivity analysis output in Chapter 7). These risk assessment and analysis techniques are important because intuition and informal engineering judgment are not always reliable when choosing the most significant risks on which to focus risk reduction effort. Additionally, the risk assessment and analysis efforts will yield useful information in terms of creating a baseline of unmitigated risks when considering the cost–benefit aspects of implementing risk reduction efforts.

The project team will need to examine the most significant project risks to see if there are management strategies or actions for reducing a risk's probability of occurrence or impact if it does occur; similarly, for opportunities, the objective is to increase (rather than decrease) its probability of occurrence or impact if it does occur. The identification of strategies and actions can be done through project-specific team efforts (e.g., brainstorming) or through the use of generic risk management action lists. The Rapid Renewal Risk Categories and Potential Risk Management Actions by Project Phase section in Appendix B contains a comprehensive list of risk management actions that correspond to common rapid renewal strategies and related risk categories that can commonly occur with these actions. Teams should use this table to spur new ideas or improve the team's ideas for risk reduction after they have exhausted their own ideas on risk reduction. An example from the project scoping phase of the section in Appendix B is shown below. This example identifies risk management actions that can help to reduce risks. There are likely to be many potential risk management actions for each risk. The risk management actions will require an investment, and the risk management action that results in the highest reduction with the least investment (i.e., most cost-effective) should be selected for implementation. Note that in some cases, combinations of actions might be employed to manage a particular risk or set of risks; in this case, synergy and overlap among the various actions should be considered to avoid underestimating or overestimating (respectively) the combined effect of those management actions. Also, in some cases, one risk management action might affect multiple risks; in this case, the multiple benefits should be considered to avoid underestimating the overall benefit of that action.

Example of potential risk management actions (from the Rapid Renewal Risk Categories and Potential Risk Management Actions by Project Phase section in Appendix B)

Rapid Renewal Strategy	Related Risk or Opportunity Category[a]	Potential Risk Management Action[b]
Accelerate the environmental documentation process Examples • Leverage master planning (see Project Scoping) • Conduct early coordination (see Planning) • Identify documentation requirements early • Identify and avoid major impacts early (historical, cultural, archaeological)	Different type of documentation required Example causes or issues • Project's impacts are greater than originally assumed (because of design changes, originally underestimated impacts), so more substantial documentation is required (e.g., environmental impact statement instead of environmental assessment) • Additional discipline studies are required • Additional (new) alternatives must be developed and documented • Documentation requirements change	• Modify the project design to reduce the impacts that are triggering a different type of documentation • Anticipate potential concerns with main alternatives, and develop additional alternatives early in process to address those concerns • Anticipate and plan for or start additional (targeted) discipline studies earlier to reduce impact to project schedule if they are later required • Develop alternative (or additional/more detailed) documentation in parallel with presumed appropriate documentation to reduce impact to schedule if alternative documentation is later required

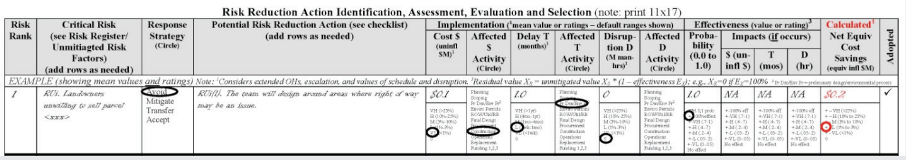
[a] The individual risk categories (and their related examples) could apply to any or all of the renewal category examples.

[b] The potential risk management actions could apply to several risk categories.

The implementation materials for this guide provide instructions and tools for how to calculate the cost–benefit analysis for each option. The example below provides a format for conducting these analyses. It provides for the four primary categories of risk response: avoid, mitigate, transfer (allocate), and accept. Some actions may use more than one of these strategies. The intent of using these categories is to spur the development of possible risk management actions. Implementation of these efforts will require resources (e.g., additional design hours, additional coordination efforts, use of more expensive materials). The results of the management actions will be a reduction in the probability of occurrence for the risk event and/or a reduction in the impact. All of these data will provide the necessary information for a cost–benefit analysis of each risk management option. However, care must be taken to not underestimate the implementation costs and to not overestimate risk reduction benefits.

Example Risk Reduction Evaluation (this is not the hypothetical case study)

There was a risk of a landowner being unwilling to sell a parcel needed to construct a project. When it was first identified, there was a high probability (50%) that the owner would not be willing to sell and the impact of this risk was $500,000 and a 2-month delay, with an expected value of about $300,000 [including increased escalation and extended overheads (OHs)] and 1 month (critical path). However, a management action was identified that would avoid this risk by designing around the parcel, at a cost of about $100,000 ($150,000 including increased escalation and extended OHs) and 1-month delay. The resulting reduction in risk meant that about $300,000 and 1 month less contingency was required; however, the resulting cost ($150,000) and delay (1 month) of the mitigation effort had to be added to the base cost and schedule. This is clearly cost-effective, with a net cost savings of $150,000 and no net schedule impact. Based on such updates of the various inputs if the action is adopted, the contingency requirements (and recovery requirements) could be recalculated.



Risk Reduction Action Identification, Assessment, Evaluation and Selection (note: print 11x17)

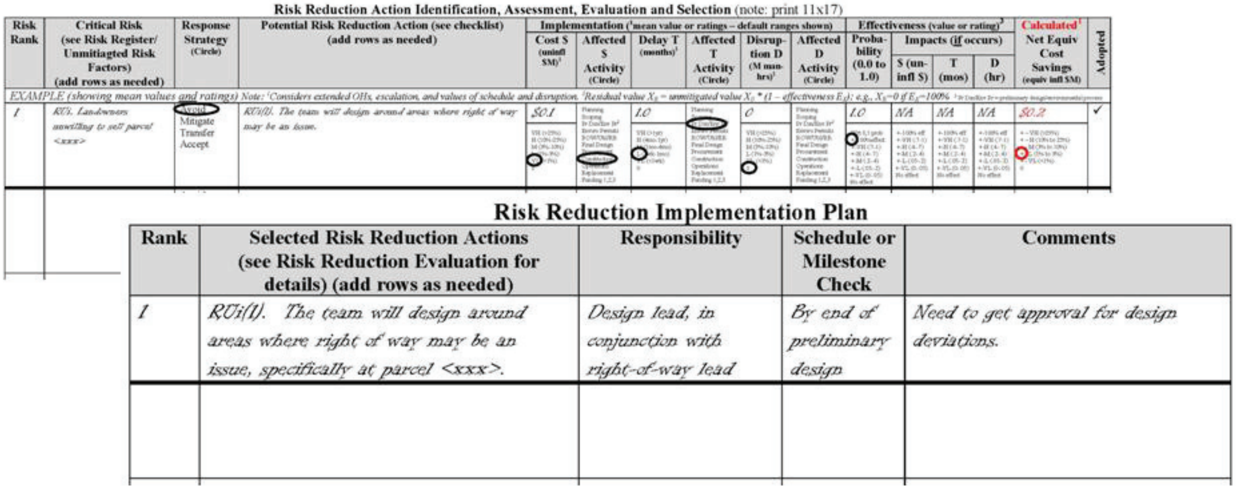
Risk Rank	Critical Risk (see Risk Register/ Unmitiagted Risk Factors) (add rows as needed)	Response Strategy (Circle)	Potential Risk Reduction Action (see checklist) (add rows as needed)	Implementation ([1]mean value or ratings – default ranges shown)						Effectiveness (value or rating)[3]				Calculated[1]	Adopted
				Cost $ (uninfl $M)[1]	Affected $ Activity (Circle)	Delay T (months)[1]	Affected T Activity (Circle)	Disruption D (M man-hrs)[1]	Affected D Activity (Circle)	Probability (0.0 to 1.0)	Impacts (if occurs) $ (un-infl $)	Impacts (if occurs) T (mos)	Impacts (if occurs) D (hr)	Net Equiv Cost Savings (equiv infl $M)	
EXAMPLE (showing mean values and ratings) Note: [1]Considers extended OHs, escalation, and values of schedule and disruption. [3]Residual value X_R = unmitigated value X_0 * (1 – effectiveness E_X); e.g., X_R=0 if E_X=100% [2]Pr Dsn/Env Pr = preliminary design/environmental process															
1	*RUi. Landowners unwilling to sell parcel <xxx>*	[✓ Avoid] Mitigate Transfer Accept	*RUi(1). The team will design around areas where right of way may be an issue.*	*$0.1*	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement [✓ Construction] Operations Replacement Funding 1,2,3	*1.0*	Planning Scoping [✓ Pr Dsn/Env Pr[2]] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	*0*	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	*1.0*	*NA*	*NA*	*NA*	*$0.2*	✓
				VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) [✓ VL (<1%)] 0		VH (>1yr) H (4mo-1yr) M (1mo-4mo) [✓ L (1wk-1mo)] VL (<1wk) 0		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) [✓ 0]		Wt 0,1 prob: [✓ +] 100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + – M (3% to 10%) [✓ +] – L (1% to 3%) + – VL (<1%) 0	

The companion Simplified Risk Management Training course addresses risk reduction in more detail, including a form (Figure 8.1; see also Appendix C) and a spreadsheet workbook template for conducting evaluations of cost-effectiveness (including automatic analyses), appropriately considering risk and opportunities, as well as the performance measures and activities for rapid renewal, especially for simple projects (see http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_R09ExcelTemplateUsersGuide.pdf).

As will subsequently be discussed, to illustrate, risk reduction plans have been developed for the hypothetical QDOT case study (see Appendix D).

Risk Allocation

Risk allocation is one specific way to reduce project risks for the owner, but warrants further discussion, especially for risky rapid renewal projects. The contract is the vehicle for risk allocation. Whether the contract is for construction, construction engineering and inspection, design, or design–build, or some other aspect of rapid renewal design and construction, the contract defines the roles and responsibilities for risks. Risk allocation in any contract affects cost, time, quality, and the potential for disputes, delays, and claims.



Risk Reduction Action Identification, Assessment, Evaluation and Selection (note: print 11x17)

Risk Rank	Critical Risk (see Risk Register/ Unmitiagted Risk Factors) (add rows as needed)	Response Strategy (Circle)	Potential Risk Reduction Action (see checklist) (add rows as needed)	Implementation (¹mean value or ratings – default ranges shown)						Effectiveness (value or rating)²				Calculated³	Adopted
				Cost $ (uninfl $M)¹	Affected $ Activity (Circle)	Delay T (months)¹	Affected T Activity (Circle)	Disruption D (M man-hrs)¹	Affected D Activity (Circle)	Probability (0.0 to 1.0)	Impacts (if occurs)			Net Equiv Cost Savings (equiv infl $M)	
											$ (un-infl $)	T (mos)	D (hr)		
EXAMPLE (showing mean values and ratings) Note: ¹Considers extended OHs, escalation, and values of schedule and disruption. ²Residual value X_R = unmitigated value X_U * (1 – effectiveness E_X); e.g., X_R=0 if E_X=100% ³[illegible]															
1	*RUi. Landowners unwilling to sell parcel <xxx>*	[✓ Avoid] Mitigate Transfer Accept	*RUi(1). The team will design around areas where right of way may be an issue.*	*$0.1*		*1.0*		*0*		*1.0*	*NA*	*NA*	*NA*	*$0.2*	✓

Risk Reduction Implementation Plan

Rank	Selected Risk Reduction Actions (see Risk Reduction Evaluation for details) (add rows as needed)	Responsibility	Schedule or Milestone Check	Comments
1	*RUi(1). The team will design around areas where right of way may be an issue, specifically at parcel <xxx>.*	*Design lead, in conjunction with right-of-way lead*	*By end of preliminary design*	*Need to get approval for design deviations.*

Figure 8.1. *Forms (Appendix C).*

The risk allocation principles embedded in the industry's guide specifications are tested and well established in case law. However, their use can promote a "one size fits all" process of risk allocation. The rigorous process of risk identification, assessment, analysis, and planning described in this document allows for a more transparent and informed understanding of project risk. When risks are understood and their consequences are measured, decisions can be made to allocate risks in a manner that minimizes costs, promotes project goals, and ultimately aligns the construction team (DOT, contractor, and consultants) with the needs and objectives of the traveling public.

The objectives of risk allocation can vary depending on unique project goals, but DOTs should attempt to follow four fundamental tenets of sound risk allocation:

1. Allocate risks to the party best able manage them.
2. Allocate the risk in alignment with project goals.
3. Share risk when appropriate to accomplish project goals.
4. Ultimately seek to allocate risks to promote team alignment with customer-oriented performance goals.

A fundamental tenet of risk allocation is to allocate the risks to the party that is best able to manage them, as long as, if it is being transferred (e.g., to the contractor or to the insurer), the transfer price is reasonable. The party assuming the risk should be best able to evaluate, control, and bear the cost, and benefit from its assumption. For example, the risk of an inadequate labor force, a breakdown in equipment, or specific means of construction is best borne by the contractor, whereas a risk of securing project funds or project site availability is best borne by the DOT. Following this principle of allocating the risks to the party that is best able to manage them will ultimately result in lowest overall price because contractors will not be forced to include as much contingency for possible financial losses or take gambles in an extremely competitive bidding environment. Inappropriate risk shifting from the owner to the contractor can result in higher prices, misaligned incentives, mistrust, and an increase in disputes.

Risks should be allocated in alignment with the project goals in a manner that maximizes the probability of project success. The definition of a clear and concise set of project objectives is essential to project success, and these objectives must be understood to properly allocate project risks. This is particularly true when using rapid renewal techniques. For instance, if the public needs a project completed sooner than would be achievable under traditional contracting and risk allocation methods, the DOT may be forced to ask the contractor to assume more risk for timely or expedited completion and it must be willing to compensate the contractor for assuming this risk.

The concept of risk sharing is often used synonymously with the concept of risk allocation. However, the term “risk sharing” can be somewhat misleading. In reality, there is no risk that is truly shared, but rather, exposure to the risk is split among the parties. Risk sharing is clearly defining the point at which the risk is transferred from one party to the other. These transfer points should be scrutinized for appropriateness and then explicitly and clearly addressed in the contract. For example, a risk that is commonly shared is the risk for unusually severe weather. A contract provision for unusually severe weather may grant the contractor a right to a time extension while not providing for additional compensation of costs. In this situation, the DOT is allocated the risk of delay while the contractor is allocated the risk of additional costs.

The ultimate goal of risk allocation should be to help align the project team with customer-oriented (e.g., public-oriented) performance goals. Although this concept may seem to be a significant departure from traditional practices in the United States, DOTs are already doing this through the use of alternative contracting techniques. For example, A + B (time + cost) procurement is used on selected projects in the majority of DOTs in the United States. In essence, A + B procurement passes the risk for completion delays to the contractor to achieve a customer goal of satisfaction with the service. In an extreme example, the use of public–private partnership techniques is shifting the risk for customer satisfaction almost entirely to the private sector. DOTs and the industry should strive to innovate and develop new risk allocation techniques that align all team members with customer goals.

Contingency Management

Contingency is an amount of money or time that is included in an estimate to cover residual risks. Contingency management involves the maintenance of adequate resources in case significant risks occur in the future. Risk management practices and tools can assist in the calculation of appropriate contingencies to account for these potential costs and delays.

If a risk occurs, its impacts are realized and the base should be adjusted accordingly; that is, costs are transferred from contingency to base. On the other hand, if a risk does not occur during its “window,” then it will never occur, and contingency is not needed to cover that risk any longer.

Contingency can be established either (see Figure 8.2):

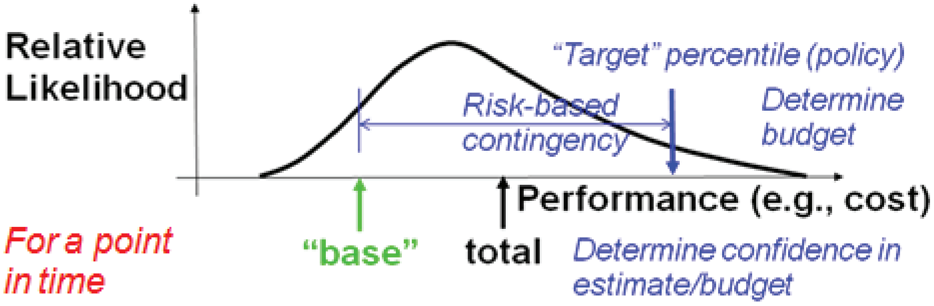


Figure 8.2. *Determination of contingency.*

- Objectively, to achieve a specified (DOT policy) level of confidence (e.g., 80th percentile), but only if quantitative risk analysis (see Chapter 7) has been conducted; or otherwise
- Subjectively (consistent with available information) or even empirically (if enough historical information is available to be analyzed), although it might not achieve the desired level of confidence.

Contingency is only needed to cover remaining risks at any point in time. Typically, as previously discussed, risks (and thus the need for contingency) decrease as the project develops. As shown in Figure 8.3, contingency can be determined by phase (based on the risks that might occur during that phase).

Contingency must be carefully managed to ensure that it is not wasted and is available when (and if) needed. Similar to any project expenditure, drawing on contingency should be subject to DOT approval, with increasing scrutiny as the amounts get larger. DOTs should have a policy to describe what project teams should do with any unused

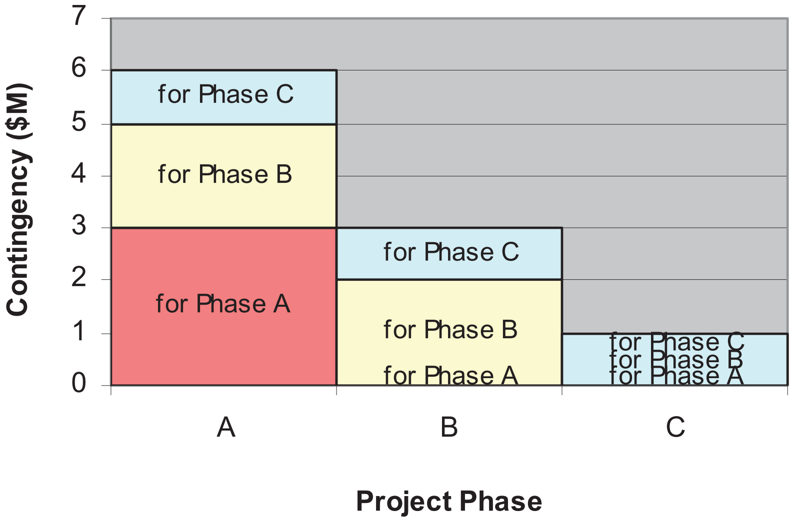


Figure 8.3. *Contingency by project phase.*

contingency. If the purpose and need of the project are met, this policy ideally would ask the project team to return the unused contingency to the overall program (for use on other less fortunate projects) instead of adding scope to the project baseline. Otherwise, contingency becomes a self-fulfilling budget, which is never underrun.

As will subsequently be discussed, to illustrate, contingency has been developed (by project development phase) for the hypothetical QDOT case study (see Appendix D).

Recovery Plans

Project teams should develop options to improve project performance, if needed, as risks are realized at various stages in project development. In some cases, remaining contingency funds might not be enough to pay for the realized risk (or schedule float might be used up), so that the realization of risks will trigger a need to adjust the project approach (i.e., adjust the project's base plan, as described in Chapter 4). In some cases, this might result because some realized risks might also create new risks that are difficult to foresee. For example, many rapid recovery strategies will require early coordination of innovative designs with partner permitting agencies. If a permit is not granted in a timely fashion, the project team will need to spend additional resources on an alternative approach to complete the project. This new approach might in fact have its own new risks.

Recovery plans consist of specific options that are available during each phase of project development to recover project cost or schedule. Typically, each such option is available only through a particular phase of project development, and is no longer available, or its recovery value is substantially reduced, after a particular point. Some typical examples of recovery plans include:

- Overtime or additional crews or equipment to accelerate remaining schedule, for which there is less "capacity" later in the project;
- Reduction (or deferral for political reasons) of project scope, especially to reduce cost, which might be relatively easy to implement before bid (during design, although it often results in delays, especially if it affects the environmental process) but might require contractual options (e.g., to include the reduced scope only if money is available) to be implemented after contract award.

To prevent delays and expedite decisions, recovery plans should be developed before depletion of contingency and their implementation. As part of this and as mentioned earlier, DOTs should establish policy on release of contingency (Should unused contingency be retained, for example, as program reserve, for later phases to reduce the need for recovery or must it be returned to the program?). Similar to contingency, specific cost and schedule recovery capacity should be specified for each phase. Ideally, such recovery capacity would be determined objectively in the same way as contingency (Figure 8.2), to provide (in conjunction with contingency) a specified level of confidence in meeting project budgets and milestones. For example, if the contingency provides an 80% confidence, recovery might be designed to increase the confidence level to 90% or 95%.

As will subsequently be discussed, to illustrate, recovery plans have been developed (by project development phase) for the hypothetical QDOT case study (see Appendix D).

Risk Management Plan

A structured risk management process will result in a formal *risk management plan* (RMP). The project development team's strategy to manage risk provides the project team with direction and a basis for planning. Ideally, the RMP should be developed during the planning and programming phases, and then updated during the preliminary and final design phases.

The RMP is the roadmap that tells the project team members how to approach all phases of risk management at a project or program level. Because it is a map, it may be specific in some areas, such as the assignment of responsibilities for DOT and contractor participants and definitions, and general in other areas to allow users to choose the most efficient way to proceed. An RMP should contain some or all of the following items:

1. Introduction (including summary, definitions, project description, risk management strategy and approach, and organization, roles, responsibilities);
2. Risk identification, assessment, and analysis (including risk register);
3. Risk reduction;
4. Contingency (including reserve and recovery plans);
5. Implementation (including risk monitoring and updating, information gathering and distribution); and
6. Risk register, documentation, and reports.

Each RMP should be adequately documented, but the level of detail will vary with the unique attributes of each project. Smaller projects might use a risk register as the only formal RMP, whereas larger projects should have a formal RMP with the sections listed above and as well as using computer-based risk management information systems. Ideally, the RMP will integrate into the overall project management plan through coordination with tasks such as periodic cost estimates, value engineering, constructability reviews, and design reviews.

As will be discussed, to illustrate, a formal RMP has been developed and is presented for the hypothetical QDOT case study (see Appendix E).

CONCLUSIONS ON RISK MANAGEMENT PLANNING

The primary objective of risk management planning is to optimize future project performance, specifically with respect to risks. Risks and opportunities that have been identified and analyzed earlier in the risk management process serve as the inputs to the risk management planning for the project. Risk management planning develops specific actions and assigns responsibilities to cost-effectively deal with risks and capitalize on opportunities. The RMP is the output of the process.

The RMP should be accurate, defensible, and cost-effective. Following a rigorous process of risk identification, assessment, and analysis before risk management planning will help to ensure accuracy and defensibility. Effective risk management planning establishes budgets and schedule milestones with contingencies to adequately cover the uncertainty that remains, even after the best risk reduction planning efforts. The process of risk management planning generally involves proactive risk reduction, risk allocation, contingency management, and the development of recovery plans. Risk reduction is a proactive process of using the most cost-effective actions, through a cost–benefit analysis, to mitigate risks that cannot be avoided. Risk allocation involves contractually assigning the residual risks to a party in the contract. The party assuming the risk should be best able to evaluate, control, bear the cost, and benefit from its assumption, at a reasonable risk transfer price. Contingency management involves the maintenance of adequate resources in case residual risks occur. If many significant risk events do in fact occur, exceeding available contingency, recovery plans must be put into action. The RMP essentially documents these plans. With this context of risk management planning in place, Chapter 9 discusses implementation of the RMP.

Example

The hypothetical QDOT case study (see Appendix D), which is used throughout the guide to adequately illustrate the various steps of the risk management process and includes a risk management plan (RMP; see Appendix E), involves management of each of the significant risks in the risk register individually and collectively (using the methods and guidance described in this chapter), as documented in that RMP and summarized below.

After risk assessment and prioritization, QDOT identified and planned specific risk management actions to address the key risks to its project objectives, both individually and collectively. The complete project RMP (see Appendix E) consists of (1) proactive risk reduction plans (RMP Section 5), (2) contingency management actions per QDOT procedure (by project phase) (RMP Section 7), and (3) recovery plans (by project phase) (RMP Section 8).

QDOT first focused on identifying cost-effective actions for reducing the highest-rated (i.e., highest-priority) risks, considering synergy among risk management actions as appropriate. For each of the high-ranking risks, the following was done: (a) possible proactive risk management actions were identified; (b) the estimated mean cost, schedule, and disruption (by activity) to implement each action was assessed; (c) the anticipated mean effectiveness for reducing the various risk factors from each action was assessed; and (d) the overall cost-effectiveness (of reduction in severity) for each action was calculated (using the Microsoft Excel workbook template). Cost-effective actions were then selected, and responsibility and schedule for implementing those actions were established.

Below is one example of risk reduction action identification and evaluation for one rapid renewal risk for this project. The cost-effectiveness of this particular action was determined to be a net savings of about $250,000 (regarding change in severity, in equivalent year-of-expenditure), which was the fourth highest of the actions identified and would be recommended.

(continued)

Risk or Opportunity Addressed[a]	Potential Risk Management Action[b]	Change in Base Factors	Change in Risk Factors	Responsibility	Schedule
RU3. Unwilling sellers	QDOT's principal risk from unwilling sellers is increased right-of-way acquisition cost. Hence, QDOT could take the following actions to reduce this risk (see guide, Table B.11): Make reasonable, early offers: conduct thorough research on the values of these properties, and present reasonable offers to the property owners. Do this early to provide more time to reach negotiated settlements (and therefore avoid court proceedings). This action would likely reduce the probability of cost increase but not the magnitude of a cost increase if it occurs.	+$0.05M to ROW, minor delay and disruption	Reduce probability of occurrence to half (from *H* to *M*), minor change in impacts	Design manager (design) and ROW manager (public outreach)	Implement now; check by end of 30% design

[a] See risk register for description.

[b] Proactive actions: mitigate, avoid, allocate.

QDOT then determined the revised base and residual risks (assuming that the selected risk reduction actions were actually implemented), from which they determined approximate mitigated mean project performance (i.e., for completion date and escalated cost) in the same way (using the Microsoft Excel workbook template) as for unmitigated mean project performance (as documented in RMP Section 6). On the basis of this information, in conjunction with industry guidance, QDOT used judgment to establish appropriate contingency requirements (as documented in RMP Section 7) and recovery requirements (as documented in RMP Section 8). Note: Subsequently, a quantitative risk analysis was conducted, which objectively determined the values for the specific QDOT-established targets of 80% and 95% confidence of the mitigated project performance (i.e., completion date and escalated cost) for establishing contingency and recovery requirements, respectively; this was done in the same way as for unmitigated project performance; see Appendix E, RMP, Addendum X.

9

IMPLEMENTING RISK MANAGEMENT PLAN

INTRODUCTION

As discussed in Chapter 8, the risk management plan is intended to optimize project performance through the following three basic elements:

- Specific actions whose purpose is to reduce particular individual risks, focusing on the higher-priority risks;
- Management of contingency to cover most of the residual risks and other uncertainties; and
- Recovery if established contingency is inadequate (i.e., to cover the rest of the residual risks and other uncertainties).

However, like any plan, the risk management plan must be appropriately implemented to be successful and actually achieve optimal project performance. Also like any plan, successful implementation requires the following (at a minimum):

Adequately and efficiently implement the risk management plan:

- Proactively reduce individual risks.
- Address changing conditions.
- Establish, track, and control contingency.
- Decide on "recovery" (if needed).

- Responsibility—assignment of a risk manager and "owners" of significant individual risks;
- Commitment—the organization has to commit to the plan;
- Resources—adequate resources (funding and staff) have to be provided to carry out the plan; and
- Authority—specific individuals have to be given adequate authority, as well as resources, for carrying out their assigned plan responsibilities.

A unique feature of the risk management plan, unlike most plans, is that it is actually an evolving document, with the expectation that it will be adjusted to reflect changes in the project as that project develops (including any changes due to recovery). This means that those project actions and conditions must be monitored and the plan periodically updated to reflect observed changes. For example:

- Planned risk reduction actions generally should be performed as planned. Their progress should be monitored and their actual impact on risks should be assessed. However, these plans might be adjusted on the basis of their progress and projected results, considering changing needs. For example, it might be determined (based on new information) that the risk being addressed is not as important as previously thought.
- Risks will either happen or not happen during various project phases. If they have not happened while their window is open, they will not happen after their window has closed and they can be retired in the risk register. Conversely, if they have happened, contingency should be reserved for that risk and this should be noted in the risk register. However, such expenditure of contingency must be carefully controlled.
- As conditions change, particular risks (either their assessed probability or impacts) whose windows have not yet closed can change (e.g., becoming either more or less likely). In fact, sometimes previously unidentified ("new") risks are identified and should be assessed and included with the other existing risks. Such changes in remaining risks should be noted in the risk register.
- As noted above, realized risks might result in spending or reserving some of the established contingency, leaving less contingency for the rest of the project. Conversely, if few risks are realized, there might be excess contingency. The adequacy of the remaining contingency needs to be periodically reevaluated to give as much advance warning as possible of either possible future inadequacy (which might trigger recovery plans) or excess contingency (which can be released for other purposes).

This process of implementing the risk management plan (which includes monitoring, updating, and implementing protocols for making significant project decisions, for example, regarding contingency and recovery) needs to be effective but should also be efficient and compatible with the DOT organization and project.

PROCESS OF IMPLEMENTING THE RISK MANAGEMENT PLAN

Implementation of the risk management plan consists of first getting set up to carry out the plan, and then actually implementing the various elements of the plan.

Preparing to carry out the plan requires the following steps:

- Organizationally committing to the plan;
- Assigning responsibility for the plan;

- Providing adequate authority and resources to carry out the plan; and
- Gathering and distributing information.

Without these steps, the plan likely will not be successfully implemented—it will be just another document on the shelf. As part of this, it is recommended that a risk manager, a position reporting directly to the project manager, be named for the project and given overall responsibility for implementing the plan; for small projects (which should not require much effort) the risk manager might simply be the project manager, whereas for larger projects (which might require significant effort) it would be a separate person (e.g., the assistant project manager). The risk manager then typically will delegate responsibility for various elements of the plan to those who are in the best position to complete them and will follow up with them to ensure that they actually complete those elements. For this to happen, the risk manager must be given adequate authority and resources (e.g., budget). However, this needs to be done as efficiently as possible to prevent wasting resources. For example, periodic risk management status meetings should be short and integrated into regular project status meetings. Similarly, risk management status reports should be streamlined, simply highlighting changes since the last report, and appropriately distributed in a timely fashion.

With an adequate organizational structure and set of procedures in place, the various elements of the plan can be successfully implemented. The basic elements of the plan, which are somewhat flexible in order to be most efficient, include the following (see Chapter 8):

- *Risk reduction actions*. A set of actions is specified in the risk management plan for reducing individual risks. These actions must be successfully performed to realize any risk reduction, although the actual amount of risk reduction, and typically to a lesser extent their cost and schedule to implement, will be uncertain beforehand. However, such actions can be adjusted (e.g., stopped) as their projected performance or need changes. The DOT must assign responsibility for each action, and then track progress of that action. The cost and schedule, as well as the results (in terms of risk reduction), of implementing that action will be reported. Figure 9.1 provides an example based on the Risk Management Plan form

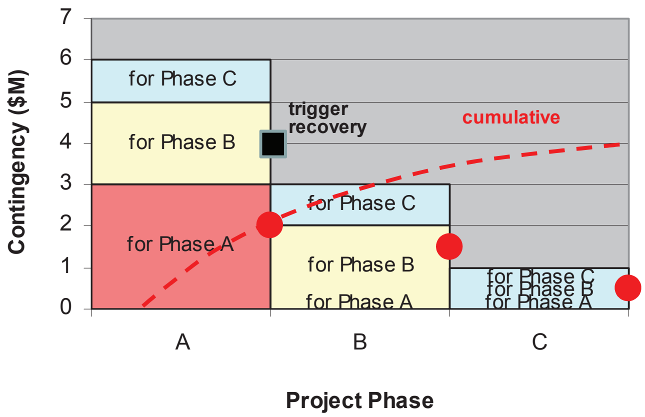
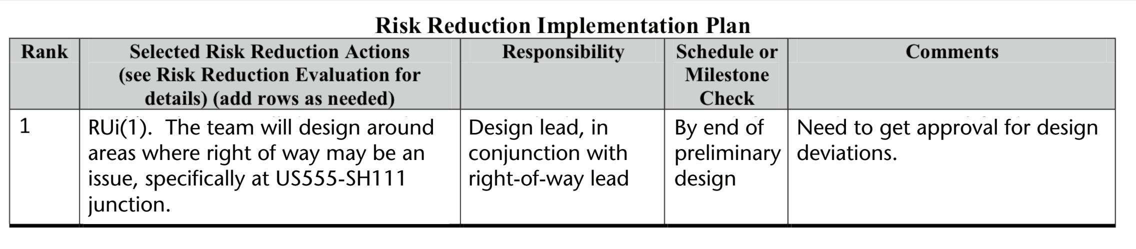


Figure 9.1. *Contingency drawdown and recovery for project phases.*

provided in Appendix C. In this example, the project team has determined that it will be more cost-effective to design around an area with a significant right-of-way risk. The management actions provide an estimate of the resources, an estimate of the risk reduction, and a person who is responsible for verifying that the risk plan has been implemented by a key milestone. Status updates can then be documented on this form.

Example Risk Reduction Action from Risk Management Plan (this is not the hypothetical case study)



Risk Reduction Implementation Plan

Rank	Selected Risk Reduction Actions (see Risk Reduction Evaluation for details) (add rows as needed)	Responsibility	Schedule or Milestone Check	Comments
1	RUi(1). The team will design around areas where right of way may be an issue, specifically at US555-SH111 junction.	Design lead, in conjunction with right-of-way lead	By end of preliminary design	Need to get approval for design deviations.

Action successfully completed, and risk eliminated <by name and date>

- *Contingency management.* Contingency allowances for cost and schedule are established in the risk management plan to cover the residual risks (after they have been reduced) with appropriate confidence. As risks are realized, some of the contingency must be reserved to cover them. However, like any project costs, such expenditures must be carefully controlled; similarly, giving up project float in the project schedule must also be carefully controlled. Conversely, if few risks occur and contingency is not used, then the excess contingency can be released for other purposes. As shown in Figure 9.1, such contingencies are typically allocated to, and tracked by, the different phases of the project. For the case shown in red circles in this example, the contingency actually spent in each phase (and thus cumulatively) was less than that budgeted (e.g., in Phase A, only $2 million of the budgeted $3 million was spent); after each phase, unused contingency could be released. DOTs typically have established protocols for approving and tracking contingency expenditure and releases, with approvals generally required at higher organizational levels as the amounts increase.
- *Recovery.* Contingency (or recovery) plans are identified in the risk management plan just in case the contingency allowances are found to be inadequate (e.g., if a disproportionate number of significant risks actually happen). For example, if as

shown in the black square in Figure 9.1, the reserved contingency exceeds the allowable contingency during a phase, then recovery is triggered (e.g., in Phase A, $4 million was spent, which was $1 million more than the $3 million budgeted for that phase, meaning that there is not enough left for later phases). Typically, such plans are somewhat drastic (e.g., deferring or eliminating scope to save cost and/or schedule) and are only intended as a last resort. However, in general, each such plan is only possible up to a specific point in project development; for example, savings associated with deferring some scope cannot be realized once that scope has been built. Clearly, such decisions must be made at a high organizational level.

Because (as described above) the plans are somewhat flexible to adapt to changing conditions, to be successfully completed, each of the above elements of the risk management plan requires specific information at various points in time:

- The status and projected results of the various risk reduction actions, as well as projected needed performance improvements;
- The status or availability of contingency, as well as projected contingency needs; and
- The status or availability of recovery actions, as well as projected recovery needs.

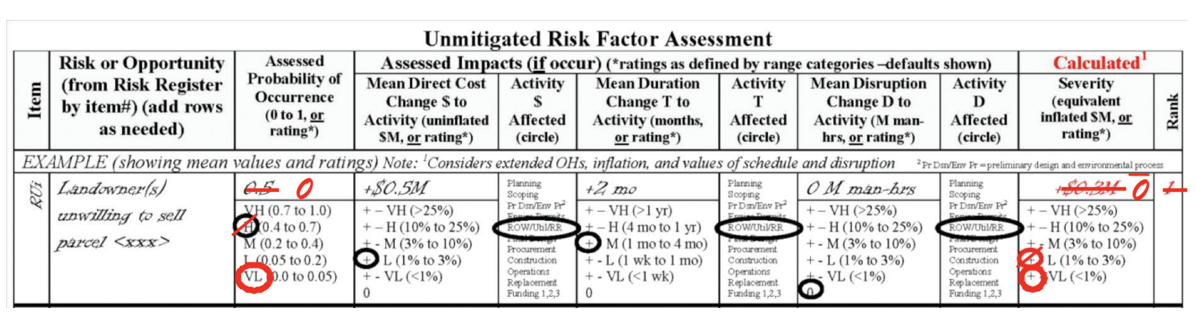
In particular, to determine changes in needs (whether for risk reduction, for contingency, or for recovery), the changes in risks should be adequately monitored and updated. Such changes in risks are due to inevitable changes in project conditions with time.

Monitoring is relatively quick, but informative. The following should be monitored periodically (e.g., monthly, or less frequently at moderately important points or changes in project development): project development status and conditions, risk reduction action status and projected results, existing risks, and contingency and recovery plans. These should be adequately documented (e.g., in a memorandum or directly in the risk register). For example: (a) the status of a risk reduction action is illustrated in the above example; (b) qualitative changes in risk might simply be described, including their cause; and (c) the status of contingency is illustrated in Figure 9.1.

Updating is more involved (including reassessment and reanalysis, if needed), but also more informative, than monitoring. The following should be updated periodically (e.g., quarterly, or less frequently at important points or changes in project development, as indicated by monitoring): base performance, risks (including adding new risks), and contingency and recovery requirements. These should be documented (e.g., in the risk register and in the risk management plan).

Example Risk Register Update (this is not the hypothetical case study)

There was a risk of a landowner being unwilling to sell a parcel needed to construct a project. When it was first identified, there was a high probability (50%) that the owner would not be willing to sell and the impact of this risk was $500,000 and 2-month delay, with an expected value of about $300,000 [including increased escalation and extended overheads (OHs)] and 1 month (critical path). However, as seen in a previous example, the management action was successfully taken to avoid this risk by designing around the parcel, at a cost of about $100,000 ($150,000 including increased escalation and extended OHs) and 1-month delay. The resulting reduction in risk meant that about $300,000 and 1 month less contingency was required; however, the resulting cost ($150,000) and delay (1 month) of the mitigation effort had to be added to the base cost and schedule. Based on such updates of the various inputs, the contingency requirements (and recovery requirements) could be recalculated.



Unmitigated Risk Factor Assessment

Item	Risk or Opportunity (from Risk Register by item#) (add rows as needed)	Assessed Probability of Occurrence (0 to 1, or rating*)	Assessed Impacts (if occur) (*ratings as defined by range categories –defaults shown)						Calculated[1]	
			Mean Direct Cost Change $ to Activity (uninflated $M, or rating*)	Activity $ Affected (circle)	Mean Duration Change T to Activity (months, or rating*)	Activity T Affected (circle)	Mean Disruption Change D to Activity (M man-hrs, or rating*)	Activity D Affected (circle)	Severity (equivalent inflated $M, or rating*)	Rank
EXAMPLE (showing mean values and ratings) Note: [1]Considers extended OHs, inflation, and values of schedule and disruption [2]Pr Dsn/Env Pr = preliminary design and environmental process										
RUi	*Landowner(s) unwilling to sell parcel <xxx>*	~~0.5~~ 0	+$0.5M	Planning Scoping Pr Dsn/Env Pr[2] Envir Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding 1,2,3	+2 mo	Planning Scoping Pr Dsn/Env Pr[2] Envir Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding 1,2,3	0 M man-hrs	Planning Scoping Pr Dsn/Env Pr[2] Envir Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding 1,2,3	~~+$0.3M~~ 0	~~1~~
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) [✓ VL] (0.0 to 0.05)	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) [✓ +] - L (1% to 3%) + - VL (<1%) 0		+ – VH (>1 yr) + – H (4 mo to 1 yr) [✓ +] - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0		+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) [✓ 0]		+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) [✓ +] - VL (<1%)	

Risk RUi updated <by name and date>

CONCLUSIONS ON IMPLEMENTING THE RISK MANAGEMENT PLAN

The risk management plan consists of three main elements designed to optimize project performance: (1) plans for individual risk reduction actions; (2) protocols for contingency management; and (3) protocols for recovery plans. Because project conditions, and hence risks, inherently change as a project moves through the development process, the risk management plan is intended to be an evolving document, adjusting as the project develops. This in turn requires monitoring (e.g., of the progress and results of specific risk reduction action, of specific risks in the risk register, and of contingency) and periodic updating (e.g., of residual risks, of risk reduction plans, and of contingency requirements). This then requires a DOT commitment to carrying out the risk management plan, including assignment of responsibility (e.g., a designated risk manager), with adequate authority and resources, and ways to gather and distribute relevant information. This also needs to be an efficient process, compatible with the DOT organization and project.

Example

The hypothetical QDOT case study (see Appendix D), which is used to illustrate the various steps of the risk management process and includes a risk management plan (RMP, Appendix E), describes an effective and efficient implementation of its RMP following the principles and process outlined in this chapter, as documented in RMP Section 9 and summarized below.

After QDOT developed the RMP, its implementation was adequately supported by management and adequate resources provided. The RMP included an organizational structure with specified responsibility and authority (i.e., the project manager served as the risk manager) to implement that RMP throughout project development. The project's designated risk manager then successfully implemented that RMP, as follows:

- Proactively and cost-effectively reduced individual risks that were within QDOT's control, including monitoring and updating the risks and the RMP over time, resulting in successful reduction of several large risks;
- Used established protocols for contingency control, including monitoring and periodic updating of contingency status (expended to date and capacity required for completion) and recommending contingency expenditure (to cover actual risk occurrences as needed) and releasing excess contingency (when no longer needed), resulting in adequacy of the initially established contingency throughout the project, with the unused contingency subsequently released; and
- Used established protocols for recovery decisions, including monitoring and periodic updating of recovery status (achieved to date and capacity required for completion) and recommending recovery actions as needed when remaining contingency was not sufficient, resulting in no recovery actions being required.

10

IMPLEMENTING THIS GUIDE

INTRODUCTION

This guide has outlined an efficient and effective process for managing risks on rapid renewal projects. However, adequate planning and logistical support are required for a DOT to successfully implement this process. This chapter summarizes key logistical issues to consider when planning, staffing, and conducting the risk management process.

Adequate planning, appropriate resources, careful coordination, and integration into continuous project management processes are the keys to successful risk management implementation. The DOT should initiate the risk management process early in the project's life cycle, and then update as appropriate. The DOT also needs to engage the appropriate participants and provide them with relevant information for each of the risk management process steps. The DOT ultimately needs to adequately plan and resource the meetings, workshops, and project management staff throughout the process to ensure an efficient and effective process. A good planner and a qualified facilitator are keys to successful implementation.

Adequately but efficiently plan and implement the risk management process described in this guide.

PROCESS OF IMPLEMENTING THIS GUIDE

When to Apply This Guide

Risk management is beneficial in all phases of project development. In general, the earlier risk management is started, the more time the project team has to react to the identified risks and the easier the risks are to manage, and thus the more benefits the project will realize from risk management. However, there is such a thing as starting too early to conduct effective risk management for individual projects. This can be true when a program is just being established, but the purpose and overall scope for individual projects have not yet been established.

Once a project's purpose and overall scope have started to take shape, various elements of the risk management process can be applied to maximize benefits. The following guidance applies to large and/or complex projects, or projects with significant specialty elements:

- When a project is in the scoping or preliminary design phase (e.g., prior to approximately 10% design) and the DOT has yet to select a preferred alternative, the process can be particularly useful for evaluating the risks of each alternative relative to the other alternatives. The process applied at this point includes structuring (Chapter 4); risk identification (Chapter 5); risk assessment (Chapter 6); and considering some elements of risk management (Chapter 8), especially proactive risk reduction for significant risks. This comparison can help the DOT make decisions among alternatives, such as design alternatives, funding alternatives, or project delivery alternatives. If cost and schedule estimates also exist for each alternative at this time, risk analysis (Chapter 7) can also be conducted to quantify uncertainty in the cost and schedule for each alternative, which can then be compared among alternatives to help make decisions. An example of this type of comparison for project cost, where one alternative (full build) is about $100 million (or 6%) less than the other (phased full build), is shown in Figure 10.1. The corresponding project schedule, disruption, and longevity can also be compared in a similar way. At this stage of project development, these elements of the risk management process can be conducted in less detail than would normally be done for a preferred alternative, especially if results are being used only to compare alternatives.

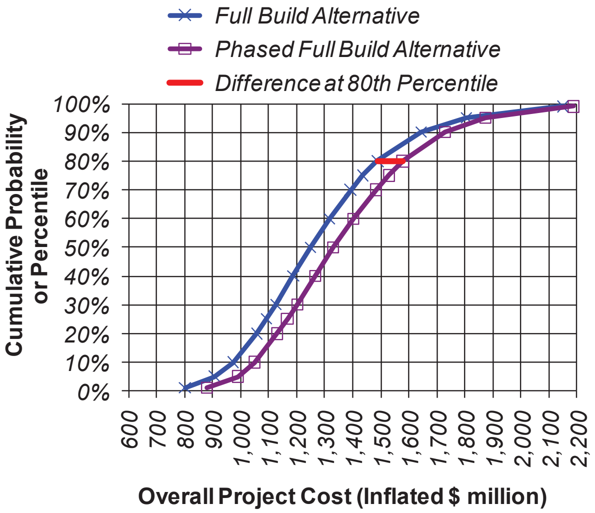


Figure 10.1. *Comparison of Cost Uncertainty for Project Alternatives.*

- After the DOT has selected a project alternative (e.g., after completion of environmental documentation, or near 30% design), the original structuring, risk identification, and risk assessment for the preferred alternative (if done previously) can be updated to reflect the greater level of project development. Additional detail can also be included at this stage to get a better picture of the preferred alternative's risks and opportunities. The DOT can also conduct risk analysis (Chapter 7) in this phase if cost and schedule uncertainty and defensible development of contingency to adequately cover those uncertainties are of interest to the DOT. Risk management planning (Chapter 8) and implementation (Chapter 9) are now also appropriate and beneficial for the preferred alternative. Again, the earlier in project development that the risk management process can be started, the greater the benefits.
- As the project progresses beyond preliminary design and the environmental process to final design, right-of-way acquisition, and utility relocations, the DOT should update the risk management process at key project milestones, at some predetermined time interval, or both. For example, the U.S. Federal Transit Administration (FTA) historically has required risk management updates at key project milestones, such as entry to final design and application for FTA's funding grant. Other agencies, such as the Washington State DOT (WSDOT), typically will conduct annual updates for their large, complex, or high-visibility projects. When appropriate, risk management can be integrated with value engineering (VE), where ways to proactively reduce significant risks or capitalize on VE opportunities can be explored.
- When a project nears construction procurement, some agencies will update the risk management process to develop a validated engineer's estimate (including contingency) and to guide risk allocation for contract document preparation. The agency could also conduct a more detailed assessment of construction risks (e.g., management of traffic or construction staging) and plan specific risk management actions for those risks (either individually or collectively), if not done previously. This could be particularly useful for rapid renewal projects, which often employ innovative construction technologies and materials.
- Unless a project has particularly complex construction staging or specialty construction, the risk management process during construction usually focuses on continuing to manage previously identified risks (rather than identifying, evaluating, and managing new risks) and on managing contingency. However, there are cases in which risk identification and subsequent steps might be conducted (or repeated) during construction. For example, when a major failure has occurred during construction, the owner might want to make sure that the contractor has identified and can effectively manage similar potential problems through project completion.

The risk management process is easily "scalable" to match project type, size, complexity, and needs. For projects that are not as large or complex, the risk management process should be much simpler. For example, structuring, risk identification, risk assessment, and risk management planning might be conducted only once, although risk management implementation would have to be carried through to the project's completion to realize the maximum benefits. WSDOT has such a policy for any project with an estimated cost between $25 million and $100 million (Washington State Department of Transportation, 2006).

How to Apply This Guide

The keys to success for the risk management process include proper planning, allocation of appropriate resources, careful coordination, and integration into continuous project management processes. Lack of preparation and focus can grind a group to a standstill, resulting in inefficiency, frustration, and wasted effort. To ensure that the risk management process fulfills its potential, the DOT must conduct an effective and efficient risk management process, as outlined below.

Leadership and Facilitation of the Risk Management Process

Project leadership should provide command emphasis for the risk management process. The project leadership has to establish and continually reinforce the need for risk management to ensure that project-team members participate appropriately. Project leadership should also communicate the need for risk management "up the chain" to ensure that the proper external resources (including independent subject-matter expertise) are provided.

Effective facilitation is essential for efficient and effective meetings and workshops that are inevitably part of the risk management process. A weak or untrained facilitator can cause a meeting or workshop to lose focus and fail. The facilitator should be knowledgeable (in general, but not necessarily with the specifics) about the various phases of rapid renewal projects. The facilitator also needs to be adequately trained in the risk management process and the underlying principles and guidance and should have practical facilitation experience (preferably for risk management). A few key points on facilitation include

- Maintain a positive, engaging presence.
- Try to achieve consensus, as well as project-team buy-in. Be fair—let all qualified voices be heard equally and do not let strong personalities dominate (bias) the discussion. Encourage participation and responsibility. As long as no adverse group dynamics are at work, follow a policy that "silence is acquiescence."
- Appropriately consider all available information.
- As tactfully as possible, keep the group focused—stay on task and on time. If bogged down, stimulate the discussion by asking different questions or asking questions differently (i.e., from a different angle).
- Always keep in mind the goals for the risk management process—adequate but efficient. Keep the level of detail and quality of the assessments appropriate and consistent with the purpose for the risk management process.
- Try to remain neutral, but do not be a pushover. The facilitator must believe (be convinced) that the assessments are reasonable and bias-free.

Participation in the Risk Management Process

Project leadership should actively participate in the risk management process. Without consistent engagement by the project leadership, the risk management process will falter. Consistent leadership will ensure that the risk management process is carried to its conclusion and that risk management objectives are met. For example, project leaders often must provide key input to the risk management process, as well as make risk-based decisions regarding the project's development. Project staff often do not have the knowledge or the authority to make such decisions, which can slow project development and hobble risk management. Project staff often do, however, have information on potential risks and risk management options. Project leaders should invite and encourage the entire team's input into the process.

Participants should be adequately qualified in their respective areas of expertise. Expertise can come in the form of project expertise (project-team members are experts about the particular project) and subject-matter expertise (discipline experts). A given participant can fulfill more than one role in the risk management process, if qualified to do so. However, the facilitator should tactfully request that participants who are not knowledgeable on a particular topic refrain from offering opinions on that topic. Unqualified opinions degrade the quality of assessments, as well as reduce the efficiency of the effort.

Participants should include key project-team members (including the cost estimator and scheduler) and independent subject-matter experts. Perhaps the easiest way to avoid bias in the risk management process is to include project experts as well as project-independent experts. The interactions of these two groups are extremely useful for highlighting potential project issues and for reaching potential solutions. The independent experts could be the same as used for VE, realizing some efficiency.

Participants should be at least minimally trained on the risk management process, their roles within the process, and on how to perform those roles. Previous chapters in this guide and the companion Simplified Risk Management Training course provide a good training basis for participants. Otherwise, the facilitator should provide minimal training at the beginning of the workshop (see Appendix C for an overview presentation that provides such training, which should be made at the beginning of a workshop).

Planning the Risk Management Process

Planning for the risk management process is important and nontrivial. A good checklist, as well as a good planner, can help immensely when planning for the risk management process. The typical planning tasks and logistical considerations for a project risk management process include the following steps:

Step 1. Initiate the Risk Management Process.

- Identify the need and scope, as well as commitment, for risk management. This includes (but is not limited to):
  - —Coordinating with the project team;

  - Possibly tying risk management and VE processes together at key milestones; and
  - Determining if qualitative or quantitative analyses are needed (e.g., to quantify project performance uncertainty, from which appropriate budget and contingency can be determined).
- Identify the funding source and secure funding for risk management. Coordinate with DOT management and the project team, and complete funding administrative requests or actions.

Step 2. Prepare for the Risk Management Meetings or Workshops.

- Identify the risk management process steps to be covered in a meeting/workshop. The DOT might implement a number of risk management process steps in one meeting (e.g., structuring, risk identification, risk assessment, and risk management planning), or have separate meetings, to suit the needs of the DOT. The DOT might tie risk management and VE together, and/or conduct a separate preparatory session up front to plan subsequent workshops and meetings, including identification of participants.
- Implement necessary contracts and task orders (DOT internal and for consultants). Give sufficient lead time to contracting personnel, and follow up as required.
- Identify and confirm participants, including facilitator, independent subject-matter experts, and project-team members. Follow up as needed. Iterate when the study schedule changes or for project risk management updates. Identify key project issues for which experts are needed (e.g., independent cost estimator and scheduler). Communicate the workshop schedule or agenda, responsibilities, and logistics to all members.
- Identify the schedule for risk management, including risk management meetings and workshops. Iterate when member participation or facilities change or for project risk management updates:
  - Select the format for the workshop (e.g., single, all-encompassing meeting versus more linear format with extended schedule and several smaller workshops or even interviews);
  - Plan for schedule changes when conflicts occur with other major events involving significant resources or personnel; and
  - Develop a meeting or workshop agenda and distribute to all participants.
- Identify, schedule, and confirm facilities for risk management meetings or workshops. Iterate when the study schedule changes. Visit the facilities prior to the workshop start date to meet the necessary contacts and to assess the facilities. Facilities include
  - Venue: location, buildings (including access, after-hours access, and visitors' passes), quiet main meeting room to comfortably accommodate all participants and one to two smaller breakout rooms, and parking.

  - —Support services and materials: printing and copying; information technology (computer network, phone, e-mail); LCD projectors (×2); notebook computer (for technical documentation); projection screen; dry-erase board and markers; paper flipchart and markers; power extension cords (3-prong grounded); daily refreshments; “working” meals; and miscellaneous office supplies.
- Send a risk management workshop requirements packet to the project team (i.e., instructions for project-team preparation), such as project description and cost and schedule estimates. Follow up as needed.
- Review and modify the requirements packet as needed, and deliver to the project team as soon as possible.
- Establish and communicate the deadline for project team’s response.
- Send project information (with instructions) to independent experts to review beforehand—especially review relevant design and cost/schedule estimate information for subsequent structuring.

Step 3. Conduct the Risk Management Meetings or Workshops (according to Chapters 4 through 8 of this guide).

- Kick off the risk management meeting workshop. Ensure that participants’ travel schedules are consistent with their required workshop participation. The risk management facilitator should arrive early to set up the facilities and provide an overview of the process (see Appendix C) and develop common understanding of the project.
- Develop consensus on all risk management inputs. Document assessments in real time (e.g., on a computer screen using the Microsoft Excel workbook template, on a whiteboard). Having a separate notetaker working with the facilitator helps immensely. Break out into smaller groups for specialized topics, for which a second facilitator will be needed. A second facilitator also provides redundancy in case something happens to the first facilitator, thereby protecting the large investment made for the workshop. Provide adequate time (e.g., after the workshop) to review and finalize risk management inputs as well as to develop and implement the risk model (if needed).
- Prepare a workshop risk management results briefing (if results are to be briefed outside workshop participants). As early as possible, forecast the briefing schedule and communicate to briefing attendees (especially if not participating in a workshop). For example, the briefing might precede a separate VE workshop.
- Present and discuss risk management results.

Step 4. Document the Risk Management Process and Results.

- Prepare and submit a draft risk management report, including risk management plan (which includes the risk register).

- Finalize the risk management report based on feedback from the project team and other workshop participants.

Step 5. Implement the Risk Management Plan (according to Chapter 9 of this guide).

- Ensure DOT commitment and resources.
- Establish responsibility and authority.
- Plan for and conduct monitoring and updates as appropriate (as above), as well as manage contingency.

A separate logistics planner, working in concert with the risk facilitator, can help accomplish the above steps.

Companion Implementation and Training Materials

As previously noted, a qualified facilitator, as well as DOT management and project-team commitment, planning, and participation of appropriate project team and independent experts are keys to successful implementation of the risk management process outlined in this guide. A companion Simplified Risk Management Training course for this guide has been developed especially to train DOT facilitators to conduct important parts of the risk management process described in this guide on relatively simple projects. Also, forms and a Microsoft Excel workbook template have been developed (and are included in the training) to help the facilitator conduct the important aspects of risk management on simple projects (see Appendix C and Figure 10.2). This training is also useful for DOT management and potential participants, including key project-team members and independent experts (e.g., from DOT headquarters), to help them better understand the process. However, this training is not required for everyone who participates in the risk management process. Typically, the facilitator will provide a short overview of the process at the start of a workshop to adequately explain the process for the participants, and it will be up to the facilitator to subsequently guide the participants through that process. Such an overview presentation has been developed and is provided in Appendix C.

The training course is 2 days, in which a hypothetical (but realistic) DOT rapid renewal project is evaluated for illustration and concept reinforcement. The class consists of individual modules, generally one for each chapter in this guide. However, whereas this guide focuses on the concepts (the what), the class focuses on the implementation (the how to) and includes simple exercises and examples to accomplish this. Notes, in the form of annotated versions of all the PowerPoint slides shown in the class, provide additional details to what is provided in this guide. The focus is on structuring, risk identification, risk assessment (including risk severity analysis and prioritization), risk management planning, and risk management implementation, especially for relatively simple projects that a DOT can evaluate in house, which will help to optimize the performance of those projects.

