Active Risk Management™ For Construction in Natural and Built Environments

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Risk and Its Sources

Every construction project faces risks that threaten successful completion of the project as measured by cost, schedule and quality. The construction industry is seeking better ways to manage these risks. Since its formation in 1982, Geocomp has been working with clients in the infrastructure market to identify and quantify risks for specific projects, then develop risk management strategies that provide the most benefit to the project in terms of cost, schedule and quality. This work has lead to the concept of Active Risk Management which recognizes that risk management efforts must extend throughout the life of a project and must be based on quantitative information that is current and complete. This document represents the synthesis of our experience into a logical and consistent approach that has saved clients large sums of money by actively managing risk throughout the project.

Project risk is an uncertain event or condition that potentially impacts the project objectives for cost, schedule, and quality. Impacts may be both positive and negative. A risk has a cause and, if it occurs, a consequence. Risk is the combination of the likelihood of the uncertain event times its consequence. A likely event with moderate consequences may expose the project to more risk than an unlikely event with high consequences.

Risk = Likelihood * Consequence

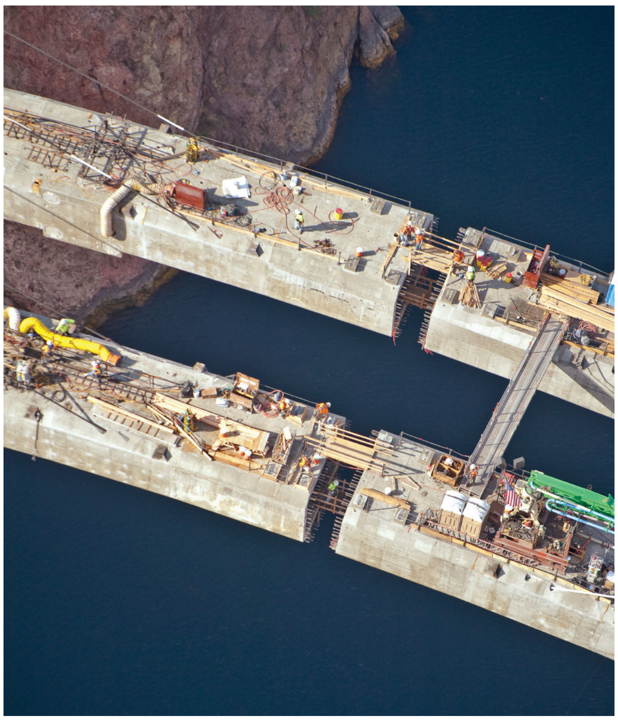
Risk management is a systematic process of identifying, analyzing, planning, monitoring and responding to risk. It involves processes, tools, and techniques that help the project team minimize the probability and consequences of adverse events and maximize the probability and consequences of positive events. Many organizations practice some form of risk management on construction projects. Generally these activities focus on risk assessment and risk allocation by individual members of the project team. They are organized to manage that member's risk by transferring, avoiding, mitigating or accepting specific risk element. This is not necessarily managing project risk.

"What risk? Everything is bright and clear down here."

Geocomp Corporation has developed the concept of **Active Risk Management™** (ARM™) describe an organized risk management strategy that transcends the entire project. ***Active risk management*** is a systematic process of identifying, analyzing, planning, monitoring and responding to project risk *over the life of the project*. It involves processes, tools, and techniques that help the project team minimize the probability and consequences of adverse events (threats) and maximize the probability and consequences of positive events (opport-unities) throughout the life of the project. Active risk management is most effective when started early in the life of the project and continued throughout the project.

Risk can be managed by (1) retention - adopting "conservative" approaches and praying for a good outcome with the hopes of getting lucky, (2) transference - transferring it to another party via a contract such as purchasing insurance, (3) allocation – spreading the risk among those best positioned to accept it, (4) abatement - using management tools to identify sources of risk and minimize their consequence, (5) avoidance - not undertaking the project and (6) using a combination of these approaches. The first and fifth approaches were predominant in heavy civil construction until the mid-1900's. The second and third approaches evolved in the last half of the 1900's. Today, the second and third approaches represent what many people refer to as "risk management" in underground construction.

Transferring risk to another party and allocating risk can be effective for a specific team member on the project, but these management practices may not be very effective at dealing with some of the substantial risks encountered during the construction and operation of the project.