The class does not include detailed training in full quantitative risk analysis (Chapter 7) to quantify the uncertainty in project performance, which can be used to defensibly establish budgets and milestones (and contingencies). Such analyses require

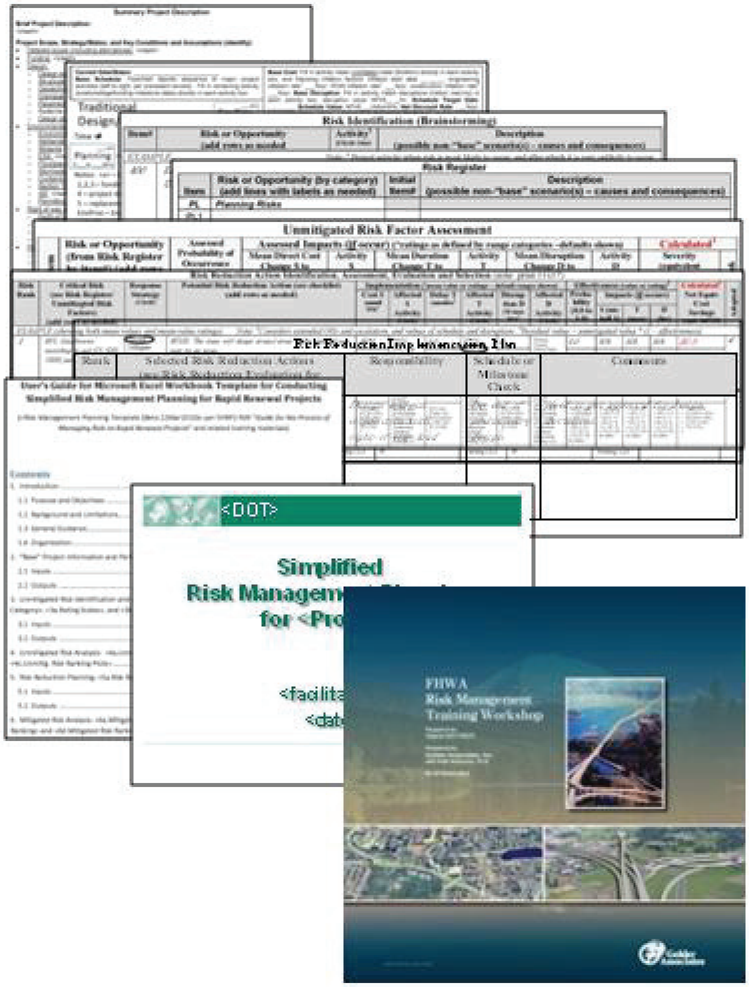


Figure 10.2. *Overview presentation of forms and template (Appendix C) and training materials.*

specialized skills that cannot be developed in a 2-day class. Instead, the training will allow a DOT to effectively supervise such analyses, as well as supervise the evaluation of more complex projects.

To help the facilitator conduct selected parts of the risk management process on relatively simple projects, specific forms have been developed to guide and document information developed in the workshop. In addition to hard-copy forms (PDFs), these forms also have been replicated in a Microsoft Excel workbook template for data entry and subsequent automatic analysis of that information. Such analyses include determination of (a) the mean values of base and total (base + risk) performance measures; (b) the severity (in terms of combined change in total performance measures) of each risk and opportunity, based on which they are prioritized; and (c) the cost-effectiveness of possible risk management actions, based on which such actions can be recommended and resulting revised mean values of total performance measures are determined. The training includes the use of these forms and template.

CONCLUSIONS ON IMPLEMENTING THIS GUIDE

The risk management process presented has the potential to greatly improve the ability of project leadership and team members to make critical decisions as well as improve project performance with respect to the rapid renewal objectives. However, the process must be adequately planned and resources made available, and then followed through to its completion, to obtain these benefits in an efficient way. The following are keys to success:

- Prepared technical resources (project-team and project-independent experts);
- A (preferably two) qualified facilitator/analyst (to ensure an accurate, defensible, and efficient process);
- A good planner (for logistics);
- Organizational leader and system to provide
  - —Active organizational support;
  - —Adequate resources and participation; and
  - —Commitment to implement the process.

This chapter has offered important guidance on the logistics of the risk management process, including when and how to apply the process, to help ensure that the DOT realizes the full benefits of risk management. Additional guidance is provided in companion materials, including training materials, workshop introductory overview presentation, and specific forms and a Microsoft Excel workbook template.

Example

The hypothetical QDOT case study (see Appendix D), which is used to adequately illustrate the various steps of the risk management process and includes a risk management plan (RMP; Appendix E), involves implementation of the risk management process on this project (as described in Chapters 2 through 9), following the principles and process outlined in this chapter, as documented in the RMP and summarized below.

QDOT did the following (as documented in the RMP):

- Assembled relevant project information (i.e., regarding scope, strategy and status, conditions and assumptions, cost estimate, schedule);
- Convened a group of key project team staff and independent subject-matter experts from the key project disciplines in a series of workshops facilitated by a qualified risk elicitor/analyst, to conduct risk assessment and risk management planning (consistent with the principles, processes, and guidance described throughout the guide), culminating in an RMP (including the risk register); and
- Assigned a risk manager (with appropriate authority and resources) to implement the resulting RMP, including monitoring, updating, and recommending project risks, risk reduction plans, contingency, and recovery.

This process was well planned, supported by management, and adequately resourced. Adequate support and resources (including an organizational structure) were then provided to implement that plan throughout project development.

Construction of the QDOT project was successfully completed on January 31, 2013, at an inflated cost of $22.0 (with $2.0 million remaining as a cost contingency and 2.0 months remaining as a schedule contingency). There were few unanticipated problems and no recovery actions.

Performance of QDOT US-555 and SH-111 Project

Project Performance	Base	Base + Contingency	Actual	Unused Contingency
Cost (YOE$M)	$17.0	$24.0	$22.0	+$2.0
Schedule (months)	35.0	40.0	38.0	+2.0

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CONCLUSIONS

In the past, many transportation projects have performed poorly (e.g., in terms of ultimate cost and schedule to completion), often because of unexpected problems as described in Chapter 1. This might be amplified for rapid renewal projects as described in Chapter 3, which are intended to accelerate schedule and minimize disruption through construction, while not adversely affecting either cost through construction or postconstruction longevity. However, by definition, these rapid renewal methods are typically innovative with limited past experience from which to learn, and might be more susceptible to not performing as expected.

This guide presents a formal risk management process (see Chapter 2) to better understand and to actually optimize project performance specifically for rapid renewal projects, especially by anticipating and planning for potential problems ("risks"). This process, which is a significant expansion of a previously developed risk management process for non–rapid-renewal projects (for which the expanded process is also applicable), consists of a well-defined series of steps (Figure 11.1), each of which has been described in appropriate detail, including possible variations, in this guide. Sufficient information is also provided in this guide to ensure compatibility and consistency among the various steps, and to ultimately ensure adequate accuracy and defensibility of results (where "adequacy" depends on how the results will be used), as efficiently as possible.

The steps that follow are sequential and in some cases iterative:

Step 1. Structuring (Chapter 4). Define the base project scenario (including the relevant project performance measures of cost, schedule, and disruption through construction, and postconstruction longevity, and trade-offs among them), against which risk and opportunity can subsequently be identified and assessed, and eventually managed.

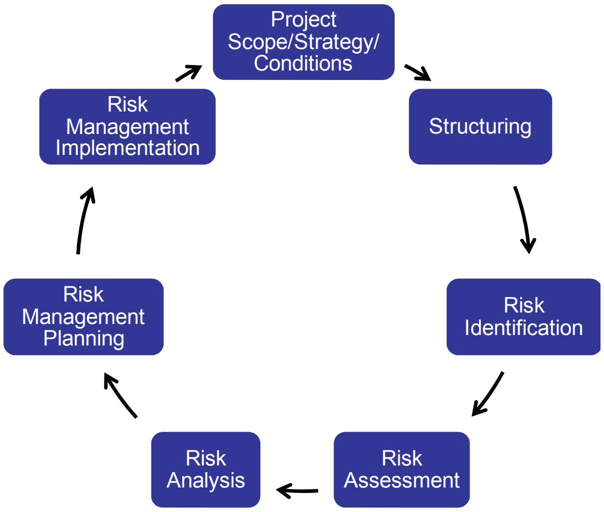

Figure 11.1. *Iterative risk management process.*

Step 2. Risk Identification (Chapter 5). Identify a comprehensive and nonoverlapping set of risks and opportunities (i.e., scenarios that might occur, changing the base project performance). In addition to brainstorming and then analysis of risks, lists of common risks have been developed that can be checked to ensure completeness (Appendix B). Document the set of risks and opportunities in *risk register* at the start of the project.

Step 3. Risk Assessment (Chapter 6). Assess the severity of each of the risks and opportunities in the risk register and then prioritize them on that basis. Generally this is done by (a) subjectively assessing the relevant risk factors (i.e., impacts *if* the scenario occurs and the probability of the scenario occurring), either qualitatively (e.g., high versus low, when these descriptors are quantitatively defined by ranges of values) or quantitatively (mean values or, for quantitative risk analysis, full probability distributions); and then (b) analytically combining the risk factors to determine changes in project performance measures and thereby severity. Document the risk-factor assessments in the project risk register.

Step 4. Risk Analysis (Chapter 7). Analytically combine the base and risk factors to determine the project performance measures (e.g., ultimate project escalated cost) as well as changes in those measures (e.g., combined using trade-offs as a measure of severity) associated with each risk. This can include quantification of the uncertainty in those performance measures, as a function of subjectively assessed uncertainties in (and correlations among) the base and risk factors. This requires specialized skills to be conducted appropriately.

Step 5. Risk Management Planning (Chapter 8). Identify and evaluate possible ways to proactively reduce risks, focusing on those that are most severe. Evaluate each possible action in terms of its cost-effectiveness, considering changes in both base (e.g., additional cost) and risk (e.g., reduced probability) factors, and select those that are cost-effective. Consider reanalyzing the project performance measures for this risk reduction program, including quantification of uncertainty, based on which appropriate budgets and milestones can be established (e.g., to achieve a specified level of confidence). As part of these budgets and millstones, establish contingencies (in the form of additional funds and schedule float, as well as recovery plans) and procedures to control their use. Document this in the risk management plan.

Step 6. Risk Management Implementation (Chapter 9). Implement the risk management plan as the project proceeds, including (a) monitoring the status of risk reduction activities and changes in risk (whether due to risk reduction or simply changes in project development, conditions, and information); and (b) monitoring budget and milestone, especially with respect to contingencies. This might involve periodic updates (iterate previous steps 1–5) at regular intervals or at major milestones or changes. For example, contingencies might be reduced as engineering reports or designs are completed and risks are avoided or reduced.

This guide also provides adequate information to help ensure successful implementation of the risk management process described in this guide, which requires adequate planning and resources, especially qualified facilitators and experts (Chapter 10). As part of this, a 2-day Simplified Risk Management Training course has been developed to train DOT staff to successfully implement this guide, focusing on training DOT facilitators to (a) implement the risk management process directly on relatively simple rapid renewal (as well as non–rapid renewal) projects; and (b) supervise the evaluation of more complex projects and/or quantitative risk analysis. In addition to this training course [which includes annotated slides and application to a hypothetical project (Appendix D)], to help these facilitators, an overview of the process and forms for documenting inputs (which are also available electronically in a Microsoft Excel workbook template that also automates the necessary analyses) have been developed for relatively simple rapid renewal (as well as non–rapid renewal) projects (see Appendix C).

The benefits of the risk management process described in this guide primarily include improved project performance as well as better understanding and clarity of the project and its range of possible performance. Moreover, it does this defensibly and efficiently. In fact, if done correctly (according to the guidance presented here), the investment (e.g., in training, workshops, and documentation) will be small relative to the benefits of improved project performance, plus the more intangible benefits of better project understanding and ability to defend significant project decisions.

However, the risk management process described in this guide currently has some limitations, which must be carefully managed and communicated:

- *DOT Commitment.* A formal risk management process, in which potential project problems and uncertainties are acknowledged up front, is
  - —A different way of dealing with such potential problems, and such changes are often difficult to implement within a DOT; and
  - —Incompatible with some current DOT cultures, which (although generally conservative and risk averse) tend to ignore risks, either because they are optimistic or because they are afraid such acknowledgment will affect project approvals.

A lack of DOT commitment often leads to inadequate resources and, as discussed below, poor results, which in turn can be used to justify that lack of commitment.

- *Accuracy and defensibility.* For accuracy,
  - —Comprehensive and nonoverlapping sets are needed for risks and opportunities, as well as for base cost, schedule, and disruption, and for potential risk management actions. However, this is typically difficult to achieve, especially for innovative project delivery methods where experience might be limited.
  - —Adequate assessments of the various base and risk factors (including changes in those factors associated with risk reduction actions) are needed. However, this typically is difficult to achieve, because the unique nature of individual projects creates general lack of definitive information on risks. Subjective assessments, which involve interpretations of all available information and are thus subject to various types of biases, are generally required.
  - —Adequate models of project performance are needed. However, this typically is difficult to achieve, especially to quantify the uncertainty in (and sensitivity of) those project performance measures, because of their complex nature. Too much approximation, or possibly even errors, which might not be recognized because of model complexity, can cause misleading results.

  Similarly, the above must not only be accurate enough, but must also be defensible enough, for the purpose. This in turn requires clear and reasonable, as well as adequately documented, logic and basis, especially regarding subjective assessments and models.

- *Efficiency.* A formal risk management process on a project can take significant effort, analogous to a VE study in both its initial conduct and subsequent implementation. It must be adequately planned, resourced, and facilitated to provide adequate accuracy and defensibility as efficiently as possible. However, if poorly planned, resourced, or facilitated, it might take a lot of unnecessary effort to achieve the required level of accuracy or defensibility. For example:
  - —Some resources or information might not be available when needed, so that the process is delayed while they are gathered, or some resources might not be needed during part of the process, but they have not been released;
  - —The model and assessments might be defined in too much detail ("lost in the weeds" and bogged down) or in not enough detail, necessitating a redo; and
  - —Assessments, models, or documentation might be incomplete (or even erroneous), necessitating a redo.

Additional work may be necessary in the future to reduce the above identified limitations of the risk management process described in this guide. In particular:

- Publication and distribution of this guide, accompanied by training at various levels of detail and pilot applications, will help explain why, what, when, and how such a formal risk management process should be conducted. This should help change the DOT culture and develop DOT commitment, as well as foster adequate accuracy and defensibility in an efficient manner.

- Detailed training of DOT facilitators and planners, including quality control and pilot applications, will help ensure adequate accuracy and defensibility, as well as efficiency, of the application of the process on particular projects.
- Analysis of the results of many applications of the process (case studies) will
  - —Demonstrate feasibility and value of the process, where value might simply be a qualitative evaluation by the project manager, to further DOT commitment;
  - —Even before projects are complete, enhance the checklist of risks and potential risk reduction actions, as well as the assessment of the risk factors and of risk reduction factors, improving accuracy and defensibility; and
  - —After projects are complete, help to validate the process, which in turn will result in better defensibility and furthering DOT commitment.
- Further development of the following elements of the risk management process will enhance accuracy and defensibility, as well as efficiency, which in turn will further DOT commitment:
  - —Databases regarding input assessments (from many applications);
  - —Improved and more accessible (less complicated) risk models, especially to evaluate more complicated projects or to conduct full uncertainty analysis; and
  - —Better documentation formats (especially of forms, and ultimately of the risk register and risk management plan).

It is anticipated that this additional work will eventually proceed, resulting in an improved risk management process and thus even better project performance. Hence, the following additional work is recommended:

- **The guide (and tools).** The benefit of the research will be in the form of improved project performance (regarding cost, schedule, disruption, and longevity) but only *if* the guide (and tools) is appropriately applied by DOTs to their projects. However, before organizing and then training a DOT to conduct risk management (which is discussed separately below), DOTs must first be convinced of the benefits of risk management. This can best be done by making DOTs aware of the process (i.e., wide exposure) and clearly demonstrating its value (e.g., through case studies). Hence, in addition to "marketing" (exposure is needed in multiple ways, that is, in the form of papers or brochures, presentations or webinars, and users' conference), case studies should be collected and evaluated, and new applications encouraged (e.g., through cost sharing or subsidies) and documented as case studies. To demonstrate the benefits of implementing the guide, specific metrics (e.g., total and average project cost savings) should be developed and reported. Also, the guide and tools should be "fixed" (as needed) and improved (as appropriate).

- **Training.** Training is needed to implement the guide. Such training needs to be at different levels (from developing full capability to only familiarity), depending on needs, and should to be available in different ways or formats (live versus recorded, on-site vs. remote, National Highway Institute (NHI) versus non-NHI format, lecture versus application), some of which (e.g., recorded, remote, NHI) would need development first. In addition to marketing (emphasizing cost-effectiveness of risk management), such training can be encouraged in various ways, for example, by cost sharing or subsidies and by offering continuing education units.

GLOSSARY

base (in risk context). Value exclusive of risk and opportunity (i.e., per specific set of assumptions).

bias (in risk context). Error in value (e.g., due to conservatism).

conditional value. Value if specific condition is true.

contingency. Value in addition to base intended to cover risks and other uncertainties (e.g., for project cost and for project schedule).

contingency management. Process of establishing appropriate contingency (e.g., to achieve specific level of confidence that budget and milestones will not be exceeded) and controlling its expenditure.

correlation (or correlated). Relationship between uncertain variables (e.g., tendency for one variable to be on the high end of its range if another variable is on the high end of its range).

critical path. The set of project activities that have zero float (i.e., a delay in an activity on critical path will delay project completion).

critical path analysis. Process of analyzing a project schedule to determine each activity's float and to identify the critical path.

deterministic analysis. Process of calculating a single value for each output, based on single values of each input.

disruption. A measure of project performance expressed in terms of the amount of hours lost by the public, which when combined with an average cost per hour produces user cost.

escalation. Process by which the costs of things change with time (including inflation).

escalation rate. Rate at which the cost of something changes with time, typically expressed in terms of percent cost increase per year (which might vary from year to year and for different items).

expected value. Mean value.

facilitator (in risk context). Specialist who guides the risk management process, for example, working with appropriate project staff and subject matter experts to structure the project, identify and assess project risks, and develop risk management plans, along with conducting the various analyses.

float (in schedule context). Amount of time an activity can be extended before it becomes critical path.

ignorance (in risk context). Lack of perfect information about the value of a particular factor, which leads to uncertainty.

impacts (in risk context). Changes in base performance values (e.g., in project cost) associated with occurrence of a particular risk; often described as an impact "scenario" (a particular set of project performance impacts, such as acceleration to a particular project activity).

independent (in risk context). No relationship between uncertain variables (i.e., not correlated).

longevity. A measure of project performance considering cost and disruption associated with operations and replacement, in combination with the time to replacement.

mean value. Measure of the middle of the range of an uncertain variable; probability-weighted average value.

mitigated (or mitigation, in risk context). After additional proactive risk reduction is attempted.

Monte Carlo simulation. Numerical method of approximately calculating probability distributions of outputs by sampling numerous sets of input values from their probability distributions, calculating the output values for each set of input values, and statistically analyzing the sets of output values.

NVP. Net present value.

opportunity. Potential event that, if it occurs, would affect project performance, often expressed in terms of an impact scenario and its probability of occurring; typically refers to potential events with desirable impacts.

percentile (in probability context). Value associated with a particular cumulative probability (e.g., the 90th percentile has a 90% chance of not being exceeded).

probability. Chance of occurrence, with possible values ranging from 0% (will not occur) to 100% (will occur).

probability distribution. Expression of relative likelihood of each possible value of an uncertain variable.

recovery (in risk context). Actions to reduce project cost and/or schedule (e.g., scope reductions), typically in reaction to exceeding available contingency.

residual risk. Remaining risk, typically after mitigation.

risk. Potential event that, if it occurs, would affect project performance, often expressed in terms of an impact scenario and its probability of occurring; typically refers to potential problems with undesirable impacts although can include opportunities as negative risks.

risk analysis. Process of calculating project performance including risks, and often the sensitivity of that performance to the various risks (i.e., to prioritize the risks for further assessment or for risk reduction).

risk assessment. Process of assessing the factors describing each identified risk (i.e., impacts and likelihood of occurrence).

risk identification. Process of identifying project risks (e.g., through brainstorming, checklists), typically with the objective of developing a comprehensive and non-overlapping set of risks, as documented in a risk register.

risk management. Process of controlling risks (and thereby project performance) through proactive risk reduction, contingency management and/or recovery, as documented in a risk management plan.

risk management plan (RMP). Documentation of the plans for conducting risk management, including organization; should be kept up-to-date.

risk reduction. Process of proactively taking actions intended to reduce the impacts and/or probability of specific risks.

risk register. Documentation of project risks, ideally composed of a comprehensive and nonoverlapping set of risks (typically categorized), including adequate descriptions of their impacts and likelihood; should be kept up-to-date.

severity (or risk severity). A measure of a risk's impact on project performance, combining mean values of cost, schedule, and disruption through construction, and postconstruction longevity.

standard deviation. Measure of the range of an uncertain variable; square root of the variance.

subjective assessment. Process of assessing a value based on judgment, in the absence of definitive data.

trade-off (or trade-off value). Equivalent amounts of different project performance measures, often expressed in terms of the amount a decision maker would be willing to pay to change each project performance measure by a unit amount (e.g., dollars per month of schedule).

uncertainty. Value of a particular variable is not known for certain and might have various values.

unconditional value. Value that does not depend on specific conditions being true.

unmitigated (in risk context). Before any additional proactive risk reduction is attempted.

variability. Different values of a particular factor (e.g., at different times or locations), which leads to uncertainty.

variance. Measure of the range of an uncertain variable (probability-weighted square of the differences relative to the mean value); square of the standard deviation.

VE. Value engineering.

YOE. Year of expenditure.

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INVENTORY OF RAPID RENEWAL STRATEGIES AND METHODS

INTRODUCTION

As noted in Chapter 3, rapid renewal addresses aging infrastructure through rapid design and construction methods that cause minimal disruption and produce long-lived facilities. To understand the risks (i.e., potential problems and potential opportunities) associated with rapid renewal, it was first necessary to develop an inventory of rapid renewal strategies and methods. This inventory informs the risk management process as to what aspects, and their associated risks, are unique to rapid renewal projects as opposed to those projects following the more traditional linear project development process and methods. However, the process of selecting a particular rapid renewal strategy or method (or selecting any other project element, for that matter) is outside the scope of this guide. Instead, the performance of particular alternatives can be evaluated, based on this guide, and used to help select the optimal one.

The inventory of rapid renewal strategies and methods is summarized in hierarchical form in Table A.1, and in more detail in the bulleted lists that follow. This inventory is based primarily on the following:

- A review of 25 case studies from the Federal Highway Administration (FHWA) Accelerated Construction Technology Transfer Program, which represents the state of the art in rapid renewal innovations. Each case study involved an intense 2-day workshop in which a multidisciplinary team of 20 to 30 national transportation experts with various skill sets worked with local agency professionals to identify and recommend rapid renewal strategies and methods for that project (which varied in size from $1 million to $3.4 billion).
- A survey of various state DOTs.
- Personal experience of the research team members.

However, some of these rapid renewal strategies and methods are not unique to rapid renewal (e.g., brand the project, consider an owner-controlled insurance program) while others are actually risk management (e.g., require pavement warranty). However, they have all been included for comprehensiveness.

The extensive inventory of rapid renewal strategies and methods summarized here in Table A.1 and in bulleted lists was "condensed" to a more generalized and more manageable set of rapid renewal strategies. This refined set served as a basis for identification and classification of categories of risks (Appendix B) that are relatively unique to rapid renewal projects, and their subsequent prioritization and management.

TABLE A.1. RAPID RENEWAL INVENTORY

Construction	Structures	Traffic Engineering/ Safety/ITS	Innovative Contracting/ Financing	Geotechnical Materials/ Advanced Testing
• Closures • Preliminary Work/ Staging • Project Administration Streamlining • Construction Operations	• Prefabrication • Component Reuse • High-Performance Materials • Integral Designs • Standardized Design • Construction Placement • Temporary Structures • Long-Life Structural Design	• Advance Planning • Alternate Routes • Alternate Modes • Improved Physical Separation • Coordinated Emergency Response • Signage and Signalization • Closures • Work Zones	• Alternative Financing • Project Delivery • Procurement • Contract Payment • Warranties • Alternative Insurance • Advance Contract Packaging • Bonding/ Performance Securities	• Subsurface Exploration • Walls • Pavements • Alternative Materials • Intelligent Compaction • Material Testing
Public Relations	**Environment**	**Roadway/Geometric Design**	**Right-of-Way/ Utilities/Railroad Coordination**	**Long-Life Pavements/ Maintenance**
• Team Integration • Single-Point Communication • Additional Investment • Project Branding • Stakeholder Awareness • Performance Measurement	• Master Planning • Context-Sensitive Solutions • Comprehensive Scoping • Advance Permitting	• Alternate Access • Alternate Geometrics • Advance Roadwork	• Advance Right-of-Way Planning • Early Utility Location • Common Utility Crossings • Early Railroad Coordination	• Life-Cycle Design • Performance Indicators • Long-Life Materials • Maintenance Involvement

Note: ITS = Intelligent Transportation Systems.

Construction

- Closures
  - —Use total or directional closures (closing one direction at a time) and use alternate routes.
  - —Include specified minimum closure times and appropriate incentives or disincentives.
  - —Consider partial closures if total closure is not feasible.
- Preliminary Work/Staging
  - —Perform any preliminary work ahead of mainline work (e.g., local roadway improvements, advance substructure work).
  - —Consider staging other work:
    - ▪ Overpass structures;
    - ▪ Drainage, grading, and fencing;
    - ▪ Retaining walls and sound walls; and
    - ▪ Substructure work.
- Project Administration Streamlining
  - —Consider DOT construction management (a single point of contact) for the whole corridor.
  - —Have higher approval authority/streamlined process for contract change orders.
  - —Use a dispute review board.
- Construction Operations
  - —Recycle existing materials such as concrete, asphalt, and base.
  - —Consider innovative construction materials (e.g., precast panels, high-early-strength concrete, thin white topping).
  - —Add temporary or permanent lighting for 24-hour construction.

Structures

- Prefabrication
  - —Use precast/prefabricated components (e.g., full-depth decks, partial-depth decks, decks with girders, substructures, and barriers).
- Component Reuse
  - —Reuse existing piers.
  - —Reuse existing substructures.

- High-Performance Materials
  - Use high-performance steel.
  - Use high-performance concrete (e.g., lightweight concrete, self-consolidating concrete).
- Integral Designs
  - Use integral abutments.
  - Use integral overlays.
- Standardize Design
  - Standardize design for repetitive elements.
- Construction Placement
  - Use horizontal skidding or longitudinal launching.
  - Consider using barges.
  - Use self-propelled modular transporters.
- Temporary Structures
  - Use temporary bridge structures.
- Long-Life Structural Designs
  - Aim for a 75- to 100-year design life.

Traffic Engineering/Safety/Intelligent Transportation Systems

- Advanced Planning
  - Conduct an origin–destination study.
  - Prepare traffic impact statement or concept of operations.
- Alternate Routes
  - Prepare for closures through use of alternate routes.
  - Provide for turn-lane improvements and ramp enhancements.
- Alternate Modes
  - Prepare for closures through the use of alternate modes of transportation (e.g., transit services, employer-based programs).
- Improve Physical Separation
  - Use barrier or buffer lane separation.
  - Implement enforcement/crash investigation sites.
  - Build emergency pullouts.
- Coordinate Emergency Response
  - Coordinate with local jurisdictions and emergency responders.
  - Have a stronger police presence.

  - —Have a predefined incident response plan and use an incident detection system.
  - —Use an on-call wrecker service or DOT highway helpers (HERO).
  - —Develop a worker safety plan and provide agency and contractor work zone training.
  - —Use highway advisory radio.
  - —Coordinate with 511.
- Signage and Signalization
  - —Provide real-time travel information.
  - —Use dynamic message signs, closed-circuit TV, and detectors to support lane operations.
  - —Provide better traffic signal coordination.
- Closures
  - —Use off-peak rolling road closures, weekend closures, directional closures.
  - —Provide contractor incentives and disincentives (e.g., lane rentals).
- Work Zones
  - —Monitor work zone safety.
  - —Use smart work zones.

Innovative Contracting/Financing

- Alternative Financing
  - —Use Grant Anticipation Revenue Vehicle (GARVEE) bonds.
  - —Charge for the use of right-of-way.
  - —Generate revenue through user fees on high-occupancy vehicle (HOV) or high-occupancy toll (HOT) lanes.
- Project Delivery
  - —Consider public–private partnerships (P3); for example, private equity or debt.
  - —Use design–build.
  - —Consider construction manager at risk.
- Procurement
  - —Use cost-plus-time (A-plus-B) bidding.
  - —Use cost-plus-time-plus-quality (A + B + Q, A + B + C).
  - —Shortlist qualified contractors; use qualifications-based selection process.
- Contract Payment
  - —Use incentives or disincentives for construction time.

  - Consider incentives and disincentives such as
    - Time-specific rewards;
    - Lane rentals;
    - Holidays;
    - A 5-day work week; and
    - Weather days.
  - Include quality assurance/quality control (QA/QC) specifications and quality-based incentives.
  - Provide no-excuse bonuses.
- Warranties
  - Require a pavement warranty.
  - Set up an advisory team or dispute review board to facilitate resolution of issues.
- Alternative Insurance
  - Consider an owner-controlled insurance program.
- Advance Contract Packaging
  - Consider advance contracts for items such as utilities, rights-of-way, ramps, or overpasses.
- Bonding/Performance Securities
  - Letter of credit;
  - Corporate or parent guarantee; and
  - Reduced bond (to owner exposure).

Geotechnical Materials and Accelerated Testing

- Subsurface Exploration
  - Consider subsurface exploration, seismic issues, and lab testing.
- Walls
  - Use mechanically stabilized earth walls (e.g., two-stage, modular block).
- Pavements
  - Rubblize existing pavement.
  - Recycle existing material.
- Alternative Materials
  - Stabilize subgrade with fly ash, lime, cement, or other available additives.
  - Consider flowable fill, foamed concrete, and geofoam.
  - Implement a geotechnical database.

- Intelligent Compaction
  - —Use intelligent compaction equipment.
- Material Testing
  - —Use contractor test results for acceptance (e.g., earthwork, base, surfacing).
  - —Change density testing from sand cones to nuclear gauge through streamlining calibration process.
  - —Use proof rolling and reduce frequency of testing.

Public Relations

- Team Integration
  - —Establish a project team with representation from all areas.
  - —Begin coordination during the planning process and include it in every stage forward.
  - —Collaborate with the media and traffic teams.
- Single-Point Communication
  - —Ensure that the communications office is the central point of contact and oversight for all communications efforts.
- Additional Investment
  - —Ensure that public outreach is a standing component in the construction budget (allocating 4% to 6% of the total project cost to public outreach is recommended).
  - —Dedicate a full-time communications specialist to the project.
- Project Branding
  - —Brand the project.
  - —Define campaign specifics.
- Stakeholder Awareness
  - —Identify project stakeholders.
  - —Identify the cultures and communities that will be affected.
  - —Target your message and develop a communications plan, making sure to include businesses, community, government, media, residents, the tourism industry, special interest groups, and the internal audience.
- Performance Measurement
  - —Do follow-up surveys to determine effectiveness of measures used and to adjust tactics as needed.

Environment

- Master Planning
  - Establish a project development process or master plan that integrates engineering, environmental analysis, agency coordination, and public involvement into a collaborative decision-making process.
- Context-Sensitive Solutions
  - Focus on context-sensitive solutions.
- Comprehensive Scoping
  - Conduct a comprehensive scoping process.
    - Define purpose and need.
    - Obtain agency and public input.
    - Establish performance measures that will support environmental streamlining and stewardship.
  - Review safety and accident data.
  - Document the project development process through comprehensive project files.
- Advance Permitting
  - Address stormwater management permitting issues during project development process.

Roadway/Geometric Design

- Alternate Access
  - Move or eliminate access.
  - Manage access.
  - Use alternate interchange configurations (e.g., diamonds, single points).
- Alternate Geometrics
  - Lower or raise profiles.
  - Use alternative weave patterns.
  - Perform early widening.
- Advance Roadwork
  - Use alternate configurations to allow for early construction access.

Right-of-Way/Utilities/Railroad Coordination

- Advance Right-of-Way Planning
  - Identify and acquire special properties.
  - Have a relocation plan in place early.
  - Advance right-of-way purchase.

- Early Utility Location
  - —Provide early identification and location of utilities.
  - —Avoid conflicts and relocations wherever possible.
  - —Conduct a consultant utility review as part of roadway design to ensure that there are no known utility conflicts.
  - —Have major utilities at the design table/planning phase.
- Common Utility Crossings
  - —Build common ducts/DOT-owned conduit crossings.
  - —Consider Level A subsurface utility engineering where appropriate.
- Early Railroad Coordination
  - —Coordinate regularly (daily, if needed) with the railroad.

Long-Life Pavements/Maintenance

- Life-Cycle Design
  - —Base design on best practices and life-cycle costs.
  - —Aim for minimal maintenance (no daytime lane closures for 50 years).
- Performance Indicators
  - —Use performance indicators as either initial construction standards or in a warranty contract for pavement rehabilitation.
- Long-Life Materials
  - —Consider the following pavement options:
    - ▪ Stone matrix asphalt;
    - ▪ Continuously reinforced concrete pavement;
    - ▪ Polymer asphalt;
    - ▪ Composite pavement; and
    - ▪ Subgrade treatments/stabilization.
- Maintenance Involvement
  - —Communicate with maintenance personnel during design and construction.

B

RAPID RENEWAL RISK CATEGORIES AND RISK MANAGEMENT ACTION CATEGORIES

Appendix B consists of three sections. They are

- Risk Checklist for Traditional Transportation Projects
- Summary Risk Checklist for Rapid Renewal Projects
- Rapid Renewal Risk Categories and Potential Risk Management Actions by Project Phase

RISK CHECKLIST FOR TRADITIONAL TRANSPORTATION PROJECTS

As shown, the items on this list do not form a formal risk register (i.e., this is not a comprehensive list of items for any particular project, and the listed items are not nonoverlapping by intention). The list is only intended to serve as a supplemental checklist to identify items missed during brainstorming. Identified items then need to be redefined and recast to ensure a comprehensive, nonoverlapping set of events in the risk register, adequately considering significant relationships (e.g., correlation, dependency) among items in the list, if any.

Some items shown are really base uncertainty (i.e., uncertainty within the base project or estimate assumptions), while the remainder are truly risk and opportunity events (i.e., uncertain conditions and events outside the base assumptions).

When identifying and quantifying risk, consider the issues of ownership/allocation (It’s a risk to whom? And who pays?), impacts of insurance in capping costs, influence of “below-the-line” markups, correlation between cost and time impacts, among others.

Uncertainty in "soft" costs and schedule

(Other than identified through other items, and excluding additional costs that result from project delays, which are accumulated directly and additionally through simulation.) Fundamental question: Is the base estimate for each in terms of a percentage of construction cost? Or a detailed line-item estimate?

- Design completion;
- Plans, specifications, and estimates completion;
- Administration costs (owner);
- Oversight costs (regulator);
- Construction management and construction inspection;
- Project management;
- Design support during construction/construction engineering;
- Mobilization;
- Sales tax;
- Financing, including interest costs;
- Insurance;
- Surety capacity and bonding;
- Annual inflation rates [construction, right-of-way, engineering, other];
- Stipends; and
- Extended overheads from project delays (if not captured separately).

Contracting, procurement, and project delivery

- Project delivery method [design–build, design–bid–build, public–private partnership (P3)], including uncertainty in ultimate method, and new or unique method to owner;
- Single versus multiple contracts (if not captured under market conditions);
- Construction market conditions (contractor pricing strategy or markup; cyclic market, and location within cycle at time of bid; number of viable bidders), including the potential for delay to the procurement process and/or rebidding;
- Significant increase in material, labor, or equipment costs (beyond what is included in inflation rates and market conditions);
- Delays procuring critical materials, labor, or specialized equipment;
- Bid protests;
- Claims related to clarity of bid and contract documents;
- Errors and omissions;
- Other issues related to unclear contract documents (identified either during procurement or later during construction);

- Other delays to contract procurement process (e.g., bonding and insurance issues);
- Owner approach to specifications (e.g., prescriptive versus performance based);
- Incomplete or vague specifications; and
- Contractor nonperformance (inefficiency if the impacts are not due to or captured by other risk items; default; bankruptcy).

Construction and constructability

See also "geotechnical and structural;" there is some overlap in these two lists.

- Additional pavement resurfacing;
- Additional geometry realignment;
- Uncertainty in construction unit costs (e.g., earthworks);
- Uncertainty in construction quantities (e.g., bridges, walls);
- Inadequate staging areas identified for construction;
- Dewatering issues during construction;
- Issues related to tunnel construction procedures (see also tunneling under Geotechnical and Structures);
- Issues related to other construction procedures;
- Uncertainty in planned construction sequencing, staging, phasing, and duration;
- Planned construction phasing does not work (need new plan);
- Maintenance of traffic or work-zone traffic control issues:
    - —Labor for assumed plan if plan is adequate.
    - —Proposed plan is not adequate.
    - —Issues related to detours.
- Difficult or multiple contractor interfaces;
- Uncertainty in structure demolition sequence and method;
- Force majeure during construction (acts of nature that affect construction, such as earthquakes, tornadoes);
- Safety issues (personnel, adjoining structures);
- Material reuse, removal, restoration;
- Condition of existing structures (repair required?);
- Accidents or incidents during construction (traffic, collapse, crane toppling, slope failure, vandalism);
- Critical equipment failure;
- Excessive scour or flooding;
- New or unproven systems, processes, or materials;
- Marine construction issues;

- Other difficult or specialized construction issues;
- Tie-ins with existing facilities, roadways, structures, or local access;
- Failure prior to replacement (e.g., bridges);
- Additional temporary erosion and sediment control costs;
- Railroad conflicts (anticipated or unanticipated);
- Utility conflicts (anticipated or unanticipated);
- Work-window restrictions (e.g., fish windows, weather shutdown windows); and
- Other third-party delays during construction.

Design

- Uncertainty in, or risk or opportunity related to, the base design elements (e.g., due to early design, project definition, or development), including type, size, and location and unit prices and quantities. Consider related (i.e., correlated or dependent) impacts to design, right-of-way, environmental documentation, permitting, utilities, and construction. Consider relationships to other issues in this list (conditionality/correlation). Example items include
  - —Horizontal alignment (e.g., geometry, grade);
  - —Vertical alignment (e.g., underground versus surface versus aerial);
  - —Bridges (superstructure and substructure);
  - —Retaining walls;
  - —Earthworks;
  - —Noise walls;
  - —Other structures;
  - —Stormwater collection and treatment;
  - —Paving;
  - —Right-of-way (e.g., full versus partial takes; uncertain parcels/quantities);
  - —Maintenance of traffic, traffic control;
  - — Transportation demand management , intelligent transportation systems ;
  - —Construction staging/phasing;
  - —Electrical (systems, signals, illumination); and
  - —Mechanical.
- Design errors and omissions or errors in plans, specs, or estimates (discovered during construction);
- Urban design and construction issues;
- Changes in design standards (e.g., increased seismic criteria for structures);
- Design deviations (e.g., design speeds, vertical clearances, turn radii);

- Access deviations (e.g., FHWA);
- Additional aesthetics, context-sensitive solutions;
- Allowances for miscellaneous items (known pay items not yet itemized in the estimate); and
- Floodplain issues.

Environmental

- Uncertainty in appropriate environmental documentation and all the related consequential events (e.g., change in design, right-of-way, scope, and construction costs);
- Challenge to environmental documentation (e.g., resulting in delay in record of decision;
- Delay in review and/or approval of environmental documentation;
- Supplemental environmental documentation or reevaluation required;
- Challenge to early-action mitigation plan (wetlands, floodplain, habitat);
- Additional habitat mitigation required on- or off-site (e.g., wetlands, fish ladders, meandering, connectivity);
- Uncertain wetland mitigation [e.g., uncertain impacts, uncertain type of mitigation (replacement, enhancement, banking); different replacement ratio than assumed];
- Difficulty identifying and acquiring suitable wetland mitigation site (including collecting required growing-season data);
- Biological assessment consultation issues or delay;
- New species listings (Endangered Species Act);
- Encounter unanticipated listed species during construction;
- Uncertain stormwater treatment standards or quantities;
- Uncertain stormwater discharge criteria (e.g., receiving body exemptions);
- Uncertain groundwater treatment standards or quantities;
- Encounter unanticipated contaminated or hazardous materials (and possibly extent of liability for remediation);
- Encounter unanticipated contaminated groundwater (and possibly extent of liability for remediation);
- Additional noise mitigation required;
- Additional view mitigation required;
- Unanticipated National Historic Preservation Act (NHPA) Section 106 issues (archaeological, cultural, or historical finds) encountered during design or construction;
- Known NHPA Section 106 issues different than anticipated;
- Unanticipated 4(f) issues;
- Known 4(f) issues different than anticipated; and

- Other regulatory issues (e.g., environmental impact statement, National Environmental Policy Act).

External influences and management

These include political, regulatory, municipalities, and economic.

- Difficulty obtaining other agency approvals or agreements (higher level, municipalities);
- Conflicts with other projects (municipalities, counties, state);
- Other predecessor projects not completed on time (delay current project);
- Coordination with other entities (e.g., railroads);
- Coordination between multiple contractors on this project;
- Force majeure during design (e.g., earthquake causes existing facility to fail, requiring accelerated design and construction of new facility);
- Public opposition;
- Political opposition;
- Funding shortfall (and related delay or increased financing cost);
- Funding delay;
- Legal challenges (other than environmental);
- Intergovernmental agreements and jurisdiction;
- Labor issues (contract negotiations, strike);
- Tribal issues (e.g., fishing rights, tribal employment rights office employment);
- Program management or executive oversight issues;
- Project management issues, workload management;
- Revenue issues (ridership, regulations or policies);
- Cash-flow constraints; and
- Other significant constraints, milestones, or promises to be met.

Geotechnical and structural

- Uncertainty in bridge or culvert design (including type, size, and location of foundations and superstructure);
- Difficult bridge construction (e.g., transportation or erection of large components; other specialty construction; groundwater, adverse ground conditions; obstructions; scour; other foundation problems);
- Uncertainty in retaining wall design (including type, length, height of foundations and superstructure);
- Difficult retaining wall construction (e.g., groundwater, adverse ground conditions; obstructions; other foundation problems);

- Slope stability issues—e.g., natural, manufactured (cuts, embankments);
- Liquefaction design issues;
- Uncertainty in seismic design criteria;
- Uncertainty in ground improvement design (e.g., what type, how much is required);
- Uncertainty in ground improvement performance (construction—need additional or different type of improvement);
- Damage to nearby structures during construction or as result of construction;
- Tunneling-specific issues:
  - —Uncertain or early design (including uncertainty in tunneling method, lining);
  - —Tunnel boring machine (TBM) problems [e.g., TBM operator issues or inexperience; machine procurement; machine assembly, disassembly, and recovery; machine maintenance; power-supply problems; drive rate or productivity (various causes, including obstructions or other poor ground conditions); drive misalignment; other problems];
  - —Liner problems (e.g., damaged liner segments; bad gasket or seal resulting in leakage);
  - —Problems with shaft or emergency exit construction;
  - —Problems with cross-passage excavation; and
  - —Other tunnel construction problems.
- Compatibility of new structures when placed adjacent to existing structures; and
- Other general geotechnical risk.

Operations and maintenance (O&M)

- Uncertain annual costs for typical maintenance;
- Additional resurfacing or redecking cycles required;
- Additional significant (unplanned) maintenance required; and
- Uncertain O&M period (e.g., for P3 concessions).

Permitting

- Difficulty obtaining permit approval (by permit type, e.g., 401, 404, National Pollutant Discharge Elimination System, U.S. Coast Guard, shoreline)—human resource issues, incomplete or inadequate permit applications, or simple disagreement by approving agencies;
- Uncertain permit requirements (current and in the future);
- Challenges to permits once issued (e.g., shoreline, 401, 404);
- Air quality permitting issues;
- Noncompliance with permits (environmental or construction);

Right-of-way/real estate

- Global right-of-way problems (e.g., for widening, drainage, pipelines, detention, staging);
- Additional right-of-way required (e.g., plans change; inaccurate early estimates);
- Difficult or additional condemnation (either globally or for particular parcels);
- Additional relocation required (either globally or for particular parcels—business versus residential);
- Additional demolition required, including unanticipated remediation, either globally or for particular parcels;
- Accelerating pace of development in project corridor;
- Changes in land use and/or demographics in project corridor;
- Workforce shortages;
- Process delays (e.g., right-of-way plan development by team, plan approval process);
- Planned right-of-way donations do not occur, or opportunity for additional donations;
- Difficulty obtaining rights-of-entry;
- Railroad right-of-way problems;
- Issues related to required easements (surface, subsurface); and
- Other right-of-way issues;

Scope issues

These are issues other than those identified through other items elsewhere in this list, such as design.

- Additional capacity required (e.g., lanes);
- Additional interchanges required (system-to-system or service);
- Additional local improvements required (e.g., additional paving or signals on local connections);
- Additional transit facility, park-and-ride, and so forth required;
- Other additional structures required (e.g., wildlife crossings);
- Scope reduction opportunity, value engineering;
- Replace structures instead of retrofitting (or vice versa);
- Tolling facilities;
- Managed lanes;
- Note on scope changes: scope changes can occur during design and/or construction, and can be due to
  - —Incomplete design;

  - —Stakeholder influences leading to additional scope (e.g., aesthetics, political pressure);
  - —Errors in design;
  - —Construction problems; and
  - —Regulatory changes.

Systems

- Software problems (technical, labor);
- Electrical system problems (technical, labor);
- Mechanical system problems (technical, labor);
- Problems with station finishes (technical, labor);
- Track installation problems (technical, labor); and
- Problems related to systems integration and testing.

Traffic and access issues

- Uncertainty in traffic management costs (intelligent transportation systems, transportation demand management);
- Access to site during construction; and
- Business or economic disruption mitigation.

Utilities issues

- Delay in completing utility agreements (e.g., due to disagreement over responsibility to move, disagreement over cost sharing, delay in reviews and approvals by utility);
- Late changes to design delays utility planning (e.g., have to redo utility design);
- Utility relocations to be completed by others (utility companies, municipalities) are not completed on time;
- Unexpected utilities encountered during construction;
- Damage to utilities during construction (known or unknown);
- Utility integration with project and/or utility betterments not as planned; and
- Cost sharing with utilities not as planned.

Vehicles

- Uncertainty in required number and/or type of vehicles;
- Uncertainty in contracted price for vehicles (may include uncertainty in number/type of vehicles);
- Delay in vehicle delivery; and

- Cost increase due to change orders (for various reasons, perhaps detailed separately; separate from uncertainty in contract price).

SUMMARY RISK CHECKLIST FOR RAPID RENEWAL PROJECTS

The lists below summarize categories or types of rapid renewal risks by project phase. The lists do not attempt to capture specific risks related to rapid renewal. Use these lists of risk categories as a quick check to make sure no major types of risks were missed during initial risk brainstorming.

Because the lists below only address categories of risks, they do not constitute a proper risk register. To develop a risk register, the DOT must identify a comprehensive, nonoverlapping set of individual (i.e., specific) risks and opportunities for the particular project being considered. More detail is provided in the Rapid Renewal Risk Categories and Potential Risk Management Actions by Project Phase section for each of the entries below.

Finally, the DOT should remember to consider risks and opportunities for all aspects of a project, not just for the rapid renewal elements covered specifically in this guide.

Planning

- Planning assumptions and projections are inaccurate.
- Resources are not available from all disciplines for advanced planning.
- Advanced planning for rapid renewal projects is not coordinated with transportation network.
- Uncompleted or infeasible rapid renewal projects erode public trust.
- Planning partners do not have resources to partner in advancing rapid renewal projects.

Project scoping (including project delivery and funding or financing)

- Project contains unrealistic scope considering budget and political landscape.
- Master planning/integrated development process is inefficient or poorly implemented.
- Owner is not capable of managing the delivery method.
- Delivery method is not appropriate for the project.
- Procurement protest occurs preaward.
- Dispute occurs postaward.
- Market cannot support selected delivery method, method restricts competition.
- Other cost and/or schedule premiums result from delivery method.
- Cost premiums result from innovative payment structure.
- Insufficient market interest in innovative payment processes exists to create competition.

- Poor market conditions make securing financing difficult.
- Enabling legislation is not in place to allow alternative financing.
- Changes in legislation before financial close (e.g., tolling, competing facilities) jeopardize alternative financing.
- Other delay in funding process occurs.
- Actual revenues are significantly less than anticipated (operations and maintenance).
- Surety market cannot support project's bond requirements.
- Bonding capability of contractors is not adequate.
- Lack of payment bond results in subcontractor protests or claims.
- Contractor defaults.

Environmental process and permits

- Additional documentation is required (but not a change in document type).
- Approval/signatory organizations cannot accommodate streamlined processing/approval.
- Challenge to environmental documentation occurs once determination has been issued.
- Challenge to permits once issued occurs.
- Delay in permit review or approval occurs.
- Development of permit application takes longer than anticipated.
- Different type of environmental documentation is required.
- Other delay to completion of environmental process related to attempted acceleration occurs.
- Review and approval process takes longer than anticipated for other reasons.
- Streamlined mitigation effort will not work (management issue).
- Streamlined mitigation effort will not work (technical issue).
- Unanticipated or additional permits are required.

General principles of design and construction

- Key design decisions are delayed.
- Other key project-related decisions are delayed or changed.
- Stakeholders are not able (or willing) to support accelerated design process.
- Unanticipated changes are encountered in design standards.
- Standardized designs are not available or suitable.
- Approval of design exceptions or denial of design exceptions is delayed.
- Staffing for accelerated design is not available.

- Owning agency is not staffed or structured for streamlined approvals.
- Stakeholders are unable or unwilling to accommodate streamlined approvals.
- Delays to other activities delay the design approval.
- Mistakes in the design delay the design approval.
- Constructability review is not allowed (policy).
- Constructability review is not successful.
- Constructability review is successful but leads to significant changes in design.

Design and construction (by discipline)

- Consider each of the following categories of rapid renewal risks and opportunities separately for each design discipline and/or major project component (e.g., structures, geotechnical and earthwork, drainage and stormwater management, roadway, pavement, and intelligent transportation systems).
  - —Innovative designs
    - ▪ Innovative and/or long-life designs are not the right solution for the project.
    - ▪ Innovative designs can work technically but require design exceptions or
    - ▪ have difficult permitting requirements.
  - —Alternative or long-life materials
    - ▪ Candidate alternative and/or long-life materials will not work (technical issues identified during design).
    - ▪ There is a delay in procuring candidate alternative and/or long-life materials.
  - —Rehabilitation
    - ▪ Rehabilitation is not the best option (identified during design).
    - ▪ There are problems with rehabilitation during construction.
  - —Prefabrication
    - ▪ Candidate prefabrication technique will not work (technical issues identified during design).
    - ▪ There is a delay in procuring prefabricated elements.
    - ▪ There are problems with prefabricated elements during construction.
  - —Rapid replacement technologies
    - ▪ Candidate rapid placement technique will not work (technical issues identified during design).
    - ▪ There is a delay in procuring rapid replacement equipment and/or specialized labor.
    - ▪ There are problems with rapid replacement technique during construction.

- Maintenance of traffic—full or directional closures
  - —Planned closures and related detour routes are not allowed (political or management issue).
  - —Planned closures and routes will not work (technical issue identified during design).
  - —Planned closures and routes will work but are not most efficient (better plan identified later during design).
  - —Implemented closure plan does not work (problem identified during construction).

Right-of-way, utilities, and railroad

- Right-of-way
  - —Late changes to the design cause delay in right-of-way planning.
  - —Right-of-way plans are not completed as planned, for other reasons.
  - —Funding for accelerated or advance right-of-way acquisition is delayed or reduced.
  - —There are problems procuring critical (high-priority) parcels, such as
    - ▪ Challenge to possession-and-use;
    - ▪ Condemnation required;
    - ▪ Difficulties relocating tenants;
    - ▪ Unanticipated contamination or utilities discovered; and
    - ▪ Additional demolition required.
  - —There is a delay to right-of-way certification (agency process delay).
- Utilities
  - —Late changes to the design cause delay in utility planning.
  - —Utility agreements are not reached as planned (from causes other than late design changes).
  - —There is an encountered and/or damaged utility during construction (if the owner's contractor performs the work).
  - —Third party does not complete relocation as planned (if third party performs the work).
- Railroad
  - —Late changes to the design cause delay in railroad planning.
  - —Railroad agreements are not reached as planned (from causes other than late design changes).
  - —Railroad facility damaged during construction (if owner's contractor performs the work).
  - —Railroad does not complete agreed railroad-related work as planned (if railroad performs the work).

Procurement and contracting strategy

- Litigation initiated by an interested party challenging the propriety of the alternative procurement process.
- Public concern (and political pressure) resulting from the use of alternative procurement processes that heavily weight nonprice factors.
- Public reaction to alternative procurements that trade off early accelerated completion with full road closures.
- Limited competition arising from projects perceived as being created for large contractors.
- Other problems procuring contract (e.g., bid protest, unclear documents, contractor default).
- Litigation initiated by an interested party challenging the propriety of the alternative contract packaging.
- Public concern (and political pressure) resulting from the use of alternative contract packaging.
- Expenditure of funds in advance of full procurement (for advance procurement).

Operations and maintenance (O&M)

- Required O&M effort is greater than planned (more frequent, more extensive, or both).
- O&M contractor does not perform per contract requirements.

Replacement

- Replacement required sooner than planned.
- Replacement facility does not perform as intended.

RAPID RENEWAL RISK CATEGORIES AND POTENTIAL RISK MANAGEMENT ACTIONS BY PROJECT PHASE

This section provides substantially more detail for each of the items identified in the Summary Risk Checklist for Rapid Renewal Projects section. For each project phase, the following is provided in a separate table:

- General rapid renewal strategies that might be employed during that project phase.
- For each rapid renewal strategy, the table lists categories, or types, of risks and opportunities that might result from following a particular rapid renewal strategy; the categories of risks and opportunities were identified as “risks to the owner” and to the owner’s rapid renewal objectives for the project (i.e., minimizing cost, minimizing schedule, minimizing disruption, and maximizing longevity).

- Potential risk management actions to address the various categories of risks and opportunities.

The tables in this section therefore contain more background and detail on each risk category, including the corresponding rapid renewal strategy and example risks and risk management actions. The authors encourage DOTs to review the more detailed documentation in this section to develop a better understanding for how each risk category was developed and what each category means.

The tables for each project phase include

- Table B.1. Planning
- Table B.2. Project Scoping
- Table B.3. Environmental Process and Permits
- Table B.4. General Principles of Design and Construction
- Tables B.5–B.10. Design and Construction (by Discipline)
    - —Table B.5. Structures
    - —Table B.6. Geotechnical and Earthworks
    - —Table B.7. Drainage and Stormwater Management
    - —Table B.8. Roadway, Geometrics, and Intelligent Transportation Systems
    - —Table B.9. Pavement
    - —Table B.10. Maintenance of Traffic
- Table B.11. Right-of-Way
- Table B.12. Utilities
- Table B.13. Railroad
- Table B.14. Procurement and Contracting Strategy
- Table B.15. Operations and Maintenance
- Table B.16. Replacement

Notes for all tables:

1. The risk categories are not intended to be specific risks, only general categories of potential issues that serve as prompts for identifying specific issues. Therefore, the listed categories cannot be taken together to form a proper risk register (i.e., they are not a comprehensive, nonoverlapping list of risks and opportunities).
2. The potential risk management actions are assumed to not already be part of the project plan. All actions should cost-effectively improve performance measures. The actions are not necessarily presented as one-to-one correspondence with risk categories because some actions might address more than one risk category.

TABLE B.1. PROJECT PHASE: PLANNING

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Conduct programmatic/portfolio planning Examples: • Long-range requirements, resources, and constraints • Short-range requirements, resources, and constraints	Inaccurate planning assumptions and projections Examples: • Inaccurate traffic projections • Inaccurate population growth projections • Intermodal transportation plans not coordinated or inaccurate	The following potential risk management actions could apply to a number of the risk categories in the column to the left. • Focus internal planning efforts on rapid renewal projects as a priority over traditional projects • Create awareness with planning partners (e.g., metropolitan planning organizations, municipalities) of rapid renewal projects • Secure public awareness or buy-in for rapid renewal project early in planning • Conduct early coordination and secure buy-in with local businesses that could be affected by closures and detours • Secure additional planning resources to monitor and update rapid renewal project approaches
Conduct early coordination—internal Examples: • Develop integrated team (technical disciplines, project development, finance, communications) • Prioritize planning studies on rapid renewal projects	Resources not available from all disciplines for advanced planning Examples: • Technical staff not available for research (e.g., right-of-way, utilities) • Technical staff not familiar with planning process (e.g., right-of-way, utilities) Advanced planning for rapid renewal projects not coordinated with transportation network Examples: • Funding opportunities for alternative transportation modes makes advanced planning obsolete • Advancement of rapid renewal project creates strain on traditional planning areas	

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TABLE B.1. PROJECT PHASE: PLANNING (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Conduct early coordination—external Examples: • Develop stakeholder awareness • Gather political support • Establish single-point communication • Brand the project • Conduct public outreach and seek additional investment	Uncompleted or infeasible rapid renewal project erodes public trust Examples: • Funding for rapid renewal project not available as "sold" to the public • Rapid renewal project identified in planning as infeasible because of environmental constraints • Public opposition from small stakeholder groups successful in stopping project • Opposition from industry groups (e.g., trucking and freight stakeholder groups) Planning partners do not have resources to partner in advancing rapid renewal projects Example: • Metropolitan planning organizations do not have staff to advance rapid renewal project and still meet other commitments	

TABLE B.2. PROJECT PHASE: PROJECT SCOPING

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Conduct early and comprehensive scoping Examples: • Obtain stakeholder input early • Develop and confirm purpose and need early • Develop and test viable alternatives early • Balance scope, budget, and political goals of the project	Project contains unrealistic scope considering budget and political landscape	The following potential risk management actions could apply to a number of the risk categories in the column to the left. • Conduct a thorough assessment of how much the agency is willing (or can afford) to spend on the project • Make an early decision on scope that is mandatory versus discretionary, with due consideration for financing options and political and stakeholder concerns • Determine plan for implementing what is determined to be discretionary scope • Consider multiple project phasing options early in the process so that the project can be staged
Employ master planning/integrated project development process Example: • Integrate engineering, environmental analysis, agency coordination, public involvement into collaborative decision-making process	Master planning/integrated development process is inefficient or poorly implemented	Examples • Conduct outreach within the agency to discuss how to best integrate functions • Ensure early retention of any consultants who will be assisting agency's personnel • Consider using outside partnering consultant to assist in coordination efforts

Note: Project scoping includes project delivery and funding or financing.