"What do you mean we are six inches off?

Active Risk Management provides the project team with more complete information on the risks they face in an understandable format – cost and schedule at risk – and does so in near real-time. This not only helps team members make informed decisions based on quantitative data, but also to monitor the progress of risk management efforts over the duration of the project.

Active Risk Management provides quantitative information on the impacts of each risk component to cost, schedule and quality so that the most significant risks can be managed with the most effective approach. Risk Assessment is the process of identifying events which may impact the project and determining the likelihood and the consequences of each event to provide the basis for informed decisions on a course of actions. These events, likelihoods and consequences can change throughout the life of a project. Risk assessment is the first part of a risk management program. It is a systematic process of identifying and analyzing risk. It applies methods of uncertainty analysis with project management tools to consider all potential risks and find those with the highest potential impact on the project objectives.

The physical processes of construction inherently involve substantial uncertainty that creates risk to the owner, contractor, and engineer. These risks are in addition to the conventional risks - those from injury, contract, regulatory, legal, financial, and other risks - associated with the project. No amount of planning and engineering can predict with 100-percent certainty how the various elements of the project will actually behave during construction. Among the unknowns are: the geologic profile; the engineering properties of each component of the geologic profile; the groundwater conditions; the in situ stresses; the effects of environmental conditions, construction activities, and time on the underground conditions; limitations of analysis and design methodologies; unknown obstructions; location, condition and performance during construction of existing utilities and other structures; and interactions between the ground and structures. There may also be uncertainty in the forces from extreme events that the project will experience. On top of these are the uncertainties that derive from the mistakes, poor judgment, and improper actions of the work force. These types of risk are referred to as "operational risks". Operational risks are often ignored in the contract, financial, and legal discussions of risk management; yet they may jeopardize the entire project.

One approach to managing risks is to develop a conservative design based on what the project team considers a worst-case scenario, and hope for the best. But unexpected factors, such as excessive ground movements or unexpected groundwater flow can damage completed work or adjacent facilities. These, in turn, can cause project delays, add substantial costs, degrade quality or risk the health and safety of workers and the public.

A more cost-effective way to mitigate risks is to design for the most likely scenario based on an investigation of the underground conditions and potential hazards. The design includes a risk assessment to determine which sources of uncertainty dominate the operational risks, which risks can be reduced with design modifications, and which risks can be avoided with observation and remedial work during construction, i.e. monitoring how the site actually performs as construction begins with adjustments to the design and/or construction methodology as required by the observed performance. The risk assessment is continually reviewed and updated as new information becomes available. This approach is the essence of Active Risk Management.™

Active Risk Management uses expert judgment with tools from decision theory, and probability theory to make numerical assessments of each component of operational risk for underground construction. Information from complex analyses is integrated with opinions from lay experts and measurements of actual conditions as they unfold to produce a balanced assessment of all sources of operational risk. This approach has helped owners and contractors make informed decisions regarding design and construction of major facilities – decisions that have saved hundreds of millions of dollars by avoiding overly conservative approaches and focusing resources on the most beneficial actions.

IDENTIFY	Establish the components of risk
ACCESS	Determine the likelihood of each risk element and the consequences
PLAN	Define strategies to minimize likelihood and control consequences
MONITOR	Measure anything that can indicate risk, evaluate the results and update the risk assessment
CONTROL	Take action to reduce risk at every opportunity.

Figure 1. Circle of Risk Improvement

Quantitative risk assessment provides a way of numerically estimating the probability that a project will meet its cost and time objectives. Quantitative analysis is based on a simultaneous evaluation of the impact of all identified and quantified risks. The result is the probability that the project will meet its objectives for cost, time, quality and scope, and the effects of the factors that may influence these objectives.

Effective risk management consists of several steps that can be visualized as a continuous circle of improvement shown in **Figure 1**. Effective risk management requires the process of risk mitigation to be completed and repeated throughout the project duration as new information becomes available. Past risk management practice on many projects has typically been to prepare a risk assessment during the planning phase of a project, then to ignore it for the remainder of the project. This practice does not provide the substantial benefits of a complete risk management program. Effective risk management of project construction starts in the planning phase and continues until after the facility is placed into service. Effective risk management for a facility should continue throughout its life.