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TABLE B.2. PROJECT PHASE: PROJECT SCOPING (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Use innovative project delivery, including: • Design–build • Design–build–finance–operate–maintain • Contingency Management (CM) at-risk • Public–private partnership (private equity or debt) Examples: • Ensure authorizing legislation • Ensure agency has experienced staff • Develop project delivery selection methodology		The following potential risk management actions could apply to a number of the risk categories in the column to the left. • Secure enabling legislation early (applies to many) • Conduct outreach to the state attorney general (AG) and obtain AG opinions for statutory areas that are unclear or evolving • Conduct broad training programs on alternative project delivery with staff • Use FHWA resources for training and education • Secure general engineering consultants with experience in innovative project delivery methods • Conduct outreach to other DOTs that have a history of success in implementing alternative delivery programs
	Owner not capable of managing the delivery method (could lead to delay in contracting, change in delivery method, etc.) For example, caused by: • Untrained internal resources • Management systems not established • Resources not available as needed • Lack of timely dispute resolution (e.g., from unclear documents; lack of experience)	• Implement training programs for all personnel involved in project delivery decisions • Develop programmatic approach for alternative delivery methods with policy statements and general guidelines before the need for a specific project • Establish a specialized group within the agency to handle rapid renewal projects delivered through alternative project delivery methods • Use staff augmentation contracts to assist agency personnel in implementing the procurement and contracting of the project and assist in training • Develop comprehensive lessons learned from project experiences

(continued)

TABLE B.2. PROJECT PHASE: PROJECT SCOPING (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Delivery method not appropriate for the project (could lead to delay in contracting, change in delivery method, etc.) For example, caused by: • Method conflicts with owner goals • Project risk profile mismatched to delivery method • Stakeholders not aligned • Owner's goals changed • No enabling legislation	In addition to the above: • Develop comprehensive process for project delivery selection and establishing project goals, with broad participation from interested agency departments • Integrate project delivery selection with risk registering process • Consider bringing key stakeholders into the training process and project delivery selection process
	Procurement protest preaward (could lead to delay in contracting, change in delivery method, etc.) For example, caused by: • Insufficient history within owner organization with delivery method • Unfamiliarity of agency with evaluation of nonprice factors • Unclear evaluation factors • Inappropriate discussions with proposers • Challenges to the legality of the statute allowing the delivery system	In addition to some of the items above (including training and lessons-learned compilation): • Ensure that the team is supported by experienced individuals (internal or consultants) • Perform outreach to public to determine where the potential statutory challenges may lie • Develop a requirement in the procurement documents for any protests over the process (i.e., legality of the procurement) to be raised early rather than after any short-list evaluations • Develop a comprehensive process for how communications with proposers will be handled

(continued)

TABLE B.2. PROJECT PHASE: PROJECT SCOPING (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Dispute postaward (could lead to delays and price increases) For example, caused by: • Inadequate scope definition • Ambiguous specifications • Overly active involvement of the agency in contractor's means and methods	In addition to the above: • Consider having a third-party peer review of technical scoping documents to assess completeness, accuracy, and whether they are overly prescriptive • Consider having a period of time immediately after award for contractor to assess project scope and determine whether there are any material problems with the request for proposal (RFP) documents that could not have been determined during the proposal period • Develop an internal process and training for project personnel on how to review submittals
	Market cannot support selected delivery method and/or method restricts competition: For example, caused by: • Contractor's lack experience • Restrictions by agencies on ability of design professionals to participate on the contractor's team because of conflicts of interest	In addition to the above, particularly relative to legislative solutions and outreach: • Consider having a more liberal conflict-of-interest policy (per federal model) • Conduct regular meetings with contractor and consulting engineering associations to assess what is needed to obtain sufficient interest
	Other cost and/or schedule premiums resulting from delivery method (aside from issues listed separately) For example: • Contractor perception of high risk • Contractor concern over whether the project is "real" given scope appearing to exceed budget	In addition to the above: • Have contracts with reasonable risk allocation • Ensure that the proposers understand that agency is taking steps to be a "good owner" in managing the process

(continued)

TABLE B.2. PROJECT PHASE: PROJECT SCOPING (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Use innovative contract payment processes Examples: • Milestone construction-related payments • Availability of payments for public–private partnership projects • Incentives/disincentives • Warranty and operations and maintenance (O&M) payment		The following potential risk management actions could apply to a number of the risk categories in the column to the left. • Identify other agencies that have successfully used innovative payment terms • Investigate and implement best practices • Consult with marketplace to evaluate what has worked well and what has not • Establish that contract payment process correlates with behavior changes expected from contracting teams
	Cost premiums resulting from payment structure For example: • Contractor unfamiliarity leads to pricing premiums • Contractor concerns over unreasonable risk (not getting paid)	In addition to the above: • Use outreach process to assess market interest in the alternative approach, particularly for innovative warranty, O&M, or availability payments • Create balanced contracts that eliminate major uncertainty for contracting community • Determine financing costs (if any) to be incurred by the contractor in the innovative process • Assess the cost-to-benefit of using disincentives
	Insufficient market interest in innovative payment processes to create competition	In addition to the above: • Evaluate surety market to assess its concerns over the approach • Conduct regular meetings with contractor and consulting engineering associations to assess what is needed to obtain sufficient interest

(continued)

TABLE B.2. PROJECT PHASE: PROJECT SCOPING (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Seek alternative financing Examples: • Grant Anticipation Revenue Vehicle (GARVEE) bonds • Generate revenue through user fees (e.g., HOV/HOT lane tolling)		The following potential risk management actions could apply to a number of the risk categories in the column to the left. • Secure enabling legislation early (applies to many), e.g., related to open-road tolling (transponders versus toll booths) and/or tolling enforcement • Retain an outside financial advisor to be integrally involved in the development of the project and financial modeling • Develop realistic revenue projections • Develop realistic scope, cost, and schedule requirements • Develop financial terms early, including industry review • Repackage project (e.g., multiple, smaller projects) to improve market conditions • Obtain a detailed traffic and revenue study and financial model that can be used to assess the project and how the marketplace is likely to respond to the preferred financing approach • Assess the cost-to-benefit of using alternative financing, particularly in the event that financial close does not take place in a timely fashion

(continued)

TABLE B.2. PROJECT PHASE: PROJECT SCOPING (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Poor market conditions make securing financing difficult (reduced and/or delayed funding) Examples: • Difficult market • Market collapses • Proceeding on the assumption that there will be sufficient market interest to provide proposals on a revenue-negative project • Miscalculating the amount of agency funds needed to make the project viable to the financing community	See above
	Enabling legislation not in place to allow alternative financing	In addition to the above: • Work with AG's office and state financing department to assess likelihood of passing such legislation • Consider lessons learned from jurisdictions where this has been used • Make early "go/no-go" decision on project viability without alternative financing
	Changes in legislation before financial close (e.g., tolling, competing facilities) jeopardize alternative financing	• Ensure that RFP documents have mechanisms to address changes in law to provide assurances to financers that they are not evaluating a potential moving target • Ensure that there is a project contingency to fund changes in law • Conduct regular meetings with legislators to assess potential concerns and the likelihood of legislative changes

(continued)

TABLE B.2. PROJECT PHASE: PROJECT SCOPING (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Other delay in funding process Examples: • Approvals for grant funding or public loans (reduced and/or delayed funding) • Process complexity leads to delays • Revenue projections not strong enough to support or get required funding	See above
	Actual revenues significantly less than anticipated Examples: • Ability of concessionaire to live up to contract obligations • Bankruptcy of the concessionaire • For projects using availability payments, ability of agency to fund overruns • Impacts to O&M	In addition to the above: • Realistically determine whether the commercial deal is good for both sides • Use contracts that allow the agency to take over the project in the event of financially distressed concessionaire • Ensure that concessionaire has strong financial balance sheet • Develop a policy for how to establish and use reserves
Use alternative bonding or performance security Examples: • Letters of credit • Corporate guarantees		The following potential risk management actions could apply to a number of the risk categories in the column to the left. • Repackage the project (e.g., multiple, smaller projects with multiple contractors) to accommodate surety market or bonding capacity • Secure payment bond to protect subcontractors

(continued)

TABLE B.2. PROJECT PHASE: PROJECT SCOPING (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Surety market cannot support project's bond requirements Examples: • Contractual risks are too great • Duration of performance obligations are too long • Overall bond amounts are too great	In addition to the above: • Perform outreach to the surety market on the overall agency program as well as project-specific terms and conditions • For projects in excess of $250 million, consider reducing bonding amounts • Evaluate legislative changes needed to have flexibility in bonding terms (including amount) • Use contracts that have reasonable risk allocation • Consider using a combination of bonds, letters of credit, and guarantees on larger projects
	Bonding capability of contractor(s) not adequate Examples: • Project is considered too long in duration to tie up bonding capacity • Dollar value of project exceeds bonding limits	In addition to the above: • Perform outreach to the contracting community • Allow joint ventures • Consider using "staged" bonds, where warranty obligations are covered by a separate bond rather than the performance bond
	Lack of payment bond results in subcontractor protests or claims (subcontractors view that their payment rights are unprotected)	In addition to the above: • Require payment bonds to be issued, even if the dollar value is less than the full contract value • Create trust fund obligations through legislation
	Contractor defaults (various degrees of severity)	In addition to the above: • Ensure that the contract has appropriate takeover language in the event of a default • Ensure that the performance security is stable and available • Provide notice of a problem to the surety • Develop payment provisions that do not allow the contractor to "front-end load" and be too far ahead of owner

TABLE B.3. PROJECT PHASE: ENVIRONMENTAL PROCESS AND PERMITS

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Accelerate the environmental documentation process Examples: • Leverage master planning (see Project Scoping) • Conduct early coordination (see Planning) • Identify documentation requirements early • Identify and avoid major impacts early (historical, cultural, archaeological)	The individual risk categories (and their related examples, below) might apply to any or all the renewal category examples (shown to the left).	
	Different type of documentation required Example causes or issues: • Project's impacts are greater than originally assumed (because of design changes, originally underestimated impacts, etc.), so more substantial documentation is required (e.g., environmental impact statement instead of environmental assessment) • Additional discipline studies are required • Additional (new) alternatives must be developed and documented • Documentation requirements change	The following potential risk management actions could apply to a number of the risk categories in the column to the left. • Modify the project design to reduce the impacts that are triggering different type of documentation • Anticipate potential concerns with main alternatives, and develop additional alternatives early in the process to address those concerns • Anticipate/plan for and/or start additional (targeted) discipline studies earlier to reduce impact to project schedule if they are later required • Develop alternative (or additional/more detailed) documentation in parallel with presumed appropriate documentation to reduce impact to schedule if alternative documentation is later required
	Additional documentation required (but not a change in document type) Example causes or issues: • Project's impacts are greater than originally assumed (because of design changes, originally underestimated impacts, uncertain impacts from new rapid renewal methods, etc.) • Additional discipline studies are required (e.g., more extensive cultural survey) • Additional (new) alternatives must be developed and documented	Similar to above

(continued)

TABLE B.3. PROJECT PHASE: ENVIRONMENTAL PROCESS AND PERMITS (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Other delay to completion of environmental process related to attempted acceleration Example causes or issues: • Discipline studies take longer than planned in the accelerated schedule (e.g., gathering growing-season data) • Signatory agencies unable to accommodate accelerated process (e.g., consultation on biological assessment takes longer than planned, lack of staff to participate in accelerated process preapproval, indecisive agency) • Stakeholders resistant to accelerated process (e.g., feel uncomfortable or rushed by the accelerated process)	• Early on, identify a quick-response team to address problems with the accelerated environmental process (might include actions listed below) • Early on, develop a contingency plan to accelerate discipline studies. For example: — Establish on-call contracts with discipline specialists who might be needed later — Identify additional staffing — Develop solutions for issues obtaining rights-of-entry for field visits • If not already done, provide staffing support for signatory agencies (and plan for it early so it is ready to go when needed) • If not already done, increase public and stakeholder outreach related to the accelerated process to ease concerns about the process
Seek streamlined environmental approval process/approvals Examples: • Resolve appropriate environmental document type early • Seek streamlined biological assessment and consultation process • Provide staff to signatory agencies to expedite review	Approval/signatory organizations cannot accommodate streamlined processing/approval Example causes or issues: • Inadequate staffing or heavy workload • Incompatible process or procedures • Unresolved or unclear requirements • Unresolved disputes or agreements	• Early on, develop a contingency plan to mitigate problems with streamlined processing/approval. For example: — Identify a quick-response team to address problems with the process — If not already done, provide staffing support for signatory agencies (and plan for it early so it is ready to go when needed) — If not already done, establish a process to quickly resolve differences/disputes or clarify requirements • If not already done, increase public and stakeholder outreach related to the accelerated process to ease concerns about the process

(continued)

TABLE B.3. PROJECT PHASE: ENVIRONMENTAL PROCESS AND PERMITS (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Review and approval process takes longer than anticipated for other reasons Example causes or issues: • Receive larger number or more substantial comments (e.g., on draft document or to specific discipline reports) than anticipated	See above
	Challenge to environmental documentation once determination has been issued Example causes or issues: • Challenge to determination by stakeholder or other third party, whether viable or frivolous	• Identify potential future sources of challenges and monitor (or perhaps even engage them positively) • Early on, develop a contingency plan to respond to a challenge if it occurs. For example: — Potentially take actions as outlined earlier for environmental documentation and process (above) — Identify on-call legal resources — Identify potential bargaining position (e.g., mitigation, design change), including securing relevant policy decisions or positions from leadership

(continued)

TABLE B.3. PROJECT PHASE: ENVIRONMENTAL PROCESS AND PERMITS (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Pursue accelerated environmental permitting Examples: • Develop permit applications coincident with design • Learn requirements early • Form multiagency permitting teams (dispute resolution) • Provide staff to signatory agencies to expedite review	Development of permit application takes longer than anticipated Example causes or issues: • Project's impacts are greater than originally assumed (because of design changes, originally underestimated impacts, etc.) • Permit conditions are different than anticipated (especially resulting from uncertainty in rapid renewal element permitting) • Late changes to project design or environmental documentation	• Early on, develop a contingency plan to accelerate development of the permit application. For example: — Establish on-call contracts with discipline specialists who might be needed later — Identify additional staffing — Anticipate potential disputes over unclear requirements and work to avoid them • If not already done, provide staffing support for reviewing agencies (and plan for it early so it is ready to go when needed) • If not already done, increase public and stakeholder outreach related to the accelerated process to ease concerns about the process
	Delay in permit review or approval Example causes or issues: • Permitting agency uncomfortable with rapid renewal elements • Stakeholders withhold support • Agency unable to manage or is not staffed for accelerated permitting process	• Early on, develop a contingency plan to mitigate problems with streamlined permit processing/approval. For example: — Identify a quick-response team to address problems with the process — If not already done, provide staffing support for reviewing agencies (and plan for it early so it is ready to go when needed) — If not already done, establish a process to quickly resolve differences/disputes or clarify requirements

(continued)

TABLE B.3. PROJECT PHASE: ENVIRONMENTAL PROCESS AND PERMITS (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Unanticipated or additional permits required Example causes or issues: • Project's impacts are greater than originally assumed (because of design changes, originally underestimated impacts, etc.) • Permit conditions are different than anticipated (especially resulting from uncertainty in rapid renewal element permitting)	See above
	Challenge to permits once issued Example causes or issues: • Stakeholders or opposition groups attempt to hold up project	• Identify potential future sources of challenges and monitor (or perhaps even engage them positively) • Early on, develop a contingency plan to respond to a challenge if it occurs. For example: — Potentially take actions as outlined earlier for permit development (above) — Identify on-call legal resources — Identify potential bargaining position (e.g., mitigation, design change), including securing relevant policy decisions or positions from leadership

(continued)

TABLE B.3. PROJECT PHASE: ENVIRONMENTAL PROCESS AND PERMITS (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Streamline mitigation planning and implementation Examples: • Use wetland banks • Leverage/improve existing mitigation sites (on-site or off-site), potentially including partnering with other agencies • Proactively implement mitigation for noise or view	Streamlined mitigation effort will not work (management issue) Example causes or issues: • Stakeholder or governing agency does not approve plan (e.g., does not acknowledge or believe that the plan will work; mitigation not in same drainage basin as impacts) • Unforeseen regulatory constraint • Unable to acquire required mitigation site (or unacceptable delay)	• Early on, develop a contingency plan to respond to and overcome resistance to the proposed mitigation plan if it occurs. For example: — Anticipate potential concerns with the proposed mitigation plan and develop additional alternative mitigation concepts early in design to address those concerns — Identify potential bargaining position (e.g., different or more mitigation, design change), including securing relevant policy decisions or positions from leadership
	Streamlined mitigation effort will not work (technical issue) Example causes or issues: • Plan does not adequately mitigate impacts (e.g., need more or different mitigation) • Plan not feasible from a technical standpoint (e.g., cannot sustain over time) • Wetland bank fails and cannot supply project's mitigation	• Modify the design to reduce impacts • Anticipate potential technical issues with the proposed mitigation plan, and develop additional alternative mitigation concepts early in design to address those issues

TABLE B.4. PROJECT PHASE: GENERAL PRINCIPLES OF DESIGN AND CONSTRUCTION

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Accelerate the design process Examples: • Overlap design activities (make less sequential) • Involve stakeholders early • Learn requirements and constraints early • Resolve significant design decisions early • Equally develop and "carry" multiple alternatives until selection of preferred alternative • Ensure adequate staffing • Employ design exceptions as strategy • Use standardized designs for repetitive items	Key design decisions are delayed Example causes or issues: • Technical—the current design has a significant technical problem • Management—the current design does not have management support • Political—the current design does not have political support or meet existing political commitments Note: This type of delay could result from (and be included under) other risk categories listed in this document. Do not double-count impacts.	• Early on, develop a contingency plan to accelerate design in the face of decision delays. For example: — Establish on-call contracts with discipline specialists who might be needed later — Identify additional staffing — Develop alternative design concepts and/or carry parallel design documentation to reduce impacts
	Other key project-related decisions are delayed or changed Example causes or issues: • Funding delayed • Purpose and need, project definition, and/or scope significantly modified late in design, requiring redesign • Project delivery method changed (which affects design documentation) Note: This type of delay could result from (and be included under) other risk categories listed in this document. Do not double-count impacts.	Similar to above

(continued)

TABLE B.4. PROJECT PHASE: GENERAL PRINCIPLES OF DESIGN AND CONSTRUCTION (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Stakeholders not able (or willing) to support accelerated design process Example causes or issues: • Not able to make internal decisions or provide input on accelerated schedule • Do not support current alternative	• Early on, develop a contingency plan to respond to and overcome potential inability to support, or resistance to, the proposed design. For example: — Anticipate potential concerns with the proposed design, and develop additional alternatives or concepts early in design to address those concerns — Identify potential bargaining position (e.g., design change, mitigation), including securing relevant policy decisions or positions from leadership — Provide staffing support to stakeholders to educate stakeholders on and/or help them evaluate the design
	Encounter unanticipated changes in design standards Example causes or issues: • Seismic (geotechnical, structural) • Hydraulic/stormwater • Environmental Note: This could be covered separately under specific design disciplines	• Reduce the likelihood of being surprised, by conducting frequent searches for potential design changes and staying in contact with issuing agencies • Reduce the impacts if a change occurs by evaluating impacts from potential standards changes early; potentially carry or develop multiple design alternatives • Employ performance specifications to allow for contractor innovation
	Standardized designs not available or suitable Example causes or issues: • Not cost-effective or technically effective	• Modify design (or specs) to allow standardized designs (when feasible) • Develop standardized designs for repeatable elements (if possible)

(continued)

TABLE B.4. PROJECT PHASE: GENERAL PRINCIPLES OF DESIGN AND CONSTRUCTION (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Delay in approval of design exceptions, or denial of design exceptions Example causes or issues: • Requested exceptions create too many adverse impacts • Requested exceptions not acceptable for other reasons (e.g., stakeholder concerns)	• Early on, develop a contingency plan to accelerate approval of design exceptions. For example: — Document how proposed design achieves objectives despite (or perhaps because of) proposed exceptions — Develop process for rapidly resolving any issues with approval authority • Early on, develop a contingency plan to mitigate impacts of denial of exceptions. For example: — Develop alternative design concepts and/or carry parallel design documentation to reduce impacts
	Staffing for accelerated design not available Example causes or issues: • Staff redirected to higher priorities • Key technical staff not available at critical times	• Early on, develop a contingency plan to accelerate design in the face of staffing issues. For example (if not already done): — Establish on-call contracts with discipline specialists who might be needed later — Identify additional staffing • Employ performance specifications to allow for contractor innovation
Seek streamlined design approvals Examples: • Speed processing by providing staff support to approval authority • Coordinate early and often with approval authority	Owning agency not staffed or structured for streamlined approvals Example causes or issues: • Workload too great or right staff not available • Existing process does not accommodate accelerated approvals	• Early on, develop a contingency plan to mitigate problems with streamlined processing/approval. For example: — Identify a quick-response team to address problems with the process — Establish on-call contracts with discipline specialists who might be needed during approvals process — Identify additional internal staffing and have them available

(continued)

TABLE B.4. PROJECT PHASE: GENERAL PRINCIPLES OF DESIGN AND CONSTRUCTION (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Stakeholders unable or unwilling to accommodate streamlined approvals Example causes or issues: • Not able to review or make internal decisions/approvals on the streamlined schedule • Do not support submitted design	• Early on, develop a contingency plan to mitigate problems with streamlined processing/approval. For example: — Identify a quick-response team to address problems with the process — If not already done, provide staffing support for approving stakeholders (and plan for it early so it is ready to go when needed) — If not already done, establish a process to quickly resolve differences/disputes or clarify requirements
	Delays to other activities delay the design's approval Example causes or issues: • Delay to environmental process • Delay to permitting Note: This type of delay could result from (and be included under) other risk categories listed in this document. Do not double-count impacts.	• Conduct early and frequent coordination with other disciplines, and assess potential impacts to design from delays to those activities • Elevate issues for higher (and perhaps timelier) resolution
	Mistakes in the design delay the design's approval Example causes or issues: • Mistakes resulting from accelerated pace of the design process (e.g., incomplete or inadequate checks and reviews)	• Conduct concept and design reviews (internal or external) early on to identify potential problems • Conduct early and frequent coordination with other disciplines to avoid miscommunication, misunderstanding, etc. • Have accelerated design approval process in place (if not already in place) to mitigate delay

(continued)

TABLE B.4. PROJECT PHASE: GENERAL PRINCIPLES OF DESIGN AND CONSTRUCTION (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Hold industry constructability reviews early Examples: • Engage nonbidding contractors to review and "war game" construction phasing plan • Seek contractor opinion (nonconflicted) on potential new rapid renewal construction techniques • Seek contractor opinion (nonconflicted) on other ways to accelerate construction (e.g., overlap activities)	Constructability review not allowed (policy) Example causes or issues: • Concerns about conflicts of interest • Other existing policy prohibits engaging contracting industry for this purpose	• Seek change in policy early on to allow reviews when needed
	Constructability review not successful Example causes or issues: • Unable to engage qualified contractors with no conflicts of interest • Feedback is biased or otherwise unreliable or unhelpful	• Early on, ensure a viable pool of independent and available contractors (e.g., perhaps by using retired or out-of-town contractors)
	Constructability review successful, but leads to significant changes in design Example causes or issues: • Fatal flaw found, requiring redesign • Significant change in concept recommended and reviewed/accepted, leading to redesign	• Hold reviews early so that impact to design schedule is minimized • Be ready to make quick decisions on contractor recommendations (e.g., elevate and quickly resolve) • Develop and carry alternative designs and/or construction phasing/staging plans throughout the design process (one might reflect contractor recommendations)

TABLE B.5. PROJECT PHASE: DESIGN AND CONSTRUCTION—STRUCTURES

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Use innovative and/or long-life designs	Innovative and long-life designs not the right solution Example causes or issues: • Inadequate funding • Adequate funding but innovative and long-life designs are not the most cost-effective approach • Innovative designs too risky (e.g., no demonstrated performance history; uncertain constructability) • Interim (short-term) solution more appropriate (e.g., adjacent or follow-on project will build permanent solution)	• Develop additional alternatives or concepts early in design to reduce delay if innovative or long-life designs do not work out • Secure funding in advance for long-life designs • Gather performance information for innovative designs early (before selecting design) • Coordinate with adjacent projects early to better anticipate any interim solutions required from current project
Use alternative and/or long-life materials Examples: • High-performance steel • High-performance concrete • Lightweight aggregates • Fiber reinforcement	Candidate materials will not work (technical issues identified during design) Example causes or issues: • Cannot get materials permitted • Planned materials not the best choice for desired structure (e.g., strength, stiffness, durability, cost) • Planned materials too risky (e.g., no demonstrated performance history) • Other project conditions preclude the materials' application (e.g., too cold during construction)	• Test materials and materials designs early on pilot section or parallel project of smaller scale • Develop additional alternatives or concepts early in design to reduce delay if candidate materials do not work out • Gather performance information for candidate materials early (before selecting them for design) (i.e., evaluate feasibility early on)
	Delay in procuring candidate materials Example causes or issues: • Inadequate supply when needed (delay); for example, material supply source does not meet environmental requirements • Costs higher (other than because of limited supply) and/or benefits not as great as anticipated, so delay in decision to use the materials • Required expertise in using materials not available when needed	• Early on, identify material sources and evaluate potential availability (i.e., conduct feasibility study) • Have contractors guarantee supply in contract, or make provisions for schedule recovery or use of alternative, equivalent materials if material procurement is delayed

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TABLE B.5. PROJECT PHASE: DESIGN AND CONSTRUCTION—STRUCTURES (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Reuse or rehabilitate existing components Examples: • Rehabilitate columns and piers • Rehabilitate bridge decks • Supplement existing foundations	Rehabilitation not the best option (identified during design) Example causes or issues: • Replacement turns out to be more technically viable — Improved compatibility with new structures — Difficulty performing rehabilitation — Rehabilitation does not provide desired performance • Replacement turns out to be more cost-effective (e.g., because of limited amount of rehabilitation required)	• In parallel, develop design for replacement or new structure (to reduce delay if rehabilitation turns out to not be the best option) • Gather/confirm technical and cost performance information for existing structures early in design, to help make early decisions on approach and funding
	Problems with rehabilitation during construction Example causes or issues: • Discover that more or different rehabilitation is required (e.g., selected technique will not deliver required performance) • Discover that rehabilitation will not work (e.g., structure is in worse condition than previously believed)	• Either internally or through contractor, try to anticipate potential problems in advance, and then develop alternative designs and/or remedial measures to reduce delay if problems occur • Select contractor with demonstrated success in candidate rehabilitation methods • Ensure that contract provisions allow for rapid and fair resolution of these issues
Prefabricate key elements Examples: • Full-depth decks • Partial-depth decks • Decks with girders • Decks with barriers • Retaining-wall panels • Noise-wall panels	Candidate prefabrication technique will not work (technical issues identified during design) Example causes or issues: • Transportation of prefabricated elements difficult or not possible • Inadequate site access (e.g., cannot maneuver on-site) • Planned structure not suitable for construction via prefabricated elements • Other project conditions preclude use of prefabrication	• In parallel, develop design for alternative prefabrication or on-site fabrication (to reduce delay if prefabrication turns out to not be the best option) • Gather and confirm technical and cost performance information for prefabricating structures early in design, to help make early decisions on approach, procurement, and funding • Employ performance specifications to allow for contractor innovation

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TABLE B.5. PROJECT PHASE: DESIGN AND CONSTRUCTION—STRUCTURES (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Delay in procuring prefabricated elements Example causes or issues: • Fabrication facility not available when needed • Problems with design (e.g., errors) or constructability discovered during fabrication process • Costs higher and/or benefits not as great as anticipated, so decision to use prefabricated elements is delayed	• Early on, identify fabricators and evaluate potential availability of required items (i.e., conduct feasibility study) • Have contractors guarantee availability and schedule of prefabricated items in contract, or make provisions for schedule recovery if procurement is delayed
	Problems with prefabricated elements during construction Example causes or issues: • Specialized construction equipment malfunctions or breaks down • Difficulty maneuvering prefabricated elements • Damage to prefabricated elements during erection • Other construction-related accident	• Either internally or through contractor, try to anticipate potential problems in advance, and then develop alternative designs and/or remedial measures to reduce delay if problems occur • Select contractor with demonstrated success in candidate prefabricated construction • Ensure that contract provisions allow for rapid and fair resolution of these issues
Use rapid-placement/construction techniques Examples: • Longitudinal launching • Horizontal skidding • Self-propelled modular transporters (SPMTs) • Barges • Temporary structures	Candidate rapid-placement technique will not work (technical issues identified during design) Example causes or issues: • Inadequate access (e.g., cannot get SPMTs into position) • Cannot get technique permitted • Planned structure not suitable for construction via the technique • SPMTs will cross utilities that cannot be disrupted • Other project conditions preclude the technique's application	• In parallel, develop design for alternative rapid replacement or accelerated traditional technique (to reduce delay if chosen rapid replacement technique turns out to not be the best option) • Gather and confirm technical and cost performance information for the intended rapid replacement technique early in design, to help make early decisions on approach, procurement, and funding • Coordinate with affected utilities early in the process and provide partnering facilitator if needed • Employ performance specifications to allow for contractor innovation

(continued)

TABLE B.5. PROJECT PHASE: DESIGN AND CONSTRUCTION—STRUCTURES (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Delay in procuring rapid replacement equipment and/or specialized labor Example causes or issues: • Specialized equipment or labor not available when needed • Costs higher and/or benefits not as great as anticipated, so decision to use the technique is delayed	• Early on, identify sources of relevant equipment and labor, and evaluate potential availability (i.e., conduct feasibility study) • Have contractors guarantee availability and schedule of specialized equipment items in contract, or make provisions for schedule recovery (e.g., alternative equipment; alternative construction method) if procurement is delayed
	Problems with rapid replacement technique during construction Example causes or issues: • Specialized equipment malfunctions or breaks down • Technique does not work as intended (various reasons) • Construction accident	• Either internally or through contractor, try to anticipate potential problems in advance, and then develop alternative designs (using alternative construction techniques) and/or remedial measures (for selected technique) to reduce delay if problems occur • Select contractor with demonstrated success using the proposed rapid-placement technique • Ensure that contract provisions allow for rapid and fair resolution of these issues • Conduct thorough survey of existing conditions, including independent peer review • Develop contingency plans for the case that technique does not work as intended

TABLE B.6. PROJECT PHASE: DESIGN AND CONSTRUCTION—GEOTECHNICAL AND EARTHWORKS

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Use innovative and long-life designs	Innovative and long-life designs not the right solution Example causes or issues: • Inadequate funding • Adequate funding but innovative and long-life designs not the most cost-effective approach • Innovative designs too risky (e.g., no demonstrated performance history; uncertain constructability) • Interim (short-term) solution more appropriate (e.g., follow-on project will build permanent solution)	• Develop additional alternatives or concepts early in design to reduce delay if innovative or long-life designs do not work out • Secure funding in advance for long-life designs • Gather performance information for innovative designs early (before selecting design) • Coordinate with adjacent projects early to better anticipate any interim solutions required from current project
Use alternative and/or long-life materials Examples: • Flowable fill; foamed concrete; geofoam • Stabilize subgrade (e.g., with fly ash)	Candidate materials will not work (technical issues identified during design) Example causes or issues: • Cannot get materials permitted • Planned materials not the best choice for desired geotechnical structure (e.g., strength, hydraulic conductivity, compressibility, durability, cost) • Planned materials too risky (e.g., no demonstrated performance history) • Other project conditions preclude the materials' application (e.g., too cold during construction)	• Test materials and materials designs early on pilot section or parallel project of smaller scale • Develop additional alternatives or concepts early in design to reduce delay if candidate materials do not work out • Gather performance information for candidate materials early (before selecting them for design) (i.e., evaluate feasibility early on) • Employ performance specifications to allow for contractor innovation
	Delay in procuring candidate materials Example causes or issues: • Inadequate supply when needed (delay); for example, material supply source does not meet environmental requirements • Costs higher (other than because of limited supply) and/or benefits not as great as anticipated, so decision to use the materials is delayed • Required expertise in using materials not available when needed	• Early on, identify material sources and evaluate potential availability (i.e., conduct feasibility study) • Have contractors guarantee supply in contract, or make provisions for schedule recovery or use of alternative, equivalent materials if material procurement is delayed

(continued)

TABLE B.6. PROJECT PHASE: DESIGN AND CONSTRUCTION—GEOTECHNICAL AND EARTHWORKS (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Reuse or rehabilitate existing components Examples: • Supplement existing foundations (e.g., micropiles) • Stabilize existing foundations (e.g., with ground support)	Rehabilitation not the best option (identified during design) Example causes or issues: • Replacement turns out to be more technically viable — Improved compatibility with new structures — Difficulty performing rehabilitation — Rehabilitation does not provide desired performance • Replacement turns out to be more cost-effective (e.g., because of limited amount of rehabilitation required)	• In parallel, develop design for replacement or new structure (to reduce delay if rehabilitation turns out to not be the best option) • Gather and confirm technical and cost performance information for existing structures early in design, to help make early decisions on approach and funding
	Problems with rehabilitation during construction Example causes or issues: • Discover that more or different rehabilitation is required (e.g., selected technique will not deliver required performance) • Discover that rehabilitation will not work (e.g., foundation or structure is in worse condition than previously believed) • Construction accident	• Either internally or through contractor, try to anticipate potential problems in advance, and then develop alternative designs and/or remedial measures to reduce delay if problems occur • Select contractor with demonstrated success in candidate rehabilitation methods • Ensure contract provisions allow for rapid and fair resolution of these issues

(continued)

TABLE B.6. PROJECT PHASE: DESIGN AND CONSTRUCTION—GEOTECHNICAL AND EARTHWORKS (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Prefabricate key elements	Candidate prefabrication technique will not work (technical issues identified during design) Example causes or issues: • Transportation of prefabricated elements difficult or not possible • Inadequate site access (e.g., cannot maneuver on-site) • Planned geotechnical structure not suitable for construction via prefabricated elements • Other project conditions preclude the use of prefabrication	• In parallel, develop design for alternative prefabrication or on-site fabrication (to reduce delay if prefabrication turns out to not be the best option) • Gather and confirm technical and cost performance information for prefabricating geotechnical structures early in design, to help make early decisions on approach, procurement, and funding • Employ performance specifications to allow for contractor innovation
	Delay in procuring prefabricated elements Example causes or issues: • Fabrication facility not available when needed • Problems with design (e.g., errors) or constructability discovered during fabrication • Costs higher and/or benefits not as great as anticipated, decision to use the prefabricated elements is delayed	• Early on, identify fabricators and evaluate potential availability of required items (i.e., conduct feasibility study) • Have contractors guarantee availability and schedule of prefabricated items in contract, or make provisions for schedule recovery if procurement is delayed
	Problems with prefabricated elements during construction Example causes or issues: • Specialized construction equipment malfunctions or breaks down • Difficulty maneuvering prefabricated elements • Damage prefabricated elements during construction • Other construction-related accident	• Either internally or through contractor, try to anticipate potential problems in advance, and then develop alternative designs and/or remedial measures to reduce delay if problems occur • Select contractor with demonstrated success in candidate prefabricated construction • Ensure that contract provisions allow for rapid and fair resolution of these issues

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TABLE B.6. PROJECT PHASE: DESIGN AND CONSTRUCTION—GEOTECHNICAL AND EARTHWORKS (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Use rapid-placement/construction techniques Examples: • Top-down excavation support • Innovative ground improvement • Rapid-embankment consolidation/ construction • Intelligent compaction equipment	Candidate rapid-placement technique will not work (technical issues identified during design) Example causes or issues: • Inadequate access (e.g., cannot get specialized equipment into position) • Cannot get technique permitted • Planned geotechnical structure not suitable for construction via the technique • Other project conditions preclude the technique's application	• In parallel, develop design for alternative rapid replacement or accelerated traditional technique (to reduce delay if chosen rapid replacement technique turns out to not be the best option) • Gather and confirm technical and cost performance information for the intended rapid replacement technique early in design, to help make early decisions on approach, procurement, and funding
	Delay in procuring rapid replacement equipment and/or specialized labor Example causes or issues: • Specialized equipment or labor not available when needed • Costs higher and/or benefits not as great as anticipated, so decision to use the technique is delayed	• Early on, identify sources of relevant equipment and labor, and evaluate potential availability (i.e., conduct feasibility study) • Have contractors guarantee availability and schedule of specialized equipment items in contract, or make provisions for schedule recovery (e.g., alternative equipment, alternative construction method) if procurement is delayed
	Problems with rapid-placement technique during construction Example causes or issues: • Specialized equipment malfunctions or breaks down • Technique does not work as intended (various reasons) • Construction accident	• Either internally or through contractor, try to anticipate potential problems in advance, and then develop alternative designs (using alternative construction techniques) and/or remedial measures (for selected technique) to reduce delay if problems occur • Select contractor with demonstrated success using the proposed rapid-placement technique • Ensure contract provisions allow for rapid and fair resolution of these issues

TABLE B.7. PROJECT PHASE: DESIGN AND CONSTRUCTION—DRAINAGE AND STORMWATER MANAGEMENT

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Use innovative and long-life designs Example: • Seek sustainable/natural solutions for treatment	Innovative and/or long-life designs not the right solution Example causes or issues: • Innovative and long-life designs are not the most cost-effective or schedule-appropriate approach • Innovative designs too risky (e.g., no demonstrated performance history; uncertain constructability) • Interim (short-term) solution more appropriate (e.g., adjacent or follow-on project will build permanent solution)	• Work with interdisciplinary team to identify alternative locations and technologies to assist in drainage/stormwater management
Use alternative and/or long-life materials Examples: • Natural materials for conveyance, detention, and treatment structures/ponds • Use materials that allow for rapid installation and subsequent construction	Candidate materials will not work (technical issues identified during design) Example causes or issues: • Cannot get materials permitted • Planned materials will not work within project physical constraints • Planned materials too risky (e.g., no demonstrated performance history)	• Test materials and materials designs early on pilot section or parallel project of smaller scale • Concurrently create a design with traditional material as a contingency • Develop contingency plans to achieve rapid construction via more traditional means (e.g., phased placement, alternative shifts) • Gather performance information for candidate materials early (before selecting them for design) (i.e., evaluate feasibility early on) • Employ performance specifications to allow for contractor innovation
	Delay in procuring candidate materials Example causes or issues: • Inadequate supply when needed (delay); for example, material supply source does not meet environmental requirements • Costs higher (other than because of limited supply) and/or benefits not as great as anticipated, so decision to use the materials is delayed • Required expertise in using materials not available when needed	• Early on, identify material sources and evaluate potential availability (i.e., conduct feasibility study) • Have contractors guarantee supply in contract, or make provisions for schedule recovery or use of alternative, equivalent materials if material procurement is delayed

(continued)

TABLE B.7. PROJECT PHASE: DESIGN AND CONSTRUCTION—DRAINAGE AND STORMWATER MANAGEMENT (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Reuse or rehabilitate existing components Examples: • Culverts • Tie into existing drainage system (outfalls, treatment)		The following potential risk management actions could apply to a number of the risk categories in the column to the left: • Conduct early testing of existing components • Explore designs that involve modifications to existing components
	Rehabilitation not the best option (identified during design) Example causes or issues: • Replacement turns out to be more technically viable — Improved compatibility with new drainage facilities — Difficulty performing rehabilitation — Rehabilitation does not provide desired performance • Replacement turns out to be more cost-effective (e.g., because of limited amount of rehabilitation required)	• In parallel, develop design for replacement/new drainage facility (to reduce delay if rehabilitation turns out to not be the best option) • Gather and confirm technical and cost performance information for existing facility early in design, to help make early decisions on approach and funding
	Problems with rehabilitation during construction Example causes or issues: • Discover that more or different rehabilitation is required (e.g., selected technique will not deliver required performance) • Discover that rehabilitation will not work (e.g., existing drainage facility is in worse condition than previously believed) • Construction accident	• Either internally or through contractor, try to anticipate potential problems in advance, and then develop alternative designs and/or remedial measures to reduce delay if problems occur • Select contractor with demonstrated success in candidate rehabilitation methods • Ensure contract provisions allow for rapid and fair resolution of these issues

(continued)

TABLE B.7. PROJECT PHASE: DESIGN AND CONSTRUCTION—DRAINAGE AND STORMWATER MANAGEMENT (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Prefabricate key elements Examples: • Replacement culverts • Inlet and outlet structures	Candidate prefabrication technique will not work (technical issues identified during design) Example causes or issues: • Transportation of prefabricated elements difficult or not possible • Inadequate site access (e.g., cannot maneuver on-site) • Other project conditions preclude the use of prefabrication	• In parallel, develop design for alternative prefabrication or on-site fabrication (to reduce delay if prefabrication turns out to not be the best option)
	Delay in procuring prefabricated elements Example causes or issues: • Fabrication facility not available when needed • Problems with design (e.g., errors) or constructability discovered during fabrication process • Costs higher and/or benefits not as great as anticipated, so delay in decision to use the prefabricated elements	• Early on, identify fabricators and evaluate potential availability of required items (i.e., conduct feasibility study) • Have contractors guarantee availability and schedule of prefabricated items in contract, or make provisions for schedule recovery if procurement is delayed
	Problems with prefabricated elements during construction Example causes or issues: • Specialized construction equipment malfunctions or breaks down • Difficulty maneuvering prefabricated elements • Prefabricated elements damaged during construction • Other construction-related accident	• Either internally or through contractor, try to anticipate potential problems in advance, and then develop alternative designs and/or remedial measures to reduce delay if problems occur • Select contractor with demonstrated success in candidate prefabricated construction • Ensure that contract provisions allow for rapid and fair resolution of these issues

TABLE B.8. PROJECT PHASE: DESIGN AND CONSTRUCTION—ROADWAY, GEOMETRICS, AND INTELLIGENT TRANSPORTATION SYSTEMS

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Use innovative and long-life designs Examples: • Consider alternative alignment/geometrics • Provide alternative access	Innovative designs require exemptions from FHWA or other agency Examples: • Alternative alignment does not meet current design standards • Innovative intelligent transportation systems (ITS) design does not meet the approval of FHWA under current standards	The following potential risk management actions could apply to a number of the risk categories in the column to the left: • Conduct early and thorough investigation of existing alignment/geometrics to optimize reuse and minimize disruption during construction • Study use of alternative technical solutions for intelligent transportation systems (ITS) that may allow for reuse of existing infrastructure • Develop additional alternatives or concepts early in design to reduce delay if innovative or long-life designs do not work out • Secure funding in advance for long-life designs • Gather performance information for innovative designs early (before selecting design)
Use alternative and long-life equipment Example: • Ensure compatibility with existing system	Candidate equipment will not work (technical issues identified during design) Example causes or issues: • Planned equipment not compatible with equipment in adjacent locations • Planned materials too risky (e.g., no demonstrated performance history)	

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TABLE B.8. PROJECT PHASE: DESIGN AND CONSTRUCTION—ROADWAY, GEOMETRICS, AND INTELLIGENT TRANSPORTATION SYSTEMS (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Reuse or rehabilitate existing components Examples: • Fiber backbone • Communications equipment	Testing of existing components is not reliable Examples: • Existing components cannot be accessed for testing • Adequate testing methods not available • Testing samples do not reflect the condition of the entire component Existing component will not be compatible with new design or construction method Examples: • Impossible to integrate existing component with new design • Existing component will be damaged during construction	

TABLE B.9. PROJECT PHASE: DESIGN AND CONSTRUCTION—PAVEMENT

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Use innovative and long-life designs Examples: • Conduct life-cycle analysis (e.g., asphalt versus concrete) • Consider maintenance requirements • Establish performance indicators	Innovative and long-life designs not the right solution Example causes or issues: • Inadequate funding • Adequate funding but innovative and long-life designs not the most cost-effective approach • Innovative designs too risky (e.g., no demonstrated performance history; uncertain constructability) • Interim (short-term) solution more appropriate (e.g., follow-on project will build permanent solution)	• Develop additional alternatives or concepts early in design to reduce delay if innovative or long-life designs do not work out • Secure funding in advance for long-life designs • Gather performance information for innovative designs early (before selecting design) • Coordinate with adjacent projects early to better anticipate any interim solutions required from current project • Employ performance specifications to allow for contractor innovation
Use alternative and long-life materials Examples: • Stone matrix asphalt (SMA) • Continuously reinforced concrete pavement (CRCP) • Polymer asphalt • Composite pavement • Subgrade treatment/stabilization	Candidate materials will not work (technical issues identified during design) Example causes or issues: • Cannot get materials permitted • Planned materials not the best choice for desired pavement performance (e.g., durability, cost) • Planned materials too risky (e.g., no demonstrated performance history) • Other project conditions preclude the materials' application (e.g., too cold during construction)	• Test materials and materials designs early on pilot section or parallel project of smaller scale • Develop additional alternatives or concepts early in design to reduce delay if candidate materials do not work out • Gather performance information for candidate materials early (before selecting them for design) (i.e., evaluate feasibility early on) • Use performance specifications to allow for contractor innovation
	Delay in procuring candidate materials Example causes or issues: • Inadequate supply when needed (delay); for example, material supply source does not meet environmental requirements • Costs higher (other than because of limited supply) and/or benefits not as great as anticipated, so delay in decision to use the materials • Required expertise in using materials not available when needed	• Early on, identify material sources and evaluate potential availability (i.e., conduct feasibility study) • Have contractors guarantee supply in contract, or make provisions for schedule recovery or use of alternative, equivalent materials if material procurement is delayed

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TABLE B.9. PROJECT PHASE: DESIGN AND CONSTRUCTION—PAVEMENT (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Reuse or rehabilitate existing components Example: • Rubblize/recycle existing pavement	Rehabilitation not the best option (identified during design) Example causes or issues: • Replacement turns out to be more technically viable — Improved compatibility with new or adjacent pavement sections — Difficulty performing rehabilitation — Rehabilitation does not provide desired performance • Replacement turns out to be more cost-effective (e.g., because of limited amount of rehabilitation required)	• In parallel, develop design for replacement pavement alternative (to reduce delay if rehabilitation turns out to not be the best option) • Gather and confirm technical and cost performance information for existing pavement early in design, to help make early decisions on approach and funding
	Problems with rehabilitation during construction Example causes or issues: • Discover that more or different rehabilitation is required (e.g., selected technique will not deliver required performance) • Discover that rehabilitation will not work (e.g., pavement is in worse condition than previously believed) • Construction accident	• Either internally or through contractor, try to anticipate potential problems in advance, and then develop alternative designs and/or remedial measures to reduce delay if problems occur • Select contractor with demonstrated success in candidate rehabilitation methods • Ensure contract provisions allow for rapid and fair resolution of these issues

(continued)

TABLE B.9. PROJECT PHASE: DESIGN AND CONSTRUCTION—PAVEMENT (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Prefabricate key elements Example: • Roadway panels (concrete, prestressed)	Candidate prefabrication technique will not work (technical issues identified during design) Example causes or issues: • Transportation of prefabricated elements difficult or not possible • Inadequate site access (e.g., cannot maneuver on-site) • Planned pavement section not suitable for construction via prefabricated elements • Other project conditions preclude the use of prefabrication	• In parallel, develop design for alternative prefabrication or on-site fabrication (to reduce delay if prefabrication turns out to not be the best option) • Gather and confirm technical and cost performance information for prefabricating pavement sections or panels early in design, to help make early decisions on approach, procurement, and funding
	Delay in procuring prefabricated elements Example causes or issues: • Fabrication facility not available when needed • Problems with design (e.g., errors) or constructability discovered during fabrication • Costs higher and/or benefits not as great as anticipated, so decision to use prefabricated elements is delayed	• Early on, identify fabricators and evaluate potential availability of required items (i.e., conduct feasibility study) • Have contractors guarantee availability and schedule of prefabricated items in contract, or make provisions for schedule recovery if procurement is delayed

TABLE B.10. PROJECT PHASE: DESIGN AND CONSTRUCTION—MAINTENANCE OF TRAFFIC

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
		The following potential risk management actions could apply to a number of the risk categories in the column to the left: • Use performance-based specs • Use contractor incentives at key coordination points within contract and between contracts in a phased situation • Reduce traffic demand during closures. Examples: — Provide alternative modes — Provide additional alternate routes • Conduct early coordination with agencies and other stakeholders. Examples: — Presentation of case studies — Additional outreach — Early preparation of business case for closure • Seek early contractor involvement and/or constructability reviews • Conduct detailed (or earlier) traffic and/or safety analysis • Develop multiple alternatives early, including alternative staging or closures • Develop contingency plan for implemented closures

(continued)

TABLE B.10. PROJECT PHASE: DESIGN AND CONSTRUCTION—MAINTENANCE OF TRAFFIC (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Use innovative maintenance-of-traffic (MOT) strategies Examples: • Provide alternative modes • Provide alternative routes • Use creative closure strategies (incentive/disincentive; directional closures; total versus partial closures) • Develop and "carry" alternative MOT plans	Planned closures and related detour routes not allowed (management issue) Example causes or issues: • Local agency will not approve (various reasons) • Owning agency will not approve (various reasons) • Not viable or allowed by project delivery or contracting approach • Contractor will not reasonably bid the approach Planned closures and related detour routes will not work (technical issue identified during design) Example causes or issues: • Unacceptable traffic capacity • Unacceptable safety impacts (to public or workers) • Unacceptable noise, dust, vibration, or other impacts to adjacent public Planned closures and related routes are not the most efficient Example causes or issues: • Another plan identified later which could work better (e.g., different or more closures; alternate routes instead of closures) Implemented closure plan does not work (during construction) Example causes or issues: • Causes unacceptable traffic impacts • Creates unacceptable ancillary impacts (e.g., adjacent businesses)	

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TABLE B.10. PROJECT PHASE: DESIGN AND CONSTRUCTION—MAINTENANCE OF TRAFFIC (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Test the MOT plan before construction Examples: • Simulate plan performance (e.g., using traffic models) • “War game” the MOT plan with constructors (e.g., on a tabletop project graphic, stepping through the construction staging/sequencing)	Similar to above	

TABLE B.11. PROJECT PHASE: RIGHT-OF-WAY

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Accelerate right-of-way (ROW) planning Examples: • Overlap ROW planning with project design and environmental activities • Coordinate early and often with design team • Carry multiple alternatives • Provide additional staff to support planning and appraisals • Approach sellers early with plans • Seek accelerated ROW funding • Seek streamlined ROW plan approval process	Late changes to the design cause delay in ROW planning Example causes or issues: • Change in design late in process cascades to ROW design changes (especially if ROW planning and design are overlapped), resulting in delay in agreements and/or ROW plan review/approval	• Early on, develop a contingency plan to accelerate ROW planning after late design changes. For example: — Develop and carry multiple design alternatives, and have corresponding ROW plans partially developed, to reduce impact if design changes — Coordinate early and often with design team — Early on, establish on-call contracts with real estate appraisal specialists who might be needed later
	ROW plans not completed as planned (other than from design changes) Example causes or issues: • Delay in review and/or approval of plans. For example: — Design/planning schedule too aggressive — Inadequate staffing — Agency waiting for project funding or contractor notice to proceed (NTP) • Accelerating pace of development in project area triggers plan revision	• Early on, develop a contingency plan to mitigate problems reaching utility agreements. For example: — Identify a quick-response team to address problems with the process — If not already done, establish a process to quickly resolve problems with the plans or clarify requirements

(continued)

TABLE B.11. PROJECT PHASE: RIGHT-OF-WAY (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Accelerate ROW acquisition Examples: • Seek accelerated ROW funding • Conduct advance ROW acquisition; prioritize parcels for acquisition (get what is needed to start construction first) • Ensure adequate staffing • Seek willing sellers (e.g., better offers) • Provide relocation assistance to displaced tenants • Conduct accelerated environmental remediation/clearance of select parcels	Funding for accelerated or advance ROW acquisition delayed or reduced	Coordinate early and often with program management to ensure funding is approved and available when needed
	Problems procuring critical (high-priority) parcels Example causes or issues: • Challenge to possession and use, condemnation, or other seller action that delays DOT ability to occupy parcels and/or increases ROW cost • Delays relocating tenants off-site, such as — Relocation effort larger than anticipated — No suitable replacement property or facility found — Legal challenge to relocation plan • Unanticipated contamination discovered, requiring remediation before site can be used • Delays demolishing structures on-site (other than from contamination issues) • Unanticipated utilities encountered on-site, requiring relocation before can use site • Other delays obtaining rights-of-entry • Staffing shortage (cannot complete acquisition offers as planned)	• Early on, develop a contingency plan to mitigate problems with procurement of high-priority parcels. For example: — Identify a quick-response team to address problems with the procurement process (e.g., see example causes at left) — Establish on-call contracts with ROW specialists, relocation specialists, environmental remediation contractors, and/or demolition contractors who might be needed during acquisition process (assumes accelerated acquisition is done in advance of main construction contract) — Identify additional internal staffing and have on hand
	Delays to ROW certification (agency process delay)	• Coordinate early and often with certifying authority to ensure process and requirements are understood • Identify additional internal staffing and have on hand

TABLE B.12. PROJECT PHASE: UTILITIES

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Accelerate utility planning and agreements Examples: • Overlap utility planning with project design and environmental activities • Coordinate early and often with design team and utility companies • Carry multiple alternatives • Provide staff to support the utility's review/approval process • Develop common/shared utility crossings • Seek accelerated utility-plan approval process	Late changes to the design cause delay in utility planning Example causes or issues: • Change in design late in process cascades to utility design changes (especially if utility planning and design are overlapped), resulting in delay in agreements and/or design review/approval	• Early on, develop a contingency plan to accelerate utility planning after late design changes. For example: — Develop and carry multiple alternatives early in design, to reduce impact if design changes — Coordinate early and often with utility companies — Early on, establish on-call contracts with utility specialists who might be needed later • If not already done, provide staffing support for utility companies (and plan for it early so it is ready to go when needed)
	Utility agreements not reached as planned (other than from design changes) Example causes or issues: • Delay in review and/or approval of agreements, by either owner or utility. For example: — Design/planning schedule too aggressive — Inadequate staffing — Utility waiting for project funding or contractor NTP • Disagreement over the proposed terms of the agreement. For example: — Cost sharing — Scope of the utility relocation — Work windows or closures — Responsibility for work — Questions related to the need for or legality of the planned relocation	• Early on, develop a contingency plan to mitigate problems reaching utility agreements. For example: — Identify a quick-response team to address problems with the process — If not already done, provide staffing support for utilities (and plan for it early so it is ready to go when needed) — If not already done, establish a process to quickly resolve differences/disputes or clarify requirements — Identify potential bargaining position (e.g., mitigation, design change), including securing relevant policy decisions or positions from leadership

(continued)

TABLE B.12. PROJECT PHASE: UTILITIES (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Accelerate utility relocation Examples: • Provide incentive for utility to relocate on time • Cost sharing • Relocate critical utilities first (so construction can be started)	Utility encountered and/or damaged during construction (if owner's contractor performs the work) Example causes or issues: • Previously unknown utility encountered, perhaps because of accelerated relocation schedule (e.g., utility location effort was inadequate; potholing not conducted so schedule could be accelerated) • Existing utility damaged even though known it was there	• Either internally or through contractor, try to anticipate potential problems in advance and then develop potential remedial measures to reduce delay if problems occur • If not already done, have contractor confirm utility locations • Ensure contract provisions allow for rapid and fair resolution of these issues
	Third party does not complete agreed relocation as planned (if third party performs the work) Example causes or issues: • Third party (e.g., utility company or municipality) too busy with other work (i.e., does not prioritize this relocation effort) • Other delay to third-party design, review/approval, or subcontracting effort • Funding delay • Third party simply "drags its feet" for other reasons	• Early on, develop a contingency plan to mitigate delays in third-party utility relocations. For example: — Identify a quick-response team to address problems — If not already done, provide staffing support for utilities (and plan for it early so it is ready to go when needed) — If not already done, establish a process to quickly resolve differences/disputes or clarify requirements — Identify potential bargaining position (e.g., mitigation, design change, additional funding), including securing relevant policy decisions or positions from leadership

TABLE B.13. PROJECT PHASE: RAILROAD

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Accelerate railroad planning and agreements Examples: • Overlap railroad planning with project design and environmental activities • Coordinate early and often with design team and railroad representative • Carry multiple alternatives • Provide staff to support the railroad's review/approval process • Propose mitigation to speed agreements	Late changes to the design cause delay in railroad planning Example causes or issues: • Change in design late in process cascades to railroad-related design changes (especially if railroad planning and design are overlapped), resulting in delay in agreements and/or design review/approval	• Early on, develop a contingency plan to accelerate railroad planning after late design changes. For example: — Develop and carry multiple alternatives early in design, to reduce impact if design changes — Coordinate early and often with railroad companies — Early on, establish on-call contracts with railroad specialists who might be needed later — If not already done, provide staffing support for railroad companies (plan for it early so it is ready to go when needed)
	Railroad agreements not reached as planned (other than from design changes) Example causes or issues: • Delay in review and/or approval of agreements by either owner or railroad; for example: — Design/planning schedule too aggressive — Inadequate staffing — Railroad company waiting for project funding or contractor NTP • Disagreement over the proposed terms of the agreement. For example: — Cost sharing — Scope of the work to be done on, over, under, or adjacent to railroad property or at crossings — Work windows or closures — Responsibility for work — Questions related to the need for or legality of the planned work	• Early on, develop a contingency plan to mitigate problems reaching railroad agreements. For example: — Identify a quick-response team to address problems with the process — If not already done, provide staffing support for railroads (and plan for it early so it is ready to go when needed) — If not already done, establish a process to quickly resolve differences/disputes or clarify requirements — Identify potential bargaining position (e.g., mitigation, design change), including securing relevant policy decisions or positions from leadership