Numerous sources of risk exist on a complex project. Some examples of possible risks compiled from various sources are listed in **Table 1**. The list is not complete and may contain items not applicable to any one project. However, it illustrates the point that a large underground project faces many sources of risk. It becomes easy to overlook or forget a significant source of risk that later threatens the project objectives.

Using established methods and tools, qualitative risk analysis assesses the probability and the consequences of each identified risk to determine

Table 1: Some Sources of Risk in Infrastructure Construction

External Risks

- ☐ Priorities change on existing program
- ☐ Inconsistent cost, time, scope, and quality objectives
- ☐ Local communities pose objections
- ☐ Funding changes uncertainties
- ☐ Political factors change
- ☐ Stakeholders request late changes
- ☐ New stakeholders emerge and demand new work
- ☐ Influential stakeholders request additional needs to serve their own commercial purposes
- ☐ Threat of lawsuits
- ☐ Stakeholders choose time and/or cost over quality
- ☐ Inflation and interest rates
- ☐ Labor Disputes
- ☐ Acts of God-storm, flood, earthquake, fire, attack

Environmental Risks

- ☐ Permits or agency actions delayed
- ☐ New information required for permits
- ☐ Environmental regulations change
- ☐ Water quality regulation changes
- ☐ Reviewing agency requires higher-level review than assumed
- ☐ Lack of specialized staff (biology, anthropology, archeology, etc.)
- ☐ Historic site, endangered species, wetlands present
- ☐ EIS required
- ☐ Controversy on environmental grounds expected
- ☐ Environmental analysis on new alignments is required
- ☐ Project in an area of high sensitivity for paleontology
- ☐ Project on a Scenic Highway, Wild or Scenic River
- ☐ Project in a floodplain or a regulatory floodway
- ☐ Project does not conform to the state plan for air quality at the program and plan level
- ☐ Water quality issues
- ☐ Negative community impacts expected
- ☐ Hazardous waste potential
- ☐ Growth inducement issues
- ☐ Cumulative impact issues
- ☐ Pressure to compress the environmental schedule

Right of Way Risks

- ☐ Landowners unwilling to sell
- ☐ Utility relocation may not happen in time
- ☐ Freeway agreements
- ☐ Railroad involvement
- ☐ Right of Way appraisal takes more time and/or money
- ☐ Access/egress issues

Regulatory Risks

- ☐ Water quality regulations change
- ☐ New permits or new information required
- ☐ Reviewing agency requires higher-level review than assumed
- ☐ Different agency claims unexpected authority

Organizational Risks

- ☐ Inexperienced staff assigned
- ☐ Losing critical staff at crucial point of the project
- ☐ Insufficient time to plan
- ☐ Unanticipated project manger workload
- ☐ Internal "red tape" causes delay getting approvals, decisions
- ☐ Functional units not available, overloaded
- ☐ Lack of understanding of internal funding procedures
- ☐ Priorities change on existing program
- ☐ Inconsistent cost, time, scope and quality objectives
- ☐ Cash flow
- ☐ Poor subcontractor
- ☐ Contract dispute

Technical Risks

- ☐ Design incomplete or in error
- ☐ Right of Way analysis in error
- ☐ Environmental analysis incomplete or in error
- ☐ Inaccurate assumptions on technical issues in planning
- ☐ Surveys late and/or in error
- ☐ Materials/geotechnical/foundation in error
- ☐ Structural designs incomplete or in error
- ☐ Hazardous waste site analysis incomplete or in error
- ☐ Need for design exceptions
- ☐ Consultant design not up to client standards
- ☐ Context sensitive solutions inadequate

Project Management Risks

- ☐ Project purpose and need is poorly defined
- ☐ Project scope definition is poor or incomplete
- ☐ Project scope, schedule, objectives, cost, and deliverables are not clearly defined or understood
- ☐ No control over staff priorities
- ☐ Too many projects
- ☐ Consultant or contractor delays
- ☐ Estimating and/or scheduling errors
- ☐ Unplanned work that must be accommodated
- ☐ Communication breakdown with project team
- ☐ Pressure to deliver project on an accelerated schedule
- ☐ Lack of coordination/communication
- ☐ Lack of upper management support
- ☐ Change in key staffing throughout the project
- ☐ Inexperienced workforce/inadequate staff
- ☐ Resource availability
- ☐ Local agency issues
- ☐ Public awareness/support
- ☐ Failed agreements