(continued)

TABLE B.13. PROJECT PHASE: RAILROAD (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Accelerate railroad-related construction Examples: • Provide incentive for railroad to provide longer or more frequent work windows • Cost sharing • Complete critical railroad-related construction first (so general construction can be started)	Railroad facility damaged during construction (if owner's contractor performs the work) Example causes or issues: • Track fouled or blocked (i.e., railroad cannot operate during necessary windows) • Railroad crossing structure (bridge) damaged • Other railroad infrastructure (e.g., signals, switches, crossings) damaged	• Either internally or through contractor, try to anticipate potential problems in advance, and then develop potential remedial measures to solve the problems • If not already done, have contractor confirm locations of key rail infrastructure • Ensure contractor has a plan that safeguards railroad infrastructure • Ensure contract provisions allow for rapid and fair resolution of these issues
	Railroad does not complete agreed railroad-related work as planned (if railroad performs the work) Example causes or issues: • Railroad too busy with other work (i.e., does not prioritize this effort) • Other delay to railroad-driven design, review/approval, or subcontracting effort • Funding delay • Railroad simply "drags its feet" for other reasons	• Early on, develop a contingency plan to mitigate delays in railroad-conducted work. For example: — Identify a quick-response team to address problems — If not already done, provide staffing support for railroads (and plan for it early so it is ready to go when needed) — If not already done, establish a process to quickly resolve differences/disputes or clarify requirements — Identify potential bargaining position (e.g., mitigation, design change, additional funding), including securing relevant policy decisions or positions from leadership

TABLE B.14. PROJECT PHASE: PROCUREMENT AND CONTRACTING STRATEGY

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Use alternative procurement method Examples: • Cost-plus-time (A + B) bidding • Cost-plus-time-plus-quality (A + B + Q) bidding • Short-list qualified contractors and then use qualifications-based selection process • Unsolicited proposals, followed by sole-source negotiations		Many of the same risks and risk management actions that were identified in Table B.2, Project Scoping, relative to innovative project delivery methods, are applicable to this category. Specific attention is brought to the following actions, each of which applies to the risks discussed to the left. Examples: • Develop a procurement plan that meets the goals of the overall project and stakeholders, and in particular focus on what the goals are in using an alternative procurement and contracting approach • Ensure that the team is supported by experienced individuals (internal or consultants) • Ensure early retention of any consultants who will be assisting agency personnel • Secure enabling legislation early to allow alternative procurement approaches to work • Conduct outreach to the AG and obtain AG opinions for statutory areas that are unclear or evolving • Conduct broad training programs on procurement and contracting innovations with staff • Conduct outreach to other DOTs that have a history of success in implementing alternative procurement and contracting programs • Consider bringing key stakeholders into the training process for implementation of procurement approach • Perform outreach to public to determine where the potential statutory challenges may lie

(continued)

TABLE B.14. PROJECT PHASE: PROCUREMENT AND CONTRACTING STRATEGY (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Litigation initiated by an interested party challenging the propriety of the alternative procurement process Example causes or issues: • Challenges to the ability of a state to select construction projects on something other than full, open competitive bidding • Challenges as to the reasonableness of the selection factors	In addition to the above: • Create a team that develops a formal procurement and contracting plan that is reasonable, logical, and objective • Perform outreach to legislators who are concerned about alternative procurement practices • Ensure that the AG's office is cognizant of potential issues and prepared to act quickly to address any challenges
	Public concern (and political pressure) resulting from the use of procurement processes that heavily weight nonprice factors Example causes or issues: • Perceived conflict of interest when a designer–builder is first selected to perform preliminary engineering and then has sole-source negotiation rights for final design and construction • Perception that contracts awarded on qualifications basis are "sweetheart" contracts and the result of cronyism	In addition to the above: • Perform outreach to the public to make the procurement process transparent and to explain the rationale and public benefit behind the procurement choice • Use independent outside consultants to evaluate pricing of the contracting teams • Use escrowed bid documents to obtain access to the documents • Use open-book negotiation process • Require contractor (designer–builder) to certify the currency, completeness, and accuracy of its open-book submissions • Consider, when applicable, the use of construction-management-at-risk contracting principles, where the bulk of the work is competitively subcontracted to third parties, and with prime contractor being responsible for managing such work and interfaces
	Public reaction to procurements that trade off early accelerated completion with full road closures	In addition to the above: • Develop a comprehensive outreach program to explain the benefits of this system • Determine and widely disseminate maintenance-of-traffic (MOT) plans that minimize disruption

(continued)

TABLE B.14. PROJECT PHASE: PROCUREMENT AND CONTRACTING STRATEGY (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
	Limited competition arising from projects perceived as being created for large contractors	In addition to the above: • Assess whether the project can be broken down into alternative contract packaging (see below) • Require proposers to submit a subcontracting plan that demonstrates how it will use small businesses and have this as a significant selection factor
	Other problems procuring contract Example causes or issues: • Bid protest • Unclear contract documents or language resulting in claims, whether credible or not, which could be a problem during contract procurement, during construction, or both • Contractor default (most likely during construction)	In addition to the above: • Prequalify contractors • Short-list a minimum of three contractors • Ask contractors' association to provide feedback on draft contract documents (e.g., a request for proposal, or RFP) • Set reasonable minimum bonding requirements
Use alternative contract packaging Examples: • Larger number of smaller contracts • Allowances for work that is not sufficiently designed at the time of bid or is to be undertaken far in the future and that will be performed by smaller contractors	See above	In addition to the above: • Conduct a thorough evaluation as to the goals and detriments of alternative contract packaging • Develop an outreach program for the smaller contractors and disadvantaged business enterprises • Consider lessons learned from other agencies that have used allowance type of contracting arrangements
Use advance procurement Examples: • Early procurement of long-lead items • Advance earthwork/embankment construction contracts • Advance remediation of contaminated sites		In addition to the above: • Ensure that the project delivery, procurement, and risk management plans are fully aligned • Integrate early procurement of components into a qualifications-based selection process for the prime contractor
	Expending funds in advance of full procurement	See above, particularly as it relates to understanding how the plans integrate

(continued)

TABLE B.14. PROJECT PHASE: PROCUREMENT AND CONTRACTING STRATEGY (continued)

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Use delayed-start provision in contract Examples: • Purchase construction right-of-way (ROW) to allow for prefabrication of elements • Allow contractor to revise designs before beginning work to minimize traffic impact • Allow contractor to do off-line work that will not impede traffic	Perception of delayed start will erode internal or external confidence in rapid renewal goals	In addition to the above: • Educate stakeholders on need for delayed start • Align incentives and disincentives with start of mainline work rather than start of contract
	Mobilization costs are higher and at risk if contractor defaults	In addition to the above: • Use best-value procurement to ensure that a solvent and experienced contractor is selected • Monitor work and payment closely

TABLE B.15. PROJECT PHASE: OPERATIONS AND MAINTENANCE

Rapid Renewal Strategy	Related Risk or Opportunity Category	Potential Risk Management Action
Consider private O&M contractor	Required O&M effort greater than planned (either more frequently, more extensive, or both) Example causes or issues: • Quality of constructed facility not as anticipated or required • Extreme seasonal weather impacts • Traffic demand greater than anticipated, or mix of vehicle types not as anticipated	• Ensure adequate contractual provisions (e.g., warranty) in contract with constructor • Ensure adequate quality control and assurance during construction of facility (to minimize risk of poorly constructed facility) • Conduct uncertainty-based traffic modeling for project's projected lifetime
	O&M contractor does not perform per contract Example causes or issues: • Performs O&M tasks when required, but not to technical standards • Fails to perform O&M tasks per requirements (regardless of how specified)	• Ensure adequate contractual provisions (e.g., performance bond) in contract with O&M contractor • Develop contingency plan in advance to quickly mobilize agency O&M resources if needed

TABLE B.16. PROJECT PHASE: REPLACEMENT

Rapid Renewal Category	Related Risk or Opportunity Category	Potential Risk Management Action
	Replacement required sooner than planned Example causes or issues: • Demand increases faster than anticipated, requiring additional capacity • Poor design, materials, and/or construction quality	• Conduct uncertainty-based demand modeling during design (consider uncertainties and risks that could affect modeling results) • Ensure adequate contractual provisions (e.g., warranty) in contract with constructor • Ensure adequate quality control and quality assurance during construction of facility (to minimize risk of poorly constructed facility) • Delay replacement with additional maintenance (develop contingency plan in advance for funding and resources)
	Replacement does not perform as intended (e.g., inadequate capacity; poor construction)	

C

SIMPLIFIED RISK MANAGEMENT OVERVIEW, FORMS, TEMPLATE, AND TEMPLATE USER'S GUIDE

A Microsoft PowerPoint overview presentation of the risk management process, a set of forms, a complementary Microsoft Excel workbook template, and a template user's guide are provided to help conduct risk management on relatively simple rapid renewal projects, according to the process described in this guide. All materials are available online at www.trb.org/Main/Blurbs/168369.aspx.

These components of the risk management process specifically consider the key relevant performance objectives (i.e., construction cost, schedule and disruption, and postconstruction longevity) and project delivery methods (traditional design–bid–build and nontraditional design–build). They can also be applied to nonrapid renewal projects and can consider a reduced set of project performance objectives for those projects.

The PowerPoint overview is intended to be presented by the risk facilitator at the beginning of a risk management workshop to adequately familiarize the participants with the risk management process that will be used throughout that workshop.

The forms developed for this guide are

- Summary Project Description
- Risk Identification (Brainstorming)
- Risk Register
- Rating Category Definition
- Unmitigated Risk Factor Assessment
- Risk Reduction Action Identification, Assessment, Evaluation, and Selection
- Risk Reduction Implementation Plan

Although the forms can also be used to document the results of calculations (as described in this guide), these calculations are separate and must be done separately.

The template (a Microsoft Excel workbook) has been developed that allows users to enter the data directly and then automatically performs the appropriate calculations (as described in this guide) The template is available at www.trb.org/Main/Blurbs/168369.aspx. It consists of 14 macro-free linked worksheets in a single workbook, highlighting user inputs while hiding and protecting other parts to prevent confusion, mistakes, and inadvertent misuse. A rapid renewal risk management planning template user's guide has been developed, documenting and explaining the various worksheets, and is provided as a separate document as part of the R09 project. Access the template user's guide at http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_R09ExcelTemplateUsersGuide.pdf.

Summary Project Description

Brief Project Description:
<insert>

Project Scope, Strategy/Status, and Key Conditions and Assumptions (identify):

- Detailed scope (including alternatives): <insert>
- Funding: <insert>
- Design:
  - Design level: <insert>
  - Structural: <insert>
  - Geotechnical: <insert>
  - Drainage: <insert>
  - Pavement: <insert>
  - Systems (including lighting and ITS)
  - Design deviations: <insert>
- Environmental:
  - Environmental documentation: <insert>
  - Wetlands: <insert>
  - Streams: <insert>
  - ESA: <insert>
  - Floodplain: <insert>
  - Stormwater: <insert>
  - Contaminated/hazardous waste: <insert>
  - Section 106: <insert>
  - 4(f): <insert>
  - Permitting (incl 404): <insert>
- Right of way and other agreements
  - Right-of-Way: <insert>
  - Utilities: <insert>
  - Railroad: <insert>
  - Other stakeholders: <insert>
- Procurement:
  - Delivery method: <insert>
  - Contract packaging: <insert>
  - Market (general and specialty): <insert>
- Construction:
  - Construction access/restrictions (including seasonal, events, shifts/hours): <insert>
  - Maintenance of traffic/business: <insert>
  - Construction phasing: <insert>
- Post-construction ("longevity"):
  - O&M: <insert>
  - Replacement: <insert>

Project Schedule (delivery, O&M, replacement – abstracted on next sheet):
<summarize major activities/milestones, including discussion of basis and bias/conservatism>

Project Cost Estimate (delivery, O&M, replacement – abstracted on next sheet):
<summarize major elements and costs, including discussion of basis and bias/conservatism, escalation, NPV for long term, disruption cost, and schedule and longevity value>

Project Disruption Estimate (delivery, O&M, replacement – abstracted on next sheet):
<summarize major elements and disruption, including discussion of basis and bias/conservatism>

Project Tradeoffs (disruption, schedule, longevity):
<summarize policy values for combining performance measures>

Project Performance Analysis:
<summarize project schedule, cost (including inflation), disruption, longevity, and combined performance>

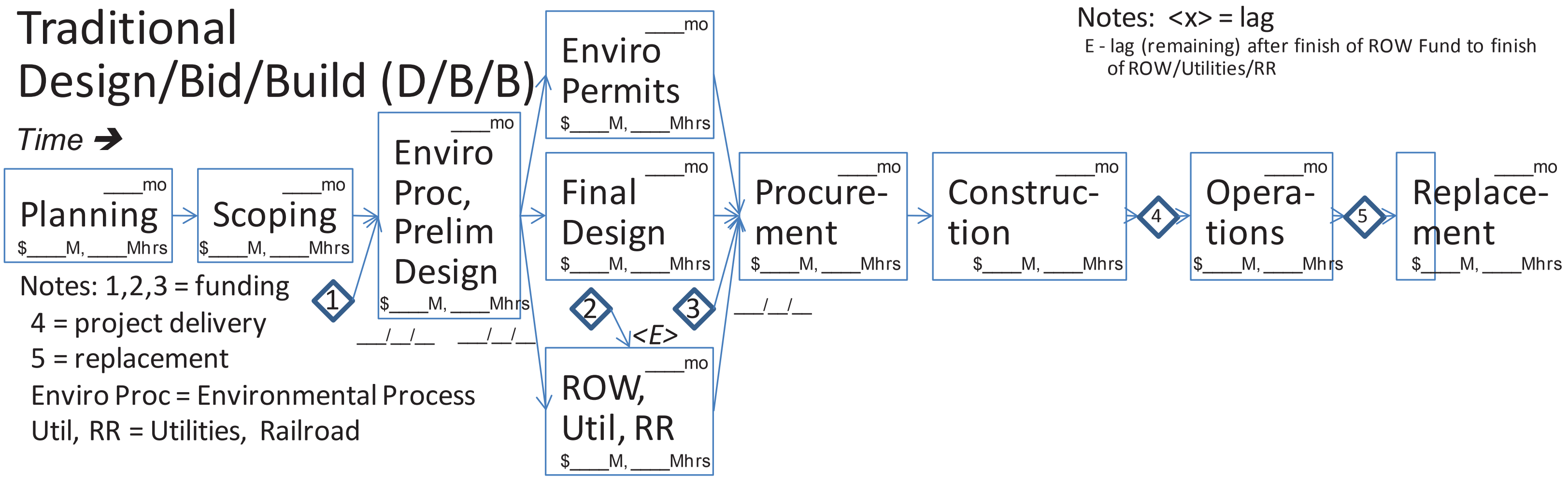
Project Schematics (Scope and Flowchart, customized or simplified – see next sheet):
<insert>

Project Base – Uses simplified "standard" flowcharts, which are really applicable to either traditional single phase/contract design/bid/build procurement or single phase/contract design/build procurement. A more detailed, custom flowchart would be needed for better schedule analysis (especially for multi-phase/contract procurement) and for quantitative risk analysis. Fill in the appropriate flowchart for the selected project delivery method, and fill in the other factors noted above.

Current Date/Status: ____________________________

Base Schedule: Flowchart depicts sequence of major project activities (left-to-right, per precedent arrows). Fill in remaining activity durations/lags/funding milestone dates directly in each activity box.

Base Cost: Fill in activity mean <u>uninflated</u> costs ($million) directly in each activity box, and following inflation factors: inflation start date ________; engineering inflation rate^1 ___%/yr, ROW inflation rate^1 ___%/yr, construction inflation rate^1 ___%/yr;
(note: ^{1} mean average rate from escalation start date through end of that phase)
Base Disruption: Fill in activity mean disruptions (million lost-hrs) in each activity box, disruption value NPV$____/hr;
Schedule Target Date: ________; **Schedule Value:** NPV$___million/mo; **Net Discount Rate**: ___%/yr;
Longevity Value: NPV$___/longevity$;
Extended OH Rates^2: preCN uninflated $___million/mo, CN (incl penalty) uninflated $___million/mo
(note: ^{2} mean average rate during each phase, equal to specific fraction of average "burn" rates during each phase)



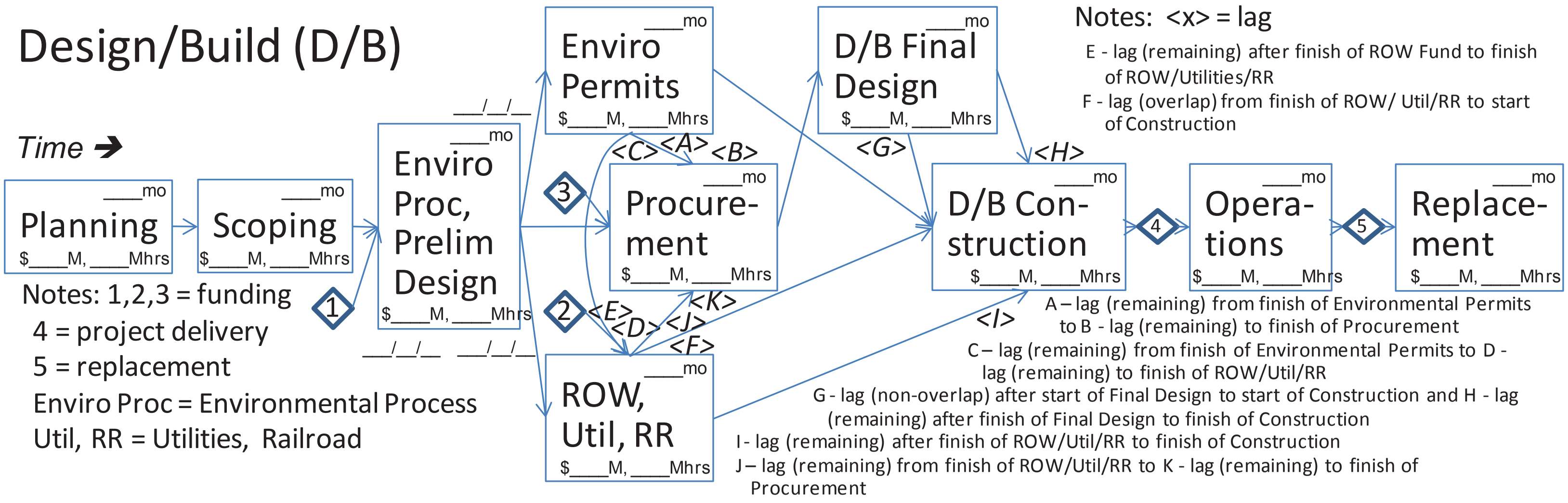
Project Base – Uses simplified “standard” flowcharts, which are really applicable to either traditional single phase/contract design/bid/build procurement or single phase/contract design/build procurement. A more detailed, custom flowchart would be needed for better schedule analysis (especially for multi-phase/contract procurement) and for quantitative risk analysis. Fill in the appropriate flowchart for the selected project delivery method, and fill in the other factors noted above.

Current Date/Status: ____________________________

Base Schedule: Flowchart depicts sequence of major project activities (left-to-right, per precedent arrows). Fill in remaining activity durations/lags/funding milestone dates directly in each activity box.

Base Cost: Fill in activity mean uninflated costs ($million) directly in each activity box, and following inflation factors: inflation start date _______; engineering inflation rate[1] ___%/yr, ROW inflation rate[1] ___%/yr, construction inflation rate[1] ___%/yr;
(note: [1] mean average rate from escalation start date through end of that phase)
Base Disruption: Fill in activity mean disruptions (million lost-hrs) in each activity box, disruption value NPV$____/hr;
Schedule Target Date: ________; **Schedule Value:** NPV$___million/mo; **Net Discount Rate**: ___%/yr;
Longevity Value: NPV$___/longevity$;
Extended OH Rates[2]: preCN uninflated $___million/mo, CN (incl penalty) uninflated $___million/mo
(note: [2] mean average rate during each phase, equal to specific fraction of average “burn” rates during each phase)

Design/Build (D/B)



Notes: 1,2,3 = funding
4 = project delivery
5 = replacement
Enviro Proc = Environmental Process
Util, RR = Utilities, Railroad

Notes: <x> = lag
E - lag (remaining) after finish of ROW Fund to finish of ROW/Utilities/RR
F - lag (overlap) from finish of ROW/ Util/RR to start of Construction
A – lag (remaining) from finish of Environmental Permits to B - lag (remaining) to finish of Procurement
C – lag (remaining) from finish of Environmental Permits to D - lag (remaining) to finish of ROW/Util/RR
G - lag (non-overlap) after start of Final Design to start of Construction and H - lag (remaining) after finish of Final Design to finish of Construction
I - lag (remaining) after finish of ROW/Util/RR to finish of Construction
J – lag (remaining) from finish of ROW/Util/RR to K - lag (remaining) to finish of Procurement

Activity (master list)	**Base Cost (unesc$M)**	**Base Disruption (M-hrs)**	**Base Duration (months)**	**Lag Label**	**Lag (mos)**	**Base Early Start Date**	**Base Early End Date**	**Float (months)**	**Base Cost (esc$M)**
Planning				A					
Scoping				B					
Design Funding									
Prelim Design/Env Proc				C					
Environmental Permits				D					
ROW/Util/RR Funding				E					
ROW/Util/RR				F					
Final Design				G					
Construction Funding									
Procurement				H					
Construction				I					
subtotal									
Operations				J					
Replacement				K					
subtotal				**←longevity (NPV$M)**					
Total				**←combined ($M)**					

Risk Identification (Brainstorming)

Item#	Risk or Opportunity (add rows as needed	Activity[1] (Circle One)	Description (possible non-“base” scenario(s) – causes and consequences)
EXAMPLE	Note: [1] Project activity when risk is most likely to occur, and after which it is very unlikely to occur.		[2] Pr Dsn/Env Pr = preliminary design and environmental process
100	*Landowner(s) unwilling to sell parcel <xxx>*	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding	*Additional right-of-way needed for project, as currently designed. However, current owner of needed property might be unwilling to sell at price offered by DOT, so that have to proceed with condemnation, with some additional admin cost but especially delay to ROW process.*
		Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding	
		Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding	
		Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding	
		Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding	

Risk Identification (Brainstorming)

Item#	**Risk or Opportunity (add rows as needed**	**Activity[1] (Circle One)**	**Description (possible non-“base” scenario(s) – causes and consequences)**
EXAMPLE	Note: [1] Project activity when risk is most likely to occur, and after which it is very unlikely to occur.		[2] Pr Dsn/Env Pr = preliminary design and environmental process
100	*Landowner(s) unwilling to sell parcel <xxx>*	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding	*Additional right-of-way needed for project, as currently designed. However, current owner of needed property might be unwilling to sell at price offered by DOT, so that have to proceed with condemnation, with some additional admin cost but especially delay to ROW process.*
		Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding	
		Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding	
		Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding	
		Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding	

Risk Register

Item	Risk or Opportunity (by category) (add lines with labels as needed)	Initial Item#	Description (possible non-“base” scenario(s) – causes and consequences)
PL	***Planning Risks***		
PL1			
PL2			
PL3			
SC	***Scoping Risks***		
SC1			
SC2			
SC3			
SC4			
PD	***Prelim Design / Enviro Process Risks***		
PD1			
PD2			
PD3			
PD4			
PD5			
PD6			
EP	***Environmental Permits Risks***		
EP1			
EP2			
EP3			
RU	***ROW/Utility/RR/etc Risks***		
RU1			
RU2			
RU3			
RU4			
FD	***Final Design Risks***		
FD1			
FD2			
FD3			
FD4			

Risk Register

Item	Risk or Opportunity (by category) (add lines with labels as needed)	Initial Item#	Description (possible non-“base” scenario(s) – causes and consequences)
CP	***Procurement Risks***		
CP1			
CP2			
CP3			
CP4			
CP5			
CN	***Construction Risks***		
CN1			
CN2			
CN3			
CN4			
CN5			
CN6			
CN7			
CN8			
CN9			
CN10			
OM	***Operations Risks***		
OM1			
OM2			
OM3			
RP	***Replacement Risks***		
RP1			
RP2			
RP3			
FN	***Funding Risks***		
FN1			
FN2			
FN3			

Note: Transfer risks from Risk ID Form (brainstorming) to appropriate category. Edit to be comprehensive/nonoverlapping. See checklists.

Rating Category Definition

Rating	Impacts if Event Occurs						Probability of Event Occurring (0=impossible to 1=guaranteed)		Severity (equivalent inflated $ million)	
	Change to Affected Activity Direct Cost $ (uninflated $ million)		Change to Affected Activity Duration T (months)		Change to Affected Activity Disruption D (million person-hours lost)					
	Low end of range	High end of range	Low end of range	High end of range	Low end of range	High end of range	Low end of range	High end of range	Low end of range	High end of range
VH	+25%	>+25%	+12	>+12	+25%	>+25%	0.7 (2:3)	1.0 (1:1)	+25%	>+25%
H	+10%	↖	+4	↖	+10%	↖	0.4 (2:5)	↖	+10%	↖
M	+3%	↖	+1	↖	+3%	↖	0.2 (1:5)	↖	+3%	↖
L	+1%	↖	+0.2	↖	+1%	↖	0.05 (1:20)	↖	+1%	↖
VL	0	↖	0	↖	0	↖	0.0 (0:1)	↖	0	↖
-VL	-1%	↖	-0.2	↖	-1%	↖			-1%	↖
-L	-3%	↖	-1	↖	-3%	↖			-3%	↖
-M	-10%	↖	-4	↖	-10%	↖			-10%	↖
-H	-25%	↖	-12	↖	-25%	↖			-25%	↖
-VH	<-25%	↖	<-12	↖	<-25%	↖			<-25%	↖
Base	$________				_________Mhrs				$__________	

Note: Can express values directly (e.g., default values are shown for probability of event occurring) or as % of base value (e.g., default values are shown for direct cost as % of total uninflated base cost through construction, for disruption as % of total base disruption through construction, and for severity as % of combined project performance. High end of one range is same as low end of next higher range (as indicated by arrows), and does not need to be repeated. Default values can be over-ridden.

Unmitigated Risk Factor Assessment Form

Unmitigated Risk Factor Assessment

Item	Risk or Opportunity (from Risk Register by item#) (add rows as needed)	Assessed Probability of Occurrence (0 to 1, or rating*)	Assessed Impacts (if occur) (*ratings as defined by range categories –defaults shown)						Calculated[1]	
			Mean Direct Cost Change $ to Activity (uninflated $M, or rating*)	Activity $ Affected (circle)	Mean Duration Change T to Activity (months, or rating*)	Activity T Affected (circle)	Mean Disruption Change D to Activity (M man-hrs, or rating*)	Activity D Affected (circle)	Severity (equivalent inflated $M, or rating*)	Rank
EXAMPLE (showing mean values and ratings) Note: [1]Considers extended OHs, inflation, and values of schedule and disruption [2] Pr Dsn/Env Pr = preliminary design and environmental process										
RUi	*Landowner(s) unwilling to sell parcel <xxx>*	*0.5* VH (0.7 to 1.0) [✓ H] (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	*+$0.5M* + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) [✓ +] - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding 1,2,3	*+2 mo* + – VH (>1 yr) + – H (4 mo to 1 yr) [✓ +] - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding 1,2,3	*0 M man-hrs* + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) [✓ 0]	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding 1,2,3	*+$0.3M* + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) [✓ +] - L (1% to 3%) + - VL (<1%)	*1*
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	mo + – VH (>1 yr) + – H (4 mo to 1 yr) + - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	M man-hrs + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%)	
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	mo + – VH (>1 yr) + – H (4 mo to 1 yr) + - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	M man-hrs + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%)	
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	mo + – VH (>1 yr) + – H (4 mo to 1 yr) + - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	M man-hrs + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%)	
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	mo + – VH (>1 yr) + – H (4 mo to 1 yr) + - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	M man-hrs + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%)	

Unmitigated Risk Factor Assessment Form

Unmitigated Risk Factor Assessment

Item	Risk or Opportunity (from Risk Register by item#) (add rows as needed)	Assessed Probability of Occurrence (0 to 1, <u>or</u> rating*)	Assessed Impacts (<u>if</u> occur) (*ratings as defined by range categories –defaults shown)						Calculated[1]	Rank
			Mean Direct Cost Change $ to Activity (uninflated $M, <u>or</u> rating*)	Activity $ Affected (circle)	Mean Duration Change T to Activity (months, <u>or</u> rating*)	Activity T Affected (circle)	Mean Disruption Change D to Activity (M man-hrs, <u>or</u> rating*)	Activity D Affected (circle)	Severity (equivalent inflated $M, <u>or</u> rating*)	
EXAMPLE (showing mean values and ratings) Note: [1]Considers extended OHs, inflation, and values of schedule and disruption									[2] Pr Dsn/Env Pr = preliminary design and environmental process	
RUi	Landowner(s) unwilling to sell parcel <xxx>	0.5 VH (0.7 to 1.0) [✓ H] (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	+$0.5M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) [✓ +] - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding 1,2,3	+2 mo + – VH (>1 yr) + – H (4 mo to 1 yr) [✓ +] - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding 1,2,3	0 M man-hrs + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) [✓ 0]	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits [✓ ROW/Util/RR] Final Design Procurement Construction Operations Replacement Funding 1,2,3	+$0.3M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) [✓ +] - L (1% to 3%) + - VL (<1%)	1
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	mo + – VH (>1 yr) + – H (4 mo to 1 yr) + - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	M man-hrs + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%)	
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	mo + – VH (>1 yr) + – H (4 mo to 1 yr) + - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	M man-hrs + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%)	
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	mo + – VH (>1 yr) + – H (4 mo to 1 yr) + - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	M man-hrs + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%)	
		VH (0.7 to 1.0) H (0.4 to 0.7) M (0.2 to 0.4) L (0.05 to 0.2) VL (0.0 to 0.05)	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	mo + – VH (>1 yr) + – H (4 mo to 1 yr) + - M (1 mo to 4 mo) + - L (1 wk to 1 mo) + - VL (<1 wk) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	M man-hrs + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	$ M + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%)	

Risk Reduction Action Identification, Assessment, Evaluation and Selection (note: print 11x17)

Risk Rank	Critical Risk (see Risk Register/ Unmitiagted Risk Factors) (add rows as needed)	Response Strategy (Circle)	Potential Risk Reduction Action (see checklist) (add rows as needed)	Implementation (^{1}mean value or ratings – default ranges shown)						Effectiveness (value or rating)^3				Calculated^1 Net Equiv Cost Savings (equiv infl $M)	Adopted
				Cost $ (uninfl $M)^1	Affected $ Activity (Circle)	Delay T (months)^1	Affected T Activity (Circle)	Disruption D (M man-hrs)^1	Affected D Activity (Circle)	Probability (0.0 to 1.0)	Impacts (if occurs)				
											$ (un-infl $)	T (mos)	D (hr)		
EXAMPLE (showing mean values and ratings) Note: ^{1}Considers extended OHs, escalation, and values of schedule and disruption. ^{3}Residual value X_R = unmitigated value X_0 * (1 – effectiveness E_X); e.g., X_R=0 if E_X=100% ^{2} Pr Dsn/Env Pr = preliminary design/environmental process															
1	RUi. Landowners unwilling to sell parcel <xxx>	[✓ Avoid] Mitigate Transfer Accept	RUi(1). The team will design around areas where right of way may be an issue.	$0.1 VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) [✓ VL] (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement [✓ Construction] Operations Replacement Funding 1,2,3	1.0 VH (>1yr) H (4mo-1yr) M (1mo-4mo) [✓ L] (1wk-1mo) VL (<1wk) 0	Planning Scoping [✓ Pr Dsn/Env Pr^2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	0 VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	1.0 Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	NA +-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	NA +-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	NA +-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	$0.2 + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	✓
		Avoid Mitigate Transfer Accept		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>1yr) H (4mo-1yr) M (1mo-4mo) L (1wk-1mo) VL (<1wk) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	
		Avoid Mitigate Transfer Accept		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>1yr) H (4mo-1yr) M (1mo-4mo) L (1wk-1mo) VL (<1wk) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	
		Avoid Mitigate Transfer Accept		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>1yr) H (4mo-1yr) M (1mo-4mo) L (1wk-1mo) VL (<1wk) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	
		Avoid Mitigate Transfer Accept		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>1yr) H (4mo-1yr) M (1mo-4mo) L (1wk-1mo) VL (<1wk) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	
		Avoid Mitigate Transfer Accept		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>1yr) H (4mo-1yr) M (1mo-4mo) L (1wk-1mo) VL (<1wk) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	
		Avoid Mitigate Transfer Accept		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>1yr) H (4mo-1yr) M (1mo-4mo) L (1wk-1mo) VL (<1wk) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr^2 Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	

Risk Reduction Action Identification, Assessment, Evaluation and Selection (note: print 11x17)

Risk Rank	Critical Risk (see Risk Register/ Unmitiagted Risk Factors) (add rows as needed)	Response Strategy (Circle)	Potential Risk Reduction Action (see checklist) (add rows as needed)	Implementation ([1]mean value or ratings – default ranges shown)						Effectiveness (value or rating)[3]				Calculated[1] Net Equiv Cost Savings (equiv infl $M)	Adopted
				Cost $ (uninfl $M)[1]	Affected $ Activity (Circle)	Delay T (months)[1]	Affected T Activity (Circle)	Disruption D (M man-hrs)[1]	Affected D Activity (Circle)	Probability (0.0 to 1.0)	Impacts (if occurs)				
											$ (uninfl $)	T (mos)	D (hr)		
EXAMPLE (showing mean values and ratings) Note: [1]Considers extended OHs, escalation, and values of schedule and disruption. [3]Residual value X_R = unmitigated value X_0 * (1 – effectiveness E_X); e.g., $X_R=0$ if $E_X=100\%$ [2] Pr Dsn/Env Pr = preliminary design/environmental process															
1	RUi. Landowners unwilling to sell parcel <xxx>	[✓ Avoid] Mitigate Transfer Accept	RUi(1). The team will design around areas where right of way may be an issue.	$0.1 VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) [✓ VL] (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement [✓ Construction] Operations Replacement Funding 1,2,3	1.0 VH (>1yr) H (4mo-1yr) M (1mo-4mo) [✓ L] (1wk-1mo) VL (<1wk) 0	Planning Scoping [✓ Pr Dsn/Env Pr[2]] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	0 VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	1.0 Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	NA +-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	NA +-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	NA +-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	$0.2 + – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	✓
		Avoid Mitigate Transfer Accept		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>1yr) H (4mo-1yr) M (1mo-4mo) L (1wk-1mo) VL (<1wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	
		Avoid Mitigate Transfer Accept		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>1yr) H (4mo-1yr) M (1mo-4mo) L (1wk-1mo) VL (<1wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	
		Avoid Mitigate Transfer Accept		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>1yr) H (4mo-1yr) M (1mo-4mo) L (1wk-1mo) VL (<1wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	
		Avoid Mitigate Transfer Accept		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>1yr) H (4mo-1yr) M (1mo-4mo) L (1wk-1mo) VL (<1wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	
		Avoid Mitigate Transfer Accept		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>1yr) H (4mo-1yr) M (1mo-4mo) L (1wk-1mo) VL (<1wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	
		Avoid Mitigate Transfer Accept		VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>1yr) H (4mo-1yr) M (1mo-4mo) L (1wk-1mo) VL (<1wk) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	VH (>25%) H (10%-25%) M (3%-10%) L (1%-3%) VL (<1%) 0	Planning Scoping Pr Dsn/Env Pr[2] Enviro Permits ROW/Util/RR Final Design Procurement Construction Operations Replacement Funding 1,2,3	Wrt 0,1 prob: +-100%effect +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+-100% eff +-VH (.7-1) +-H (.4-.7) +-M (.2-.4) +-L (.05-.2) +-VL (0-.05) No effect	+ – VH (>25%) + – H (10% to 25%) + - M (3% to 10%) + - L (1% to 3%) + - VL (<1%) 0	

Risk Reduction Implementation Plan

Rank	Selected Risk Reduction Actions (see Risk Reduction Evaluation for details) (add rows as needed)	Responsibility	Schedule or Milestone Check	Comments
1	*RUi(1). The team will design around areas where right of way may be an issue, specifically at parcel <xxx>.*	*Design lead, in conjunction with right-of-way lead*	*By end of preliminary design*	*Need to get approval for design deviations.*

Risk Reduction Implementation Plan

Rank	Selected Risk Reduction Actions (see Risk Reduction Evaluation for details) (add rows as needed)	Responsibility	Schedule or Milestone Check	Comments
1	RUi(1). The team will design around areas where right of way may be an issue, specifically at parcel <xxx>.	Design lead, in conjunction with right-of-way lead	By end of preliminary design	Need to get approval for design deviations.

D

HYPOTHETICAL RAPID RENEWAL CASE STUDY

A hypothetical case study has been developed and used throughout the guide to adequately illustrate the various steps of the risk management process. These steps (each related to a chapter in the guide) are discussed. A *risk management plan* (RMP) that contains the details of the process for this hypothetical case study is provided in Appendix E.

RISK MANAGEMENT PROCESS FOR QDOT PROJECT

QDOT is planning a significant highway reconstruction/expansion project. The objectives are to minimize cost, schedule, and disruption during construction and maximize longevity of the constructed facility after construction. Recognizing the uncertainty and risk inherent in this project, QDOT decided to conduct risk management planning, followed by implementation of the resulting RMP, to optimize satisfaction of these objectives (as described in general terms in Chapter 2 of the guide and specifically for this application in Section 1 of the RMP in Appendix E; see Figure D.1. However, it was decided not to conduct quantitative risk analysis (e.g., to objectively establish contingencies) at this time. To accomplish this (as described in Chapter 10 of the guide and specifically for this application in Section 9 of the RMP in Appendix E), QDOT:

- Convened a group of project team staff and independent subject-matter experts from the key project disciplines, facilitated by a qualified risk elicitor and analyst, to conduct risk assessment and risk management planning (consistent with the principles, processes, and guidance described throughout the guide).
- Assigned a risk manager (with adequate authority and resources) to implement the resulting RMP.

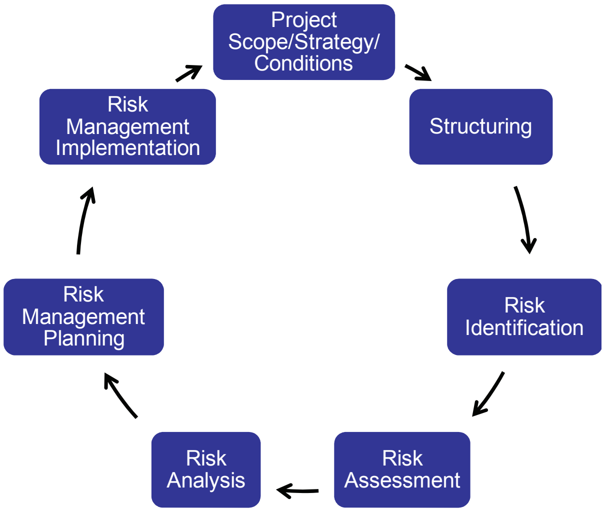


Figure D.1. *Iterative risk management process.*

QDOT RAPID RENEWAL PROJECT

QDOT is planning to reconstruct and expand segments of two existing (intersecting) highways, US-555 and SH-111, through a rapidly developing suburban area. The existing highways are nearly 40 years old, have increasingly inadequate capacity, and are expensive to maintain. These facilities are the only viable east-west (US-555) and north-south (SH-111) routes for commercial traffic for several miles in either direction. Therefore, it is imperative that the necessary improvements be made quickly and with minimal disruption. QDOT would also like to minimize construction costs and future repair cycles and maintenance requirements, as well as eventual replacement issues. To achieve these objectives, QDOT plans to encourage contractor innovation through the use of performance-based specifications and incentives, and to procure with an innovative project delivery method (i.e., design–build). It is expected that accelerated bridge construction techniques, minimally disruptive maintenance of traffic, and innovative pavement design, among other rapid renewal elements (as described in Appendix A; see Figure D.2), will be considered for this project. As described in Chapter 3, it is important that the project be adequately understood (and documented) before starting the risk management process. The project is described in Section 2 of the RMP (Appendix E).

Construction	**Structures**	**Traffic Engineering/ Safety/ITS**	**Innovative Contracting/ Financing**	**Geotechnical Materials/ Advanced Testing**
• Closures • Preliminary Work/ Staging • Project Administration Streamlining • Construction Operations	• Prefabrication • Component Reuse • High-Performance Materials • Integral Designs • Standardized Design • Construction Placement • Temporary Structures • Long-Life Structural Design	• Advance Planning • Alternate Routes • Alternate Modes • Improved Physical Separation • Coordinated Emergency Response • Signage and Signalization • Closures • Work Zones	• Alternative Financing • Project Delivery • Procurement • Contract Payment • Warranties • Alternative Insurance • Advance Contract Packaging • Bonding/ Performance Securities	• Subsurface Exploration • Walls • Pavements • Alternative Materials • Intelligent Compaction • Material Testing

Public Relations	**Environment**	**Roadway/Geometric Design**	**Right-of-Way/ Utilities/Railroad Coordination**	**Long-Life Pavements/ Maintenance**
• Team Integration • Single-Point Communication • Additional Investment • Project Branding • Stakeholder Awareness • Performance Measurement	• Master Planning • Context-Sensitive Solutions • Comprehensive Scoping • Advance Permitting	• Alternate Access • Alternate Geometrics • Advance Roadwork	• Advance Right-of-Way Planning • Early Utility Location • Common Utility Crossings • Early Railroad Coordination	• Life-Cycle Design • Performance Indicators • Long-Life Materials • Maintenance Involvement

Note: ITS = Intelligent Transportation Systems.

Figure D.2. *Rapid renewal categories.*

STRUCTURING QDOT PROJECT FOR RISK ASSESSMENT AND MANAGEMENT

Following the principles outlined in Chapter 4 and as documented in Section 2 of the RMP (see Appendix E):

1. QDOT presented the project's scope, strategy, status, key conditions and assumptions, and associated cost, schedule, and disruption estimates to the combined group of key project team staff and independent subject-matter experts.
2. Facilitated by a "base lead," the group reviewed, de-biased (i.e., removed any over- or underestimates), and validated the cost, schedule, and disruption estimates for the assumptions stated below. The results were base cost, schedule, and disruption estimates, exclusive of risk and opportunity. Subsequently, a quantitative risk

analysis was conducted, for which uncertainties in and correlations among the base costs, schedule, and disruption estimates were assessed (see RMP Addendum X in Appendix E).

3. Facilitated by a "risk lead," the group adopted a design–build standard simplified flowchart describing the sequence of major project activities (see Figure D.3). This simplified flowchart serves as the basis for subsequent risk identification and assessment, and then proactive individual risk reduction identification and evaluation. Note: Subsequently, a quantitative risk analysis was conducted, for which a more detailed flowchart was developed (see RMP Addendum X in Appendix E).
4. "Mean" (i.e., probability-weighted average) base project performance (i.e., schedule, uninflated and inflated cost, and disruption, both total for the project and by project activity) was then approximately calculated using an appropriate risk model (a Microsoft Excel workbook template). For subsequent risk and risk management evaluations, QDOT-established trade-off values (which are policy rather than technical issues) that allowed the various project performance measures to be combined, for example, (a) combining postconstruction schedule, cost, and disruption into longevity; and (b) combining schedule, cost, and disruption through construction with longevity into severity.

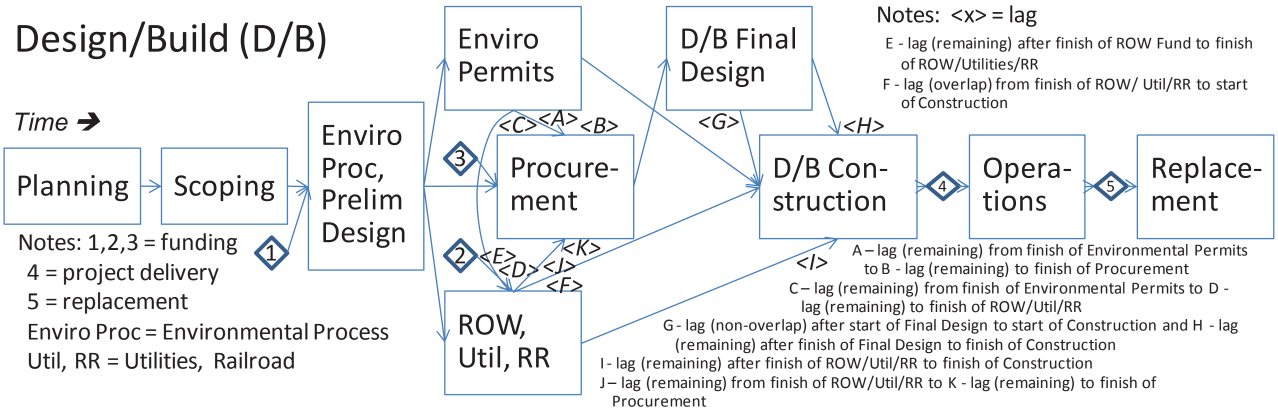


Figure D.3. *Standard simplified project flowchart for design–build for QDOT US-555/SH-111 Project.*

RISK IDENTIFICATION FOR QDOT PROJECT

Following the principles and process outlined in Chapter 5 and as documented in Section 3 of the RMP in Appendix E, the facilitated combined group of key project team staff and independent subject-matter experts identified, categorized, and documented in the project risk register nearly 60 current risks and opportunities (relative to the base) with potential cost, schedule, and/or disruption impacts (see Table D.1). The risks and opportunities (collectively termed risks) spanned all remaining phases of the project and were categorized by the project phase in which they were most likely to occur (and after which they could be retired): for example, 4 planning risks, 7 scoping risks, 16 preliminary design or environmental process risks, 2 environmental permit risks, 8 procurement risks, 10 right-of-way/utilities risks, and 12 construction risks. At this point in the risk assessment, however, the group did not discuss the likelihood or severity of any of the risks.

Initially, risks were simply brainstormed by the group and then categorized. Once the initial list of risks was categorized, the group added risks to complete each category, finally referring to the checklists (Appendix B), and then edited the risks to eliminate any overlap.

TABLE D.1. SELECT RAPID RENEWAL RISKS FOR QDOT US-555/SH-111 PROJECT

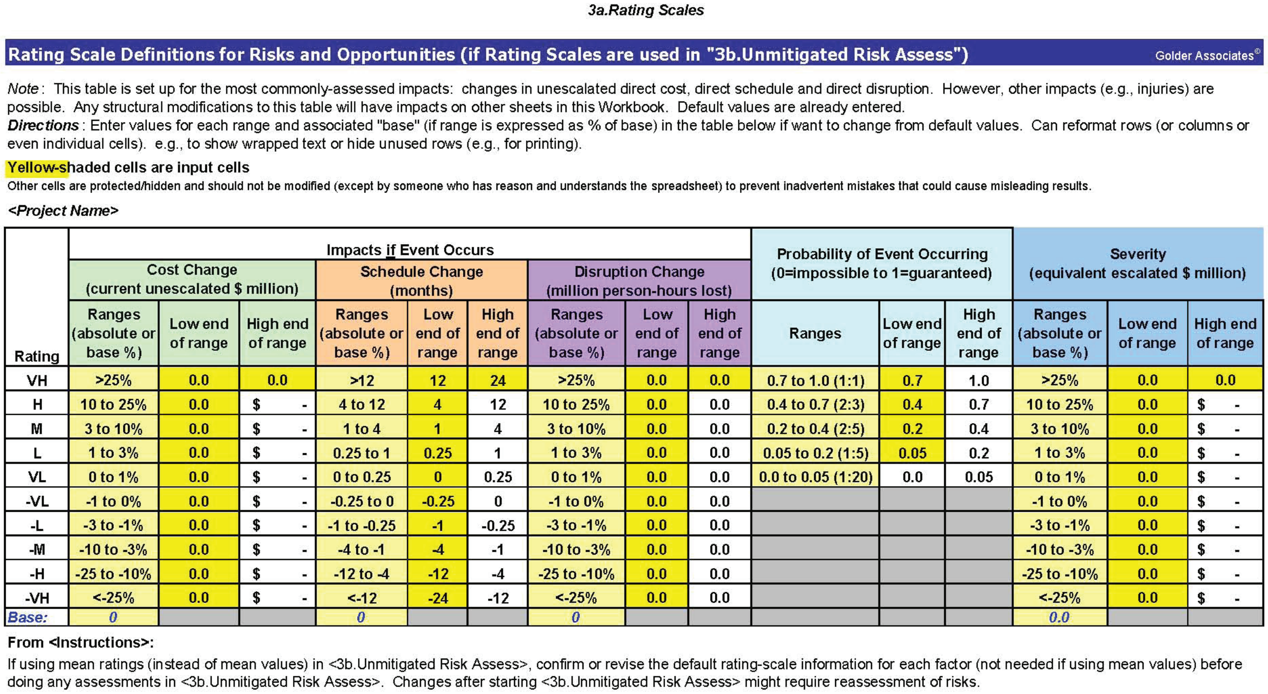
Project Phase	Risk ID	Title of Risk or Opportunity
Preliminary design/environmental process	PD13	Change in environmental documentation
Right-of-way, utilities, and railroad	RU3	Unwilling sellers
Procurement	CP2	Uncertain design–build contracting market conditions at time of bid
Construction	CN3	Problems with planned accelerated bridge construction technique

RISK ASSESSMENT FOR QDOT PROJECT

QDOT initially decided that assessing the current risks in terms of mean-value ratings (e.g., *L*, *M*, and *H*) would be sufficient for its intended use of the risk assessment results (i.e., prioritizing the risks for proactive individual risk reduction). Following the principles and process outlined in Chapter 6 and as documented in Section 3 of the RMP in Appendix E, the group first defined mean-value rating scales for the various risk factors (see Table D.2):

- Each of the three types (cost, schedule, and disruption) of impacts of occurrence (e.g., a medium [*M*] cost impact was defined to correspond to a value between 3% and 10% of the base project cost, in uninflated dollars).
- The probability of occurrence (e.g., a medium [*M*] probability corresponded to a probability of occurrence between 0.2 and 0.4).

TABLE D.2. RISK FACTOR RATING SCALE DEFINITIONS FOR QDOT US-555/SH-111 PROJECT



3a.Rating Scales

Rating Scale Definitions for Risks and Opportunities (if Rating Scales are used in "3b.Unmitigated Risk Assess") Golder Associates©

Note: This table is set up for the most commonly-assessed impacts: changes in unescalated direct cost, direct schedule and direct disruption. However, other impacts (e.g., injuries) are possible. Any structural modifications to this table will have impacts on other sheets in this Workbook. Default values are already entered.

Directions: Enter values for each range and associated "base" (if range is expressed as % of base) in the table below if want to change from default values. Can reformat rows (or columns or even individual cells). e.g., to show wrapped text or hide unused rows (e.g., for printing).

Yellow-shaded cells are input cells

Other cells are protected/hidden and should not be modified (except by someone who has reason and understands the spreadsheet) to prevent inadvertent mistakes that could cause misleading results.

<Project Name>

Rating	Impacts if Event Occurs									Probability of Event Occurring (0=impossible to 1=guaranteed)			Severity (equivalent escalated $ million)		
	Cost Change (current unescalated $ million)			Schedule Change (months)			Disruption Change (million person-hours lost)								
	Ranges (absolute or base %)	Low end of range	High end of range	Ranges (absolute or base %)	Low end of range	High end of range	Ranges (absolute or base %)	Low end of range	High end of range	Ranges	Low end of range	High end of range	Ranges (absolute or base %)	Low end of range	High end of range
VH	>25%	0.0	0.0	>12	12	24	>25%	0.0	0.0	0.7 to 1.0 (1:1)	0.7	1.0	>25%	0.0	0.0
H	10 to 25%	0.0	$ -	4 to 12	4	12	10 to 25%	0.0	0.0	0.4 to 0.7 (2:3)	0.4	0.7	10 to 25%	0.0	$ -
M	3 to 10%	0.0	$ -	1 to 4	1	4	3 to 10%	0.0	0.0	0.2 to 0.4 (2:5)	0.2	0.4	3 to 10%	0.0	$ -
L	1 to 3%	0.0	$ -	0.25 to 1	0.25	1	1 to 3%	0.0	0.0	0.05 to 0.2 (1:5)	0.05	0.2	1 to 3%	0.0	$ -
VL	0 to 1%	0.0	$ -	0 to 0.25	0	0.25	0 to 1%	0.0	0.0	0.0 to 0.05 (1:20)	0.0	0.05	0 to 1%	0.0	$ -
-VL	-1 to 0%	0.0	$ -	-0.25 to 0	-0.25	0	-1 to 0%	0.0	0.0				-1 to 0%	0.0	$ -
-L	-3 to -1%	0.0	$ -	-1 to -0.25	-1	-0.25	-3 to -1%	0.0	0.0				-3 to -1%	0.0	$ -
-M	-10 to -3%	0.0	$ -	-4 to -1	-4	-1	-10 to -3%	0.0	0.0				-10 to -3%	0.0	$ -
-H	-25 to -10%	0.0	$ -	-12 to -4	-12	-4	-25 to -10%	0.0	0.0				-25 to -10%	0.0	$ -
-VH	<-25%	0.0	$ -	<-12	-24	-12	<-25%	0.0	0.0				<-25%	0.0	$ -
Base:	*0*			*0*			*0*						*0.0*		

From <Instructions>:

If using mean ratings (instead of mean values) in <3b.Unmitigated Risk Assess>, confirm or revise the default rating-scale information for each factor (not needed if using mean values) before doing any assessments in <3b.Unmitigated Risk Assess>. Changes after starting <3b.Unmitigated Risk Assess> might require reassessment of risks.

- The severity of combined impacts (considering the probability of occurrence and trade-offs) [e.g., a medium (*M*) severity was defined to correspond to a value between 3% and 10% of the base combined performance, in equivalent inflated dollars].

The group then discussed each of the identified risks in the risk register and quantified (by consensus) each of them in terms of mean-value ratings (or sometimes directly in terms of mean values) for the following, before any additional mitigation: (a) the cost, schedule, and/or disruption impacts (and the affected activity) if the risk occurs; and (b) the probability that the risk (as defined by its impacts) will occur (during the particular project phase under which it is categorized) (see Table D.3). Note: Subsequently, a quantitative risk analysis was conducted, for which these unmitigated assessments were refined; see RMP Addendum X in Appendix E.

Using an appropriate risk model, for example, the Microsoft Excel workbook template that incorporates the algorithms presented in Chapter 6 (see Table D.4), QDOT used the assessments to determine: (a) the approximate unmitigated mean-value contribution of each risk to the project objectives of cost, schedule, and disruption; and (b) by combining with QDOT's established "value trade-offs" among the objectives, an unmitigated mean-value longevity and then severity for each risk, based on which the risks were ranked. Note: Subsequently, a quantitative risk analysis was conducted, for which the contribution of each risk and other uncertainty to the potential budget, before any additional mitigation, was determined more accurately; see RMP Addendum X in Appendix E.

TABLE D.3. UNMITIGATED RISK FACTOR ASSESSMENTS FOR SELECT RAPID RENEWAL RISKS FOR QDOT US-555/SH-111 PROJECT

Project Phase	Example Risk or Opportunity	Probability of Occurrence	Mean Value or Ratings[a] to Affected Activity		
			Mean Cost Change if Occurs	Mean Duration Change if Occurs	Mean Disruption Change if Occurs
Preliminary design/ environmental process	PD13. Change in environmental documentation	*L*	+*M* to preliminary design/ environmental process	+*H* to preliminary design/ environmental process	0
Right-of-way, utilities, and railroad	RU3. Unwilling sellers	*H*	+*M* to ROW/ utilities/railroad	0	0
Procurement	CP2. Uncertain design–build contracting market conditions at time of bid	25%	+$1.2M to construction	+1 month to procurement	0
Construction	CN3. Problems with planned accelerated bridge construction technique	*H*	+*L* to construction	+*L* to construction	+*L* to construction

[a] See definitions in Table D.2.

TABLE D.4. UNMITIGATED RISK SEVERITY DETERMINATION AND RANKING FOR SELECT RAPID RENEWAL RISKS FOR QDOT US-555/SH-111 PROJECT

Project Phase	Example Risk or Opportunity	Mean Severity (equivalent YOE$M or rating)[a]	Rank
Preliminary design/ environmental process	PD13. Change in environmental documentation	*L*	11
Right-of-way, utilities, and railroad	RU3. Unwilling sellers	*M*	3/4
Procurement	CP2. Uncertain design-build contracting market condition at time of bid	0.38	9
Construction	CN3. Problems with planned accelerated bridge construction technique	*L*	12

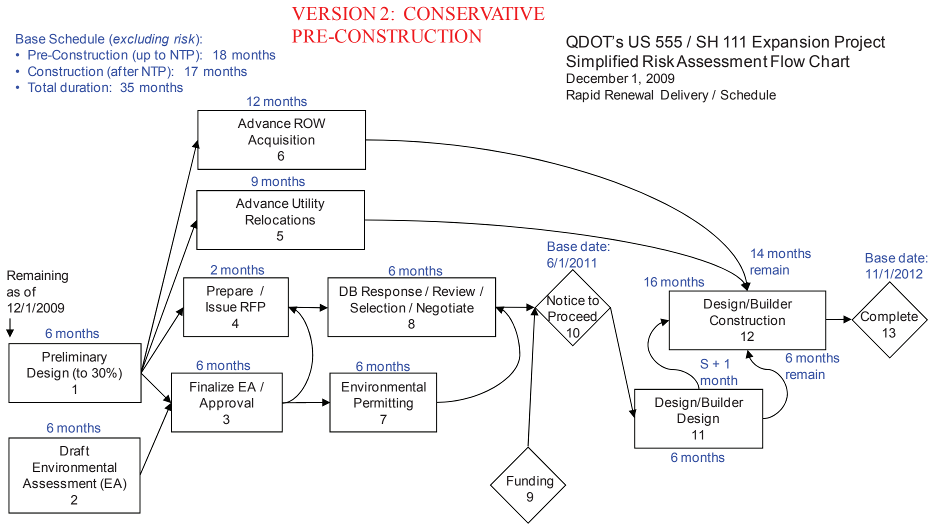
[a] See definitions in Table D.2; YOE$M = year-of-expenditure in millions of dollars.