Construction Risks

- ☐ Inaccurate contract time estimates
- ☐ Permit work windows
- ☐ Design incomplete or in error
- ☐ Design not constructible
- ☐ Complex project without experience
- ☐ Right of Way issues
- ☐ Environmental issues
- ☐ Contract dispute
- ☐ Error in quantities
- ☐ Material shortages
- ☐ Unexpected geotechnical issues
- ☐ Unexpected water
- ☐ Change requests because of errors
- ☐ Surveys late and/or surveys in error
- ☐ Materials/geotechnical/foundation in error
- ☐ Unexpected hazardous waste conditions
- ☐ Disposal of spoils
- ☐ Need for design exceptions
- ☐ Unexpected Utilities
- ☐ Survey errors
- ☐ Buried man-made objects/unidentified hazardous waste
- ☐ Fire
- ☐ Theft and vandalism
- ☐ Equipment failure
- ☐ Injuries and fatalities
- ☐ Disputes
- ☐ Quality issues
- ☐ Performance issues
- ☐ Sabotage
- ☐ Power shortage or loss
- ☐ Shortage of skilled labor
- ☐ Damaged utilities
- ☐ Damage to neighboring facilities
- ☐ Complaints from neighbors
- ☐ Errors and Omissions
- ☐ Readiness for execution
- ☐ Startup issues

its overall importance. These tools help to correct biases that often creep into the project plan. In particular, careful and objective definitions of different levels of probability and impact of risk events are keys to credibility of the results.

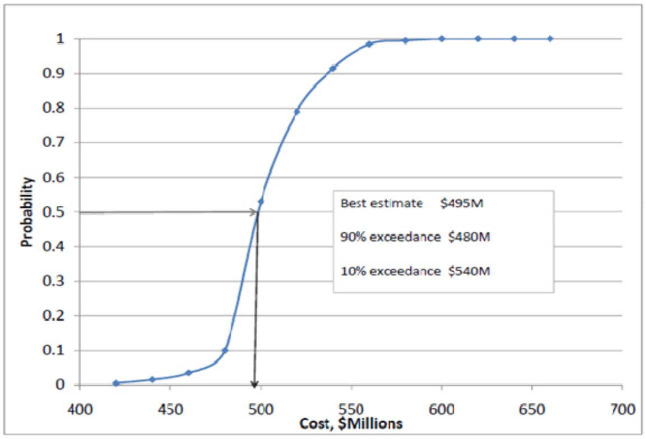


Figure 2: Uncertainty in unit costs and quantities

Another source of project risk comes from uncertainties associated with how well the completed system works, i.e. meets the intended functional requirements. These “efficacy risks” depend greatly on the detailed design as it relates to the intended function of the facility. They may be missed entirely in the standard design process but can be identified in the risk assessment methodology.

Risks to project cost and schedule involve two principal elements: uncertainties in quantities and unit costs for known elements, and unknown conditions and events. During the planning phase of a project, quantities and unit prices may have considerable uncertainty. These uncertainties can be readily estimated by asking the sources of the information to expand their estimates to include best estimate, realistic low value and realistic high value for each cost and schedule item. For example, instead of carrying fuel cost in the price estimate as a fixed number of $3.00 per gallon, the estimator might do some investigation to determine that fuel cost during the project could be as low as $2.00 and as high as $4.00. The estimator might also determine that the best estimate of fuel quantity for the project is 1,000,000 gallons but it could be as low as 900,000 gallons and as high as 1,300,000 gallons. These types of variability have traditionally been handled by the estimators making individual conclusions about what amount to put into a price estimate and then adding a contingency to the project total cost. As an example, $3,300,000 ($3.00*1,000,000 plus a 10% contingency on this element) might be the value placed into the project estimate with another 6% contingency added to the total price estimate for a total fuel cost estimate of $3,500,000. However the actual uncertainty in the total fuel cost should vary from $1,800,000 to $4,200,000. The problem with the contingency approach is that different estimators use different means to decide what their single number will be that generally includes some conservatism and then another contingency gets added at the end. No one knows what the final project price really represents relative to all the uncertainties in the individual price elements. Explicit consideration of the uncertainties in each element of the project costs can be used to obtain a range of probable cost for the project.

This is illustrated in **Figure 2.** The best estimate of the project cost is $495 million. When uncertainties in unit prices and quantities are considered

Table 2: Simplified Risk Registry

Risk Event	Consequence (ranges are lowest, median and highest estimates)	Likelihood
Unit Costs, Quantities Escalation	0 months -1/13/42 millions	50% from estimates
Permitting Delays	2/3/4 months $.18/.21/.25 millions	25-30-35% (from permitting experts)
Bad weather	1/1.3/2 months 1/1.5/2.5 millions	9-12-15% (from weather records)
Unexpected site conditions	2.5/3/4 months 30/54/90 millions	7-10-15% (from geotechnical experts)
Disruption in material delivery due to market conditions	4/5/6 months 7/8/9 millions	15-20-25% (from suppliers estimates)
Subcontractor performance issues	3 months 5/6/7.5 millions	8-10-12% (from project manager)
Accelerated construction methods with new technology	1/1.5/2.5 months -2/-3/-4 millions	30-40-50% (from consultant)

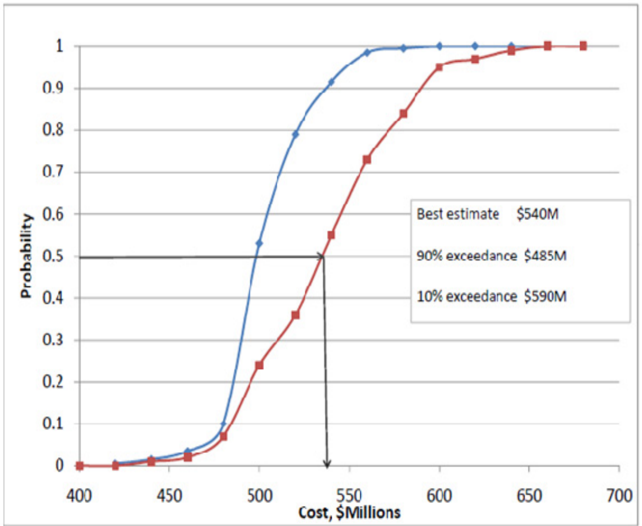


Figure 3: Cost with Risk Event Uncertainty

there is a 10% chance that the cost will be greater than $540 million. Similar calculations could be done on uncertainties in schedule components and their impact on estimated cost. This approach provides a more rational and consistency methodology to quantify all uncertainties in the project cost elements.

The second source of risk from unknown conditions and events can also be quantified with risk assessment tools. In this case each potential event that could possibly occur is identified along with its consequences and likelihood of occurrence.

An example of a simplified risk registry for these unknowns is given in **Table 2**.

These risk costs are added to the project cost uncertainties to obtain the overall uncertainty for project cost. Note that the last entry in Table 2 is actually an opportunity, i.e. it reduces cost and schedule if proved workable. **Figure 3** shows the result. Accounting for risk costs from event uncertainties increases the best estimate of cost from $495M to $540 million. It increases the 10% exceedance from $540M to $600M.

The range of probable cost for the project with all uncertainties and identified risks accounted for is $485 to 590M (10% and 90% exceedence values).

Prudent decision makers would consider this range of probable cost in preparing budgets for the project and bids for the construction. It is useful to note that a cost estimate using mean values for unit prices and quantities and adding a 10% contingency to account for uncertainty would yield a cost of $545M. Figure 3 shows that there is a 50% chance that this cost will be exceeded due to unquantified uncertainties and risks.