RISK ANALYSIS FOR QDOT PROJECT

QDOT used the mean base and unmitigated risk assessments to determine (using the Microsoft Excel workbook template) the approximate mean unmitigated project performance (i.e., schedule, uninflated and inflated cost, and disruption, both total for the project and by project activity) in the same way as for base project performance. Although these results were very approximate (because of simplifications in the analysis), they provided insight into the collective effect of the risks, before any additional mitigation. This information and these tools were also used to determine the mean severity of each risk, in terms of how much the combined performance measure is affected by that risk.

Note: Subsequently, a quantitative risk analysis was conducted (see RMP Addendum X in Appendix E), for which

- A detailed flowchart was developed (by consensus) by the facilitated group (see Figure D.4).
- Uncertainties in the unmitigated base cost estimate and schedule were assessed (by consensus) by the facilitated group; for example, bridge structure cost ranges (10th to 90th percentile) from –20% to +20%, and is moderately correlated (coefficient of 0.75) with other construction cost items.
- Unmitigated risk factor assessments were refined (by consensus) by the facilitated group (e.g., see Table D.5).



Notes:
1. Single Design/Build contract.
2. Advance Right-of-Way (ROW) Acquisition includes appraisals, offers, acquisition, relocation, and demolition for parcels that QDOT anticipates will be critical to early construction by the Design/Builder.
3. Advance Utility Relocations includes coordination, approvals, and relocations of utilities that QDOT anticipates will be critical to early construction by the Design/Builder. Additional relocations that might be required will be the responsibility of the Design/Builder during construction. Assumes minimal new ROW required for utility relocations.
4. QDOT will complete the Environmental Assessment (EA) and obtain all environmental permits before Notice to Proceed (NTP).
5. Construction duration *includes* typical winter shut-down period from November 15th through March 15th.
6. Construction includes construction permits, remaining utility relocations, and all construction-related effort. Remaining ROW acquisition by QDOT also occurs during this timeframe.

Figure D.4. *Detailed flowchart developed by the facilitated group.*

TABLE D.5. QUANTITATIVE ASSESSMENT FOR A SELECT RAPID RENEWAL RISK FOR QDOT US-555/SH-111 PROJECT

Risk or Opportunity	Probability of Occurrence	Cost Change if Occurs (2009 $ million)	Duration Change if Occurs (months)
PD13. Change in environmental documentation	Mutually exclusive scenarios: A. 50% (base) B. 40% C. 8% D. 2%	A. 0 (base) B. +0.1 to Activity 2 C. +0.5 to Activity 2 D. +0.5 to Activity 2 and +1.0 to Activity 12	A. 0 (base) B. +1.0 to Activity 2 C. +6.0 to Activity 2 D. +6.0 to Activity 2

- A more sophisticated, probabilistic (via Monte Carlo simulation) integrated cost and schedule model was developed to represent the more detailed flowchart and implemented with the more refined unmitigated base and risk assessments.
- Uncertainties in unmitigated project performance (i.e., project completion date and cost through construction, both unescalated and escalated) were determined (e.g., see Figure D.5).
- Contributions of each risk and base uncertainty toward the target (80th percentile) escalated cost through construction and project completion date were determined; for example, PD13 contributes $0.2 million to 80th percentile of escalated project cost, and ranks 13th.

RISK MANAGEMENT PLANNING FOR QDOT PROJECT

After risk assessment and prioritization, QDOT followed the principles and process outlined in Chapter 8 of the guide to identify and plan specific risk management actions to address the key risks to its project objectives, both individually and collectively, as documented in the RMP (Appendix E). The complete project RMP consisted of (1) proactive risk reduction plans (Section 5 of the RMP), (2) contingency management actions per QDOT procedure (by project phase) (Section 7 of the RMP), and (3) recovery plans (by project phase) (Section 8 of the RMP).

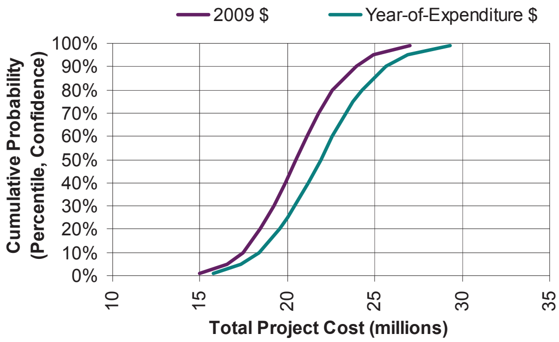


Figure D.5. *Unmitigated project performance (cost) uncertainty.*

QDOT first focused on identifying cost-effective actions for the highest-rated (i.e., highest-priority) risks, considering synergy among risk management actions as appropriate. For each of the high-ranking risks, the following was done (see Table D.6): (a) possible proactive risk management actions were identified; (b) the estimated mean cost, schedule, and/or disruption (by activity) to implement each action was assessed; (c) the anticipated mean effectiveness regarding reducing the various risk factors from each action was assessed; and (d) the overall cost-effectiveness (in terms of reduction in severity) for each action was calculated (using the Microsoft Excel workbook template). Cost-effective actions were then selected, and responsibility and schedule for implementing those actions were established (see Table D.7).

TABLE D.6. RISK REDUCTION ACTION EVALUATION FOR SELECT RAPID RENEWAL RISK FOR QDOT US-555/SH-111 PROJECT

Risk or Opportunity Addressed[a]	Potential Risk Management Actions[b]	Change in Base Factors	Change in Risk Factors
RU3. Unwilling sellers	QDOT's principal risk from unwilling sellers is increased right-of-way (ROW) acquisition cost. Hence, QDOT could take the following actions to reduce this risk (see Table B.11): • *Make reasonable, early offers*: Conduct thorough research on the values of these properties and present reasonable offers to the property owners. Do this early to provide more time to reach negotiated settlements (and therefore avoid court proceedings). This action would likely reduce the probability of cost increase, but not the magnitude of a cost increase if it occurs.	+$0.05M To ROW; minor delay and disruption	Reduce Probability of occurrence cut in half (from *H* to *M*); minor change in impacts

Note: Cost-effectiveness of this action was determined to be a net savings of about $250,000 (regarding change in severity, in equivalent YOE), which was the fourth highest of the actions identified.

[a] See risk register for description.

[b] Proactive actions: mitigate, avoid, allocate.

TABLE D.7. RISK REDUCTION PLAN FOR SELECT RAPID RENEWAL RISK FOR QDOT US-555/SH-111 PROJECT

Risk or Opportunity Addressed[a]	Potential Risk Management Actions	Responsibility	Schedule
RU3. Unwilling sellers	QDOT's principal risk from unwilling sellers is increased right-of-way (ROW) acquisition cost. Hence, QDOT could take the following actions to reduce this risk (see Table B.11): • *Make reasonable, early offers:* Conduct thorough research on the values of these properties and present reasonable offers to the property owners. Do this early to provide more time to reach negotiated settlements (and therefore avoid court. proceedings). This action would likely reduce the probability of cost increase, but not the magnitude of a cost increase if it occurs.	Project engineer – design manager (design) and ROW manager (public outreach)	Midway through ROW/utilities/ railroad, implement now; check by end of 30% design

[a] See risk register for description.

[b] Proactive actions: mitigate, avoid, allocate.

QDOT then determined the revised base and residual risks (assuming the selected risk reduction actions were actually implemented), from which they determined approximate mitigated mean project performance (i.e., for completion date and escalated cost) in the same way (using the Microsoft Excel workbook template) as for unmitigated mean project performance (as documented in Section 6 of the RMP in Appendix E). On the basis of this information, in conjunction with industry guidance, QDOT used judgment to establish appropriate contingency requirements (as documented in Section 7 of the RMP) and recovery requirements (as documented in Section 8 of the RMP). Note: Subsequently, a quantitative risk analysis was conducted, which objectively determined the values for the specific QDOT-established target percentiles of 80% and 95% confidence of the mitigated project performance (i.e., completion date and escalated cost) for establishing contingency and recovery requirements, respectively; this was done in the same way as for unmitigated project performance (see RMP Addendum X in Appendix E).

RISK MANAGEMENT IMPLEMENTATION FOR QDOT PROJECT

After QDOT developed the RMP (see Appendix E), its implementation was adequately supported by management and adequately resourced (according to the principles outlined in Chapter 9 of the guide and as documented in Section 9 of the RMP). The RMP included an organizational structure with specified responsibility and authority (i.e., the project manager served as the risk manager) to implement that RMP throughout project development. The project's designated risk manager then successfully implemented that RMP, including (see Figure D.6)

- Proactively and cost-effectively reducing individual risks that were within QDOT's control, including monitoring and updating the risks and the RMP as time progressed—several large risks were successfully reduced.
- Using established protocols for contingency control, including monitoring and periodic updating of contingency status (expended to date and capacity required for completion) and recommending contingency expenditure (to cover actual risk

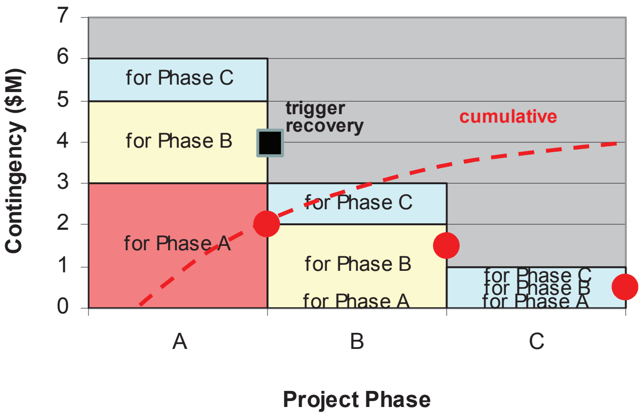


Figure D.6. *Contingency and recovery management.*

occurrences as needed) and releasing excess contingency (when no longer needed)—the initially established contingency was adequate throughout the project, with the unused contingency subsequently released.

- Using established protocols for recovery decisions, including monitoring and periodic updating of recovery status (achieved to date and capacity required for completion) and recommending recovery actions as needed when remaining contingency was not sufficient—no recovery actions were necessary.

IMPLEMENTING RISK MANAGEMENT PROCESS FOR QDOT PROJECT

To implement the risk management process on this project (as described in Chapters 2–9 of the guide and adopted in the RMP in Appendix E), QDOT did the following (as described in Chapter 10 and documented in the RMP):

- Assembled relevant project information (i.e., regarding scope, strategy/status, conditions/assumptions, cost estimate, schedule).
- Convened a group of key project team staff and independent subject-matter experts from the key project disciplines, facilitated by a qualified risk elicitor/analyst, to conduct risk assessment and risk management planning (consistent with the principles, processes, and guidance described throughout the guide), culminating in an RMP (including the risk register).
- Assigned a risk manager (with appropriate authority and resources) to implement the resulting RMP, including monitoring, updating, and/or recommending project risks, risk reduction plans, contingency, and recovery.

This process was well planned, supported by management, and adequately resourced. Adequate support and resources (including an organizational structure) were then provided to implement that plan throughout project development.

Construction of the QDOT project was successfully completed on January 31, 2013, at an inflated cost of $22.0 million (with $2.0 million remaining cost contingency and 2.0 months remaining schedule contingency), with few unanticipated problems and no recovery actions (see Table D.8).

TABLE D.8. PERFORMANCE OF QDOT US-555/SH-111 PROJECT

Project Performance	Base	Base + Contingency	Actual	Excess Contingency
Cost (YOE$M)	17.0	24.0	22.0	+$2.0
Schedule (months)	35.0	40.0	38.0	+2.0

E

RISK MANAGEMENT PLAN

CONTENTS

EXECUTIVE SUMMARY

QDOT is planning to reconstruct and expand segments of two existing (intersecting) highways, US-555 and SH-111, through a rapidly developing suburban area. QDOT wants to minimize cost, schedule, and disruption through construction and maximize longevity after construction. To achieve these objectives, QDOT will use design–build project delivery as well as encourage accelerated construction methods.

To further improve and control ultimate project performance when innovative methods are being used, QDOT conducted formal risk management. Such risk management involves appropriately anticipating and planning for potential problems (risks) as well as opportunities (negative risks), and is documented in this project *risk management plan*.

This risk management plan consists of the following elements:

- Description of the project;
- Identification of current risks and assessment of their factors;
- Analysis of project performance and ranking of risks in terms of their contribution to this project performance;
- Identification of ways to proactively reduce significant individual risks and evaluation of their cost-effectiveness;
- Selection, planning, and implementation of cost-effective ways to proactively reduce significant individual risks;
- Establishment and management of cost and schedule contingency to cover (to a high level of confidence) remaining risks throughout the project;
- Establishment and management of “recovery” plans (in case contingencies are insufficient); and
- Establishment of organizational structure and resources to successfully implement the risk management plan.

1.0 INTRODUCTION

1.1 Purpose and Objectives

The primary purpose of this risk management plan is to provide appropriate plans (and adequate justification of those plans) for improving and controlling “performance” (i.e., cost, schedule, disruption, and longevity) of the project, by focusing on controlling project risks (both individually and collectively).

Quantification of the uncertainty in project performance, for example, to help establish budgets, milestones, and contingencies at QDOT-specified confidence levels, is not currently part of the scope of this risk management plan but could be added later (e.g., by addendum).

1.2 Approach

The approach taken in developing this plan consists of the following steps:

- *Project Description (Section 2)*. Develop an adequate understanding of the project (as documented in a specific format) and its likely base (without "risk") performance (i.e., regarding schedule, cost, and disruption through construction, and postconstruction longevity). As part of this, develop a simple but adequate cost- and disruption-loaded project schedule.
- *Premitigation Risk Identification and Assessment (Section 3)*. Develop a comprehensive and nonoverlapping set of project performance risks, which are possible events that, if they occur, can change project performance, and categorize the list by when during project development the risks would occur. For each of the risks, adequately assess the factors defining those risks, including the likely impacts (e.g., change in unescalated cost to a particular project activity) if the risk occurs, and the likelihood of the event (as defined by those impacts) occurring.
- *Premitigation Risk Analysis (Section 4)*. Determine likely project performance, including the risks, and especially the relative significance of the various risks in affecting that performance ("sensitivity"), before any additional mitigation.
- *Risk Reduction Planning (Section 5)*. Identify possible actions to proactively reduce individual risks, focusing on the most significant risks, and evaluate their cost-effectiveness. Select and adequately plan (i.e., assign responsibility and resources) the set of cost-effective actions.
- *Postmitigation Risk Analysis (Section 6)*. Determine likely project performance, including the risks, and especially the relative significance of the various risks in affecting that performance ("sensitivity"), considering additional mitigation.
- *Contingency Management (Section 7)*. Establish contingency requirements (cost and schedule allowances) for the various phases of project development, based on likely project performance considering collectively the residual risks for each phase if the risk reduction plans are adopted and implemented. Also establish adequate procedures for how those contingencies will be controlled.
- *Recovery Planning (Section 8)*. Establish plans for what to do if contingencies turn out to be insufficient (e.g., defer scope through contract options) during various phases of project development. Also establish adequate procedures for how those plans will be triggered.
- *Risk Management Plan Implementation (Section 9)*. Identify the organizational structure and resources required to successfully implement this risk management plan.

Each of the above steps is briefly discussed in the following sections, with details presented in attachments. A filled-in planning template for a hypothetical project is available at http://www.trb.org/Main/Blurbs/168369.aspx.

2.0 PROJECT DESCRIPTION

2.1 Project Summary

QDOT is planning to reconstruct and expand segments of two existing (intersecting) highways, US-555 and SH-111, through a rapidly developing suburban area. The existing highways are nearly 40 years old, have increasingly inadequate capacity, and are expensive to maintain. These facilities are the only viable east-west (US-555) and north-south (SH-111) routes for commercial traffic for several miles in either direction. Therefore, it is imperative that the necessary improvements be made quickly and with minimal disruption. QDOT would also like to minimize construction costs and future repair cycles and maintenance requirements, as well as eventual replacement issues.

To achieve these objectives, QDOT plans to encourage contractor innovation through the use of performance-based specifications and incentives, and to procure with an innovative project delivery method (i.e., design–build or D-B). It is expected that accelerated bridge construction techniques, minimally disruptive maintenance of traffic, and innovative pavement design, among other rapid renewal elements, will be considered for this project.

A detailed project description, including major assumptions and conditions, is presented in Attachment 1.

2.2 Base Project Schedule

As presented in Attachment 2 (which includes Tables E.1, E.2, and E.3), for the assumptions outlined above, the base project schedule (without risk) was developed from QDOT's latest project schedule, using a standard simplified project flowchart for D-B with base durations, lags, and milestones for the various activities. QDOT's project schedule was first reviewed and "de-biased," removing any float. In general terms of overall preconstruction and construction schedules, the base project schedule (before risk and opportunity) is 18 months from present time to reach contractor notice to proceed (NTP), then 17 months for D-B design and construction, with a target completion date of November 1, 2012. The project team is also assuming a 50-year time to replacement (which takes 2 years).

2.3 Base Project Cost

As presented in Attachment 2 (Tables E.1 and E.3), for the assumptions outlined above, the base project cost (without risk) was developed from QDOT's latest cost estimate and allocated to the activities in the D-B standard simplified project flowchart, to create a simple cost-loaded schedule. QDOT's project cost estimate was first reviewed and de-biased, removing any contingency. The base total project cost (through delivery, without contingency) is approximately $16.4 million in current (uninflated) dollars. By major project component or phase, the base costs (in current uninflated dollars) are approximately as follows:

- For capital project delivery:
  - $1.2 million for QDOT preconstruction effort (including preliminary design, contract procurement, environmental documentation, and permitting);

  - —$2.0 million for right-of-way (ROW) acquisition;
  - —$1.0 million for utility relocations;
  - —$11.9 million for D-B design and construction plus QDOT contract administration.
- For postconstruction:
  - —Operations and maintenance costs average about $0.5 million per year.
  - —Replacement costs are about the same as the current project delivery costs ($16 million).

On average, mean inflation is about 3.0% per year for engineering, 3.0% per year for ROW and 3.0% per year for construction. Mean extended overheads (i.e., delay costs) associated with schedule delays are about $0.10 million per month for preconstruction and about $0.23 million per month during construction, based on average "burn rates."

2.4 Base Project Disruption

As presented in Attachment 2 (Tables E.2 and E.3), for the assumptions outlined above, QDOT estimates its total disruption (through replacement) at about 2.8 million hours. By major project component or phase, the mean disruptions are approximately determined (considering how much of that phase experiences disruption, how many people are affected during disruption and the impact) as follows:

- Utility relocation: 0.2 million hours.
- Construction: 0.5 million hours.
- Operations and maintenance: 1.4 million hours.
- Replacement: 0.7 million hours.

2.5 Trade-offs

As presented in Attachment 2 (Table E.3), QDOT has established the following trade-offs for combining performance (cost, disruption, schedule, and longevity):

- The "value" (or user costs) of disruption (in terms of how much QDOT is willing to pay now to avoid disruption) is about $10 per person-hour.
- The value of the planned completion date (in terms of how much QDOT is willing to pay now to prevent delay) is about $0.1 million per month.
- The value of longevity (in terms of how much QDOT is willing to pay now to prevent discounted longevity costs) is about $1.00 per net present value (NPV) dollars.
- The net long-term (during operations and replacement) discount rate (for determining longevity NPV dollars) is about 5.0% per year.

2.6 Base Project Performance Analysis

As presented in Attachment 2 (Table E.3), the following mean base project performance measures were determined (using a Microsoft Excel workbook template) based on the D-B standard simplified project flowchart (Figure E.1), using mean input values (as discussed above):

- Mean base project schedule (start and end dates, float);
- Mean base project cost (both uninflated and inflated) through construction;
- Mean base project disruption through construction;
- Mean base project longevity (combined measure of postconstruction project cost, schedule, and disruption); and
- Mean combined project performance (combined measure of cost, schedule, and disruption through construction, and postconstruction longevity, for subsequently determining severity of risks).

The mean base performance produced by quantitative risk analysis might differ from that produced by the template for several reasons: (a) the quantitative risk analysis is typically done in more detail; and (b) the means of the input ranges used in quantitative risk analysis might differ from the directly assessed mean inputs used in the template.

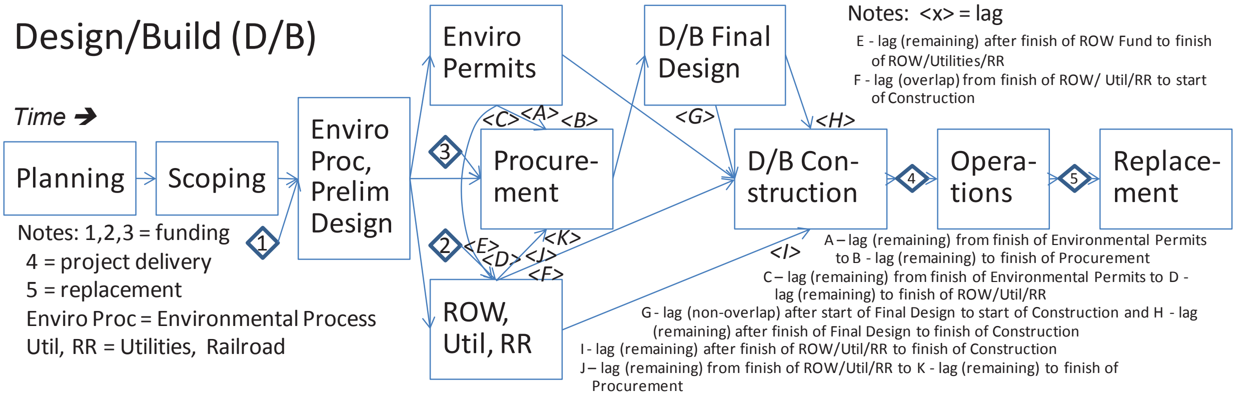


Figure E.1. *Standard simplified design–build flowchart for QDOT's US-555/SH-111 mean-value risk assessment.*

3.0 PREMITIGATION RISK IDENTIFICATION AND ASSESSMENT

3.1 Assumptions and Exclusions

Assumptions are necessary for any analysis, and the results of the analysis must clearly state the assumptions on which they are based. Risk assessments attempt to include all relevant issues so that the results are as inclusive and robust as possible (i.e., the results will "stand the test of time"). The more risks that are excluded, the more "constrained" or "conditional" the results are. However, in many cases an owner has good reason to exclude particular issues from the analysis. The major assumptions for (and exclusions from) this risk assessment are shown in the bulleted items below. *All results presented are conditional on these assumptions being true* (unless noted specifically).

- Uncertainty in the timing or availability in funding (e.g., cash-flow constraints or contractor financing) was excluded. These issues could be addressed with separate model scenarios.
- "Project-canceling" risks were excluded (e.g., significant change in purpose and need).

In other words, the question being addressed is, "How much will the project cost and how long will it take if it is funded and completed as currently planned?"

3.2 Premitigation Risk Register

In a facilitated environment, the project team and project-independent subject-matter experts identified a comprehensive, nonoverlapping set of risks and opportunities relative to the project base, first by brainstorming and then by categorizing, editing, and/or adding. These risks to project cost, schedule, and disruption were documented in the *risk register.*

Each risk and opportunity is defined by several risk factors:

- The cost, duration, and/or disruption changes to specific flowchart activities (i.e., the "impact scenario") if the risk occurs, and
- The probability of occurrence (as defined by the impact scenario), recognizing that the chance that the risk event does not occur (i.e., no impacts) equals 1.0 minus the probability of occurrence.

The group (by consensus) characterized each of these risk factors in a mean-value (i.e., probability-weighted average) sense, via either mean values (e.g., in dollars and months) or predefined mean risk ratings (e.g., *H*, *M*, *L*). These factor assessments were also documented in the risk register.

The full risk register (before mitigation) and associated risk-factor rating scales are presented in Attachment 3:

- Table E.4 presents the risk-factor rating-scale definitions (from the Microsoft Excel workbook template); and
- Table E.5 presents the risk register, in terms of a categorized list of risks (from the Microsoft Excel workbook template) that has been edited and added to so that the list is comprehensive and nonoverlapping, and their mean-value or mean-

rating-factor assessments before additional mitigation (from the Microsoft Excel workbook template).

A mean-rating-factor or mean-value risk assessment approach (as used here) provides single mean values or ratings of project performance, essentially ignoring uncertainties and correlations among those uncertainties. To formally address such uncertainties and correlations and to produce ranges (probability distributions) rather than single mean values, a quantitative risk analysis should be conducted.

4.0 PREMITIGATION RISK ANALYSIS

The base performance factors (as summarized in Chapter 2) and the risk factors before mitigation (as summarized in Chapter 3) were appropriately combined (using the Microsoft Excel workbook template) to determine the following:

- Approximate mean values of base + risk project performance before any additional mitigation, including:
  - —Project schedule (duration, start and end dates, and float by activity, and key milestone dates);
  - —Project cost (unescalated and escalated, by activity and collectively);
  - —Project disruption (by activity and collectively);
  - —Project longevity (combination via trade-offs of postconstruction schedule, cost, and disruption); and
  - —Project combined performance (combination via trade-offs of escalated project cost, schedule, and disruption through construction, and longevity).
- Mean severity of each risk, in terms of its contribution to mean combined project performance before any additional mitigation, and ranking of risks on that basis. Severity is an expression of how much QDOT would logically be willing to pay (on average, for various reasons) to eliminate that risk.

The following results are presented in Attachment 4:

- Premitigation base + risk project performance is presented in Table E.6. However, these mean values of project performance are very approximate (for various reasons) and should be used with caution. More accurate results would require quantitative risk analysis, which is currently outside the scope of this risk management plan.

The top risks are presented in rank order of mean severity, in tabular form (Table E.7) and graphically (Figure E.3).

5.0 RISK REDUCTION PLANNING

In a facilitated environment, the project team and project-independent subject-matter experts:

- First identified possible ways to reduce the significant risks (and exploit the significant opportunities), as discussed in Chapter 4; and
- Then assessed (by consensus) the various factors that define the cost-effectiveness of each action in reducing risks (or exploiting opportunities), thereby improving project performance. These factors include
  - —Mean changes in the base factors (cost, schedule, and disruption by activity) associated with implementing the action (regardless of effectiveness), for example, Action A will cost about $1.0 million to implement; and
  - —Mean changes in the risk factors (cost, schedule, and disruption impacts by activity, and probability of occurrence) as a result of that action, for example, Action A will reduce the probability of Risk R occurring by about 1/2.

These actions, and their assessed factors, were documented in the risk reduction plan.

The cost-effectiveness of each action was then determined (in terms of its net change in combined project performance) by appropriately combining the above information (along with trade-offs, using the Microsoft Excel workbook template). Cost-effective actions were then selected and plans developed for them, including responsibility and schedule for completion.

The risk reduction plan, presented in Attachment 5, includes the following:

- The possible risk reduction actions for the highest-ranking risks are identified in Table E.8.
- The assessed cost-effectiveness factors for each action are documented in Table E.8.
- The calculated (using the Microsoft Excel workbook template) cost-effectiveness of each action is presented in Table E.9.
- The selected cost-effective set of actions and plans for implementing them are presented in Table E.10.
- The calculated (using the Microsoft Excel workbook template) postmitigation risk register (in terms of mean value/ratings) for the selected set of actions is presented in Table E.11.

6.0 POSTMITIGATION RISK ANALYSIS

The base performance factors (as summarized in Chapter 2) and the mitigation implementation and risk factors after mitigation (as summarized in Chapter 5) were appropriately combined (using the Microsoft Excel workbook template) to determine the following:

- Approximate mean values of base + risk project performance considering additional mitigation, including
    - —Project schedule (duration, start and end dates, float by activity, and key milestone dates);
    - —Project cost (unescalated and escalated, by activity and collectively);
    - —Project disruption (by activity and collectively);
    - —Project longevity (combination via trade-offs of postconstruction schedule, cost, and disruption); and
    - —Project combined performance (combination via trade-offs of escalated project cost, schedule, and disruption through construction, and longevity).
- Mean severity of each risk, in terms of its contribution to mean combined project performance considering additional mitigation, and ranking of risks on that basis. Severity is an expression of how much QDOT would logically be willing to pay (on average, for various reasons) to eliminate that risk.

These following results are presented in Attachment 6:

- Mitigated base + risk project performance is presented in Table E.12. However, these mean values of project performance are very approximate (for various reasons) and should be used with caution. More accurate results would require quantitative risk analysis, which is currently outside the scope of this risk management plan.
- The top risks are presented in rank order of mean severity, in tabular form (Table E.13) and graphically (Figure E.4).

7.0 CONTINGENCY MANAGEMENT

Contingency funds and float are needed on top of the base cost and schedule, respectively, to adequately cover (with appropriate confidence) the risks that actually occur during a project. Clearly, such contingencies generally cannot be based on worst-case assumptions, because that would usually be unaffordable (e.g., commit too much money and time, possibly starving other projects). Instead, a reasonable level of confidence is needed, appropriately reflecting the “pain” of exceeding available contingency; that is, the more pain that is involved, the higher the confidence level should be. In the past, cost contingencies have often been based strictly on judgment (with industry guidance), as a percentage of the project cost; however, such empirically derived contingencies have often proven to be inadequate, although occasionally they prove to be excessive. Often, there is no explicit schedule contingency, resulting in missed milestones.

The amount of cost and schedule contingency needed for each phase would ideally be developed by quantitative risk analysis, in which the uncertainty in project cost and schedule would be determined and the values associated with a specified confidence level (which would be a QDOT policy issue) could be identified. In the absence of such analyses, judgment must be used. Hence, the contingency required for this project through each project phase was identified in a facilitated workshop with the project team and project-independent subject-matter experts, considering the risks for each phase (see Attachment 7).

A specific protocol has been established for managing contingency expenditures and release (see Attachment 7).

8.0 RECOVERY PLANNING

Various actions can be taken throughout project development if contingency becomes insufficient. For example, if remaining schedule contingency has become (or is becoming) insufficient to cover the remaining risks, work can sometimes be accelerated (albeit at a premium price) by working more or longer workshifts or critical path scope can be deferred (e.g., through contract options). As another example, if remaining cost contingency has become (or is becoming) insufficient, then generally either additional funds must be obtained (e.g., from program reserve) or some scope must be deferred (e.g., through contract options).

The amount of recovery needed for each phase would ideally be developed in the same way as contingency should be, that is, by quantitative risk analysis. In the absence of such analyses, judgment must be used. Hence, the recovery required for this project through each project phase was identified in the same facilitated workshop with the project team and project-independent subject-matter experts as for establishing contingency, considering the risks for each phase (see Attachment 8). The recovery actions (and their approximate net recovery value) that are available and that satisfy the requirements for this project through each project phase were identified in a facilitated workshop with the project team and project-independent subject-matter experts (see Attachment 8).

A specific protocol has been established for implementing the recovery plans (see Attachment 8).

9.0 RISK MANAGEMENT PLAN IMPLEMENTATION

To successfully implement this risk management plan, and thereby realize improved project performance, the following is required:

- DOT commitment to the risk management plan.
- Designated project risk manager, with adequate authority and resources to carry out this risk management plan to
  - Monitor and periodically update the risk register, that is, regarding changes in risk factors and in associated results.
  - Monitor and periodically update this risk management plan, that is, regarding:
    - Status/progress and results of selected risk reduction actions and possible redirection;
    - Adequacy of remaining contingency and recommendations regarding contingency management and implementation of recovery plans; and
    - Status/adequacy of recovery plans.

Monitoring is typically done via short interviews with select project staff (e.g., as part of weekly or monthly project progress meetings), whereas updating requires additional effort (e.g., short workshop). Adequate information systems are required to support implementation of the risk management plan, for example, regarding gathering, interpreting, and distributing relevant information.

10.0 CONCLUSIONS

A suitable risk management plan has been defensibly developed for the QDOT US-555/SH-111 project to improve and control project performance (i.e., schedule, cost, and disruption through construction and postconstruction longevity). This plan consists of three main elements:

1. A program of actions intended to proactively and cost-effectively reduce the significant project risks, where the risks were meaningfully evaluated in terms of their severity with respect to the project's combined performance (combination via trade-offs of schedule, cost, and disruption through construction and post-construction longevity).
2. Establishment and management of cost and schedule contingency throughout project development to cover the remaining risks (collectively) with a high level of confidence.
3. Establishment and management of recovery plans throughout project development in case the remaining contingency is insufficient.

In addition, the requirements for successfully implementing this risk management plan have been identified, for example, organizational structure and resources.

ATTACHMENT 1. PROJECT DESCRIPTION

QDOT is planning to reconstruct and expand segments of two existing (intersecting) highways, US-555 and SH-111, through a rapidly developing suburban area (see Figure E.2). The existing highways are nearly 40 years old, have increasingly inadequate capacity, and are expensive to maintain. These facilities are the only viable east-west (US-555) and north-south (SH-111) routes for commercial traffic for several miles in either direction. Therefore, it is imperative that the necessary improvements be made quickly and with minimal disruption. QDOT would also like to minimize construction costs, future repair cycles and maintenance requirements, and eventual replacement issues. To achieve these objectives, QDOT plans to encourage contractor innovation through the use of performance-based specifications and incentives, and to procure with an innovative project delivery method (i.e., design–build or D-B). It is expected that accelerated bridge construction techniques, minimally disruptive maintenance of traffic, and innovative pavement design, among other rapid renewal elements, will be considered for this project.

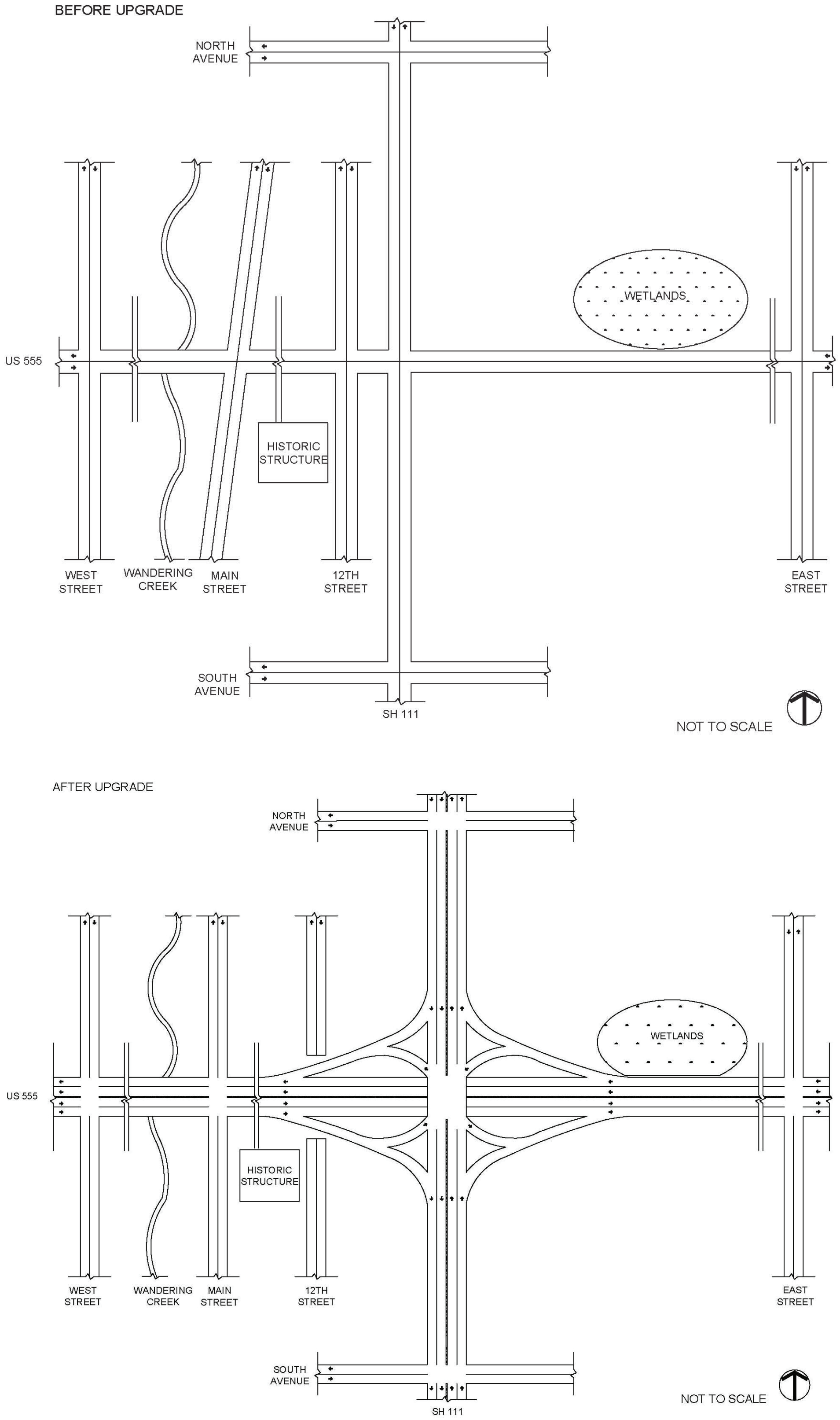


Figure E.2. *QDOT US-555/SH-111 project schematic before and after upgrade.*

Detailed Scope (Including Alternatives)

- Upgrade the existing unlimited-access, two-lane US-555 into a limited-access, four-lane highway. This includes reconstruction of the existing roadway section.
  - —The limits of the upgrade are still not established, but the current assumption is from just west of West Street (1 mile west of SH-111) to just east of East Street (1 mile east of SH-111), including signalized intersections at each street.
  - —US-555 will have four 11-ft lanes and no shoulders. A concrete median barrier will separate eastbound and westbound lanes. Concrete pavement is assumed for longevity; however, QDOT is open to innovative designs (e.g., composite pavement) from the contractor. QDOT currently assumes that FHWA will approve a design exception / deviation to build the facility with 11-ft lanes and no shoulders.
  - —QDOT anticipates that US-555 will be widened to the north of the existing facility where possible because right-of-way is more readily available to the north. Even with no shoulders as assumed, and if the roadway embankment is supported by retaining walls as assumed, widening to the north will affect a 10- to 15-ft-wide strip of existing Class 3 wetlands along the east half of the upgrade. The cost estimate assumes this alternative.
- Upgrade the existing unlimited-access, two-lane SH-111 into a limited-access, four-lane highway. This includes reconstruction of the existing roadway section.
  - —The limits of improvement for SH-111 are from just north of North Avenue (1/2 mile north of interchange) to just south of South Avenue (1/2 mile south of interchange), including signalized intersections at each avenue.
  - —SH-111 will also have four 11-ft lanes and no shoulders. A concrete median barrier will separate northbound and southbound lanes. Concrete pavement is assumed for longevity; however, QDOT is open to innovative designs from the contractor. QDOT currently assumes that FHWA will approve a design exception or deviation to build the facility with 11-ft lanes and no shoulders.
  - —QDOT envisions that the contractor could propose one of two major alternatives to accomplish this upgrade while meeting its objectives for the project:
    - ▪ *Rebuild on existing alignment*. Build a detour for SH-111 around the existing facility, switch traffic onto the detour, then rapidly construct the approach embankments, abutment, and the new bridge (overpass) using accelerated bridge construction (ABC) techniques on the existing alignment, then switch traffic back onto the new facility on the original alignment and demolish the detour. This alternative is most likely and is assumed in QDOT's current cost estimate.
    - ▪ *Split or shift alignment*. Instead of widening on the existing alignment, realign (and perhaps separate northbound and southbound) around the existing alignment. This would allow rapid construction of approach embankments and bridge structures out of traffic and would keep traffic on

the existing facility in the meantime. However, this approach would require more right-of-way (with greater business impacts) and is therefore not favored by QDOT. The city in particular is opposed to this alternative, as are at least two known public groups. Note that this alternative likely would not require ABC techniques.

- Convert the at-grade intersection of US-555 and SH-111 into a grade-separated interchange.
  - —QDOT anticipates that SH-111 will be carried over the top of US-555.
  - —The type of interchange has not been finalized (the interchange design will be a function of the selected alignment for SH-111 as mentioned previously). QDOT plans to issue performance-based specifications to enable contractor innovation, but currently assumes (and estimates) the following consistent with building on the existing alignment:
    - ▪ Single-point urban interchange. The existing ROW will accommodate this design, but this design might not provide the most operational benefit. Hence, other interchange designs might be feasible.
    - ▪ The structure type for the interchange has not been finalized, but the current assumption is a two-span, precast concrete–girder structure. QDOT anticipates that the contractor will propose some sort of ABC to complete the abutment and bridge construction more rapidly than with traditional methods.
    - ▪ The design currently assumes drilled-shaft foundations for the structural piers. However, potentially poor soil conditions might require ground improvement as well.
    - ▪ No on-site fill material is available for construction of the approach embankments, which are assumed to be retained fill to minimize ROW impacts.
- Realign the arterial (Main Street) intersection to be perpendicular to US-555 (from its current significant skew). Realignment of Main Street will require new ROW near the at-grade and signalized intersection. In addition, realigning Main Street will affect several old structures. The baseline assumption is that these structures do not contain any asbestos and are not eligible for listing on the National Register of Historic Places. The existing intersection of SH-555 with 12th Street will be removed (i.e., there will be no access to SH-555 from 12th Street).

Funding

The project is fully funded at this time. Federal funding is involved.

Design

- *Design Level*. The project is in preliminary engineering (<10% design). If design–build (D-B) delivery method is chosen, QDOT would complete preliminary design (to 30% design) before turning the project over to the D-B contractor.

- *Structural*. See above.
- *Geotechnical*. See above.
- *Drainage*. See below.
- *Pavement*. See above.
- *Systems*:
    - *Lighting*. The design currently assumes new lighting only in the interchange area. However, there is some push for new lighting throughout the project (most of this area is currently lit, but some of the lighting would have to be moved during the widening).
    - *Intelligent Transportation Systems (ITS)*. ITS upgrades will be completed separately (in the future) as part of a corridor-wide upgrade.
- *Design Deviations*. See above.

Environmental

- *Environmental Documentation*. The team is conducting an environmental assessment (EA) based on the assumption of nonsignificant ROW, wetlands, and potential historic impacts (because QDOT does not know what alignment/alternative the contractor will propose, it is assuming conservative impacts). Field studies are under way. The plan is to complete the draft EA before issuing the request for proposal (RFP) for D-B, and to have the EA finalized before issuing a notice to proceed for D-B.
- *Wetlands*. See above.
- *Streams*. US-555 crosses Wandering Creek half a mile west of Main Street. The existing crossing is a small box culvert that is still serviceable, and QDOT is not planning to replace it because QDOT believes it can be extended. However, on recent projects, the state fisheries agency has required QDOT to replace similar culverts with new larger culverts.
- *Endangered Species Act*. No known issues. No listed fish species are believed to inhabit Wandering Creek this far upstream.
- *Floodplain*. None.
- *Stormwater*. The project assumes curb-and-gutter stormwater runoff collection, with assumed conveyance to the city's existing combined stormwater/sanitary sewer system. The city has indicated that it might ask the project to pay for some upgrades to its system in exchange for the increased load, but this cost has not been included in the estimate. See also Utilities.
- *Contaminated/Hazardous Waste*. There could be some unanticipated contaminated soil or groundwater (likely hydrocarbons) in the interchange area. The estimate includes a small allowance for remediation of this material if exposed through foundation excavation. QDOT has not yet decided whether it will accept the risk of additional contamination, or allocate this risk to the contractor.

- *Section 106*. Potential historical buildings. See Detailed Scope.
- *4(f)*. No known issues.
- *Permitting*. A U.S. Army Corps of Engineers 404 permit is required for the planned wetland impacts. The base assumes this will be an individual permit, but if the design can be modified, wetland impacts could be less than anticipated and a nationwide 404 permit might suffice. QDOT will secure the necessary 404 permit before issuing the NTP to the D-B contractor.

Right-of-Way and Other Agreements

- *Right-of-Way.* As described above. The area is quickly developing within project limits, with development happening more rapidly near the US-555/SH-111 interchange. The cost estimate is based on today's estimated property values, but this might be insufficient to cover the increased values from planned developments.
- *Utilities*. A number of utilities (e.g., city water and sewer, electric power, telecommunications fiber optic, and natural gas lines) are believed to cross the project, primarily beneath the proposed interchange. QDOT currently assumes (and estimates) that these utilities will be relocated at the utilities' expense. These relocations would occur in advance of construction and QDOT assumes that the utilities will relocate their lines in a timely manner. However, utility coordination is just getting started, and:
    - —There is some indication that the telecommunication utility may seek a cost-sharing arrangement because it just completed the fiber-optic upgrade.
    - —The city does not have money to relocate its water and sewer lines and might not be able to relocate in the time needed by the project. It is possible that the city will try to negotiate (with QDOT) a combined solution for relocation of the water and sewer lines and use of the sewer system by QDOT.
- *Railroad*. None.
- *Other Stakeholders*. FHWA, the city, business owners, developers, traveling public, and residents.

Procurement

- *Delivery Method*. The project delivery method has not been selected, but the current assumption is a single D-B contract to facilitate contractor innovation and to improve QDOT's chances of meeting its objectives for the project. QDOT might also use contractor incentives to reward a shortened construction schedule and minimized user impacts during construction. (Note that incentives are not included in the cost estimate; there is significant resistance by some within QDOT to using incentives with D-B procurement.)
- *Contract Packaging*. See above.
- *Market (general and specialty)*. Current market conditions are uncertain. Because of the type and size of the project, and other projects currently under way or being

bid, as well as the local contractor situation, QDOT anticipates four "good" proposals in response to its RFP, which could enhance competition. However, the successful proposals for two other recent QDOT D-B projects in this region bid higher costs than QDOT's internal estimates.

Construction

- *Construction Access/Restrictions (including seasonal, events, and workshifts)*. There are no significant restrictions along mainline US-555 and SH-111. Construction access and staging areas are good.
- *Maintenance of Traffic*. To maintain mobility and minimize "user costs" (disruption) during construction, capacity equivalent to two lanes of US-555 and two lanes on SH-111 should be maintained during construction. However, QDOT anticipates that the contractor could propose alternatives, such as directional or full closures over short durations, to complete construction while minimizing disruption to the traveling public and minimizing construction schedule.
- *Construction Phasing*. This has not been worked out in detail (QDOT does not know how the D-B contractor will build the project), but it is assumed that the interchange and roadway work can proceed simultaneously. QDOT hopes that the construction schedule for structures can be minimized through use of ABC.

Postconstruction (Longevity)

- *Operations and Maintenance*. Operations and maintenance (O&M) for this roadway is expected to be typical, primarily involving periodic repaving (e.g., every 10 years) and system (e.g., drainage system) maintenance as required. Such work can generally be done with limited lane closures and thus little disruption.
- *Replacement*. Roadway replacement (especially structures) is anticipated to be required after about 50 years. Such replacement is expected to be very similar (in terms of activities and effort, and thus cost, schedule, and disruption) to the current project; that is, there are no elements that would be especially difficult to replace.

ATTACHMENT 2. BASE PROJECT PERFORMANCE

Project performance of interest generally consists primarily of

- Schedule (especially through construction);
- Cost (both unescalated and escalated, especially through construction);
- Disruption (especially through construction); and
- Longevity (combination of schedule, cost, and disruption after construction).

Such performance is a combination of base (without risk) and risk components. This attachment discusses the base component; the risk component is discussed in Attachment 3. The base component is typically derived from project team estimates (e.g., of schedule, cost, and disruption), which are reviewed and possibly revised to remove any bias (e.g., conservatism) and stripped of any other contingency (which will be replaced by the risk component). However, for now, the focus is only on performance through construction.

Project Schedule Estimate

The current project schedule estimate consists of the following key elements (as of December 1, 2009):

- Remaining preliminary design and environmental process, 12 months long;
- Environmental permitting, 6 months long, which starts after preliminary design and environmental process are completed;
- ROW/utilities/railroad, 12 months long, which starts after preliminary design and environmental process are completed, but cannot be finished until environmental permitting is done and ROW funding is available;
- Procurement, 6 months long, which starts after preliminary design and environmental process are done and construction funding is available, but cannot be completed until environmental permitting is done and ROW/utilities/railroad is within 6 months of completion (i.e., QDOT is prioritizing ROW acquisition to get key parcels before issuing NTP to contractor, and so, procurement can be finished when only half of the ROW acquisition remains);
- D-B design, 6 months long, starts after procurement is completed;
- D-B construction, 16 months long, which starts after environmental permitting is done and at least 1 month after start of D-B design and with no more than 6 months remaining of ROW/utilities/railroad, and cannot be finished until at least 6 months after end of D-B design and at least 10 months after end of ROW/utilities/railroad;
- Operations, 50 years long, starts after construction is completed;
- Replacement, 2 years long, starts after operations is completed.

Project Cost Estimate

The current project cost estimate (through construction) is shown in Table E.1. For postconstruction, O&M costs average about $0.5 million per year, and replacement costs are about the same as the current project delivery costs ($16 million), all in 2009 dollars.

Project Disruption Estimate

The current project disruption estimate is shown in Table E.2.

Base Project Performance

The various inputs for the standard simplified D-B flowchart for this project (see Figure E.1) are summarized in Table E.3 in which they are used to calculate mean project performance (by activity and collectively): cost (unescalated and escalated), schedule (milestone dates), disruption, and longevity (postconstruction cost, schedule, and disruption), as well as combined performance. However, as previously noted, the focus for now is on performance through construction only.

TABLE E.1. PROJECT COST ESTIMATE

Quantity	Unit of Measure	Unit Cost ($)	Description of Work Items	Cost (2009 $)
Construction				
			Preparation	
21	acre	4,800.00	Clearing and grubbing	99,360
26,397	S.Y.	8.40	Removing cement concrete pavement	221,735
26,397	S.Y.	4.80	Removing asphalt concrete pavement	126,706
			Grading	
33,393	C.Y.	9.60	Roadway excavation incl. hauling	320,573
27,960	C.Y.	4.20	Common borrow incl. hauling	117,432
3,107	C.Y.	14.40	Gravel borrow incl. hauling	44,741
31,067	C.Y.	1.20	Embankment compaction	37,280
			Drainage	
42	each	2,160.00	Grate inlet Type 1 or 2	90,720
6	each	3,600.00	Drop inlet Type 1	21,600
21,120	L.F.	78.00	Plain st. culv. pipe 0.109 in. thick, 36 in. diam.	1,647,360
50	L.F.	1,800.00	St. stru. pipe arch 8-gauge, 20 ft 0 in. span	89,100
			Structure	
3,972	S.F.	145.00	Bridge no. (easy bridge)	575,940
			Surfacing	
27,047	ton	12.00	Crushed surfacing base course	324,564
			Cement concrete pavement	
16,696	C.Y.	110.00	Cement concrete pavement	1,836,560
882	S.Y.	146.00	Bridge approach slab	128,772
			Asphalt concrete pavement	
1,100	ton	36.00	Miscellaneous asphalt concrete pavement	39,600
			Erosion control and planting	
2	acre	2,400.00	Seeding, fertilizing, and mulching	4,800
1	est.	85,000.00	Temporary water pollution/erosion control	85,000
1,564	C.Y.	13.20	Topsoil Type B	20,645
1	est.	150,000.00	Miscellaneous landscaping	
			Traffic	
15,840	L.F.	120.00	Special concrete barrier Type 5	1,900,800
8	each	14,400.00	Permanent impact attenuator	115,200
214,000	L.F.	0.12	Paint line	25,680
1	L.S.	24,000.00	Permanent signing	24,000
			Other items	
4,000	L.F.	18.00	Temporary barrier glare screen	72,000
1	est.	12,000.00	Roadside cleanup	12,000
1	est.	6,000.00	Trimming and cleanup	6,000

(continued)

TABLE E.1. PROJECT COST ESTIMATE (continued)

Construction Subtotal A (before mobilization [mob], traffic control, and other miscellaneous items)				7,988,167
1	L.S.	399,408.36	Mobilization	399,408
1	L.S.	587,130.29	Traffic control (at 7% of subtotal A + mob.)	587,130
1	est.	1,006,509.07	Other misc. items (12% of subtotal A + mob.)	1,006,509
Construction Subtotal B (including mobilization, traffic control and other misc. items)				9,981,215
			Design–builder design fees (10% of B)	998,121
			Design–build construction total C	10,979,336
			Construction administration (8% of C)	878,347
			Agency Design, Environment, Permitting, and Procurement (10% of C + Construction admin.) (includes previous costs of $200,000)	1,185,768
			Right-of-way	2,000,000
			Utility relocations	1,000,000
			Project Subtotal D (before contingency)	16,043,452

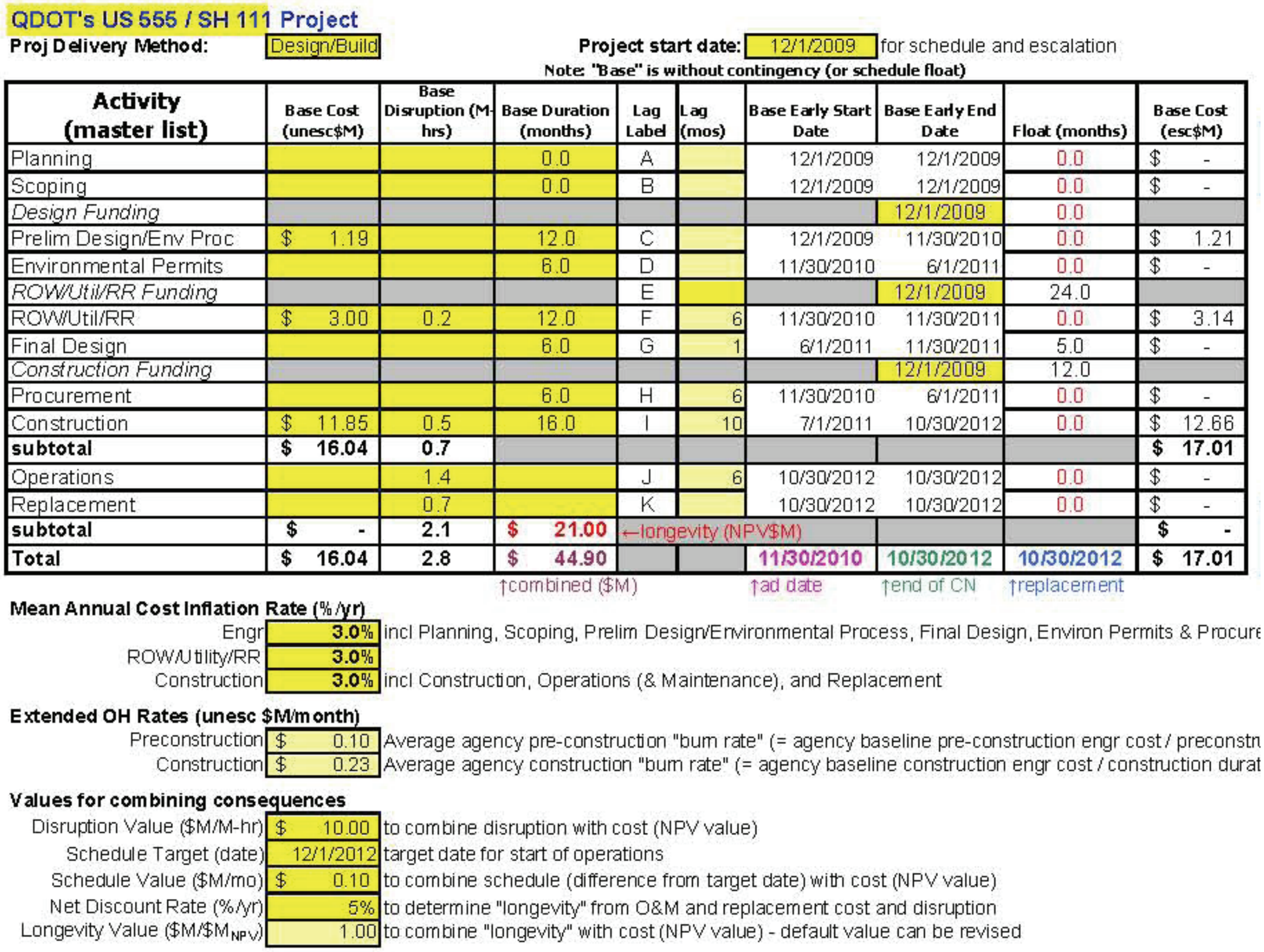
Note: Through construction only.

TABLE E.2. PROJECT DISRUPTION ESTIMATE

Activity	Duration of Activity (months)	Percentage of Activity Duration Affected	People Affected/Day	Delay/Person (hours)	Disruption (million hours)
Utilities	12	10	10,000	0.5	0.2
Construction	16	20	10,000	0.5	0.5
Operations	600	1	15,000	0.5	1.4
Replacement	24	10	20,000	0.5	0.7

Note: Including postconstruction.