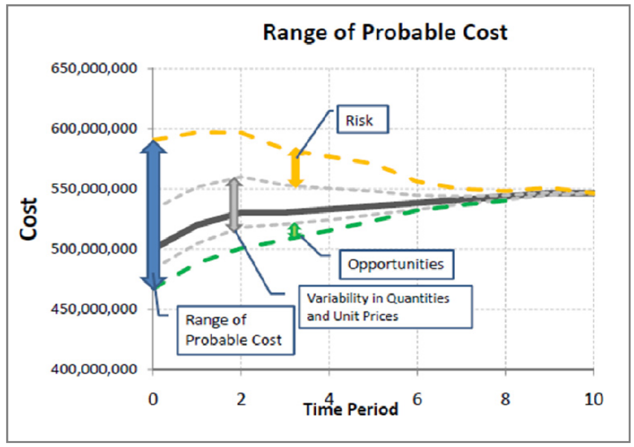


Figure 4: Range of Probable Cost over Time

This example shows the effects of uncertainties on costs during the planning phase of a project. As the project progresses new information alters the uncertainties. Pricing and quantities become more certain. As time passes risk events happen or don't happen which alters they're probability. **Figure 4** shows a plot of how cost uncertainties might change with time during construction of the project. At completion, the final cost is absolute and all uncertainty is gone.

Table 3: Ranking of Resources by Risk

Risk Source	Estimated Cost Increase	Estimated Delay
Unit costs quantities and escalation	7.8(0)	0
Disrupted delivery	7.6(5.0)	1.0
Permitting delays	5.4(5.3)	0.9
Different site conditions	11.2(1.9)	0.3
Subcontractor performance	2.4 (1.9)	0.3
Bad weather	1.2(1.0)	0.2
Accelerated construction	-5.0(-3.8)	-0.6

Values in () are cost consequences of delay

Another useful outcome of the risk assessment is a ranking of the sources of risk by their relative impacts on estimated cost and schedule. Table 3 shows typical results for the example.

The highest risk is caused by uncertainty in unit prices and cost escalation. This example was created during a time with materials shortages and rapidly changing prices. The example shows the value of combining cost and time risks. Permitting delays has little expected cost impact but 0.9 months of expected delay which due to high carrying costs of the project translates into $5.3M of delay costs. The last entry in the table illustrates tracking opportunities. By using accelerated construction methods there is an expected cost of $1.2M but the value of time savings is $3.8M for a net gain of $2.6M cost savings.

Ten Step Approach to Active Risk Management

Geocomp Consulting's approach to risk assessment involves close teamwork among the Owner, the Engineer, the Contractor (if contract has been awarded) and our team of specialists. The Owner provides information on the project scope and objectives and supplies other resources necessary to conduct the risk assessment. The Engineer provides information on possible risk events, their likelihood of occurrence and their consequences. The Contractor, or construction specialists, also provides information on possible risk events - especially those tied to the Contractor's means and methods, their likelihood of occurrence, and their consequences.

The Geocomp Risk Team provides the framework for a systematic examination of risk by the team; facilitates the definition of risk events, their likelihood of occurrence, and their consequences; tests the information for completeness and consistency with scientific requirements; develops and applies a mathematical model of risk; and interprets and reports the results to the project team. The Geocomp Risk Team is comprised of professionals experienced in all aspects of planning, design, and construction of underground facilities. We include independent consultants whose expertise closely aligns with unique aspects of the project and who understand the essential elements of risk analysis.