TABLE E.3. BASE PROJECT PERFORMANCE



QDOT's US 555 / SH 111 Project

Proj Delivery Method: Design/Build

Project start date: 12/1/2009 for schedule and escalation

Note: "Base" is without contingency (or schedule float)

Activity (master list)	**Base Cost (unesc$M)**	**Base Disruption (M-hrs)**	**Base Duration (months)**	**Lag Label**	**Lag (mos)**	**Base Early Start Date**	**Base Early End Date**	**Float (months)**	**Base Cost (esc$M)**
Planning			0.0	A		12/1/2009	12/1/2009	0.0	$ -
Scoping			0.0	B		12/1/2009	12/1/2009	0.0	$ -
Design Funding							12/1/2009	0.0	
Prelim Design/Env Proc	$ 1.19		12.0	C		12/1/2009	11/30/2010	0.0	$ 1.21
Environmental Permits			6.0	D		11/30/2010	6/1/2011	0.0	$ -
ROW/Util/RR Funding				E			12/1/2009	24.0	
ROW/Util/RR	$ 3.00	0.2	12.0	F	6	11/30/2010	11/30/2011	0.0	$ 3.14
Final Design			6.0	G	1	6/1/2011	11/30/2011	5.0	$ -
Construction Funding							12/1/2009	12.0	
Procurement			6.0	H	6	11/30/2010	6/1/2011	0.0	$ -
Construction	$ 11.85	0.5	16.0	I	10	7/1/2011	10/30/2012	0.0	$ 12.66
subtotal	**$ 16.04**	**0.7**							**$ 17.01**
Operations		1.4		J	6	10/30/2012	10/30/2012	0.0	$ -
Replacement		0.7		K		10/30/2012	10/30/2012	0.0	$ -
subtotal	**$ -**	**2.1**	**$ 21.00**	←longevity (NPV$M)					**$ -**
Total	**$ 16.04**	**2.8**	**$ 44.90**			**11/30/2010**	**10/30/2012**	**10/30/2012**	**$ 17.01**
			↑combined ($M)			↑ad date	↑end of CN	↑replacement	

Mean Annual Cost Inflation Rate (%/yr)

Engr	3.0%	incl Planning, Scoping, Prelim Design/Environmental Process, Final Design, Environ Permits & Procure
ROW/Utility/RR	3.0%	
Construction	3.0%	incl Construction, Operations (& Maintenance), and Replacement

Extended OH Rates (unesc $M/month)

Preconstruction	$ 0.10	Average agency pre-construction "burn rate" (= agency baseline pre-construction engr cost / preconstru
Construction	$ 0.23	Average agency construction "burn rate" (= agency baseline construction engr cost / construction durat

Values for combining consequences

Disruption Value ($M/M-hr)	$ 10.00	to combine disruption with cost (NPV value)
Schedule Target (date)	12/1/2012	target date for start of operations
Schedule Value ($M/mo)	$ 0.10	to combine schedule (difference from target date) with cost (NPV value)
Net Discount Rate (%/yr)	5%	to determine "longevity" from O&M and replacement cost and disruption
Longevity Value ($M/$M$_{NPV}$)	1.00	to combine "longevity" with cost (NPV value) - default value can be revised

Note: From rapid renewal risk management planning template (http://www.trb.org/main/blurbs/168369.aspx), through construction only. See also Figure E.1 for project flowchart.

ATTACHMENT 3. UNMITIGATED RISK REGISTER

The risk register for the project (as described in Attachments 1 and 2) was developed (by consensus) by a facilitated group of project team members and project-independent subject-matter experts, as follows:

- Risks were first brainstormed and then categorized, edited, and added to create a comprehensive and nonoverlappng set (see Table E.5 for the resulting set, and for initial steps, see the populated template for a hypothetical project online at http://www.trb.org/Main/Blurbs/168369.aspx). As previously noted, performance (and thus risks) through construction only is the focus.
- The factors that define risks (i.e., impacts and probability of occurrence) before any additional mitigation ("unmitigated") were then assessed for each of the risks in terms of mean value or mean ratings (see Table E.4 for rating-scale definitions for assessments, Table E.5 for the assessments for each risk, and the template for the hypothetical project online for a summary of those assessments).

TABLE E.4. RISK-FACTOR RATING SCALE DEFINITIONS

QDOT's US 555 / SH 111 Project

	Impacts if Event Occurs									Probability of Event Occurring (0=impossible to 1=guaranteed)			Severity (equivalent escalated $ million)		
	Cost Change (current unescalated $ million)			Schedule Change (months)			Disruption Change (million person-hours lost)								
Rating	Ranges (absolute or base %)	Low end of range	High end of range	Ranges (absolute or base %)	Low end of range	High end of range	Ranges (absolute or base %)	Low end of range	High end of range	Ranges	Low end of range	High end of range	Ranges (absolute or base %)	Low end of range	High end of range
VH	>25%	4.0	8.0	>12	12	24	>25%	0.2	0.4	0.7 to 1.0 (1:1)	0.7	1.0	>25%	4.0	8.0
H	10 to 25%	1.6	$ 4.00	4 to 12	4	12	10 to 25%	0.1	0.2	0.4 to 0.7 (2:3)	0.4	0.7	10 to 25%	1.6	$ 4.00
M	3 to 10%	0.5	$ 1.60	1 to 4	1	4	3 to 10%	0.0	0.1	0.2 to 0.4 (2:5)	0.2	0.4	3 to 10%	0.5	$ 1.60
L	1 to 3%	0.2	$ 0.50	0.25 to 1	0.25	1	1 to 3%	0.0	0.0	0.05 to 0.2 (1:5)	0.05	0.2	1 to 3%	0.2	$ 0.50
VL	0 to 1%	0.0	$ 0.20	0 to 0.25	0	0.25	0 to 1%	0.0	0.0	0.0 to 0.05 (1:20)	0.0	0.05	0 to 1%	0.0	$ 0.20
-VL	-1 to 0%	-0.2	$ -	-0.25 to 0	-0.25	0	-1 to 0%	0.0	0.0				-1 to 0%	-0.2	$ -
-L	-3 to -1%	-0.5	$ (0.20)	-1 to -0.25	-1	-0.25	-3 to -1%	0.0	0.0				-3 to -1%	-0.5	$ (0.20)
-M	-10 to -3%	-1.6	$ (0.50)	-4 to -1	-4	-1	-10 to -3%	-0.1	0.0				-10 to -3%	-1.6	$ (0.50)
-H	-25 to -10%	-4.0	$ (1.60)	-12 to -4	-12	-4	-25 to -10%	-0.2	-0.1				-25 to -10%	-4.0	$ (1.60)
-VH	<-25%	-8.0	$ (4.00)	<-12	-24	-12	<-25%	-0.4	-0.2				<-25%	-8.0	$ (4.00)
Base:	*16.04*			*35*			*0.7*						*16.0*		

Note: From rapid renewal risk management planning template (http://www.trb.org/main/blurbs/168369.aspx).

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
	Planning				
PL1 Excluded	**Project funding delayed or reduced** The project is currently funded for an amount that QDOT feels is adequate. However, if additional funding is required (i.e., if costs increase for various reasons), might be a delay in obtaining the additional funding. However, QDOT's objective is to evaluate the project's risk assuming funding is available without delay. Hence, QDOT wants to *exclude* uncertainty in funding at this time (but might later treat that uncertainty by defining separate "model scenarios" to evaluate the impact of various potential funding delays). Otherwise, *exclude* the risk that funding is canceled or substantially reduced (so that scope reduction is required, which would lead to a "different" project).				
PL2	**Opposition to removing access to US-555 from 12th Street** Several businesses rely on this access and might protest or challenge the removal of the access. However, removal of that access is necessary for the project. Hence, this design decision is unlikely to be reversed. However, some mitigation might be required as compensation.	*L*	+*VL* to D-B Construction	0	0

Note: See Table E.4 for risk-factor rating scale definitions; for risks through construction only. All cost impacts are assessed in current terms. Cost escalation is handled automatically through the simulation model, appropriately considering uncertainty in inflation rates and the affected project activities. Except for soft cost uncertainties that are addressed separately, and unless noted otherwise, all cost impacts in this table are fully loaded with appropriate markups. Potential markups include items that may be treated as a percentage of the construction subtotal in the cost estimate, such as sales tax, mobilization, construction engineering, design, and allowances for miscellaneous items.

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
PL3 Elsewhere	**Opposition to "splitting" alignment of SH-111 in the interchange area** The city does not like this alternative. This issue is captured as a factor influencing the probability that this split will occur; see Risk PD2.				
PL4 Minor	**Other stakeholder issues not captured separately**				
	Scoping				
SC1 Minor	Change in East-West project limits Project might be required (either for political or operational reasons) to improve longer or shorter stretch of US-555 than assumed in the base estimate. The project team and QDOT believe that this is unlikely because funding is not available for such a significant change, and the need is not clear (for the project to perform as desired).				
SC2 Minor	Change in North-South project limits Project might be required (either for political or operational reasons) to improve longer or shorter stretch of SH-111 than assumed in the base estimate. Similar to discussion for Risk SC1.				

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
SC3	**Additional local improvements required** For example: • More improvements on Main Street away from US-555 • More improvements on North Avenue and/or South Avenue away from SH-111 • More improvements on West Street and/or East Street away from US-555 Schedule impacts are design-related.	*M*	+*L* to D-B Construction	+*L* to Preliminary Design	0
SC4 Minor	**Increased aesthetics for US-555/SH-111 interchange** For example, "gateway" appearance, decorative lighting. The project already includes reasonable aesthetics, and a significant gateway theme is well outside the project's budget. The city would therefore have to pay for such improvements, which it is unlikely to be able to afford.				
SC5	**Replace culvert over Wandering Creek** Base assumes that the state fisheries agency will allow widening this culvert, especially since no listed fish species are believed to live this far up Wandering Creek. The fisheries agency has, however, required replacement of similar culverts on nearby projects.	*M*	+*L* to D-B Construction	0	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
SC6	**Provide new lighting throughout project** Base assumes new lighting only in the interchange area. The team increasingly believes that new lighting will be required throughout (mainly because they will have to relocate existing lighting to widen the roadway anyway).	*H*	+*M* to D-B Construction	0	0
SC7 Minor	**Intelligent transportation system (ITS) added to this project** Unlikely; not funded and the systemwide ITS development is lagging this project.				
	Preliminary Design and Environmental Process *For all relevant risks in this category, the following conditions apply*: Each risk includes all related or correlated design, environmental, right-of-way, and construction impacts. Impacts shown are in addition to any assessed base uncertainties.				

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TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
PD1	**Shift alignment of US-555 at east end of project** This would reduce wetland impacts by shifting alignment to the south. However, there is some resistance (city) to shifting the alignment this way because of the number of business displacements it would cause. It could also cause a problem with geometry at the intersection of East Street. The group therefore thinks that this is unlikely to occur. If it did, however, the impacts would include reduced wetland impacts, increased ROW costs (mostly due to additional demolition and business relocations), and additional design time. The change in construction cost would be minimal.	*VL*	+*M* to ROW, Utilities, Railroads	+*M* to ROW, Utilities, Railroads	0
PD2 Minor	**Split alignment of SH-111 at US-555 interchange** Instead of widening on existing alignment; would allow for more rapid construction but requires additional ROW. Benefits (reduced construction duration) probably do not outweigh the detriments (additional ROW, less efficient traffic flow, redesign). The city and at least two public groups do not like this alternative. Therefore, it is unlikely to occur.				

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TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
PD3	**Change in configuration of SH-111/US-555 interchange** QDOT's preliminary design (SPUI) is one of several viable alternatives, and it is expected that the contractor could propose a suitable alternative. It is uncertain how much such a change might cost relative to the currently assumed alternative (could be more, could be less), but QDOT will not accept a design that is significantly more expensive. Includes potential change in structure and foundation type/size, but assumes that an appropriate accelerated bridge construction technique will be used.	0	0 (Could be a significant increase or decrease with equal likelihood; hence, on average, no change)	0	0
PD4	**Ground improvement required in interchange area** QDOT HQ Design is also concerned that a recent change to the seismic design criteria (which is still being evaluated) might require localized ground improvement to mitigate for liquefaction potential. The project team thinks this is unlikely, but could have significant impacts if it occurs.	*L*	+*M* to D-B Construction	+*L* to D-B Construction	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
PD5	**Shoulders required on US-555** For example, if FHWA and QDOT HQ Design both do not approve the no-shoulder exception/deviation. The project team is reasonably confident that this design exception will be approved, based on recent, similar approvals for other nearby projects. However, if shoulders are required, the impacts are significant: additional ROW would be required, construction costs would increase, the draft environmental assessment (EA) might have to be modified (wetland impacts would increase), and design time (before request for proposal) would increase.	*VL*	+*H* to D-B Construction	+*M* to D-B Construction	0
PD6	**Shoulders required on SH-111** For example, if QDOT HQ Design does not approve the no-shoulder exception/deviation. Similar to the discussion and assessments for Risk PD5. For the quantitative risk analysis: Risk PD6 is correlated with Risk PD5. If Risk PD5 does not occur (shoulders not required on US-555), then it is likely that shoulders will not be required on this facility either. If Risk PD5 does occur, then shoulders will likely be required for SH-111 as well.	*VL*	+*H* to D-B Construction	+*M* to D-B Construction	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
PD7 Minor	**Additional cost for signalized intersections** Excludes any change in the number of intersections that is captured separately in risks related to project limits (i.e., Risks SC1 and SC2).				
PD8	**Change in pavement section and/or type** The base assumes concrete pavement to provide longevity (one of the project’s goals). QDOT is therefore most likely to specify a concrete pavement. Asphalt pavement might be selected to provide compatibility with existing pavement (beyond the project limits) and to save initial cost. However, QDOT considers maximizing longevity (including life-cycle costs) a higher priority than saving initial capital cost.	*M*	–*M* to D-B Construction	0	0
PD9 Minor	**Rehabilitate instead of reconstructing existing roadway (e.g., overlay instead)** See Guide, Appendix A, Appendix B, or Table B.9. Existing roadway is 20 years old; might not be cost-effective to rehabilitate when new lanes have to be built anyway. In addition, rehab is not as likely to meet the project objective of maximizing longevity of the facility. Note: for the quantitative risk analysis, this risk is correlated with Risk PD8 (impacts are a function of the outcome of that risk).				

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
PD10 Minor	**Change in stormwater design standards** The design incorporates the latest standards, which are only 2 years old. Hence, it is unlikely that new standards will emerge in this project's time frame.				
PD11	**Cannot use city sewer system for project runoff (or city charges for use)** The city might deny use or charge QDOT for various upgrades to the system to accommodate stormwater runoff from this project. The project team and QDOT management are "almost certain" that the city will ultimately allow use of the city's system (the city needs this project, and the additional load on the sewer system is not substantial), but will most likely ask for money to help upgrade its system. QDOT would probably capitulate as this is the best option from a cost and time perspective. This cost would occur during the project's "utility relocations" phase. This issue is correlated with the likely request by the city to help pay for a water- and sewer-line relocation (see Risk RU2 under Utilities risks). For the quantitative risk analysis, the group assesses that if Risk RU2 occurs (i.e., QDOT decides to help pay for relocation), then this risk is much less likely to occur.	*M*	+*M* to ROW, Utilities, Railroads	+*L* to ROW, Utilities, Railroads	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
PD12	**Structures affected by Main Street realignment are eligible for National Register of Historic Places** Can reasonably capture the range of credible possibilities with the following set of potential (mutually exclusive) scenarios or outcomes: A. Not historic structures (base assumption) B. Historic structures, but no significant impact to project cost or schedule (e.g., document, then acquire) C. Historic structures, creating significant impact to project cost or schedule (e.g., have to relocate structures; structures are contaminated; or have to shift project alignment to avoid)	*L*	+*M* to ROW, Utilities, Railroads	+*M* to ROW, Utilities, Railroads	0
PD13	**Change in environmental documentation** Only treat this issue here if not captured separately by specific triggers or issues elsewhere (e.g., design changes). Base assumes an EA, but an environmental impact statement (EIS) might be required if impacts are greater than assumed. Can reasonably capture the range of credible possibilities with the following set of potential (mutually exclusive) scenarios or outcomes: A. Complete EA as planned (base assumption) B. Complete EA with additional effort, but with no significant changes to the project C. EIS required, but with no significant changes to the project D. EIS required, resulting in significant change to the project design, ROW, and/or construction	*L*	+*M* to Preliminary Design/Environmental Process	+*H* to Preliminary Design/Environmental Process	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
PD14	**Delays completing environmental documentation** From various causes if not already captured separately (i.e., significant design changes; change in type of environmental documentation, Risk EP2). For example: • Additional impacts identified • Process delays (internal or external reviews, comments, and/or approvals)	*M*	No direct cost (schedule-related only)	+*M* to Preliminary Design/Environmental Process	0
PD15	Encounter unanticipated contamination in interchange area If encountered, likely to be hydrocarbon-based soil and/or groundwater contamination.	*M*	+*VL* to D-B Construction	0	0
PD16	**Additional wetland mitigation required for planned alignment** Additional mitigation could be required for various reasons. For example: • Change in mitigation requirements (ratios, buffers) • Change in wetland classification • Impacts different than assumed (i.e., underestimated originally) (this could happen for the current or shifted alignment) Note that for the quantitative risk analysis, this risk is partially a function of any potential shift in alignment at the east end of the project (Risk PD1). If Risk PD1 occurs and the base wetland impacts are reduced, the probability of this risk is reduced.	*M*	+*L* to D-B Construction	0	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
	Environmental Permits				
EP1 Minor	**Challenge to environmental determination or permits** For any reason not captured elsewhere. Could come from organized public groups for various reasons. However, very unlikely for the base project (chances could increase for some alternatives such as shifting the alignment at the east end of the project, but these impacts are captured in those risks).				
EP2	**Delay obtaining the 404 permit** From either internal or U.S. Army Corps of Engineers process delays (review, approval) or deficiencies in QDOT's application. Note that this risk is assumed to be approximately independent of Risks PD1 and EP6 (delay issues could occur regardless of the outcomes from those risks).	*L*	No direct costs (schedule-related only)	+*M* to Environmental Permits	0
	Right-of-Way				
RU1	**Uncertainty in ROW inflation rate** Regionally; before considering the localized effects of accelerating development, which is captured separately. Despite a sag in the economy, property prices have held steady, and appear to even be increasing slightly. However, this could change (e.g., if this area is lagging the economy). Over the short term of this project, local indicators and the ROW professionals anticipate an average increase of approximately 3%/year in the area.	*H*	+*M* to ROW, Utilities, Railroads	0	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
RU2	**Accelerating pace of development in interchange area** Beyond the regional ROW inflation rate captured in Risk RU1. Several new developments are planned in the area, and at least one could be implemented before this project is let. The impact to this project would be increased acquisition and perhaps relocation costs compared with what is currently assumed in the estimate.	*M*	+*M* to ROW, Utilities, Railroads	+*M* to ROW, Utilities, Railroads	0
RU3	**Unwilling sellers** Base cost excludes condemnation costs or allowance. This risk is separate from Risk RU2. Particularly in the US-555/SH-111 interchange area, property owners might not want to relocate, leading to increased cost to acquire ROW (e.g., have to go through condemnation). Note that condemnation does not normally extend the right-of-way acquisition time frame, because QDOT can usually quickly gain possession-and-use of condemned properties.	*H*	+*M* to ROW, Utilities, Railroads	0	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
RU4 In RU2	**Additional relocation or demolition required** Excludes additional relocation or demolition that might be required to accommodate changes in design or scope, which are captured as part of those separate risks. Excludes contamination, which is captured separately. For example, relocations from multitenant properties could be complex. The group assesses that this potential additional cost and time was captured in Risk RU2.				
RU5 Minor	**Additional ROW required for planned project** Excludes additional ROW that might be required for changes in design or scope, which are captured as part of those separate risks. For example, initial estimates for required ROW for the assumed design were incorrect or incomplete. The group assesses that the potential significant changes were captured as part of other risks.				
RU6	**Other delays to ROW planning** For reasons not captured as part of other specific risks. For example, late changes in design result in changes in ROW plans or internal QDOT delays to ROW plan development.	*M*	No direct costs (schedule-related only)	+*L* to ROW, Utilities, Railroads	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
	Utilities				
RU7	**Telecom utility wants a cost-sharing agreement** The Telecom's presence in the project ROW predates QDOT's, so QDOT cannot force relocation. The Telecom just recently replaced its fiber optic backbone, so it is not likely to replace it without some sort of cost sharing (or at least replace it within the time frame needed by this project).	*M*	+*L* to ROW, Utilities, Railroads	0	0
RU8	QDOT helps city pay for water- and sewer-line relocation See Guide, Appendix A (rapid renewal strategies and methods). To help maintain project schedule, QDOT might help pay for the sewer-line relocation. This "risk" is therefore really a project or policy decision within QDOT's control. This decision comes at a monetary cost but avoids schedule delay (as reflected to the right). Note that for the quantitative risk analysis, the outcome of this risk affects the likelihood of occurrence for Risk PD11.	*H*	+*M* to ROW, Utilities, Railroads	0	0
RU9 Minor	**Other utility relocations not completed on time** For issues not captured separately in other risks. For various reasons, including delayed negotiations, design, or relocation work itself.				

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TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
RU10 Minor	**Damage existing utility or encounter unanticipated utility during construction** Possible, but the time impacts are quickly mitigated. The cost impact would be the D-B contractor’s responsibility.				
	Contracting and Procurement				
CP1	**Uncertainty in construction-cost inflation rate** Excludes contracting market conditions and material supply issues, which are captured separately in Risks CP2 and CP3. This issue includes uncertainty in the general regional and national trends in construction-industry cost changes over time (general inflation), with reasonable adjustment for this region.	*H*	+*M* to D-B Construction	0	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
CP2	**Uncertain D-B contracting market conditions at time of bid** See Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Table B.14. Separate from general construction inflation and material supply issues, which are captured in Risks CP1 and CP3, respectively. This issue includes uncertainty in pricing strategy and other contractor competition factors. QDOT expects four proposals or bids, which could improve competition. However, recent experience for similar projects is that bids are coming in above QDOT's Engineer's Estimates. Can reasonably capture the range of credible possibilities with the following set of potential (mutually exclusive) scenarios or outcomes: A. Market conditions are favorable (competitive), and bids come in below the base estimate B. Market conditions are similar to that assumed in the estimate (minimal change from base) C. Market conditions are not competitive, and so bids are higher than the base but still acceptable (below threshold for canceling the procurement) D. Market is not competitive, and no acceptable bids are received, requiring rebidding and perhaps repackaging to get acceptable bids.	25% (Note: team thought ratings were insufficient to describe this risk)	+10% of base construction cost to D-B Construction	+1 to Procurement	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
CP3 Elsewhere	Material supply issues Various local factors could affect the availability of materials for this project. For example: • Cannot locate an appropriate fill source • Fill source is farther away than assumed • Aggregate prices are higher than anticipated • Steel prices are higher than anticipated • Cement prices are higher than anticipated The group believes that all of these issues are captured in either Risk CP1 or CP2.				
CP4 Minor	**Change in project delivery method** See Guide Appendix B, Summary Risk Checklist for Rapid Renewal Projects. Contract other than through the assumed single D-B contract. Only treat here if not already captured under the market conditions risk (CP2). It is unlikely that QDOT will change to a traditional delivery method (e.g., design–bid–build) given the rapid renewal-type objectives for this project. Other delivery alternatives are unlikely, either because enabling legislation does not exist or QDOT does not have adequate experience with those delivery methods.				

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TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
CP5 Minor	**Accelerate preconstruction activities to reach notice to proceed (NTP) sooner** See Guide, Appendix A and Appendix B. If not captured separately under Design, Environmental, and/or ROW risk categories. To reach NTP more quickly, QDOT could adopt a more aggressive preconstruction strategy. For example: • Moving to NTP before permitting is complete. • Could seek streamlined environmental process or design approval process (see Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Table B.3). However, it might be too late to implement these for this project (would have been better to plan for this in advance of starting work on the project). The group believes that a more aggressive permitting versus NTP strategy is possible, but introduces its own risks (i.e., if NTP is issued before the environmental permits are complete, then the contractor could have grounds for significant claims if permit conditions change relative to the RFP). Hence, it is unlikely for QDOT to pursue this strategy.				

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
CP6 Minor	**Use incentives to accelerate D-B construction** See Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Tables B.2 and B.14. The team believes that QDOT is unlikely to apply additional incentives; use of D-B delivery method and performance-based specs should provide adequate flexibility and incentive for the contractor to complete the project within QDOT's desired time frame.				
CP7	**Issues with D-B design or submittals** For example: • Internal QDOT or FHWA delays reviewing and approving submissions • Errors or omissions in D-B submissions	*M*	No direct cost (schedule-related only)	+*M* to D-B Design	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
CP8	**Other problems with D-B contract procurement** See Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Tables B.2 and B.14. Aside from issues captured separately (e.g., as part of market conditions risk). Note that project-canceling issues are excluded. Most of the remaining identified issues were assessed to be low likelihood and relatively low impact for this project. Hence, the group combined them into one larger issue and assessed their combined potential impacts. Even so, the group believes that a significant problem is unlikely (especially given QDOT's reasonable history for such procurements). If something did occur, the most likely impact to schedule would be during D-B procurement. For example: • Bid protest (preaward or postaward) • Unclear contract documents • Contractor default • Bonding or insurance issues • QDOT unfamiliarity with D-B contracting • Approach to specifications (e.g., performance-based specs)	*L*	No direct cost (schedule-related only)	+*L* to Procurement	0

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
	Construction				
CN1	**D-B construction phasing significantly different than assumed** Excludes specific changes to schedule and phasing related to changes in design, etc. that are captured under other risks. The base schedule is not believed to be overly optimistic or aggressive. It's impossible to know at this point how the D-B will actually construct the project, so the actual schedule and phasing could be significantly different than currently assumed.	25% (Note: team thought ratings were insufficient to describe this risk)	No direct cost (schedule-related only)	–2 to D-B Construction	–0.1 to D-B Construction
CN2	**Additional Maintenance of traffic required** See Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Table B.10. Either because the original plan does not work and needs to be modified, or the plan works but simply needs to be augmented.	*H*	+*L* to D-B Construction	+*VL* to D-B Construction	+*M* to D-B Construction

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
CN3	**Problems with planned accelerated bridge construction (ABC) technique** QDOT assumes the contractor will employ ABC (regardless of the structure type selected for the interchange; hence, this issue is approximately independent of Risk PD3). The performance of this planned rapid renewal method (ABC) is difficult to predict because the method the contractor will use is not known, and many ABC techniques are still evolving. • Potential problems include (see Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Table B.5): • Selected technology does not work as planned (technical issue) Delays procuring technology Note that this risk does not apply if the SH-111 alignment is split at the interchange (construction is out of traffic; ABC is not used).	*H*	+*L* to D-B Construction	+*L* to D-B Construction	+*L* to D-B Construction

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

		IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
Item	**Risk or Opportunity**	**Probability of Occurrence (%)**	**Cost Change to Activity (current $M)**	**Schedule Change to Activity (months)**	**Disruption Change to Activity (million person-hours lost)**
CN4	**Unable to construct interchange embankments as rapidly as assumed** Base assumes rapid construction techniques for the approach embankments of the SH-111 overcrossing at the interchange with US-555. The performance of this planned rapid renewal method (rapid embankment construction) is difficult to predict for the following reasons (see Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Table B.6): • Uncertainty in subsurface conditions (soft soils are suspected); • Uncertainty in what method the contractor will choose; and • Uncertainty in performance of the selected method for actual subsurface conditions (e.g., method does not perform as intended). It is therefore unclear at this point how much benefit will be achieved relative to traditional embankment construction. If the method does not work, remedial measures will be needed to accelerate embankment construction, but with some loss of time.	*M*	+*L* to D-B Construction	+*M* to D-B Construction	+*L* to D-B Construction

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
CN5	**Difficult foundation installation** Separate from ground improvement issues. Information is limited in the interchange area (additional geotechnical investigation is scheduled for later). However, anecdotal information indicates that near-surface ground conditions are poor enough to require deep foundations (assumed in the base). Could encounter obstructions, could have difficulty obtaining design capacity for various reasons.	*L*	+*L* to D-B Construction	+*L* to D-B Construction	+*VL* to D-B Construction
CN6 Minor	**Severe weather event significantly affects construction** This refers to specific, individual events, such as earthquake or flood, during construction. Could result in either delay or significant damage. Very low likelihood of significant impact in this geographic location.				
CN7	**Colder-than-usual winter** Usually, construction work can proceed year-round in some manner (the base schedule accounts for this). However, an extreme winter could result in perhaps a 1-month delay.	*L*	No direct cost (schedule-related only)	+*VL* to D-B Construction	+*VL* to D-B Construction
CN8 Minor	**Significant accident during construction** Low likelihood. If one occurs, time impact is likely to be minimal and cost impacts could be covered by D-B insurance.				

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
CN9	**Limited construction staging area in vicinity of interchange** Either QDOT or the contractor will likely have to find a suitable staging area, but it might not be close to the interchange, which could increase contractor costs.	*M*	+*VL* to D-B Construction	0	0
CN10 Minor	**Fish window in Wandering Creek** Currently, no listed species are believed to inhabit Wandering Creek near US-555. Hence, in-water work windows are assumed to not apply. Even if a window did apply, however, the contractor should be able to easily stage culvert work to accommodate a window.				
CN11 Minor	**Noncompliance with permits during construction** Low likelihood of any significant noncompliance. Even if it does occur, low likelihood of significant cost impact (contractor) or schedule impact (QDOT's schedule, but contractor financially responsible).				
CN12	**Extended overheads as a function of project delays** Preconstruction (QDOT staff): $100,000/month of delay Construction: • QDOT staff: $100,000/month of delay • Contractor: For compensable delays, $250,000/month of delay (modeled as $125,000/month of total delay, assuming 50% of delays are compensable)	Not treated as a separate, explicit risk (results from other risks)			

(continued)

TABLE E.5. UNMITIGATED RISK REGISTER FOR MEAN-VALUE OR MEAN-RATING ASSESSMENT (continued)

Item	Risk or Opportunity	IF Conducting Only a Qualitative Risk Assessment (Enter Either Mean Ratings per Scale or Mean Values)			
		Probability of Occurrence (%)	Cost Change to Activity (current $M)	Schedule Change to Activity (months)	Disruption Change to Activity (million person-hours lost)
	Minor and Unidentified Risks and Opportunities Aggregate effect of items labeled Minor, above. Major means the items quantified above (i.e., all items other than those labeled Minor above)				
	Aggregate minor risks	*H*	+*L*	+*L*	+*L*
	Aggregate minor opportunities	*H*	–*L*	–*L*	–*L*
	Unidentified risks	*H*	+*L*	+*L*	+*L*
	Unidentified opportunities	*H*	–*L*	–*L*	–*L*

ATTACHMENT 4. UNMITIGATED MEAN-VALUE PROJECT PERFORMANCE

The various base and unmitigated risk factors (as described in Attachments 2 and 3) were used to calculate (using the Microsoft Excel workbook template) approximate mean unmitigated project performance (by activity and collectively), including cost (unescalated and escalated), schedule (milestone dates), disruption, and longevity (postconstruction cost, schedule, and disruption), as well as combined performance (see Table E.6). The mean severity of each risk was also determined (using the Microsoft Excel workbook template) in terms of its approximate contribution to the mean combined performance, and the risks were then sorted by their mean severity (see Table E.7 and Figure E.3). As previously noted, performance through construction only is the focus.

TABLE E.6. APPROXIMATE MEAN UNMITIGATED BASE + RISK PROJECT PERFORMANCE

QDOT's US 555 / SH 111 Project

Proj Delivery Method: Design/Build **Project start date:** 12/1/2009 for schedule and escalation

	"Base" (without contingency or schedule float)					"Risk" (additional to Base)			"Total" (Base + Risk)						
Activity (master list)	Base Cost (unesc$M)	Base Disruption (M-hrs)	Base Duration (months)	Lag label	Base Lag (mos)	Risk Cost (unesc$M)	Risk Disruption (M-hrs)	Risk Delay (months)	Total Cost (unesc$M)	Total Disruption (M-hrs)	Total Duration (months)	Total Early Start Date	Total Early End Date	Total Float (months)	Total Cost (esc$M)
Planning	$ -	0.0	0.0	A	0.0	0.00	0.0	0.0	0.00	0.0	0.0	12/1/2009	12/1/2009	0.0	$ -
Scoping	$ -	0.0	0.0	B	0.0	0.00	0.0	0.0	0.00	0.0	0.0	12/1/2009	12/1/2009	0.0	$ -
Design Funding								0.0					12/1/2009	0.0	
Prelim Design/Env Proc	$ 1.19	0.0	12.0	C	0.0	0.13	0.0	1.4	1.32	0.0	13.4	12/1/2009	1/13/2011	0.0	$ 1.34
Environmental Permits	$ -	0.0	6.0	D	0.0	0.00	0.0	0.3	0.00	0.0	6.3	1/13/2011	7/23/2011	0.9	$ 0.00
ROW/Util/RR Funding				E	0.0			0.0					12/1/2009	26.6	
ROW/Util/RR	$ 3.00	0.2	12.0	F	6.0	2.62	0.0	1.2	5.62	0.2	13.2	1/13/2011	2/17/2012	0.0	$ 5.91
Final Design	$ -	0.0	6.0	G	1.0	0.00	0.0	0.8	0.00	0.0	6.8	8/19/2011	3/11/2012	5.1	$ -
Construction Funding								0.0					12/1/2009	14.3	
Procurement	$ -	0.0	6.0	H	6.0	0.26	0.0	0.3	0.26	0.0	6.3	1/13/2011	8/19/2011	0.0	$ 0.27
Construction	$ 11.85	0.5	16.0	I	10.0	2.51	0.0	0.8	14.36	0.5	16.8	9/18/2011	2/10/2013	0.0	$ 15.46
subtotal	**$ 16.04**	**0.7**				**$ 5.53**	**0.0**		**$ 21.57**	**0.7**					**$ 22.98**
Operations	$ -	1.4	0.0	J	6.0	0.00	0.0	0.0	0.00	1.4	0.0	2/10/2013	2/10/2013	0.0	$ -
Replacement	$ -	0.7	0.0	K	0.0	0.00	0.0	0.0	0.00	0.7	0.0	2/10/2013	2/10/2013	0.0	$ -
subtotal	**$ -**	**2.1**	**$ 21.00**	**←longevity ($)**		**$ -**	**0.0**	**$ -**	**0.0**	**2.1**	**$ 21.00**	**←longevity ($)**			**$ -**
Total	**$ 16.04**	**2.8**	**$ 44.90**			**5.53**	**0.0**	**$ 6.34**	**21.57**	**2.8**	**$ 51.24**	**1/13/2011**	**2/10/2013**	**2/10/2013**	**$ 22.98**
			↑combined ($M)					↑combined ($M)			↑combined (	↑ad date	↑end of CN	↑replacement	

Mean Annual Cost Inflation Rate (%/yr)

Engr	3.0%	incl Planning, Scoping, Prelim Design/Environmental Process, Final Design, Environmental Permits & Procurement
ROW/Utility/RR	3.0%	
Construction	3.0%	incl Construction, Operations (& Maintenance), and Replacement

Extended OH Rates (unesc $M/month)

Preconstruction	0.10	Average agency pre-construction "burn rate" (= agency baseline pre-construction engr cost / preconstruction duration) - calculated default value can be revised
Construction	0.23	Average agency construction "burn rate" (= agency baseline construction engr cost / construction duration) plus <u>compensable</u> contractor OH (= % of contractor construction OH cost / construction duration) - calculated default value can be revised

Values for combining consequences

Disruption Value ($M/M-hr)	10.00	to combine disruption with cost (NPV value)
Schedule Target (date)	12/1/2012	target date for start of operations
Schedule Value ($M/mo)	0.10	to combine schedule (difference from target date) with cost (NPV value)
Net Discount Rate (%/yr)	5.0%	to determine "longevity" from O&M and replacement cost and disruption
Longevity Value ($M/$M$_{NPV}$)	1.00	to combine "longevity" with cost (NPV value) - default value can be revised

Note: From rapid renewal risk management planning template (http://www.trb.org/main/blurbs/168369.aspx), through construction only.

TABLE E.7. UNMITIGATED RISK RANKING

QDOT's US 555 / SH 111 Project

Unmitigated Risk Ranking					Unmitigated Opportunity Ranking				
Risk Rank	Percentage of Sum of Postive Mean Severities (%)	Item	Risk Title	Mean Severity (Equiv. Inflated $M)	Oppor-tunity Rank	Percentage of Sum of Negative Mean Severities (%)	Item	Opportunity Title	Mean Severity (Equiv. Inflated $M)
1	8%	CP1	Uncertainty in construction-cost inflation rate	M	1	56.4%	CN1	D/B construction phasing significantly different than assumec	-0.44
2	8%	SC6	Provide new lighting throughout project	M	2	43.6%	PD8	Change in pavement section and/or type	-L
3	8%	RU8	QDOT helps City pay for water and sewer-line relocatior	M	3	#N/A	#N/A	#N/A	#N/A
4	8%	RU3	Unwilling sellers	M	4	#N/A	#N/A	#N/A	#N/A
5	8%	RU1	Uncertainty in ROW inflation rate	M	5	#N/A	#N/A	#N/A	#N/A
6	7%	RU2	Accelerating pace of development in interchange area	M	6	#N/A	#N/A	#N/A	#N/A
7	7%	CN2	Additional Maintenance of Traffic requirec	M	7	#N/A	#N/A	#N/A	#N/A
8	5%	CN4	Unable to construct interchange embankments as rapidly as assumed	L	8	#N/A	#N/A	#N/A	#N/A
9	5%	CP2	Uncertain D/B contracting market conditions at time of bid	0.38	9	#N/A	#N/A	#N/A	#N/A
10	5%	PD11	Cannot use City sewer system for project runoff (or City charges for use)	L	10	#N/A	#N/A	#N/A	#N/A
11	5%	PD13	Change in environmental documentation	L	11	#N/A	#N/A	#N/A	#N/A
12	4%	CN3	Problems with planned accelerated bridge construction (ABC) technique	L	12	#N/A	#N/A	#N/A	#N/A
13	3%	PD12	Structures impacted by Main Street realignment are historic	L	13	#N/A	#N/A	#N/A	#N/A
14	2%	PD14	Delays completing environmental documentatior	VL	14	#N/A	#N/A	#N/A	#N/A
15	2%	PD4	Ground improvement required in interchange area	VL	15	#N/A	#N/A	#N/A	#N/A
16	2%	SC3	Additional local improvements requirec	VL	16	#N/A	#N/A	#N/A	#N/A
17	1%	PD16	Additional wetland mitigation required for planned alignmen	VL	17	#N/A	#N/A	#N/A	#N/A
18	1%	SC5	Replace culvert over Wandering Creek	VL	18	#N/A	#N/A	#N/A	#N/A
19	1%	RU7	Telecom utility wants a cost-sharing agreement	VL	19	#N/A	#N/A	#N/A	#N/A
20	1%	CN5	Difficult foundation installation	VL	20	#N/A	#N/A	#N/A	#N/A
21	1%	PD6	Shoulders required on SH 111	VL	21	#N/A	#N/A	#N/A	#N/A
22	1%	PD5	Shoulders required on US 555	VL	22	#N/A	#N/A	#N/A	#N/A
23	1%	EP2	Delay obtaining 404 permit	VL	23	#N/A	#N/A	#N/A	#N/A
24	1%	RU6	Other delays to ROW planning	VL	24	#N/A	#N/A	#N/A	#N/A
25	0%	PD1	Shift alignment of US 555 at east end of project	VL	25	#N/A	#N/A	#N/A	#N/A
26	0%	CN9	Limited construction staging area in vicinity of interchange	VL	26	#N/A	#N/A	#N/A	#N/A
27	0%	PD15	Encounter unanticipated contamination in interchange area	VL	27	#N/A	#N/A	#N/A	#N/A
28	0%	CN7	Colder-than-usual winter	VL	28	#N/A	#N/A	#N/A	#N/A
29	0%	CP8	Other problems with D/B contract procurement	VL	29	#N/A	#N/A	#N/A	#N/A
30	0%	PL2	Opposition to removing access to US 555 from 12th Street	VL	30	#N/A	#N/A	#N/A	#N/A
31	0%	CN11	Non-compliance with permits during construction	VL	31	#N/A	#N/A	#N/A	#N/A
32	0%	CN10	Fish window in Wandering Creek	VL	32	#N/A	#N/A	#N/A	#N/A
33	0%	CN8	Significant accident during construction	VL	33	#N/A	#N/A	#N/A	#N/A
34	0%	CN6	Severe weather event significantly impacts construction	VL	34	#N/A	#N/A	#N/A	#N/A
35	0%	CP6	Use incentives to accelerate D/B construction	VL	35	#N/A	#N/A	#N/A	#N/A
36	0%	PD10	Change in stormwater design standards	VL	36	#N/A	#N/A	#N/A	#N/A
37	0%	PD9	Rehabilitate instead of reconstruct existing roadway	VL	37	#N/A	#N/A	#N/A	#N/A
38	0%	SC7	ITS added to this project	VL	38	#N/A	#N/A	#N/A	#N/A
39	0%	SC4	Increased aesthetics for US 555 / SH 111 interchange	VL	39	#N/A	#N/A	#N/A	#N/A
40	0%	SC2	Change in North-South project limits	VL	40	#N/A	#N/A	#N/A	#N/A
41	0%	SC1	Change in East-West project limits	VL	41	#N/A	#N/A	#N/A	#N/A
42	0%	RU10	Damage existing utility or encounter unanticipated utility during construction	VL	42	#N/A	#N/A	#N/A	#N/A
43	0%	RU9	Other utility relocation not completed on time	VL	43	#N/A	#N/A	#N/A	#N/A
44	0%	RU5	Additional ROW required for planned project	VL	44	#N/A	#N/A	#N/A	#N/A
45	0%	PD2	Split alignment of SH 111 at US 555 interchange	VL	45	#N/A	#N/A	#N/A	#N/A
46	0%	CP4	Change in project-delivery methoc	VL	46	#N/A	#N/A	#N/A	#N/A
47	0%	EP1	Challenge to environmental determination or permits	VL	47	#N/A	#N/A	#N/A	#N/A
48	0%	CP5	Accelerate pre-construction activities to reach NTP sooner	VL	48	#N/A	#N/A	#N/A	#N/A

Note: From rapid renewal risk management planning template (http://www.trb.org/main/blurbs/168369.aspx), for risks and performance through construction only.

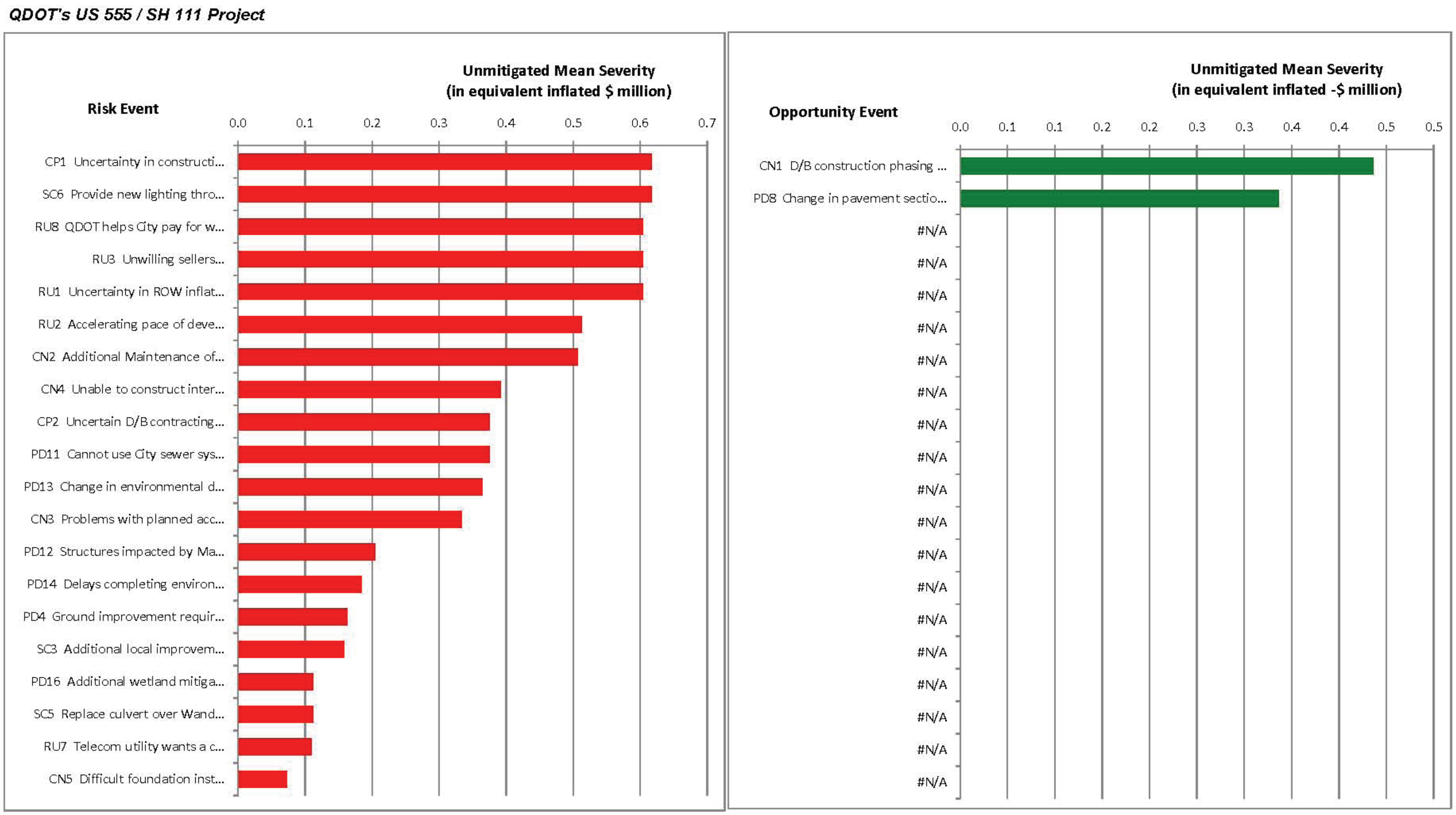


Figure E.3. *Unmitigated risk ranking for risks and performance through construction only.*

Source: From the rapid renewal risk management planning template (http://www.trb.org/main/blurbs/168369.aspx).

ATTACHMENT 5. RISK REDUCTION PLAN

The plan for proactively reducing individual risks (as identified, described, assessed, evaluated, and finally ranked in Attachments 3 and 4) for the project was developed as follows:

- Identified possible risk reduction actions for the highest-ranking risks (see Table E.8).
- Assessed the cost-effectiveness factors for each action (see Table E.8).
- Determined (using the Microsoft Excel workbook template) the cost-effectiveness of each action (see Table E.9).
- Selected a cost-effective set of actions (see Table E.9), and planned them (see Table E.10).
- Determined (using the Microsoft Excel workbook template) the mitigated risk register (mean value or mean ratings) for that set of actions (see Table E.11).

As previously noted, performance (and thus risks) through construction only is the focus.

TABLE E.8. DETAILED IDENTIFICATION OF RISK REDUCTION ACTIONS AND COST-EFFECTIVENESS ASSESSMENT

Risk	Risk or Opportunity Addressed[a]	Potential Risk Management Actions[b]	Cost to Implement Actions (impacts to affected activity)			Effectiveness of Actions[c]			
			Cost Change (current $M)	Schedule Change (months)	Disruption Change (million person-hours lost)	Probability	Cost Impact	Duration Impact	Disruption Impact
CP1	Uncertainty in construction cost inflation rate	This is a true uncertainty and given the large-scale factors controlling it, the project team is unable to mitigate this factor.							
SC6	Provide new lighting throughout project	1. Modify the project's design to avoid relocating existing lighting outside the interchange. However, this creates new risks [e.g., extra design time; additional right-of-way (ROW) requirements; maintaining old lighting]. This is not seen as a viable action at this point. 2. Accept that new lighting might be required, and optimize lighting design to minimize cost impact if it does occur. However, the savings likely would not be significant. 3. Negotiate a cost-sharing agreement with the city for the new continuous lighting, since QDOT's standards do not really require it. This action will not reduce the likelihood of the risk, but could reduce the cost to QDOT.		Minor (can work within existing schedule)			Reduce by 50% (e.g., from M to L)		

Note: Risk reduction actions are for risks and performance through construction only. Risks are ranked in terms of their mean-value severity, and only risks with a mean severity rating of Low or higher are shown.

[a] See risk register for description.

[b] Proactive actions: mitigate, avoid, allocate.

[c] Percentage reduction in risk factors relative to premitigation factors in risk register.

(continued)

TABLE E.8. DETAILED IDENTIFICATION OF RISK REDUCTION ACTIONS AND COST-EFFECTIVENESS ASSESSMENT (continued)

			Cost to Implement Actions (impacts to affected activity)			Effectiveness of Actions[c]			
Risk	Risk or Opportunity Addressed[a]	Potential Risk Management Actions[b]	Cost Change (current $M)	Schedule Change (months)	Disruption Change (million person-hours lost)	Probability	Cost Impact	Duration Impact	Disruption Impact
RU8	QDOT helps city pay for water and sewer-line relocation	This "risk" is really a project or policy decision to be made by QDOT. In that light, this is really a way to accelerate project delivery (i.e., the action is a rapid renewal method belonging to the "additional investment" strategy; see Guide, Appendix A). QDOT should be able to somewhat reduce Risk PD11 if it helps the city pay for the relocation. Hence, the impacts to Risks RU8 and PD11 are related: 1. The "cost" of this risk management action shows up under Risk RU8 in terms of an increased probability of occurrence (i.e., an increased probability of helping the city). 2. The "benefit" of this action shows up under Risk PD11 as reduced probability of occurrence (i.e., a reduced probability that the city will deny use of its system). The impacts to both RU8 and PD11 will have to be considered together to determine if this decision or action is cost-effective.				Increase by 70% (e.g., from H to VH)			

(continued)

TABLE E.8. DETAILED IDENTIFICATION OF RISK REDUCTION ACTIONS AND COST-EFFECTIVENESS ASSESSMENT (continued)

			Cost to Implement Actions (impacts to affected activity)			Effectiveness of Actions[c]			
Risk	Risk or Opportunity Addressed[a]	Potential Risk Management Actions[b]	Cost Change (current $M)	Schedule Change (months)	Disruption Change (million person-hours lost)	Probability	Cost Impact	Duration Impact	Disruption Impact
RU3	Unwilling sellers	QDOT's principal risk from unwilling sellers is increased ROW acquisition cost. Hence, QDOT could take the following actions to reduce this risk (see Guide, Table B.11): 1. Review the design to see if it can be "tweaked" to avoid any of these properties. This has already been done once, and the project team does not believe there is much room for improvement under the current design concept. 2. Make reasonable, early offers: Conduct thorough research on the values of these properties and present reasonable offers to the property owners. Do this early to provide more time to reach negotiated settlements (and therefore avoid court proceedings). This action would likely reduce the probability of cost increase, but not the magnitude of a cost increase if it occurs.	0.05 to ROW			Reduce by 50% (e.g., from H to M)			
RU1	Uncertainty in ROW inflation rate	This is a true uncertainty and, given the large-scale factors controlling it, the project team is unable to mitigate this factor.	-	-	-	-	-	-	-

(continued)

TABLE E.8. DETAILED IDENTIFICATION OF RISK REDUCTION ACTIONS AND COST-EFFECTIVENESS ASSESSMENT (continued)

			Cost to Implement Actions (impacts to affected activity)			Effectiveness of Actions[c]			
Risk	Risk or Opportunity Addressed[a]	Potential Risk Management Actions[b]	Cost Change (current $M)	Schedule Change (months)	Disruption Change (million person-hours lost)	Probability	Cost Impact	Duration Impact	Disruption Impact
RU2	Accelerating pace of development in interchange area	1. Accelerate project development activities, specifically: 2. Project design effort (see Guide, Table B.4) to preempt developers' permit applications and approvals by the city; and 3. Preparation of ROW appraisals and offers (see Guide, Table B.11) in order to make offers to developers before they begin their planned developments. 4. This could be difficult given the already-short time frame for this project. 5. Coordinate more closely with the city in an attempt to have the city avoid issuing any new development permits in ROW required by the project. This will not affect permits that have already been issued. This action would most likely reduce the likelihood of this risk occurring, but would not reduce the costs if this risk occurs.				Reduce by 50% (e.g., from M to L)			

(continued)

TABLE E.8. DETAILED IDENTIFICATION OF RISK REDUCTION ACTIONS AND COST-EFFECTIVENESS ASSESSMENT (continued)

			Cost to Implement Actions (impacts to affected activity)			Effectiveness of Actions[c]			
Risk	Risk or Opportunity Addressed[a]	Potential Risk Management Actions[b]	Cost Change (current $M)	Schedule Change (months)	Disruption Change (million person-hours lost)	Probability	Cost Impact	Duration Impact	Disruption Impact
CN2	Additional maintenance of traffic (MOT) required	To reduce the risk of an ineffective MOT program or requiring significantly more MOT, QDOT could take the following actions, which are not part of the current plan (Guide, Table B.10): 1. Reduce traffic demand during closures (i.e., look for viable detours or provide alternative modes of transport), while still meeting QDOT's goal of maintaining the equivalent of two lanes of traffic along US-555 and SH-111. QDOT would have to work with the design–build (D-B) contractor on this issue, perhaps starting with the request for proposal (RFP). 2. Seek early contractor involvement, and/or hold MOT plan brainstorming or concept reviews with industry representatives. 3. QDOT could conduct more traffic modeling under various possible construction scenarios to better understand the potential problems, and then translate these findings into requirements in the RFP. 4. Require the D-B contractor to develop a contingency MOT plan as part of the proposal.	0.05 to Final Design			Reduce by 50% (e.g., from H to M)			Reduce by 67%

(continued)

TABLE E.8. DETAILED IDENTIFICATION OF RISK REDUCTION ACTIONS AND COST-EFFECTIVENESS ASSESSMENT (continued)

			Cost to Implement Actions (impacts to affected activity)			Effectiveness of Actions[c]			
Risk	Risk or Opportunity Addressed[a]	Potential Risk Management Actions[b]	Cost Change (current $M)	Schedule Change (months)	Disruption Change (million person-hours lost)	Probability	Cost Impact	Duration Impact	Disruption Impact
CN4	Unable to construct interchange embankments as rapidly as assumed	To reduce the risk of poorer-than-anticipated performance, QDOT could take the following actions (Guide, Table B.6): 1. QDOT conducts additional investigation and analysis (beyond what is already planned) of the embankment foundation material to better ascertain which rapid construction techniques are likely to succeed. Provide these findings to the D-B contractor in anticipation that the contractor will use the information to select a more reliable construction method. 2. Require that the D-B contractor develop an alternative embankment construction technique (e.g., ground improvement) to be implemented without delay in the event that the planned technique does not work. This action could mitigate delay if the risk occurs, but could result in additional cost. The combined impact of these two actions is shown to the right. These actions could result in a reduced probability of occurrence or a reduced duration of impact from occurrence, but probably not both. The group chose to characterize the benefits from these actions in terms of the reduced likelihood of the risk occurring.	0.1 to Final Design	(can be done within existing schedule)		Reduce by 50% (e.g., from M to L)			

(continued)

TABLE E.8. DETAILED IDENTIFICATION OF RISK REDUCTION ACTIONS AND COST-EFFECTIVENESS ASSESSMENT (continued)

			Cost to Implement Actions (impacts to affected activity)			Effectiveness of Actions[c]			
Risk	Risk or Opportunity Addressed[a]	Potential Risk Management Actions[b]	Cost Change (current $M)	Schedule Change (months)	Disruption Change (million person-hours lost)	Probability	Cost Impact	Duration Impact	Disruption Impact
CP2	Uncertain D-B contracting market conditions at time of bid	To reduce the risk of experiencing impacts from potentially poor market conditions, QDOT could take the following actions (Guide, Table B.14): 1. Use an alternative procurement method. A number of local contractors who do not traditionally bid on D-B contracts might bid on this contract if it were procured via other, more traditional methods. However, this would be contrary to QDOT's rapid renewal strategy for this project. Hence, this action is unlikely. 2. Use alternative contract packaging. The single contract is already relatively small, so the group believes that creating two or more smaller packages will not have any impact on bid prices. 3. Shift the project time line to avoid any other major projects in the area that might consume resources needed for this project. This is not feasible, given QDOT's rapid renewal strategy for this project. 4. QDOT could more proactively promote awareness of the project in the contracting community (e.g., through an outreach program to smaller contractors), in hopes of generating more interest. Overall, given how small (relatively) this project is, the group does not believe that it is feasible to significantly reduce this risk or uncertainty.							

(continued)

TABLE E.8. DETAILED IDENTIFICATION OF RISK REDUCTION ACTIONS AND COST-EFFECTIVENESS ASSESSMENT (continued)

			Cost to Implement Actions (impacts to affected activity)			Effectiveness of Actions[c]			
Risk	Risk or Opportunity Addressed[a]	Potential Risk Management Actions[b]	Cost Change (current $M)	Schedule Change (months)	Disruption Change (million person-hours lost)	Probability	Cost Impact	Duration Impact	Disruption Impact
PD11	Cannot use city sewer system for project runoff (or city charges for use)	Tied to the action described under RU8 (the benefits of that action are realized under this risk).				Reduce by 50% (e.g., from M to L)			
PD13	Change in environmental documentation	QDOT is including what it believes to be conservative impacts in its environmental assessment. QDOT is also designing in an attempt to reduce project impacts and is communicating with the public about the project. Beyond these current actions, neither the project team nor the risk assessment subject-matter experts could identify any feasible way to mitigate this risk.							

(continued)

TABLE E.8. DETAILED IDENTIFICATION OF RISK REDUCTION ACTIONS AND COST-EFFECTIVENESS ASSESSMENT (continued)

			Cost to Implement Actions (impacts to affected activity)			Effectiveness of Actions[c]			
Risk	Risk or Opportunity Addressed[a]	Potential Risk Management Actions[b]	Cost Change (current $M)	Schedule Change (months)	Disruption Change (million person-hours lost)	Probability	Cost Impact	Duration Impact	Disruption Impact
CN3	Problems with planned accelerated bridge construction (ABC) technique	To reduce the risk of poorer-than-anticipated performance, QDOT could take the following actions (Guide, Table B.5): During design and/or procurement: 1. QDOT could require the D-B contractor to develop a parallel, alternative rapid bridge replacement technique as a mitigation measure, to be deployed if significant problems arise with the primary approach. 2. QDOT and/or the contractor could gather performance information for the proposed ABC technique to increase confidence that the technique will perform well for this application. 3. Prequalify and/or select contractors with a history of successful ABC under similar project circumstances. During construction, make sure contractor has the alternative technique ready to implement. Together, the group believes that these actions (which are not currently planned) should reduce the probability of the assessed impacts occurring, or reduce the magnitude of the impacts, but probably not both.	0.05 to Final Design			Reduce by 50% (e.g., from H to M)			

(continued)

TABLE E.8. DETAILED IDENTIFICATION OF RISK REDUCTION ACTIONS AND COST-EFFECTIVENESS ASSESSMENT (continued)

			Cost to Implement Actions (impacts to affected activity)			Effectiveness of Actions[c]			
Risk	Risk or Opportunity Addressed[a]	Potential Risk Management Actions[b]	Cost Change (current $M)	Schedule Change (months)	Disruption Change (million person-hours lost)	Probability	Cost Impact	Duration Impact	Disruption Impact
PD12	Structures impacted by Main Street realignment are eligible for National Register of Historic Places	These structures either will be eligible for listing or they will not. The only way for QDOT to mitigate this risk is to avoid the structures altogether, which would require shifting the alignment. Although this is a possibility, such a change would introduce additional problems that most likely would outweigh the benefits. Hence, the group believes that QDOT cannot reasonably reduce this risk.							
CN1	D-B construction phasing significantly different than assumed (opportunity)	This "opportunity" is really more of an uncertainty related to how the design–builder will phase and construct the project. In theory, QDOT could attempt to influence the D-B construction schedule by using incentives for the contractor to accelerate construction (see Guide, Tables B.2 and B.4). However, there is significant resistance within QDOT to use of contractor incentives. Hence, the group was not able to identify any significant action (beyond QDOT's current strategy) to amplify this opportunity.							

(continued)

TABLE E.8. DETAILED IDENTIFICATION OF RISK REDUCTION ACTIONS AND COST-EFFECTIVENESS ASSESSMENT (continued)

			Cost to Implement Actions (impacts to affected activity)			Effectiveness of Actions[c]			
Risk	Risk or Opportunity Addressed[a]	Potential Risk Management Actions[b]	Cost Change (current $M)	Schedule Change (months)	Disruption Change (million person-hours lost)	Probability	Cost Impact	Duration Impact	Disruption Impact
PD8	Change in pavement section and/or type	This cost “opportunity” would really reflect a change in QDOT’s objectives for this project, and is not something the project team wants to pursue (i.e., a change in pavement type from concrete to asphalt would mean a change in the project objective of maximizing longevity of the new facility). Hence, no action is planned to increase this opportunity.							

TABLE E.9. SUMMARY OF RISK REDUCTION IDENTIFICATION AND COST-EFFECTIVENESS ASSESSMENT AND EVALUATION

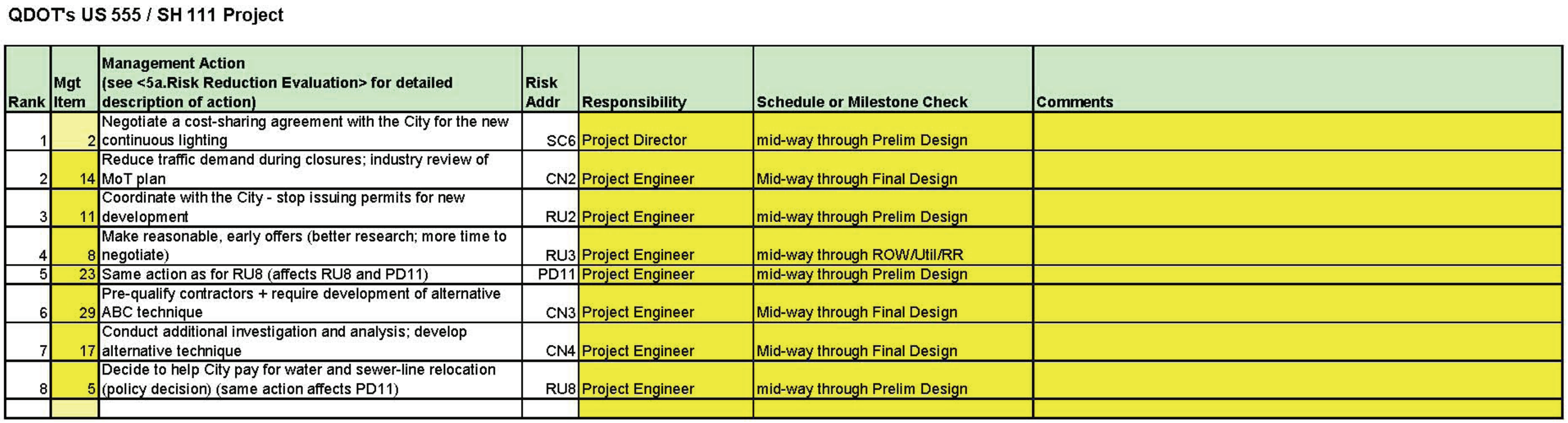
QDOT's US 555 / SH 111 Project

Possible Risk Reduction Actions for Each Critical Risk

					Implementation						Effectiveness (100% effective to 0% or no effect)					Cost-effectiveness			
					Cost		Schedule		Disruption			Impacts if Occurs							
Current Risk Rank	Risk Item	Mgt Item	Management Options (from list)	Management Action (see checklist for other possibilities)	Mean (uninfl $M)	Affected Activity	Mean Delay (months)	Affected Activity	Mean Disruption (M-hrs)	Affected Activity	Probability (100% eff→0, -100% eff→1)	Cost	Schedule	Disruption	Residual severity	Δseverity/ "cost"	Δseverity -"cost"	Selected (1=yes)?	Ranking of selected actions
1	SC6	1	Accept	none	0		0		0		0%	0%	0%	0%	0%	no cost	0.00		NA
		2	Mitigate	Negotiate a cost-sharing agreement with the City for the new continuo	0	Constructio	0	Constructio	0	Constructio	0%	50%	0%	0%	50%	no cost	0.31	1	1
		3													0%	no cost	0.00		NA
3	RU8	4	Accept	none	0		0		0		0%	0%	0%	0%	0%	no cost	0.00		NA
		5	Mitigate	Decide to help City pay for water and sewer-line relocation (policy decision) (same action affects PD11)	0	Constructio	0	Constructio	0	Constructio	-70%	0%	0%	0%	-57%	no cost	-0.35	1	8
		6													0%	no cost	0.00		NA
3	RU3	7	Accept	none	0		0		0		0%	0%	0%	0%	0%	no cost	0.00		NA
		8	Mitigate	Make reasonable, early offers (better research; more time to negotiate)	0.05	ROW/Util/RI	0	ROW/Util/RI	0	ROW/Util/RI	50%	0%	0%	0%	50%	5.8	0.25	1	4
		9													0%	no cost	0.00		NA
6	RU2	10	Accept	none	0		0		0		0%	0%	0%	0%	0%	no cost	0.00		NA
		11	Mitigate	Coordinate with the City - stop issuing permits for new development	0	ROW/Util/RI	0	ROW/Util/RI	0	ROW/Util/RI	50%	0%	0%	0%	50%	no cost	0.26	1	3
		12													0%	no cost	0.00		NA
7	CN2	13	Accept	none	0		0		0		0%	0%	0%	0%	0%	no cost	0.00		NA
		14	Mitigate	Reduce traffic demand during closures; industry review of MoT plan	0.05	Final Desig	0	Final Desig	0	Constructio	50%	0%	0%	67%	68%	6.6	0.29	1	2
		15													0%	no cost	0.00		NA
8	CN4	16	Accept	none	0		0		0		0%	0%	0%	0%	0%	no cost	0.00		NA
		17	Mitigate	Conduct additional investigation and analysis; develop alternative technique	0.1	Final Desig	0	Final Desig	0	Constructio	50%	0%	0%	0%	50%	1.9	0.09	1	7
		18													0%	no cost	0.00		NA
9	CP2	19	Accept	none	0		0		0		0%	0%	0%	0%	0%	no cost	0.00		NA
		20													0%	no cost	0.00		NA
		21													0%	no cost	0.00		NA
10	PD11	22	Accept	none	0		0		0		0%	0%	0%	0%	0%	no cost	0.00		NA
		23	Mitigate	Same action as for RU8 (affects RU8 and PD11)	0	Final Desig	0	Final Desig	0	Final Desig	50%	0%	0%	0%	50%	no cost	0.19	1	5
		24													0%	no cost	0.00		NA
11	PD13	25	Accept	none	0		0		0		0%	0%	0%	0%	0%	no cost	0.00		NA
		26													0%	no cost	0.00		NA
		27													0%	no cost	0.00		NA
12	CN3	28	Accept	none	0		0		0		0%	0%	0%	0%	0%	no cost	0.00		NA
		29	Mitigate	Pre-qualify contractors + require development of alternative ABC technique	0.05	Final Desig	0	Final Desig	0	Constructio	50%	0%	0%	0%	50%	3.2	0.11	1	6
		30													0%	no cost	0.00		NA
13	PD12	31	Accept	none	0		0		0		0%	0%	0%	0%	0%	no cost	0.00		NA
		32													0%	no cost	0.00		NA
		33													0%	no cost	0.00		NA
#N/A		58	Accept	none	0		0		0		0%	0%	0%	0%	#N/A	no cost	#N/A		NA
		59													#N/A	no cost	#N/A		NA
		60													#N/A	no cost	#N/A		NA

Note: Risk reduction identification is for risks and performance through construction only. From rapid renewal risk management planning template (http://www.trb.org/main/blurbs/168369.aspx).

TABLE E.10. RISK REDUCTION PLAN



QDOT's US 555 / SH 111 Project

Rank	Mgt Item	Management Action (see <5a.Risk Reduction Evaluation> for detailed description of action)	Risk Addr	Responsibility	Schedule or Milestone Check	Comments
1	2	Negotiate a cost-sharing agreement with the City for the new continuous lighting	SC6	Project Director	mid-way through Prelim Design	
2	14	Reduce traffic demand during closures; industry review of MoT plan	CN2	Project Engineer	Mid-way through Final Design	
3	11	Coordinate with the City - stop issuing permits for new development	RU2	Project Engineer	mid-way through Prelim Design	
4	8	Make reasonable, early offers (better research; more time to negotiate)	RU3	Project Engineer	mid-way through ROW/Util/RR	
5	23	Same action as for RU8 (affects RU8 and PD11)	PD11	Project Engineer	mid-way through Prelim Design	
6	29	Pre-qualify contractors + require development of alternative ABC technique	CN3	Project Engineer	Mid-way through Final Design	
7	17	Conduct additional investigation and analysis; develop alternative technique	CN4	Project Engineer	Mid-way through Final Design	
8	5	Decide to help City pay for water and sewer-line relocation (policy decision) (same action affects PD11)	RU8	Project Engineer	mid-way through Prelim Design	

Note: For risks through construction only; from rapid renewal risk management planning template (http://www.trb.org/main/blurbs/168369.aspx).

TABLE E.11. MITIGATED RISK FACTORS

QDOT's US 555 / SH 111 Project

Mitigated Risk Register										
		Mitigated Probability of Occurrence (0 to 1, or rating per rating scale*) Assessment	Assessed Mitigated Impacts (if occur)						Mitigated Mean Severity (escal $M, or rating per rating scale*)	Mitigated Risk Ranking (based on mit. mean severity)
			Mean Direct Cost Change (unesc $M, or rating per rating scale*)		Mean Duration Change to Schedule Activity (months, or rating per rating scale*)		Mean Disruption Change (million person-hours lost, or rating per rating scale*)			
Item	Risk or Opportunity		Assess-ment	Activity Affected (from list)	Assess-ment	Activity Affected (from list)	Assess-ment	Activity Affected (from list)		
PL	***Planning Risks***		0.01		0.00		0.00		0.02	7
PL1	Project funding delayed or reduced	0		0		0		0	0.00	51
PL2	Opposition to removing access to US 555 from 12th Street	L	VL	Construction	0	Construction	0	0	VL	30
PL3	Opposition to splitting alignment of SH 111 in the interchange area	0		0		0		0	0.00	51
PL4	Other stakeholder issues not captured separately	VL	VL	Prelim	VL	Prelim Design/Env	0	0	VL	48
PL15	#N/A			0		0		0	0.00	#N/A
SC	***Scoping Risks***		0.51		0.20		0.00		0.59	4
SC1	Change in East-West project limits	VL	VL	Construction	VL	Construction	0	0	VL	31
SC2	Change in North-South project limits	VL	VL	Construction	VL	Construction	0	0	VL	31
SC3	Additional local improvements required	M	L	Construction	L	Proc	0	0	VL	16
SC4	Increased aesthetics for US 555 / SH 111 interchange	VL	VL	Construction	VL	Construction	0	0	VL	31
SC5	Replace culvert over Wandering Creek	M	L	Construction	0	Construction	0	0	VL	17
SC6	Provide new lighting throughout project	H	M	Construction	0	Construction	0	0	L	6
SC7	ITS added to this project	VL	VL	Construction	VL	Construction	0	0	VL	31
SC15	#N/A			0		0		0	0.00	#N/A
PD	***Preliminary Design / Environmental Process Risks***		0.50		2.34		0.00		1.10	2
PD1	Shift alignment of US 555 at east end of project	VL	M	ROW/Util/RR	M	ROW/Util/RR	0	0	VL	25
PD2	Split alignment of SH 111 at US 555 interchange	VL	VL	ROW/Util/RR	VL	ROW/Util/RR	0	0	VL	42
PD3	Change in configuration of SH 111 / US 555 interchange	0	0	Construction	0	Prelim Design/Env	0	0	0.00	51
PD4	Ground improvement required in interchange area	L	M	Construction	L	Construction	0	0	VL	14
PD5	Shoulders required on US 555	VL	H	Construction	M	ROW/Util/RR	0	0	VL	21
PD6	Shoulders required on SH 111	VL	H	Construction	M	ROW/Util/RR	0	0	VL	21
PD7	Additional cost for signalized intersections	VL	VL	Construction	0	Construction	0	0	VL	50
PD8	Change in pavement section and/or type	M	-M	Construction	0	Construction	0	0	-L	184
PD9	Rehabilitate instead of reconstruct existing roadway	VL	VL	Construction	VL	Construction	0	0	VL	31
PD10	Change in stormwater design standards	VL	VL	Construction	VL	Construction	0	0	VL	31
PD11	Cannot use City sewer system for project runoff (or City charges for	L	M	ROW/Util/RR	L	ROW/Util/RR	0	0	VL	11
PD12	Structures impacted by Main Street realignment are historic	L	M	ROW/Util/RR	M	ROW/Util/RR	0	0	L	9
PD13	Change in environmental documentation	L	M	Prelim	H	Prelim Design/Env	0	0	L	5
PD14	Delays completing environmental documentation	M	0	Prelim	M	Prelim Design/Env	0	0	VL	12
PD15	Encounter unanticipated contamination in interchange area	M	VL	Construction	0	Construction	0	0	VL	26

(continued)

TABLE E.11. MITIGATED RISK FACTORS (continued)

Mitigated Risk Register										
			Assessed Mitigated Impacts (if occur)							
		Mitigated Probability of Occurrence (0 to 1, or rating per rating scale*)	Mean Direct Cost Change (unesc $M, or rating per rating scale*)		Mean Duration Change to Schedule Activity (months, or rating per rating scale*)		Mean Disruption Change (million person-hours lost, or rating per rating scale*)		Mitigated Mean Severity (escal $M, or rating per rating scale*)	Mitigated Risk Ranking (based on mit. mean severity)
Item	Risk or Opportunity	Assessment	Assess-ment	Activity Affected (from list)	Assess-ment	Activity Affected (from list)	Assess-ment	Activity Affected (from list)		
PD16	Additional wetland mitigation required for planned alignment	M	L	Construction	0	Construction	0	0	VL	17
PD25	#N/A			0		0		0	0.00	#N/A
EP	***Environmental Permits Risks***		0.00		0.30		0.00		0.07	6
EP1	Challenge to environmental determination or permits	VL	VL	Environmental	VL	Environmental	0	0	VL	46
EP2	Delay obtaining 404 permit	L	0	Environmental	M	Environmental	0	0	VL	23
EP15	#N/A			0		0		0	0.00	#N/A
RU	***ROW/Utility/RR/etc Risks***		2.04		0.57		0.00		2.27	1
RU1	Uncertainty in ROW inflation rate	H	M	ROW/Util/RR		0		0	M	3
RU2	Accelerating pace of development in interchange area	L	M	ROW/Util/RR	M	ROW/Util/RR	0	0	L	8
RU3	Unwilling sellers	M	M	ROW/Util/RR	0	ROW/Util/RR	0	0	L	7
RU4	Additional relocation or demolition required	0		0		0		0	0.00	51
RU5	Additional ROW required for planned project	VL	VL	ROW/Util/RR	VL	ROW/Util/RR	0	0	VL	42
RU6	Other delays to ROW planning	M	0	ROW/Util/RR	L	ROW/Util/RR	0	0	VL	24
RU7	Telecom utility wants a cost-sharing agreement	M	L	ROW/Util/RR	0	ROW/Util/RR	0	0	VL	19
RU8	QDOT helps City pay for water and sewer-line relocation	VH	M	ROW/Util/RR	0	ROW/Util/RR	0	0	M	1
RU9	Other utility relocation not completed on time	VL	VL	ROW/Util/RR	VL	ROW/Util/RR	0	0	VL	42
RU10	Damage existing utility or encounter unanticipated utility during	VL	VL	ROW/Util/RR	VL	ROW/Util/RR	0	0	VL	42
RU15	#N/A			0		0		0	0.00	#N/A
FD	***Final Design Risks***		0.00		0.00		0.00		0.00	8
FD1	#N/A			0		0		0	0.00	#N/A
FD15	#N/A			0		0		0	0.00	#N/A
CP	***Procurement Risks***		0.88		1.08		0.00		1.02	3
CP1	Uncertainty in construction-cost inflation rate	H	M	Construction		0		0	M	2
CP2	Uncertain D/B contracting market conditions at time of bid	0.25	1.185	Construction	1	Procurement	0	0	0.38	4
CP3	Material-supply issues	0		0		0		0	0.00	51
CP4	Change in project-delivery method	VL	VL	Procurement	VL	Procurement	0	0	VL	47
CP5	Accelerate pre-construction activities to reach NTP sooner	VL	VL	Prelim	VL	Prelim Design/Env	0	0	VL	48
CP6	Use incentives to accelerate D/B construction	VL	VL	Construction	VL	Construction	0	0	VL	31
CP7	Issues with D/B design or submittals	M	0	Final Design	M	Final Design	0	0	VL	51
CP8	Other problems with D/B contract procurement	L	0	Procurement	L	Procurement	0	0	VL	29
CP20	#N/A			0		0		0	0.00	#N/A
CN	***Construction Risks***		0.34		0.18		-0.02		0.22	5
CN1	D/B construction phasing significantly different than assumed	0.25		0	-2	Construction	-0.1	Construction	-0.44	185
CN2	Additional Maintenance of Traffic required	M	L	Construction	VL	Construction	0.0165	Construction	VL	15
CN3	Problems with planned accelerated bridge construction (ABC)	M	L	Construction	L	Construction	0	Construction	VL	13
CN4	Unable to construct interchange embankments as rapidly as	L	L	Construction	M	Construction	0	Construction	VL	10
CN5	Difficult foundation installation	L	L	Construction	L	Construction	VL	Construction	VL	20
CN6	Severe weather event significantly impacts construction	VL	VL	Construction	VL	Construction	VL	Construction	VL	31
CN7	Colder-than-usual winter	L	VL	Construction	VL	Construction	0	Construction	VL	28
CN8	Significant accident during construction	VL	VL	Construction	VL	Construction	VL	Construction	VL	31
CN9	Limited construction staging area in vicinity of interchange	M	VL	Construction	0	Construction	0	Construction	VL	26
CN10	Fish window in Wandering Creek	VL	VL	Construction	VL	Construction	VL	Construction	VL	31
CN11	Non-compliance with permits during construction	VL	VL	Construction	VL	Construction	VL	Construction	VL	31
CN12	Extended overheads as function of project delays	0		0		0		0	0.00	51
CN25	#N/A			0		0		0	0.00	#N/A
OM	***Operations Risks***		0.00		0.00		0.00		0.00	8
OM1	#N/A			0		0		0	0.00	#N/A

(continued)

TABLE E.11. MITIGATED RISK FACTORS (continued)

Mitigated Risk Register										
		Mitigated Probability of Occurrence (0 to 1, or rating per rating scale*) Assessment	Assessed Mitigated Impacts (if occur)						Mitigated Mean Severity (escal $M, or rating per rating scale*)	Mitigated Risk Ranking (based on mit. mean severity)
			Mean Direct Cost Change (unesc $M, or rating per rating scale*)		Mean Duration Change to Schedule Activity (months, or rating per rating scale*)		Mean Disruption Change (million person-hours lost, or rating per rating scale*)			
Item	Risk or Opportunity		Assess-ment	Activity Affected (from list)	Assess-ment	Activity Affected (from list)	Assess-ment	Activity Affected (from list)		
OM15	#N/A			0		0		0	0.00	#N/A
RP	***Replacement Risks***		0.00		0.00		0.00		0.00	8
RP1	#N/A			0		0		0	0.00	#N/A
RP15	#N/A			0		0		0	0.00	#N/A
FN	***Funding Risks***		0.00		0.00		0.00		0.00	8
FN1	#N/A			0		0		0	0.00	#N/A
FN10	#N/A			0		0		0	0.00	#N/A
	TOTAL (if comprehensive and non-overlapping set of risks)		4.28		4.67		-0.02		5.30	

Note: For risks and performance through construction only; from rapid renewal risk management planning template (http://www.trb.org/main/blurbs/168369.aspx).

ATTACHMENT 6. MITIGATED MEAN-VALUE PROJECT PERFORMANCE

The various revised base and mitigated risk inputs were used to calculate (using the Microsoft Excel workbook template) approximate mean mitigated project performance (by activity and collectively), including cost (unescalated and escalated), schedule (milestone dates), disruption, and longevity (postconstruction cost, schedule, and disruption), as well as combined performance (see Table E.12). The mean severity of each remaining risk was also determined using the Microsoft Excel workbook template in terms of its approximate contribution to the mean combined performance (see Table E.11), and the risks were then sorted by their mean severity (see Table E.13 and Figure E.4). As previously noted, performance (and thus risks) through construction only is the focus.

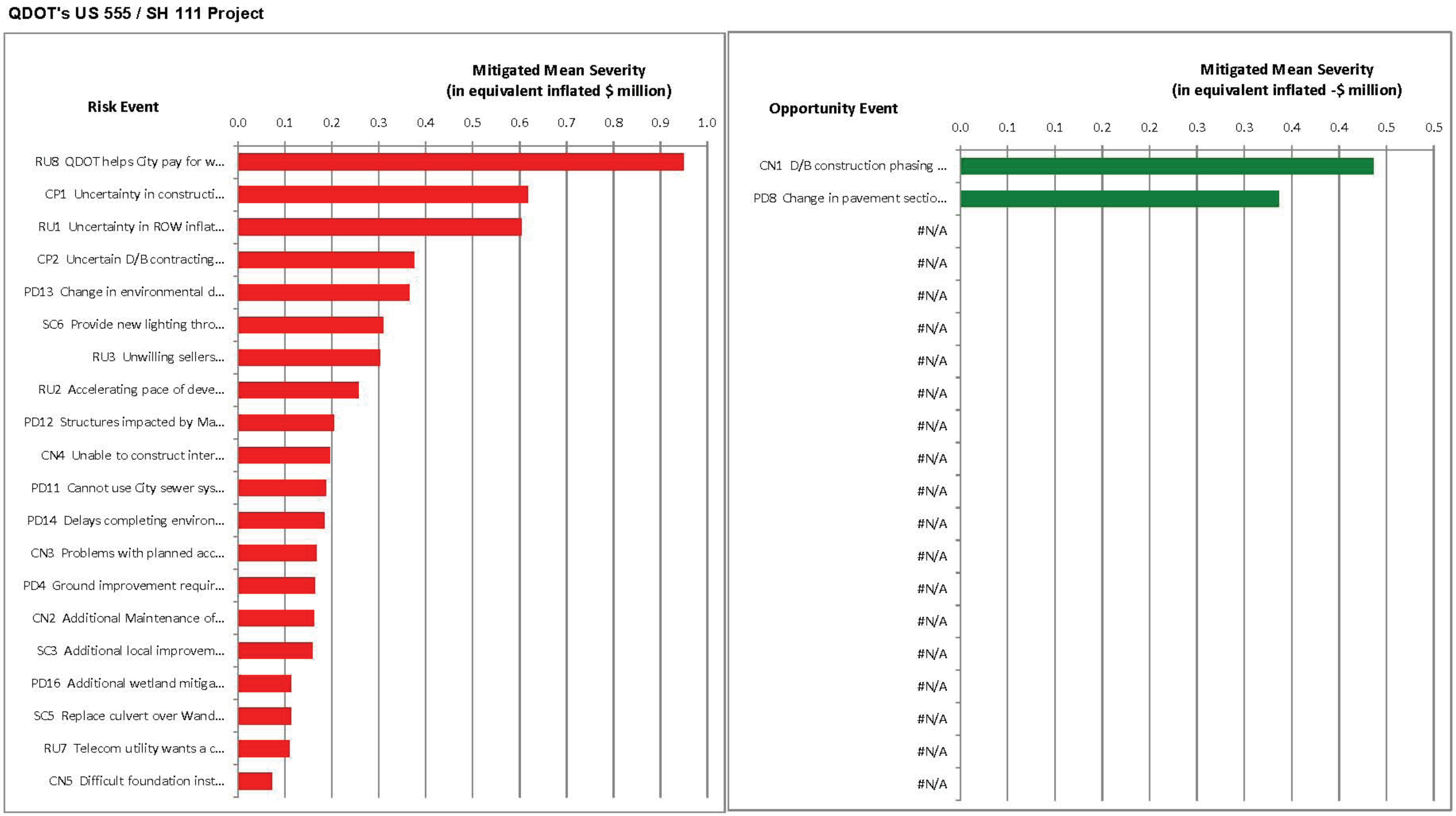
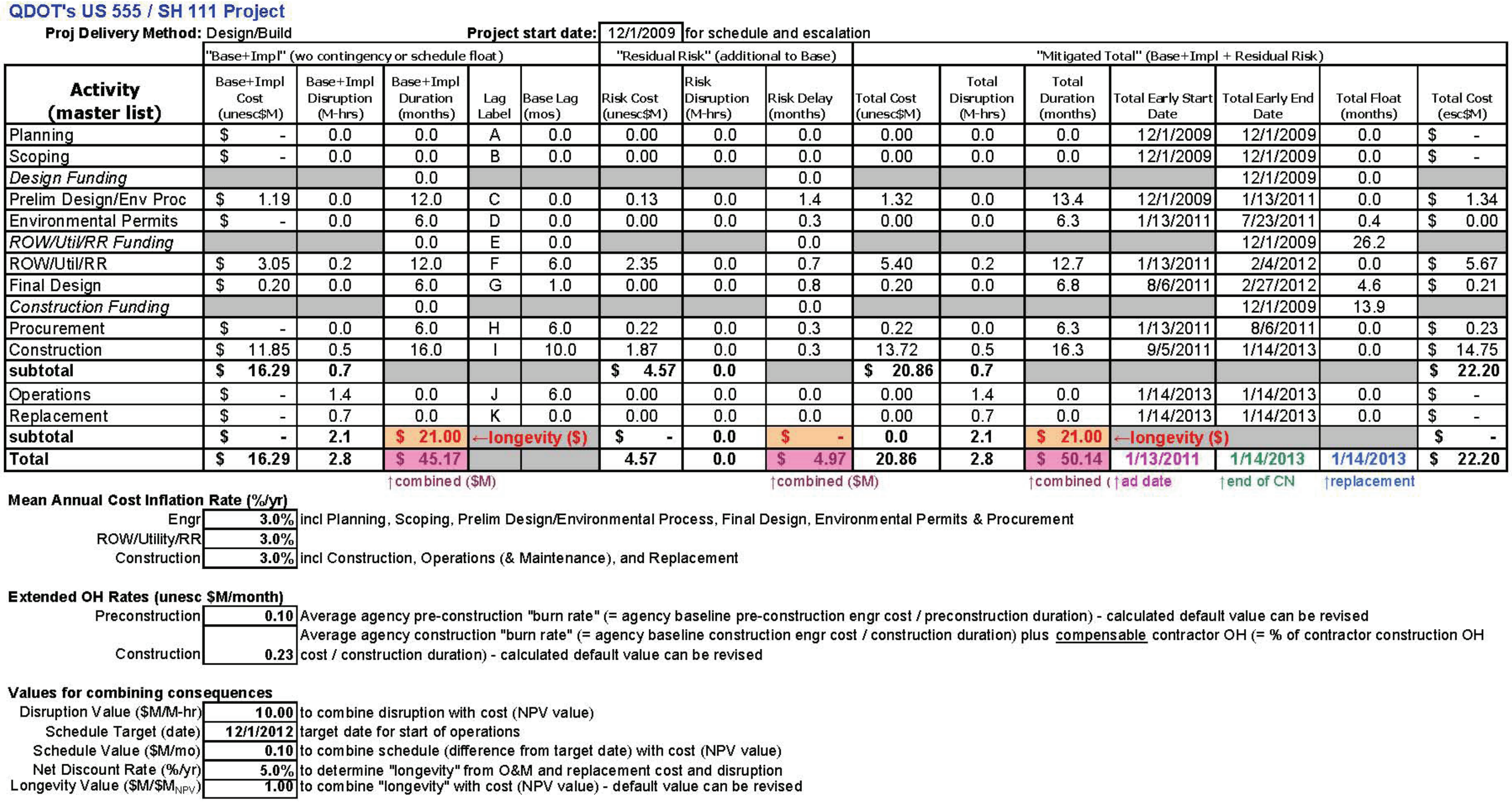


Figure E.4. *Mitigated risk ranking for risks and performance through construction only.*

Source: From the rapid renewal risk management planning template (http://www.trb.org/main/blurbs/168369.aspx).

TABLE E.12. APPROXIMATE MEAN MITIGATED BASE + RISK PROJECT PERFORMANCE



QDOT's US 555 / SH 111 Project

Proj Delivery Method: Design/Build **Project start date:** 12/1/2009 for schedule and escalation

	"Base+Impl" (wo contingency or schedule float)					"Residual Risk" (additional to Base)			"Mitigated Total" (Base+Impl + Residual Risk)						
Activity (master list)	Base+Impl Cost (unesc$M)	Base+Impl Disruption (M-hrs)	Base+Impl Duration (months)	Lag Label	Base Lag (mos)	Risk Cost (unesc$M)	Risk Disruption (M-hrs)	Risk Delay (months)	Total Cost (unesc$M)	Total Disruption (M-hrs)	Total Duration (months)	Total Early Start Date	Total Early End Date	Total Float (months)	Total Cost (esc$M)
Planning	$ -	0.0	0.0	A	0.0	0.00	0.0	0.0	0.00	0.0	0.0	12/1/2009	12/1/2009	0.0	$ -
Scoping	$ -	0.0	0.0	B	0.0	0.00	0.0	0.0	0.00	0.0	0.0	12/1/2009	12/1/2009	0.0	$ -
Design Funding			0.0					0.0					12/1/2009	0.0	
Prelim Design/Env Proc	$ 1.19	0.0	12.0	C	0.0	0.13	0.0	1.4	1.32	0.0	13.4	12/1/2009	1/13/2011	0.0	$ 1.34
Environmental Permits	$ -	0.0	6.0	D	0.0	0.00	0.0	0.3	0.00	0.0	6.3	1/13/2011	7/23/2011	0.4	$ 0.00
ROW/Util/RR Funding			0.0	E	0.0			0.0					12/1/2009	26.2	
ROW/Util/RR	$ 3.05	0.2	12.0	F	6.0	2.35	0.0	0.7	5.40	0.2	12.7	1/13/2011	2/4/2012	0.0	$ 5.67
Final Design	$ 0.20	0.0	6.0	G	1.0	0.00	0.0	0.8	0.20	0.0	6.8	8/6/2011	2/27/2012	4.6	$ 0.21
Construction Funding			0.0					0.0					12/1/2009	13.9	
Procurement	$ -	0.0	6.0	H	6.0	0.22	0.0	0.3	0.22	0.0	6.3	1/13/2011	8/6/2011	0.0	$ 0.23
Construction	$ 11.85	0.5	16.0	I	10.0	1.87	0.0	0.3	13.72	0.5	16.3	9/5/2011	1/14/2013	0.0	$ 14.75
subtotal	**$ 16.29**	**0.7**				**$ 4.57**	**0.0**		**$ 20.86**	**0.7**					**$ 22.20**
Operations	$ -	1.4	0.0	J	6.0	0.00	0.0	0.0	0.00	1.4	0.0	1/14/2013	1/14/2013	0.0	$ -
Replacement	$ -	0.7	0.0	K	0.0	0.00	0.0	0.0	0.00	0.7	0.0	1/14/2013	1/14/2013	0.0	$ -
subtotal	**$ -**	**2.1**	**$ 21.00**	**←longevity ($)**		**$ -**	**0.0**	**$ -**	**0.0**	**2.1**	**$ 21.00**	**←longevity ($)**			**$ -**
Total	**$ 16.29**	**2.8**	**$ 45.17**			**4.57**	**0.0**	**$ 4.97**	**20.86**	**2.8**	**$ 50.14**	**1/13/2011**	**1/14/2013**	**1/14/2013**	**$ 22.20**
			↑combined ($M)					↑combined ($M)			↑combined (	↑ad date	↑end of CN	↑replacement	

Mean Annual Cost Inflation Rate (%/yr)

Engr	3.0%	incl Planning, Scoping, Prelim Design/Environmental Process, Final Design, Environmental Permits & Procurement
ROW/Utility/RR	3.0%	
Construction	3.0%	incl Construction, Operations (& Maintenance), and Replacement

Extended OH Rates (unesc $M/month)

Preconstruction	0.10	Average agency pre-construction "burn rate" (= agency baseline pre-construction engr cost / preconstruction duration) - calculated default value can be revised
Construction	0.23	Average agency construction "burn rate" (= agency baseline construction engr cost / construction duration) plus <u>compensable</u> contractor OH (= % of contractor construction OH cost / construction duration) - calculated default value can be revised

Values for combining consequences

Disruption Value ($M/M-hr)	10.00	to combine disruption with cost (NPV value)
Schedule Target (date)	12/1/2012	target date for start of operations
Schedule Value ($M/mo)	0.10	to combine schedule (difference from target date) with cost (NPV value)
Net Discount Rate (%/yr)	5.0%	to determine "longevity" from O&M and replacement cost and disruption
Longevity Value ($M/$M$_{NPV}$)	1.00	to combine "longevity" with cost (NPV value) - default value can be revised

Note: Through construction only; from rapid renewal risk management planning template (http://www.trb.org/main/blurbs/168369.aspx).

TABLE E.13. MITIGATED RISK RANKING

QDOT's US 555 / SH 111 Project

Mitigated Risk Ranking					Mitigated Opportunity Ranking				
Risk Rank	Percentage of Total Mean Risk (%)	Item	Risk Title	Mean Severity (Equiv. Inflated $M)	Oppor-tunity Rank	Percentage of Total Mean Opportunity (%)	Item	Opportunity Title	Mean Severity (Equiv. Inflated $M)
1	16%	RU8	QDOT helps City pay for water and sewer-line relocatior	M	1	56.4%	CN1	D/B construction phasing significantly different than assumec	-0.44
2	10%	CP1	Uncertainty in construction-cost inflation rate	M	2	43.6%	PD8	Change in pavement section and/or type	-L
3	10%	RU1	Uncertainty in ROW inflation rate	M	3	#N/A	#N/A	#N/A	#N/A
4	6%	CP2	Uncertain D/B contracting market conditions at time of bic	0.38	4	#N/A	#N/A	#N/A	#N/A
5	6%	PD13	Change in environmental documentatior	L	5	#N/A	#N/A	#N/A	#N/A
6	5%	SC6	Provide new lighting throughout projec	L	6	#N/A	#N/A	#N/A	#N/A
7	5%	RU3	Unwilling sellers	L	7	#N/A	#N/A	#N/A	#N/A
8	4%	RU2	Accelerating pace of development in interchange area	L	8	#N/A	#N/A	#N/A	#N/A
9	3%	PD12	Structures impacted by Main Street realignment are historic	L	9	#N/A	#N/A	#N/A	#N/A
10	3%	CN4	Unable to construct interchange embankments as rapidly as assumed	VL	10	#N/A	#N/A	#N/A	#N/A
11	3%	PD11	Cannot use City sewer system for project runoff (or City charges for use)	VL	11	#N/A	#N/A	#N/A	#N/A
12	3%	PD14	Delays completing environmental documentatior	VL	12	#N/A	#N/A	#N/A	#N/A
13	3%	CN3	Problems with planned accelerated bridge construction (ABC) technique	VL	13	#N/A	#N/A	#N/A	#N/A
14	3%	PD4	Ground improvement required in interchange area	VL	14	#N/A	#N/A	#N/A	#N/A
15	3%	CN2	Additional Maintenance of Traffic requirec	VL	15	#N/A	#N/A	#N/A	#N/A
16	3%	SC3	Additional local improvements requirec	VL	16	#N/A	#N/A	#N/A	#N/A
17	2%	PD16	Additional wetland mitigation required for planned alignmen	VL	17	#N/A	#N/A	#N/A	#N/A
18	2%	SC5	Replace culvert over Wandering Creek	VL	18	#N/A	#N/A	#N/A	#N/A
19	2%	RU7	Telecom utility wants a cost-sharing agreement	VL	19	#N/A	#N/A	#N/A	#N/A
20	1%	CN5	Difficult foundation installatior	VL	20	#N/A	#N/A	#N/A	#N/A
21	1%	PD6	Shoulders required on SH 111	VL	21	#N/A	#N/A	#N/A	#N/A
22	1%	PD5	Shoulders required on US 555	VL	22	#N/A	#N/A	#N/A	#N/A
23	1%	EP2	Delay obtaining 404 permil	VL	23	#N/A	#N/A	#N/A	#N/A
24	1%	RU6	Other delays to ROW planning	VL	24	#N/A	#N/A	#N/A	#N/A
25	1%	PD1	Shift alignment of US 555 at east end of projecl	VL	25	#N/A	#N/A	#N/A	#N/A
26	1%	CN9	Limited construction staging area in vicinity of interchange	VL	26	#N/A	#N/A	#N/A	#N/A
27	1%	PD15	Encounter unanticipated contamination in interchange are	VL	27	#N/A	#N/A	#N/A	#N/A
28	0%	CN7	Colder-than-usual winter	VL	28	#N/A	#N/A	#N/A	#N/A
29	0%	CP8	Other problems with D/B contract procurement	VL	29	#N/A	#N/A	#N/A	#N/A
30	0%	PL2	Opposition to removing access to US 555 from 12th Street	VL	30	#N/A	#N/A	#N/A	#N/A
31	0%	CN11	Non-compliance with permits during constructior	VL	31	#N/A	#N/A	#N/A	#N/A
32	0%	CN10	Fish window in Wandering Creek	VL	32	#N/A	#N/A	#N/A	#N/A
33	0%	CN8	Significant accident during constructior	VL	33	#N/A	#N/A	#N/A	#N/A
34	0%	CN6	Severe weather event significantly impacts constructior	VL	34	#N/A	#N/A	#N/A	#N/A
35	0%	CP6	Use incentives to accelerate D/B construction	VL	35	#N/A	#N/A	#N/A	#N/A
36	0%	PD10	Change in stormwater design standards	VL	36	#N/A	#N/A	#N/A	#N/A
37	0%	PD9	Rehabilitate instead of reconstruct existing roadway	VL	37	#N/A	#N/A	#N/A	#N/A
38	0%	SC7	ITS added to this project	VL	38	#N/A	#N/A	#N/A	#N/A
39	0%	SC4	Increased aesthetics for US 555 / SH 111 interchange	VL	39	#N/A	#N/A	#N/A	#N/A
40	0%	SC2	Change in North-South project limits	VL	40	#N/A	#N/A	#N/A	#N/A
41	0%	SC1	Change in East-West project limits	VL	41	#N/A	#N/A	#N/A	#N/A
42	0%	RU10	Damage existing utility or encounter unanticipated utility during construction	VL	42	#N/A	#N/A	#N/A	#N/A
43	0%	RU9	Other utility relocation not completed on time	VL	43	#N/A	#N/A	#N/A	#N/A
44	0%	RU5	Additional ROW required for planned projecl	VL	44	#N/A	#N/A	#N/A	#N/A

Note: For risks and performance through construction only; from rapid renewal risk management planning template (http://www.trb.org/main/blurbs/168369.aspx).

ATTACHMENT 7. CONTINGENCY

For this project, the contingency requirements (both cost and schedule) are summarized in Table E.14 by project phase and cumulatively at the start (and end) of each project phase. As discussed in Chapter 7, in the absence of quantitative risk analysis (which was outside the scope of this risk management plan), to objectively establish contingencies, the contingencies were established by judgment, considering the project risks.

Note that if the total escalated cost was approximately normally (Gaussian) distributed (which would be reasonable based on the central limit theorem), then (a) the contingency target (80th) percentile of total escalated cost would be equal to the mean total escalated cost plus 0.84 times the standard deviation of total escalated cost, and (b) the contingency requirements would be the difference between the contingency target (80th) percentile and the base escalated cost. For example, if the standard deviation of total escalated cost was about 15% of the mean total escalated cost and the mean total escalated cost was 20% higher than the base escalated cost, then the contingency requirements would be about 13% of the mean total escalated cost and about 35% of the base escalated cost.

The protocol for using or releasing contingency follows.

TABLE E.14. CONTINGENCY REQUIREMENT BY PROJECT PHASE

	Total Remaining at Start of Phase		Available During Phase		Total Remaining at End of Phase	
Project Phase	Cost (% of total, YOE $M)	Schedule (% of total, months)	Cost (% of total, YOE $M)	Schedule (% of total, months)	Cost (% of total, YOE $M)	Schedule (% of total, months)
Preliminary design	30%, $5.1	30%, 10.5	10%, $1.7	10%, 3.5	20%, $3.4	20%, 7.0
Procurement	20%, $3.4	20%, 7	10%, $1.7	10%, 3.5	10%, $1.7	10%, 3.5
Construction	10%, $1.7	10%, 3.5	8%, $1.4	10%, 3.5	2%, $0.3	0%, 0
Postconstruction	2%, $0.3	0%, 0	2%, $0.3	0%, 0	0%, $0	0%, 0

Note: Base escalated cost through construction is $17.3 million, and base schedule is 35 months to completion.
YOE $M = year-of-expenditure in millions of dollars.

ATTACHMENT 8. RECOVERY PLANS

For this project, the cost and schedule recovery requirements for each phase are presented in Table E.15, both by project phase and cumulatively at the start of each project phase. As discussed in Chapter 8, in the absence of quantitative risk analysis (which was outside the scope of this risk management plan) to objectively establish recovery requirements, the recovery requirements were established by judgment, considering the project risks.

Note that if the total escalated cost was approximately normally (Gaussian) distributed (which would be reasonable based on the central limit theorem), then (a) the recovery target (95th) percentile of total escalated cost would be equal to the mean total escalated cost plus 1.64 times the standard deviation of total escalated cost, and (b) the recovery requirements would be the difference between the recovery target (95th) percentile and the contingency target (80th) percentile, that is, 0.80 times the standard deviation of total escalated cost. For example, if the standard deviation of total escalated cost was about 15% of the mean total escalated cost and the mean total escalated cost was 20% higher than the base escalated cost, then the recovery requirements would be about 12% of the mean total escalated cost and about 15% of the base escalated cost.

The recovery actions (and their approximate net recovery value) that are available through each project phase are summarized in Table E.16. As shown, the available recovery savings is greater than the recovery required for each phase.

The protocol for implementing recovery plans follows.

TABLE E.15. RECOVERY REQUIREMENT BY PROJECT PHASE

	Total Remaining at Start of Phase		Available During Phase		Total Remaining at End of Phase	
Project Phase	Cost (% of total, YOE $M)	Schedule (% of total, months)	Cost (% of total, YOE $M)	Schedule (% of total, months)	Cost (% of total, YOE $M)	Schedule (% of total, months)
Preliminary design	15%, $2.6	15%, 5.3	5%, $0.9	5%, 1.8	10%, $1.7	10%, 3.5
Procurement	10%, $1.7	10%, 3.5	5%, $0.9	5%, 1.8	5%, $0.8	5%, 1.7
Construction	5%, $0.8	5%, 1.7	5%, $0.8	5%, 1.7	0%, $0	0%, 0

Note: Base escalated cost through construction is $17.3 million and base schedule is 35 months to completion.
YOE $M = year-of-expenditure in millions of dollars.

TABLE E.16. RECOVERY PLAN BY PROJECT PHASE

Project Phase	Recovery Action	Net Savings	
		Cost (YOE $M)	Schedule (months)
Preliminary Design	<aaa>	<$>	<T>
	<bbb>	<$>	<T>
	<ccc>	<$>	<T>
	subtotal	<$>	<T>
Procurement	<ddd>	<$>	<T>
	<eee>	<$>	<T>
	<fff>	<$>	<T>
	subtotal	<$>	<T>
Construction	<ggg>	<$>	<T>
	<hhh>	<$>	<T>
	<iii>	<$>	<T>
	subtotal	<$>	<T>

Note: YOE $M = year-of-expenditure in millions of dollars.

ADDENDUM X TO QDOT US-555/SH-111 RISK MANAGEMENT PLAN

Quantitative Risk Analysis (Cost and Schedule Through Construction)

A quantitative risk analysis was subsequently conducted on QDOT's US-555/SH-111 project, focusing on cost and schedule through construction. This involved expanding on the previous risk management process in the following areas:

- **Flowchart.** A more detailed flowchart was developed (see Figure E.5).
- **Base Schedule.** The base schedule did not change but was developed for the more detailed flowchart (see Figure E.5 and Table E.17).
- **Base Cost.** The cost estimate changed slightly (a concrete retaining wall, which cost $191,000 before markups, was previously missed and thus added), and uncertainties in (and correlations among) the base cost factors were assessed and the costs were reallocated to the QRA flowchart (see Table E.18).
- **Unmitigated Risk Register (i.e., before risk management).** The unmitigated risk register did not change, but the factors were reassessed quantitatively and in more detail (see Table E.19).
- **Risk Model.** A risk-based probabilistic (Monte Carlo simulation) integrated project cost and schedule model was developed (using a previously developed Microsoft Excel template), per the QRA flowchart, QRA base schedule, QRA base costs (including uncertainties and allocation to flowchart activities), and QRA risk register.
- **Unmitigated Risk Results.** The following unmitigated results were generated:
  - —Approximate mean values of unmitigated base + risk schedule and cost by flowchart activity (see Table E.20);
  - —Plot of "raw" unmitigated cost and schedule simulation results (see Figure E.6); and
  - —Probability distributions for unmitigated cost (unescalated and escalated) and schedule (notice to proceed and completion date), presented two ways:
    1. Tabular summary (see Table E.21); and
    2. Graphically (see Figure E.7).
  - —Unmitigated cost risk rankings (in terms of the contribution of each to the 80th percentile of escalated project cost), presented two ways:
    1. Tabular summary (see Table E.22); and
    2. Graphically ("tornado diagrams") (see Figure E.8).
  - —Schedule risk rankings and cash flow are not shown.
- **Risk Reduction Actions.** The risk reduction plan and the cost-effectiveness factor assessments did not change. However, the revised base cost and schedule, and residual risk factors, associated with that plan were determined and used in the same risk model as for the unmitigated case.

- **Mitigated Risk Results.** The following mitigated results were generated:
    - —Approximate mean values of mitigated base + risk schedule and cost by flowchart activity (see Table E.23);
    - —Plot of "raw" mitigated cost and schedule simulation results (see Figure E.9); and
    - —Probability distributions for mitigated cost and schedule, presented two ways:
        1. Tabular summary (see Table E.24); and
        2. Graphically (see Figure E.10).
    - —Mitigated cost and schedule risk rankings and cash flow are not shown.

The assessments described above were conducted in a facilitated training workshop attended by the project team and independent subject-matter experts in 2010.

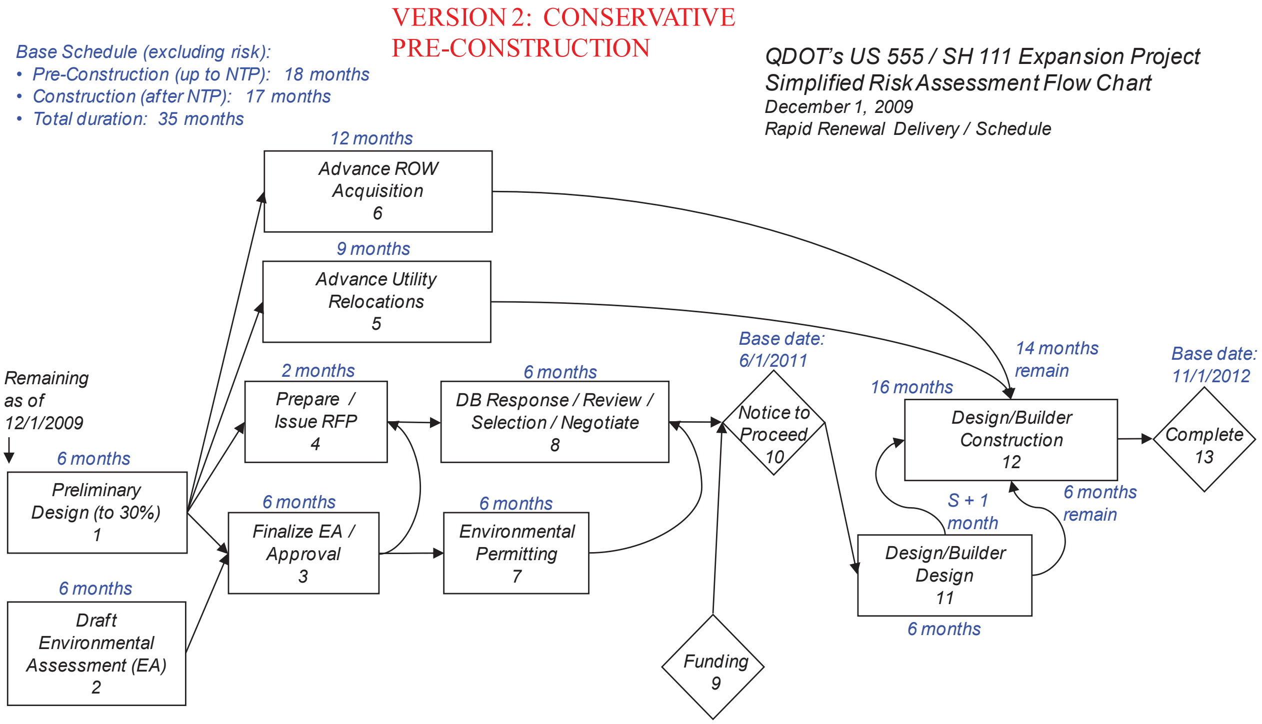
Based on the above mitigated results (assuming the risk reduction plan is adopted and conducted):

- The range (10th to 90th percentiles) in total escalated cost is $18.0 million to $25.3 million and in completion date is March 2013 to August 2013.
- Based on QDOT's established policy of
    - —Budgeting at the 80th percentile, the budget should be $23.8 million YOE and the completion date milestone should be August 2013, which translate to a cost contingency of $6.6 million YOE (relative to an escalated base cost of $17.2 million) and a schedule contingency (critical path float) of 9 months (relative to a base completion date of November 2012).
    - —Requiring recovery plans to cover beyond contingency up to the 95th percentile, recovery requirements are $2.7 million YOE (from budget of $23.8 million to 95th percentile of $26.5 million YOE) and 1 month (from milestone of August 2013 to 95th percentile of September 2013).

The contingency and recovery for each phase could be determined in a similar way from more detailed mitigated results (i.e., by phase), or simply but more approximately by prorating the total amounts by the differences for each phase between the mean mitigated values (Table E.23) and the mean base values (Tables E.17 and E.18, Part C).

- There might be more potential cost and schedule savings associated with risk reduction planning, by focusing on the significant residual risks.

Recovery plans (in case the cost and/or schedule contingencies turn out to be insufficient), to cover the revised recovery requirements, did not change.



Notes:
1. Single Design/Build contract.
2. Advance Right-of-Way (ROW) Acquisition includes appraisals, offers, acquisition, relocation, and demolition for parcels that QDOT anticipates will be critical to early construction by the Design/Builder.
3. Advance Utility Relocations includes coordination, approvals, and relocations of utilities that QDOT anticipates will be critical to early construction by the Design/Builder. Additional relocations that might be required will be the responsibility of the Design/Builder during construction. Assumes minimal new ROW required for utility relocations.
4. QDOT will complete the Environmental Assessment (EA) and obtain all environmental permits before Notice to Proceed (NTP).
5. Construction duration includes typical winter shut-down period from November 15th through March 15th.
6. Construction includes construction permits, remaining utility relocations, and all construction-related effort. Remaining ROW acquisition by QDOT also occurs during this timeframe.

Figure E.5. *QRA project flowchart through construction.*

TABLE E.17. QRA UNMITIGATED BASE SCHEDULE

#	Activity	Base Duration (months)	Base Early Start Date	Base Early End Date	Base Float (months)	On Critical Path for Base Schedule? (1 = Yes; 0 = No)
0	Previous Costs	1.0	1-Dec-09	31-Dec-09	0.0	0
0	0	0.0	1-Dec-09	1-Dec-09	0.0	0
1	Preliminary Design (to 30%)	6.0	1-Dec-09	2-Jun-10	0.0	1
2	Draft Environmental Assessment (EA)	6.0	1-Dec-09	2-Jun-10	0.0	1
3	Finalize EA/Approval	6.0	2-Jun-10	2-Dec-10	0.0	1
4	Prepare/Issue RFP	2.0	2-Jun-10	2-Dec-10	4.0	0
5	Advance Utility Relocations	9.0	2-Jun-10	3-Mar-11	5.5	0
6	Advance ROW Acquisition	12.0	2-Jun-10	3-Jun-11	2.5	0
7	Environmental Permitting	5.0	2-Dec-10	3-May-11	1.0	0
0	0	0.0	1-Dec-09	1-Dec-09	0.0	0
8	Design–Builder (D-B) Response/Review/Selection/ Negotiate	6.0	2-Dec-10	3-Jun-11	0.0	1
9	Funding	0.0	1-Jun-11	1-Jun-11	0.1	0
10	Notice to proceed	0.0	3-Jun-11	3-Jun-11	0.0	1
0	0	0.0	1-Dec-09	1-Dec-09	0.0	0
11a	Design–Builder Design a	1.0	3-Jun-11	3-Jul-11	0.0	1
11b	Design–Builder Design b	5.0	3-Jul-11	3-Dec-11	6.5	0
12a	Design–Builder Construction a	1.5	3-Jul-11	18-Aug-11	0.0	1
12b	Design–Builder Construction B	6.0	18-Aug-11	18-Jun-12	0.0	1
12c	Design–Builder Construction c	4.5	18-Jun-12	2-Nov-12	0.0	1
13	Complete	0.0	2-Nov-12	2-Nov-12	0.0	1
	Total		3-Jun-11	2-Nov-12	substantial completion	

Note: Through construction.