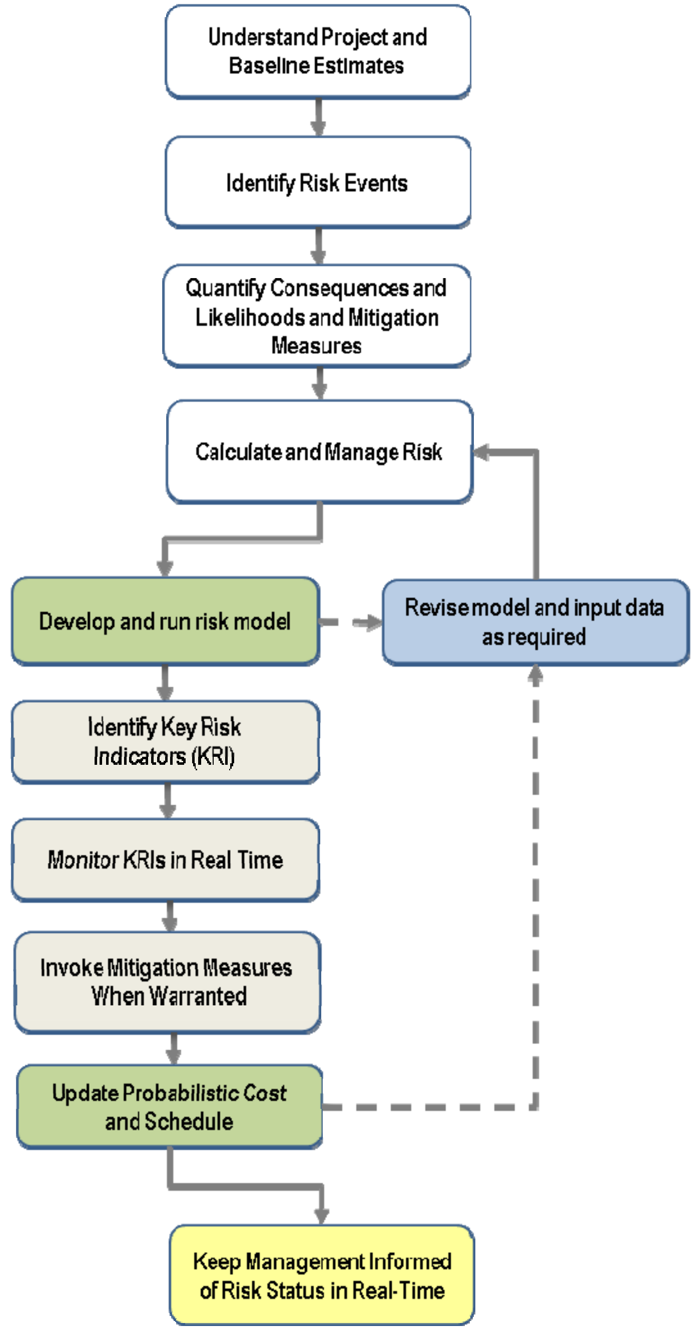
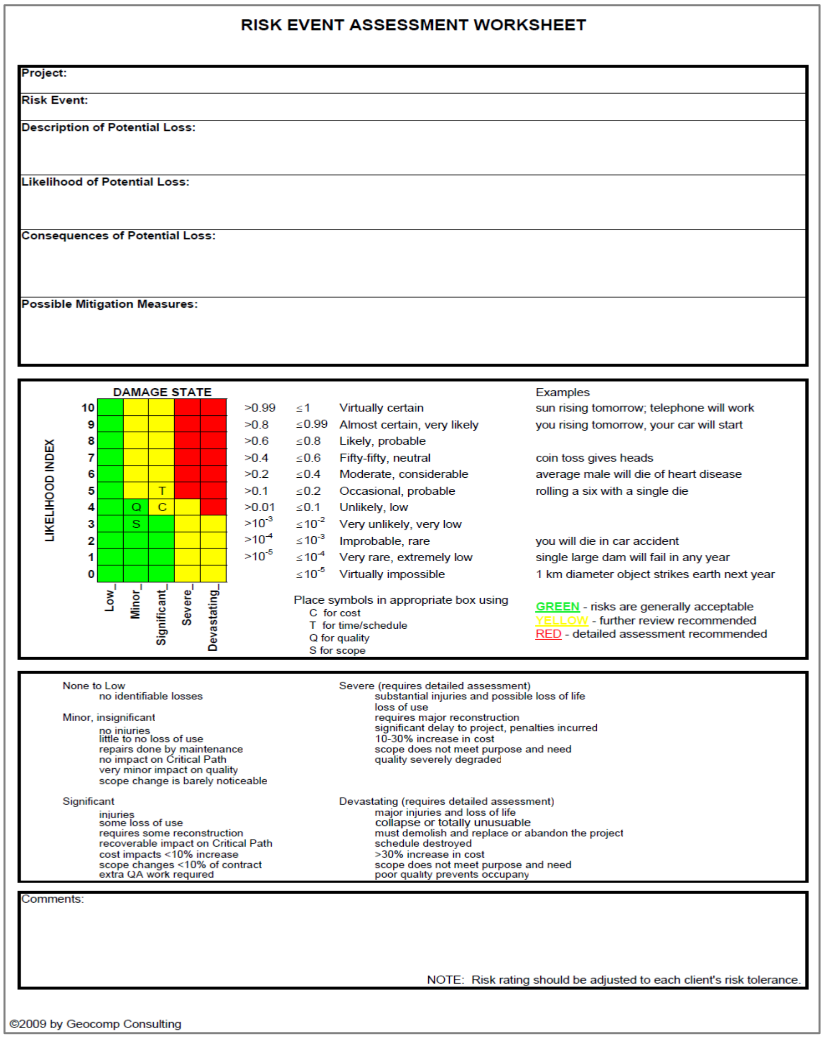


Figure 5: Work Tasks for Risk Management

Figure 5 illustrates the sequence of tasks we use to complete a risk assessment. The process runs in a linear sequence in which the specific work in each task depends on the results of previous tasks.