TABLE E.18. QRA UNMITIGATED BASE COST

(A) COST ESTIMATE[a]

QDOT Project Estimate						
Quantity	Unit of Measure	Unit Cost	Description of Work Item Low (10th Percentile)	Cost (2009 $) High (90th Percentile)	Base Cost Uncertainty (combined unit price and quantity)	
					Low (10th percentile)	High (90th percentile)
CONSTRUCTION						
			Preparation			
21	acre	$4,800.00	Clearing and Grubbing	$99,360	–10%	10%
26,397	S.Y.	$8.40	Removing cement concrete pavement	$221,735	–10%	10%
26,397	S.Y.	$4.80	Removing asphalt concrete pavement	$126,706	–10%	10%
			Grading			
33,393	C.Y.	$9.60	Roadway excavation incl. hauling	$320,573	–20%	20%
27,960	C.Y.	$4.20	Common Borrow incl. hauling	$117,432	–20%	20%
3,107	C.Y.	$14.40	Gravel borrow incl. hauling	$44,741	–20%	20%
31,067	C.Y.	$1.20	Embankment compaction	$37,280	–20%	20%
			Drainage			
42	each	$2,160.00	Grate inlet Type 1 or 2	$90,720	–5%	5%
6	each	$3,600.00	Drop inlet Type 1	$21,600	–5%	5%
21,120	L.F.	$78.00	Plain st. culv. pipe 0.109 in. thick, 36 in. diam.	$1,647,360	–5%	5%
50	L.F.	$1,800.00	St. stru. pipe arch 8 gauge 20 ft. 0 in. span	$89,100	–5%	5%
			Structure			
3,972	S.F.	$145.00	Bridge no. (easy bridge)	$575,940	–20%	20%
8,673	S.F.	$22.00	Concrete retaining wall	$190,806	–10%	10%
			Surfacing			
27,047	ton	$12.00	Crushed surfacing base course	$324,564	–10%	10%
			Cement Concrete Pavement			
16,696	C.Y.	$110.00	Cement concrete pavement	$1,836,560	–10%	10%
882	S.Y.	$146.00	Bridge approach slab	$128,772	–10%	10%
			Asphalt Concrete Pavement			
1,100	ton	$36.00	Miscellaneous asphalt concrete pavement	$39,600	–10%	10%

(continued)

TABLE E.18. QRA UNMITIGATED BASE COST

(A) COST ESTIMATE[a] (continued)

QDOT Project Estimate						
Quantity	Unit of Measure	Unit Cost	Description of Work Item Low (10th Percentile)	Cost (2009 $) High (90th Percentile)	Base Cost Uncertainty (combined unit price and quantity)	
					Low (10th percentile)	High (90th percentile)
			Erosion Control And Planting			
2	acre	$2,400.00	Seeding, fertilizing, and mulching	$4,800	–10%	10%
1	est.	$85,000.00	Temporary water pollution/erosion control	$85,000	–10%	10%
1,564	C.Y.	$13.20	Topsoil Type B	$20,645	–10%	10%
1	est.	$150,000.00	Miscellaneous landscaping			
			Traffic			
15,840	L.F.	$120.00	Special concrete barrier Type 5	$1,900,800	–10%	10%
8	each	$14,400.00	Permanent impact attenuator	$115,200	–10%	10%
214,000	L.F.	$0.12	Paint line	$25,680	–10%	10%
1	L.S.	$24,000.00	Permanent signing	$24,000	–10%	10%
			Other Items			
4,000	L.F.	$18.00	Temporary barrier glare screen	$72,000	–10%	10%
1	est.	$12,000.00	Roadside cleanup	$12,000	–10%	10%
1	est.	$6,000.00	Trimming and Cleanup	$6,000	–10%	10%
			CONSTRUCTION SUBTOTAL “A” (before Mob), Traffic Control and Other Miscellaneous Items)	$8,178,973		
A	%	5.0%	Mobilization	$408,949	–10%	20%
A + Mob	%	7.0%	Traffic Control (at 7% of subtotal A + Mob)	$601,155	0%	50%
A + Mob	%	12.0%	Other Miscellaneous Items (12% of subtotal A + Mob)	$1,030,551	–10%	20%
			CONSTRUCTION SUBTOTAL “ B” (including Mob, Traffic Control and Other Miscellaneous Items)	$10,219,627		
B	%	10.0%	DESIGN-BUILDER DESIGN FEES (10% of “B”)	$1,021,963	–10%	10%
			DESIGN-BUILD CONSTRUCTION TOTAL “C”	$11,241,590		
C	%	8.0%	CONSTRUCTION ADMINSTRATION (8% of “C”)	$899,327	–10%	20%

(continued)

TABLE E.18. QRA UNMITIGATED BASE COST (continued)

(A) COST ESTIMATE[a]

QDOT Project Estimate						
Quantity	Unit of Measure	Unit Cost	Description of Work Item Low (10th Percentile)	Cost (2009 $) High (90th Percentile)	Base Cost Uncertainty (combined unit price and quantity)	
					Low (10th percentile)	High (90th percentile)
C + Admin	%	10.0%	AGENCY DESIGN, ENV, PERMITTING, AND PROCUREMENT (10% of "C" + C. Admin)	$1,214,092	–10%	10%
			(includes previous costs of $200,000)			
			RIGHT-OF-WAY	$2,000,000	–20%	20%
			UTILITY RELOCATIONS	$1,000,000	–20%	20%
			PROJECT SUBTOTAL "D" (Before Contingency)	$16,355,009		
			CONTINGENCY (30% of Project Subtotal "D")	$-		
			TOTAL	$16,355,009		

(continued)

TABLE E.18. QRA UNMITIGATED BASE COST (continued)

(B) OTHER BASE COST FACTORS[b]

Factor	Low (10th Percentile)	High (90th Percentile)	Correlation
ROW escalation rate (%/yr)	–2.0	8.0	Correlated 0.5 year-to-year
Construction escalation rate (%/yr)	–1.0	7.0	Independent year-to-year and of ROW escalation rate
All construction cost items	(see Part A)		Correlated 0.75

(C) ALLOCATION OF COSTS TO FLOWCHART ACTIVITIES[c]

#	Activity	Base Cost (current $M)	Base Cost (YOE $M)
0	Previous Costs	0.2	0.2
0	0	0.0	0.0
1	Preliminary Design (to 30%)	0.3	0.3
2	Draft Environmental Assessment (EA)	0.2	0.2
3	Finalize EA/Approval	0.2	0.2
4	Prepare/Issue RFP	0.3	0.3
5	Advance Utility Relocations	0.8	0.8
6	Advance ROW Acquisition	2.0	2.1
7	Environmental Permitting	0.0	0.0
0	0	0.0	0.0
8	Design–Builder Response/Review/Selection/Negotiate	0.0	0.0
9	Funding	0.0	0.0
10	Notice to Proceed	0.0	0.0
0	0	0.0	0.0
11a	Design–Builder Design a	0.2	0.2
11b	Design–Builder Design b	0.9	0.9
12a	Design–Builder Construction a	2.4	2.5
12b	Design–Builder Construction b	5.1	5.5
12c	Design–Builder Construction c	3.8	4.2
13	Complete	0.0	0.0
	Total	16.4	17.3

Note: Each base cost item was allocated (by percentage) to the various schedule activities via a matrix (not shown). Costs include uncertainties and correlations, as well as allocations to flowchart; through construction.

[a] Includes uncertainties; correlations are presented in Part B.

[b] Includes escalation rate uncertainties and all correlations.

[c] Mean values are shown.

TABLE E.19. QRA UNMITIGATED RISK REGISTER

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
	Planning			
PL1 Excluded	**Project funding delayed or reduced** The project is currently funded for an amount that QDOT feels is adequate. . However, if additional funding is required (i.e., if costs increase for various reasons), there might be a delay in obtaining the additional funding. However, QDOT's objective is to evaluate the project's risk assuming funding is available without delay. Hence, QDOT wants to *exclude* uncertainty in funding at this time (but might later treat that uncertainty by defining separate "model scenarios" to evaluate the impact of various potential funding delays). Otherwise, *exclude* the risk that funding is canceled or substantially reduced (so that scope reduction is required, which would lead to a "different" project).			
PL2	**Opposition to removing access to US-555 from 12th Street** Several businesses rely on this access and might protest or challenge the removal of the access. However, removal of that access is necessary for the project. Hence, this design decision is unlikely to be reversed. However, some mitigation might be required as compensation.	10	To Activity 12: +0.1	0

Note: Table includes cost and schedule through construction. When significant dependencies among risk or opportunity events were identified during the workshop, they were generally assessed using an event tree and combined into a single event in this register. This approach ensures that the important dependencies and related conditional probabilities are assessed explicitly. Otherwise, the uncertainties, risks, and opportunities in this register have been defined to be (i.e., are assessed to be) independent of one another. Some events in this register are a function of base costs or durations. When those base costs or durations are assessed to be uncertain, the corresponding event should consider (include) changes to the base resulting from the simulated base uncertainty. All cost impacts are assessed in current terms. Cost escalation is handled automatically through the simulation model, appropriately considering uncertainty in inflation rates and the affected project activities. Except for soft cost uncertainties that are addressed separately, and unless noted otherwise, all cost impacts in this table are fully loaded with appropriate markups. Potential markups include items that may be treated as a percentage of the construction subtotal in the cost estimate, such as sales tax, mobilization, construction engineering, design, and allowances for miscellaneous items.

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TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
PL3 Elsewhere	**Opposition to "splitting" alignment of SH-111 in the interchange area** The city does not like this alternative. This issue is captured as a factor influencing the probability that this split will occur; see Risk PD2.			
PL4 Minor	Other stakeholder issues not captured separately			
	Scoping			
SC1 Minor	**Change in east-west project limits** Project might be required (for either political or operational reasons) to improve a longer or shorter stretch of US-555 than assumed in the base estimate. The project team and QDOT believe this is unlikely because funding is not available for such a significant change, and the need is not clear (for the project to perform as desired).			
SC2 Minor	**Change in north-south project limits** Project might be required (for either political or operational reasons) to improve a longer or shorter stretch of SH-111 than assumed in the base estimate. Similar to discussion for SC1.			
SC3	**Additional local improvements required** For example: • More improvements on Main Street away from US-555 • More improvements on North Avenue and/or South Avenue away from SH-111 • More improvements on West Street and/or East Street away from US-555 Schedule impacts are design related.	20	+0.25 to Activity 12	+1 to Activity 1

(continued)

TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
SC4 Minor	**Increased aesthetics for US-555/SH-111 interchange** For example, "gateway" appearance, decorative lighting. The project already includes reasonable aesthetics, and a significant gateway theme is well outside the project's budget. The city would therefore have to pay for such improvements, which it is unlikely to be able to afford.			
SC5	**Replace culvert over Wandering Creek** Base assumes that the state fisheries agency will allow widening this culvert, especially since no listed fish species are believed to live this far up Wandering Creek. However, the fisheries agency has required replacement of similar culverts on nearby projects.	25	To Activity 12: +0.3	0
SC6	**Provide new lighting throughout project** Base assumes new lighting only in the interchange area. The team increasingly believes that new lighting will be required throughout (mainly because they will have to relocate existing lighting to widen the roadway anyway).	50	To Activity 12: +0.5	0
SC7 Minor	Intelligent transportation system (ITS) added to this project Unlikely—not funded and the systemwide ITS development is lagging this project.			
	Preliminary Design/Environmental Process *For all relevant risks in this category, the following conditions apply*: Each risk includes all related/correlated design, environmental, right-of-way (ROW), and construction impacts. Impacts shown are in addition to any assessed base uncertainties.			

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TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
PD1	**Shift alignment of US-555 at east end of project** This would reduce wetland impacts by shifting alignment to the south. However, there is some resistance (city) to shifting the alignment this way because of the number of business displacements it would cause. It could also cause a problem with geometry at the intersection of East Street. The group therefore thinks that this is unlikely to occur. If it did, however, the impacts would include reduced wetland impacts, increased ROW costs (mostly due to additional demolition and business relocations), and additional design time. The change in construction cost would be minimal.	5%	+ 1.0 to Activity 6 (ROW) and –0.25 to Activity 12 (reduced wetland mitigation)	+1 to Activity 1 and +3 to Activity 6
PD2 Minor	**Split alignment of SH-111 at US-555 interchange** Instead of widening on existing alignment; this would allow for more rapid construction but requires additional ROW. Benefits (reduced construction duration) probably does not outweigh the detriments (additional ROW, less efficient traffic flow, redesign). The city and at least two public groups do not like this alternative. Therefore, it is unlikely to occur.			
PD3	**Change in configuration of SH-111/US-555 interchange** QDOT's preliminary design (SPUI) is one of several viable alternatives, and it is expected that the contractor could propose a suitable alternative. It is uncertain how much such a change might cost relative to the currently assumed alternative (could be more, could be less), but QDOT will not accept a design that is significantly more expensive. Includes potential change in structure and foundation type/size, but assumes that an appropriate accelerated bridge construction (ABC) technique will be used.	Discrete distribution: A. 25 B. 50 C. 25	To Activity 12: As a percentage of base interchange construction cost: A. –10 B. 0 (base) C. +10	Minor

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TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
PD4	**Ground improvement required in interchange area** QDOT HQ design is also concerned that a recent change to the seismic design criteria (which is still being evaluated) might require localized ground improvement to mitigate for liquefaction potential. The project team thinks this is unlikely, but could have significant impacts if it occurs.	10	To Activity 12: +0.5	To Activity 12: +0.5
PD5	Shoulders required on US-555 For example, if FHWA or QDOT HQ Design both do not approve the no-shoulder exception/deviation. The project team is reasonably confident that this design exception will be approved based on recent, similar approvals for other nearby projects. However, if shoulders are required, the impacts are significant: additional ROW would be required, construction costs would increase, the draft environmental assessment (EA) might have to be modified (wetland impacts would increase), and design time (prior to request for proposal) would increase.	5	+1 to Activity 6 (ROW) and +1 to Activity 12	+3 to Activity 6 and +1 to Activity 2 (EA)
PD6	**Shoulders required on SH-111** For example, if QDOT HQ Design does not approve the no-shoulder exception/deviation. Similar to the discussion and assessments for Risk PD5. For the quantitative risk analysis: Risk PD6 is correlated to Risk PD5. If Risk PD5 does not occur (shoulders are not required on US-555), then it is likely that shoulders will not be required on this facility either. If Risk PD5 does occur, then shoulders will likely be required for SH-111 as well.	Dependent on outcome of risk PD5: If risk PD5 occurs, 75; If risk PD5 does not occur, 0.	+1 to Activity 6 (ROW) and +1 to Activity 12	+3 to Activity 6 and +1 to Activity 2 (EA)

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TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
PD7 Minor	**Additional cost for signalized intersections** Excludes any change in the number of intersections that is captured separately in risks related to project limits (i.e., Risks SC1 and SC2).			
PD8	**Change in pavement section and/or type** The base assumes concrete pavement to provide longevity (one of the project's goals). QDOT is therefore most likely to specify a concrete pavement. Asphalt pavement might be selected to provide compatibility with existing pavement (beyond the project limits) and to save initial cost. However, QDOT considers maximizing longevity (including life-cycle costs) a higher priority than saving initial capital cost.	25	–1 to Activity 12	0
PD9 Minor	**Rehabilitate instead of reconstruct existing roadway (e.g., overlay instead)** See Appendices A and B, or Table B.9 of the guide. Existing roadway is 20 years old; it might not be cost-effective to rehabilitate if new lanes will have to be built anyway. In addition, rehab is not as likely to meet the project objective of maximizing longevity of the facility. Note that for the quantitative risk analysis, this risk is correlated with Risk PD8 (impacts are a function of the outcome of that risk).			
PD10 Minor	**Change in stormwater design standards** The design incorporates the latest standards, which are only 2 years old. Hence, it is unlikely that new standards will emerge in this project's time frame.			

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TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
PD11	**Cannot use city sewer system for project runoff (or city charges for use)** The city might deny use or charge QDOT for various upgrades to the system to accommodate stormwater runoff from this project. The project team and QDOT management are “almost certain” that the city will ultimately allow use of the city’s system (the city needs this project, and the additional load on the sewer system is not substantial), but will most likely ask for money to help upgrade its system. QDOT will probably capitulate because this is the best option from a cost-and-time perspective. This cost would occur during the project’s “utility relocations” phase. This issue is correlated with the likely request by the city to help pay for a water- and sewer-line relocation (see Risk RU2 under utilities risks). For the quantitative risk analysis, the group assesses that if Risk RU2 occurs (i.e., QDOT decides to help pay for relocation), then this risk is much less likely to occur.	If Risk RU2 does not occur, 50%; If Risk RU2 does occur, 10%	To Activity 5: +1	To Activity 5: +1
PD12	Structures affected by Main Street realignment are eligible for National Register of Historic Places Can reasonably capture the range of credible possibilities with the following set of potential (mutually exclusive) scenarios/outcomes: A. Not historic structures (base assumption) B. Historic structures, but no significant impact to project cost or schedule (e.g., document, then acquire) C. Historic structures, creating significant impact to project cost or schedule (e.g., have to relocate structures; structures are contaminated; or have to shift project alignment to avoid)	A. 50 B. 40 C. 10	A. 0 (base) B. 0 C. +1 to Activity 6 and +0.1 to Activity 2	A. 0 B. 0 C. +2 to Activity 6 and +2 to Activity 2

(continued)

TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
PD13	**Change in environmental documentation** Only treat this issue here if not captured separately by specific triggers/issues elsewhere (e.g., design changes). Base assumes an EA, but an environmental impact statement (EIS) might be required if impacts are greater than assumed. Can reasonably capture the range of credible possibilities with the following set of potential (mutually exclusive) scenarios/outcomes: A. Complete EA as planned (base assumption) B. Complete EA with additional effort, but with no significant changes to the project C. EIS required, but with no significant changes to the project D. EIS required, resulting in significant change to the project design, ROW, and/or construction	A. 50 B. 40 C. 8 D. 2 (1-in-50 chance)	A. 0 (base) B. 0.1 to Activity 2 C. 0.5 to Activity 2 D. 0.5 to Activity 2 and +1 to Activity 12	A. 0 (base) B. +1 to Activity 2 C. +6 to Activity 2 D. +6 to Activity 2
PD14	**Delays completing environmental documentation** From various causes if not already captured separately (i.e., significant design changes; change in type of environmental documentation, Risk EP2). For example: Additional impacts identified Process delays (internal or external reviews, comments, and/or approvals)	25	Simulated additional overheads	To Activity 3: +3
PD15	**Encounter unanticipated contamination in interchange area** If encountered, likely to be hydrocarbon-based soil and/or groundwater contamination.	25	To Activity 12: +0.1	0

(continued)

TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
PD16	**Additional wetland mitigation required for planned alignment** Additional mitigation could be required for various reasons. For example: • Change in mitigation requirements (ratios, buffers) • Change in wetland classification • Impacts different than assumed (i.e., underestimated originally) (this could happen for the current or shifted alignment) Note that for the quantitative risk analysis, this risk is partially a function of any potential shift in alignment at the east end of the project (Risk PD1). If Risk PD1 occurs and the base wetland impacts are reduced, the probability of this risk is reduced.	If Risk PD1 does not occur: 33 If risk PD1 does occur: 10	To Activity 12: +0.25	0 (can be done "offline")
	Environmental Permitting			
EP1 Minor	**Challenge to environmental determination or permits** For any reason not captured elsewhere. Could come from organized public groups for various reasons. However, very unlikely for the base project (chances could increase for some alternatives such as shifting the alignment at the east end of the project, but these impacts are captured in those risks).			
EP2	**Delay obtaining the 404 permit** From either internal or U.S. Army Corps of Engineers process delays (review, approval) or deficiencies in QDOT's application. Note that this risk is assumed to be approximately independent of Risks PD1 and EP6 (delay issues could occur regardless of the outcomes from those risks).	10	Simulated additional overheads	To Activity 7: +3

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TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
	Right-of-Way			
RU1	**Uncertainty in ROW inflation rate** Regionally; before considering the localized effects of accelerating development, which is captured separately. Despite a sag in the economy, property prices have held steady, and appear to even be increasing slightly. However, this could change (e.g., if this area is lagging the economy). Over the short term of this project, local indicators and the ROW professionals anticipate an average increase of approximately 3%/year in the area.	Probability distribution for base uncertainty; applies to all years, moderately correlated among years	To Activity 6: Normal distribution, with 10th percentile = –2% and 90th percentile = +8%	0
RU2	**Accelerating pace of development in interchange area** Beyond the regional ROW inflation rate captured in RU1. Several new developments are planned in the area, and at least one could be implemented before this project is let. The impact to this project would be increased acquisition and perhaps relocation costs compared with what is currently assumed in the estimate.	25%	To Activity 6: +0.5	To Activity 6: +3
RU3	**Unwilling sellers** Note that base cost excludes condemnation costs/allowance. This risk is separate from Risk RU2. Particularly in the US-555/SH-111 interchange area, property owners might not want to relocate, leading to increased cost to acquire ROW (e.g., have to go through condemnation). Note that condemnation does not normally extend the ROW acquisition time frame, because QDOT can usually quickly gain possession-and-use of condemned properties.	50	To Activity 6: +0.5	0 (QDOT can obtain possession without delay)

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TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
RU4 In RU2	**Additional relocation or demolition required** Excludes additional relocation or demolition that might be required to accommodate changes in design or scope, which are captured as part of those separate risks. Excludes contamination, which is captured separately. For example, relocation from multitenant properties could be complex. The group assesses that this potential additional cost and time were captured in Risk RU2.			
RU5 Minor	**Additional ROW required for planned project** Excludes additional ROW that might be required for changes in design or scope, which are captured as part of those separate risks. For example, initial estimates for required ROW for the assumed design were incorrect or incomplete. The group assesses that the potential significant changes were captured as part of other risks.			
RU6	**Other delays to ROW planning** For reasons not captured as part of other specific risks. For example, late changes in design result in changes in ROW plans or internal QDOT delays to ROW plan development.	25	Simulated additional overheads	To Activity 6: +1

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TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
	Utilities			
RU7	Telecom utility wants a cost-sharing agreement The Telecom's presence in the project ROW predates QDOT's, so QDOT cannot force relocation. The Telecom just recently replaced its fiber-optic backbone, so it is not likely to replace it without some sort of cost sharing (or at least replace it within the time frame needed by this project).	25	To Activity 5: +0.5	0
RU8	**QDOT helps city pay for water- and sewer-line relocation** See Appendix A of the guide. To help maintain project schedule, QDOT might help pay for the sewer-line relocation. This "risk" is therefore really a project or policy decision within QDOT's control. This decision comes at a monetary cost but avoids schedule delay (as reflected to the right). Note that for the quantitative risk analysis, the outcome of this risk affects the likelihood of occurrence for Risk PD11.	50	To Activity 5: +0.5	0 (mitigates the risk of schedule slip)
RU9 Minor	**Other utility relocations not completed on time** For issues not captured separately in other risks. For various reasons, including delayed negotiations, design, or relocation work itself.			
RU10 Minor	**Damage existing utility or encounter unanticipated utility during construction** Possible, but the time impacts are quickly mitigated. The cost impact would be the D-B contractor's responsibility.			

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TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
	Contracting and Procurement			
CP1	**Uncertainty in construction-cost inflation rate** Excludes contracting market conditions and material supply issues, which are captured separately in Risks CP2 and CP3. This issue includes uncertainty in the general regional and national trends in construction industry cost changes over time (general inflation), with reasonable adjustment for this region.	Probability distribution for base uncertainty; applies to all years, independently among years (consistent with FHWA historical analysis)	To Activities 5, 11, and 12: Normal distribution with: 10th percentile = –1% per year; 90th percentile = +7% per year	0

(continued)

TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
CP2	**Uncertain D-B contracting market conditions at time of bid** See Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Table B.14. Separate from general construction inflation and material supply issues, which are captured in Risks CP1 and CP3, respectively. This issue includes uncertainty in pricing strategy and other contractor competition factors. QDOT expects four proposals/bids, which could improve competition. However, recent experience for similar projects is that bids are coming in above QDOT's engineer's estimates. Can reasonably capture the range of credible possibilities with the following set of potential (mutually exclusive) scenarios/outcomes: A. Market conditions are favorable (competitive), and bids come in below the base estimate. B. Market conditions are similar to those assumed in the estimate (minimal change from base). C. Market conditions are not competitive, so bids are higher than the base but still acceptable (below threshold for canceling the procurement). D. Market is not competitive, and no acceptable bids are received, requiring rebidding and perhaps repackaging to get acceptable bids.	Scenarios as defined to left: A. 25 B. 40 C. 25 D. 10	To Activity 12: As a percentage of base construction cost, expressed as 10th and 90th percentiles for normal distributions A. –15%, –5% (i.e., normal distribution with 10th percentile = –15% and 90th percentile = –5% of base construction cost) B. –5%, +5% C. +5%, +10% (upset limit) D. +10%, +25%	To Activity 8: A. 0 B. 0 (base) C. 0 D. +3

(continued)

TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
CP3 Elsewhere	**Material supply issues** Various local factors could affect the availability of materials for this project. For example: • Cannot locate an appropriate fill source. • Fill source is farther away than assumed. • Aggregate prices are higher than anticipated. • Steel prices are higher than anticipated. • Cement prices are higher than anticipated. The group believes that all of these issues are captured in either Risk CP1 or CP2.			
CP4 Minor	Change in project delivery method See Guide Appendix B, Summary Risk Checklist for Rapid Renewal Projects. Contract other than through the assumed single D-B contract. Only treat here if not already captured under the market conditions risk (CP2). It is unlikely that QDOT will change to a traditional delivery method (e.g., design–bid–build) given the rapid renewal–type objectives for this project. Other delivery alternatives are unlikely, because either enabling legislation does not exist or QDOT does not have adequate experience with those delivery methods.			

(continued)

TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
CP5 Minor	**Accelerate preconstruction activities to reach notice to proceed (NTP) sooner** See Guide, Appendix A, and Appendix B, Summary Risk Checklist for Rapid Renewal Projects; or Table B.3. If not captured separately under Design, Environmental, and/or ROW risk categories. To reach NTP more quickly, QDOT could adopt a more aggressive preconstruction strategy. For example: • Moving to NTP before permitting is complete • Could seek streamlined environmental process or design-approval process (see Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects or Table B.3). However, it might be too late to implement these for this project (would have been better to plan for this in advance of starting work on the project). The group believes that a more aggressive permitting versus NTP strategy is possible, but introduces its own risks (i.e., if NTP is issued before the environmental permits are complete, then the contractor could have grounds for significant claims if permit conditions change relative to the RFP). Hence, it is unlikely for QDOT to pursue this strategy.			
CP6 Minor	**Use incentives to accelerate D-B construction** See Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Tables B.2 and B.14. The team believes that QDOT is unlikely to apply additional incentives. Use of D-B delivery method and performance-based specs should provide adequate flexibility and incentive for the contractor to complete the project within QDOT’s desired time frame.			

(continued)

TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
CP7	**Issues with D-B design or submittals** For example: • Internal QDOT or FHWA delays reviewing and approving submissions • Errors or omissions in D-B submissions	25	Simulated additional overheads	To Activity 11: +2
CP8	**Other problems with D-B contract procurement** See Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Tables B.2 and B.14. Aside from issues captured separately (e.g., as part of market conditions risk). Note that project-canceling issues are excluded; most of the remaining identified issues were assessed to be low likelihood and relatively low impact for this project. Hence, the group combined them into one “larger” issue and assessed their combined potential impacts. Even so, the group believes that a significant problem is unlikely (especially given QDOT’s reasonable history for such procurements). If something did occur, the most likely impact to schedule would be during D-B procurement. For example: • Bid protest (preaward or postaward); • Unclear contract documents; • Contractor default; • Bonding or insurance issues; • QDOT unfamiliarity with D-B contracting; and • Approach to specifications (e.g., performance-based specs).	10	Simulated additional overheads	To Activity 8: +0.5

(continued)

TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
	Construction			
CN1	**D-B construction phasing significantly different than assumed** Excludes specific changes to schedule and phasing related to changes in design, etc. that are captured under other risks. The base schedule is not believed to be overly optimistic or aggressive. It is impossible to know at this point how the D-B will actually construct the project, so the actual schedule and phasing could be significantly different than currently assumed.	Discrete Distribution: A. 25 B. 50 C. 25	No direct cost; Simulated extended overheads (compensable)	To Activity 12: A. −2 B. 0 (base) C. +1
CN2	**Additional maintenance of traffic required** See Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Table B.10. Because either the original plan does not work and needs to be modified or the plan does work but simply needs to be augmented.	50	To Activity 12: +0.25	0
CN3	**Problems with planned ABC technique** QDOT assumes the contractor will employ ABC (regardless of the structure type selected for the interchange; hence, this issue is approximately independent of Risk PD3). The performance of this planned rapid renewal method (accelerated bridge construction) is difficult to predict because the method the contractor will use is not known, and many ABC techniques are still evolving. Potential problems include (see Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Table B.5): • Selected technology does not work as planned (technical issue) • Delays procuring technology Note that this risk does not apply if the SH-111 alignment is split at the interchange (construction is out of traffic; ABC is not employed).	50	To Activity 12: +0.2	To Activity 12: +0.5

(continued)

TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
CN4	**Unable to construct interchange embankments as rapidly as assumed** Base assumes rapid construction techniques for the approach embankments of the SH-111 overcrossing at the interchange with US-555. The performance of this planned rapid renewal method (rapid embankment construction) is difficult to predict for the following reasons (see Guide, Appendix B, Summary Risk Checklist for Rapid Renewal Projects, or Table B.6): • Uncertainty in subsurface conditions (soft soils are suspected); • Uncertainty in what method the contractor will choose; and • Uncertainty in performance of the selected method for actual subsurface conditions (e.g., method does not perform as intended). It is therefore unclear at this point how much benefit will be achieved relative to traditional embankment construction. If the method does not work, remedial measures will be needed to accelerate embankment construction, but with some loss of time.	25	To Activity 12: +0.2	To Activity 12: +3
CN5	**Difficult foundation installation** Separate from ground improvement issues. Information is limited in the interchange area (additional geotechnical investigation is scheduled for later). However, anecdotal information indicates that near-surface ground conditions are poor enough to require deep foundations (assumed in the base). Could encounter obstructions, could have difficulty obtaining design capacity for various reasons.	10	To Activity 12: +0.2	To Activity 12: +0.5
CN6 Minor	**Severe weather event significantly affects construction** This refers to specific, individual events, such as earthquake or flood, during construction. Could result in either delay or significant damage. Very low likelihood of significant impact in this geographic location.			

(continued)

TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
CN7	**Colder-than-usual winter** Usually, construction work can proceed year-round in some manner (the base schedule accounts for this). However, an extreme winter could result in perhaps a 1-month delay.	10	Simulated extended overheads (compensable)	To Activity 12: +1
CN8 Minor	**Significant accident during construction** Low likelihood. If it occurs, time impact is likely to be minimal and cost impacts could be covered by D-B insurance.			
CN9	Limited construction staging area in vicinity of interchange Either QDOT or the contractor will likely have to find a suitable staging area, but it might not be close to the interchange, which could increase contractor costs.	33	To Activity 12: +0.1	0
CN10 Minor	**Fish window in Wandering Creek** Currently, no listed species are believed to inhabit Wandering Creek near US-555. Hence, in-water work windows are assumed to not apply. Even if a window did apply, however, the contractor should easily be able to stage culvert work to accommodate a window.			
CN11 Minor	**Noncompliance with permits during construction** Low likelihood of any significant noncompliance. Even if it does occur, low likelihood of significant cost impact (contractor) or schedule impact (QDOT's schedule, but contractor financially responsible).			

(continued)

TABLE E.19. QRA UNMITIGATED RISK REGISTER (continued)

Item	Risk or Opportunity	Probability of Occurrence (%)	Cost Change to Activity (current $ million)	Duration Change to Activity (months)
CN12	Extended overheads as a function of project delays Preconstruction (QDOT staff): $100,000/month of delay Construction: • QDOT staff: $100,000/month of delay • Contractor: For compensable delays, $250,000/month of delay (modeled as $125,000/month of total delay, assuming 50% of delays are compensable)	Simulated as a function of simulated project delays		
	Minor and Unidentified Risks and Opportunities Aggregate effect of items labeled Minor above. Major means the items quantified above (i.e., all items other than those labeled Minor above)			
	Aggregate minor risks	50	10% of sum of major risks to activity	10% of aggregate major risks to activity
	Aggregate minor opportunities	50	10% of sum of major opportunities to activity	10% of aggregate major opportunities to activity
	Unidentified risks	50	10% of sum of major risks to activity	10% of aggregate major risks to activity
	Unidentified opportunities	50	10% of sum of major opportunities to activity	10% of aggregate major opportunities to activity

TABLE E.20. QRA APPROXIMATE MEAN UNMITIGATED BASE + RISK PROJECT PERFORMANCE (COST AND SCHEDULE THROUGH CONSTRUCTION)

#	Activity	Mean Base + Risk Unmitigated Project Performance					
		Duration (months)	Early Start Date	Early Finish Date	Float (months)	Cost (current $M)	Cost (YOE $M)
0	Previous Costs	1.0	12/1/2009	12/31/2009		0.2	0.2
0	0	0.0	12/1/2009	12/1/2009	0.00	0.0	0.0
1	Preliminary Design (to 30%)	7.0	12/1/2009	6/2/2010	1.48	0.3	0.4
2	Draft Environmental Assessment (EA)	8.6	12/1/2009	7/20/2010	0.00	0.3	0.3
3	Finalize EA/Approval	6.0	8/18/2010	1/21/2011	0.00	0.6	0.5
4	Prepare/Issue RFP	2.0	7/2/2010	1/21/2011	8.55	0.3	0.4
5	Advance Utility Relocations	9.0	7/2/2010	3/4/2011	11.93	1.9	1.8
6	Advance Right-of-Way (ROW) Acquisition	16.6	7/2/2010	9/12/2011	7.31	2.1	2.7
7	Environmental Permitting	5.0	2/20/2011	6/22/2011	0.97	0.0	0.0
0	0	0.0	12/1/2009	12/1/2009	0.00	0.0	0.0
8	Design–Builder Response/Review/Selection/Negotiate	6.1	2/20/2011	9/23/2011	0.00	0.0	0.0
9	Funding	0.0	6/1/2011	6/1/2011	5.64	0.0	0.0
10	Notice to Proceed	0.0	8/23/2011	9/23/2011	0.00	0.0	0.0
0	0	0.0	12/1/2009	12/1/2009	0.00	0.0	0.0
11a	Design–Builder Design a	1.0	8/23/2011	10/23/2011	0.00	0.2	0.2
11b	Design–Builder Design b	5.0	9/23/2011	3/24/2012	5.43	0.9	0.9
12a	Design–Builder Construction a	5.9	9/23/2011	4/8/2012	0.00	2.4	2.6
12b	Design–Builder Construction b	6.8	3/20/2012	10/24/2012	0.00	6.1	8.8
12c	Design–Builder Construction c	8.5	9/21/2012	7/11/2013	0.00	4.0	4.3
13	Complete	0.0	7/12/2013	7/11/2013	0.00	0.0	0.0
	Total					19.2	23.1

Note: These mean values are approximate because of how the inputs are used in the model to quickly determine mean values (neither via simulation nor as true mean values). However, comparing this cost-loaded schedule with the mean base-only results (Table E.16 for schedule and Table E.17 [Part C] for cost) gives insight as to which activities are being affected by risks.

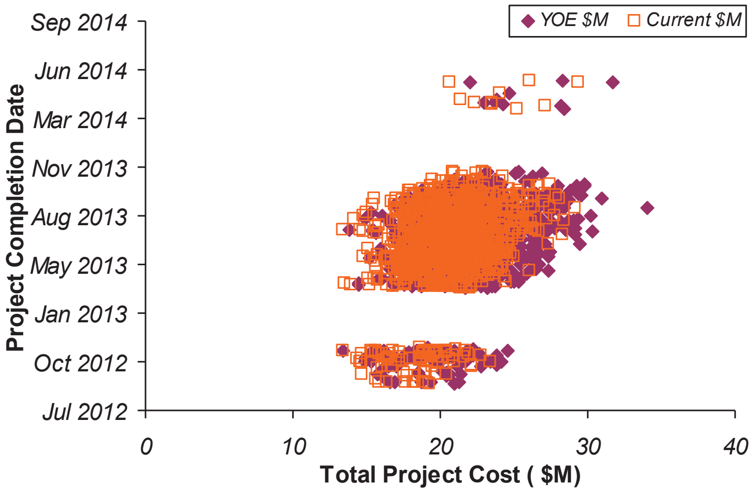
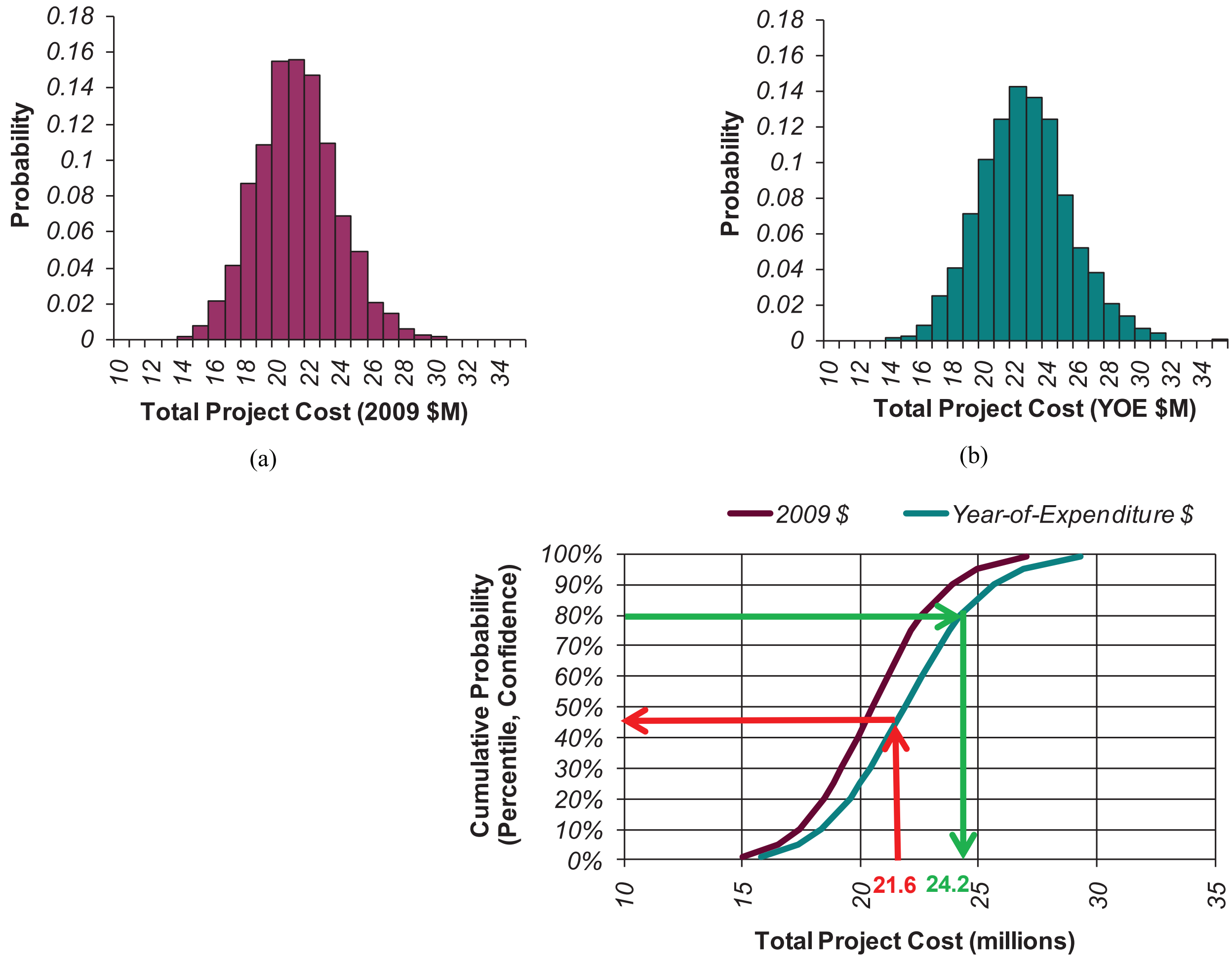


Figure E.6. *QRA "raw" unmitigated cost and schedule simulation results (through construction).*

TABLE E.21. QRA UNMITIGATED COST AND SCHEDULE UNCERTAINTIES

Statistic	Total Project Cost (2009 $M)	Total Project Cost (YOE $M)	NTP Date	Project Completion Date
Base	**16.4**	**17.3**	**Jun 2011**	**Nov 2012**
80th percentile versus base	38.0%	40.2%	30.4%	28.2%
Mean	20.6	22.0	Sep 2011	Jun 2013
SD	2.5	2.9	2.6	2.9
1%	15.0	15.8	Jun 2011	Sep 2012
5%	16.5	17.3	Jun 2011	Nov 2012
10%	17.4	18.4	Jun 2011	Mar 2013
20%	18.5	19.6	Jul 2011	Apr 2013
25%	18.9	20.0	Jul 2011	May 2013
30%	19.2	20.4	Jul 2011	May 2013
40%	19.9	21.2	Aug 2011	Jun 2013
50%	20.5	21.9	Sep 2011	Jun 2013
60%	21.1	22.6	Sep 2011	Jul 2013
70%	21.8	23.4	Oct 2011	Aug 2013
75%	22.2	23.8	Oct 2011	Aug 2013
80%	22.6	24.2	Nov 2011	Aug 2013
90%	23.9	25.7	Dec 2011	Sep 2013
95%	24.9	26.9	Feb 2012	Oct 2013
99%	27.0	29.3	May 2012	Nov 2013

Note: Through construction.

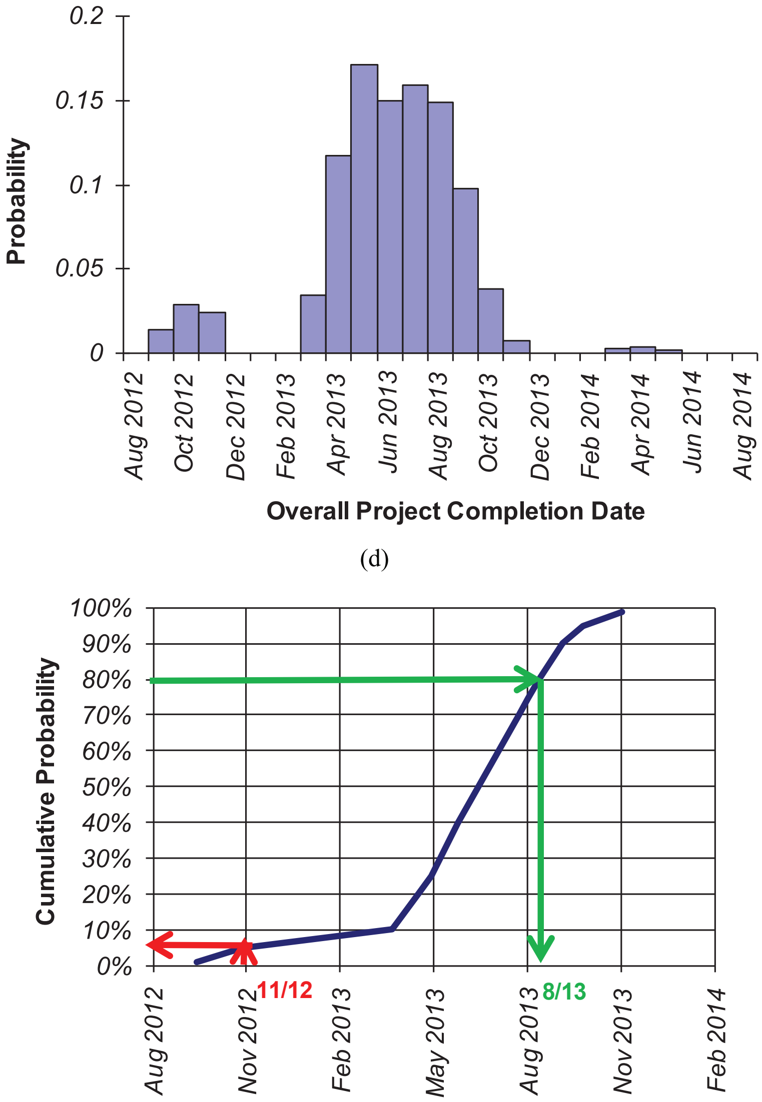


(a)

(b)

(c)

Figure E.7. *QRA unmitigated cost and schedule uncertainties (through construction). (a) Probability distribution (probability mass function) for unescalated unmitigated project cost. (b) Probability distribution (probability mass function) for escalated unmitigated project cost. (c) Comparison of probability distributions (cumulative distribution function) for unescalated and escalated unmitigated project cost. (d) Probability distribution (probability mass function) for unmitigated project completion date. (e) Probability distribution (cumulative distribution function) for unmitigated project completion date. (Continued on next page)*



(d)

(e)

Figure E.7. *QRA unmitigated cost and schedule uncertainties (through construction). (continued).*

TABLE E.22. QRA UNMITIGATED COST UNCERTAINTY CONTRIBUTORS

Rank	Contribution to 80th Percentile of Project Cost (YOE $M)	Risk
1	1.39	CN12. Extended overheads as a function of project delays
2	1.22	Compound construction inflation to midpoint of construction
3	0.39	CP2. Uncertain D-B contracting market conditions at time of bid
4	0.35	PD11. Cannot use city sewer system for project runoff (or city charges for use)
5	0.29	RU3. Unwilling sellers
6	0.28	SC6. Provide new lighting throughout project
7	0.27	Identified minor risks (aggregate)
8	0.26	Unidentified risks (aggregate)
9	0.26	RU8. QDOT helps city pay for water- and sewer-line relocation
10	0.20	RU2. Accelerating pace of development in interchange area
11	0.19	Traffic control (at 7% of subtotal A + Mobilization)
12	0.18	CN2. Additional maintenance of traffic required
13	0.16	PD13. Change in environmental documentation
14	0.15	R2. Accelerating pace of development in interchange area
15	0.14	PD12. Structures affected by Main Street realignment are eligible for National Register of Historic Places
16	0.14	CN3. Problems with planned accelerated bridge construction (ABC) technique
17	0.14	PD5. Shoulders required on US-555
18	0.11	PD16. Additional wetland mitigation required for planned alignment
19	0.11	PD3. Change configuration of SH-111/US-555 interchange
20	0.11	PD6. Shoulders required on SH-111
21	0.10	CONSTRUCTION ADMINSTRATION (8% of C)
22	0.10	SC5. Replace culvert over Wandering Creek
Rank	Contribution to 80th Percentile ($M YOE)	Opportunity
1	-0.22	PD8. Change in pavement section and/or type

Note: >$100,000 YOE; through construction.

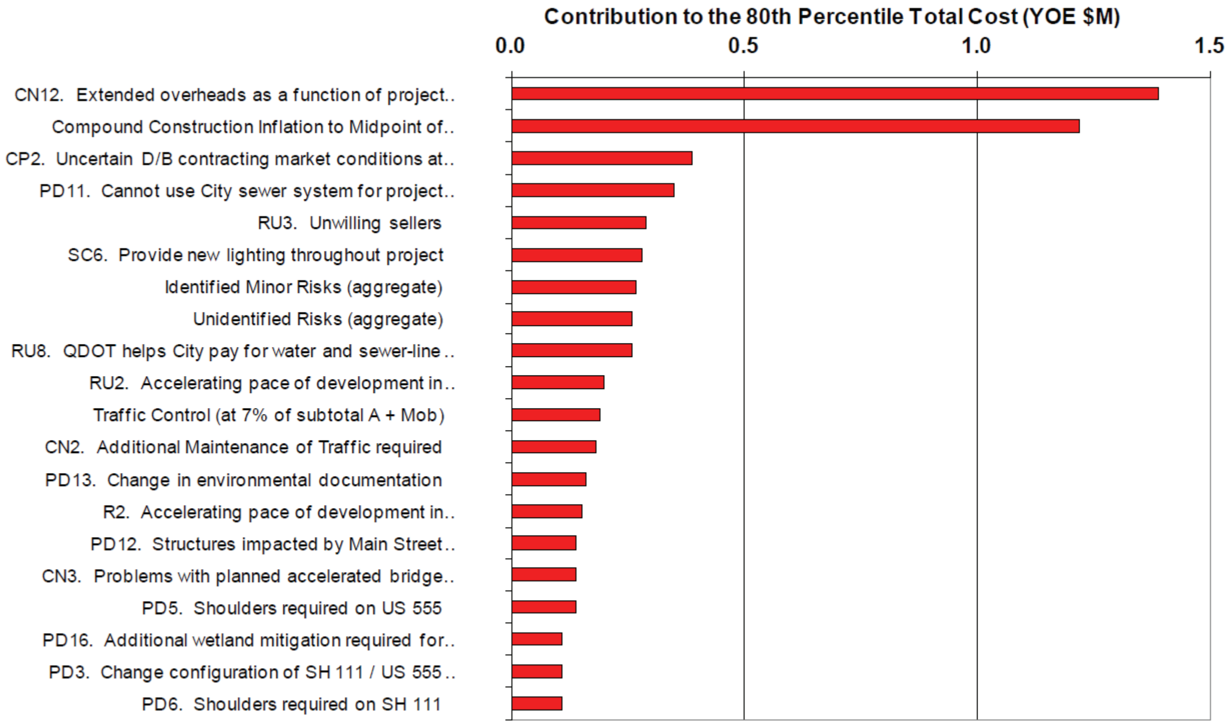


Figure E.8. *QRA Unmitigated cost uncertainty key contributors (through construction).*

TABLE E.23. QRA APPROXIMATE MEAN MITIGATED BASE + RISK PROJECT PERFORMANCE (THROUGH CONSTRUCTION)

No.	Activity	Mean Base + Risk Postmitigation Project Performance					
		Duration (months)	Early Start Date	Early Finish Date	Float (months)	Cost (current $M)	Cost (YOE $M)
0	Previous Costs	1.0	12/1/2009	12/31/2009		0.2	0.2
0	0	0.0	12/1/2009	12/1/2009	0.00	0.0	0.0
1	Preliminary Design (to 30%)	6.0	12/1/2009	6/2/2010	1.03	0.4	0.5
2	Draft Environmental Assessment (EA)	7.1	12/1/2009	7/5/2010	0.00	0.3	0.3
3	Finalize EA/Approval	6.0	7/2/2010	1/7/2011	0.00	0.6	0.5
4	Prepare/Issue RFP	2.0	7/2/2010	1/7/2011	8.11	0.3	0.4
5	Advance Utility Relocations	9.0	7/2/2010	3/3/2011	13.69	0.8	0.8
6	Advance Right-of-Way (ROW) Acquisition	15.0	7/2/2010	6/3/2011	10.58	2.1	2.7
7	Environmental Permitting	5.0	1/1/2011	6/9/2011	1.08	0.0	0.0
0	0	0.0	12/1/2009	12/1/2009	0.00	0.0	0.0
8	Design–Builder Response/Review/Selection/Negotiate	8.0	1/1/2011	9/9/2011	0.00	0.0	0.0
9	Funding	0.0	6/1/2011	6/1/2011	4.28	0.0	0.0
10	Notice to Proceed	0.0	7/5/2011	9/9/2011	0.00	0.0	0.0
0	0	0.0	12/1/2009	12/1/2009	0.00	0.0	0.0
11a	Design–Builder Design a	1.0	7/5/2011	10/10/2011	0.00	0.3	0.3
11b	Design–Builder Design b	5.0	8/4/2011	3/10/2012	6.54	0.9	0.9
12a	Design–Builder Construction a	5.5	8/4/2011	3/26/2012	0.00	2.4	2.6
12b	Design–Builder Construction b	7.8	9/19/2011	10/10/2012	0.00	7.9	8.8
12c	Design–Builder Construction c	8.5	7/21/2012	6/27/2013	0.00	4.0	4.3
13	Complete	0.0	4/7/2013	6/27/2013	0.00	0.0	0.0
	Total					20.1	22.2

Note: These mean values are approximate because of how the inputs are used in the model to quickly determine mean values (neither via simulation nor as true mean values). However, comparing this cost-loaded schedule with the mean base-only results (Table E.16 for schedule and Table E.17 [Part C] for cost) gives insight as to which activities are being affected by risks, and comparing this cost-loaded schedule with the mitigated results (Table E.19) gives insight as to which activities are being affected by risk reduction plans.

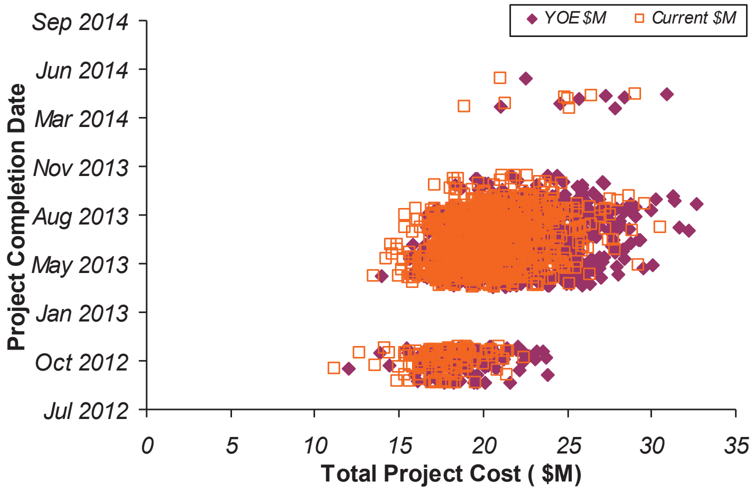
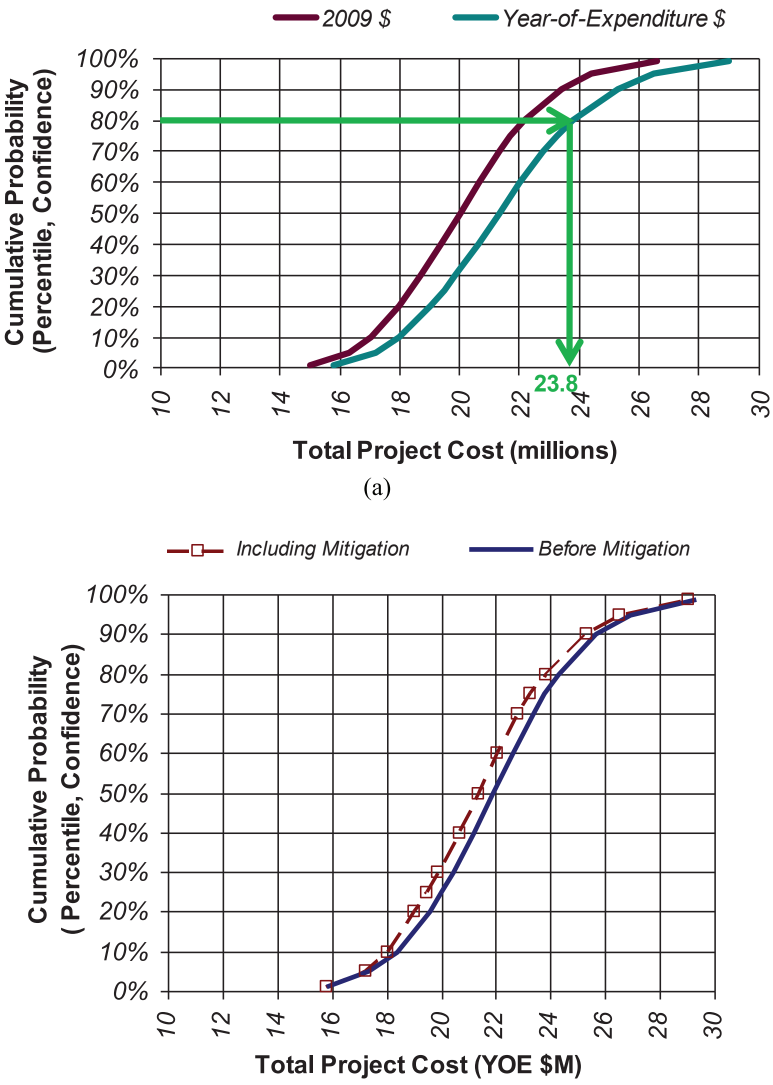


Figure E.9. *QRA "raw" mitigated cost and schedule simulation results (through construction).*

TABLE E.24. QRA MITIGATED COST AND SCHEDULE UNCERTAINTIES

Statistic	Total Project Cost (2009 $M)	Total Project Cost (YOE $M)	NTP Date	Project Completion Date
Base	**16.3**	**17.2**	**Jun 2011**	**Nov 2012**
80th percentile versus base	36.0%	38.1%	30.1%	26.5%
Mean	20.1	21.5	Sep 2011	May 2013
SD	2.5	2.9	2.6	3.0
Minimum	11.2	12.0	Jun 2011	Aug 2012
Maximum	30.5	33.9	Aug 2012	May 2014
1%	15.0	15.8	Jun 2011	Sep 2012
5%	16.3	17.2	Jun 2011	Oct 2012
10%	17.1	18.0	Jun 2011	Mar 2013
20%	18.0	19.0	Jul 2011	Apr 2013
25%	18.3	19.5	Jul 2011	Apr 2013
30%	18.7	19.8	Jul 2011	May 2013
40%	19.4	20.6	Aug 2011	May 2013
50%	20.0	21.3	Sep 2011	Jun 2013
60%	20.6	22.0	Sep 2011	Jun 2013
70%	21.3	22.8	Oct 2011	Jul 2013
75%	21.7	23.3	Oct 2011	Jul 2013
80%	**22.2**	**23.8**	**Nov 2011**	**Aug 2013**
90%	23.4	25.3	Dec 2011	Aug 2013
95%	24.4	26.5	Feb 2012	Sep 2013
99%	26.6	29.0	May 2012	Oct 2013

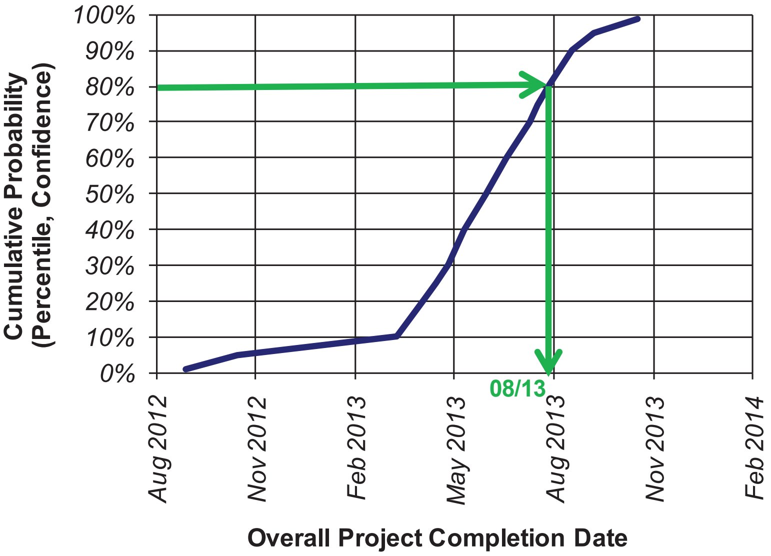
Note: Through construction.



(a)

(b)

Figure E.10. *QRA Mitigated cost and schedule uncertainties (through construction). (a) Comparison of probability distributions (cumulative distribution function) for unescalated and escalated mitigated project cost. (b) Comparison of probability distributions (cumulative distribution function) for escalated mitigated and escalated unmitigated project cost. (c) Probability distribution (cumulative distribution function) for mitigated project completion date. (d) Comparison of probability distributions (cumulative distribution function) for mitigated and unmitigated project completion date. (Continued on next page)*



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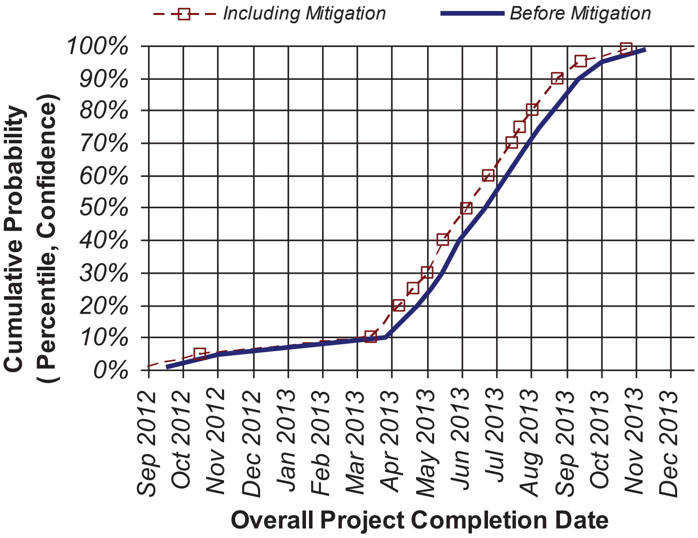

(d)

Figure E.10. *QRA mitigated cost and schedule uncertainties (through construction). (continued)*

RELATED SHRP 2 RESEARCH

Performance Specifications for Rapid Highway Renewal (R07)

Project Management Strategies for Complex Projects (R10)

Integrating the Priorities of Transportation Agencies and Utility Companies (R15)

Identification of Utility Conflicts and Solutions (R15B)

Strategies for Improving the Project Agreement Process Between Highway Agencies and Railroads (R16)

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**Membership as of March 2014.*