Step 1: Understand Project Purpose and Scope and Baseline Estimates

All members of our team participate in a briefing by the project team to provide us with an overview of the purpose and scope of the project objectives and constraints as well as the baseline cost and schedule estimates. The project team will also describe their prior approaches to risk management and allocation, including insurance and contract provisions for the project. Results of the briefing are intended to orient our team with significant project components and requirements so they can identify the specific activities required to assess risk elements and the people available to provide information. We present our proposed approach for this risk assessment, identify the types of information that we will require, and describe the methods and tools we will use to obtain information and test its validity.



RISK EVENT ASSESSMENT WORKSHEET

Project:

Risk Event:

Description of Potential Loss:

Likelihood of Potential Loss:

Consequences of Potential Loss:

Possible Mitigation Measures:

				Examples
10	>0.99	≤1	Virtually certain	sun rising tomorrow; telephone will work
9	>0.8	≤0.99	Almost certain, very likely	you rising tomorrow, your car will start
8	>0.6	≤0.8	Likely, probable	
7	>0.4	≤0.6	Fifty-fifty, neutral	coin toss gives heads
6	>0.2	≤0.4	Moderate, considerable	average male will die of heart disease
5	>0.1	≤0.2	Occasional, probable	rolling a six with a single die
4	>0.01	≤0.1	Unlikely, low	
3	$>10^{-3}$	$\leq 10^{-2}$	Very unlikely, very low	
2	$>10^{-4}$	$\leq 10^{-3}$	Improbable, rare	you will die in car accident
1	$>10^{-5}$	$\leq 10^{-4}$	Very rare, extremely low	single large dam will fail in any year
0		$\leq 10^{-5}$	Virtually impossible	1 km diameter object strikes earth next year

Place symbols in appropriate box using
C for cost
T for time/schedule
Q for quality
S for scope

GREEN - risks are generally acceptable
YELLOW - further review recommended
RED - detailed assessment recommended

None to Low
no identifiable losses

Minor, insignificant
no injuries
little to no loss of use
repairs done by maintenance
no impact on Critical Path
very minor impact on quality
scope change is barely noticeable

Significant
injuries
some loss of use
requires some reconstruction
recoverable impact on Critical Path
cost impacts <10% increase
scope changes <10% of contract
extra QA work required

Severe (requires detailed assessment)
substantial injuries and possible loss of life
loss of use
requires major reconstruction
significant delay to project, penalties incurred
10-30% increase in cost
scope does not meet purpose and need
quality severely degraded

Devastating (requires detailed assessment)
major injuries and loss of life
collapse or totally unusuable
must demolish and replace or abandon the project
schedule destroyed
>30% increase in cost
scope does not meet purpose and need
poor quality prevents occupany

Comments:

NOTE: Risk rating should be adjusted to each client's risk tolerance.

Figure 6: Risk Event Worksheet

We also review the project's cost estimate, the detailed project schedule as planned, the principal assumptions used to produce this information, and the known sources of uncertainty. Results of this briefing provide our team with the baseline conditions and components for cost and schedule that we can examine for elements of risk.

Step 2: Identify Risk Events

Our teams leads a workshop with selected members of the project team to discuss the purpose of the risk assessment; provide background information on the meaning of risk, consequences and uncertainties; and describe methodologies used to determine probability of a risk event occurring. We divide the participants into specialty working groups to examine specific groups of risk, including Contractual, Financial, Regulatory, External, and Operational Risks. The goal of Step 2 is to identify every possible source of risk to the project from as many sources of information as practical. Potential risk elements are categorized and summarized into consistent and discrete risk events in the Risk Registry.

Step 3: Quantify the consequences and likelihoods, and potential mitigation measures

During Step 2 we will make extensive use of a tool shown in **Figure 6** that we have developed to help us make preliminary risk assessments. **Figure 6** is completed for each potential source of risk by knowledgeable project staff and members of our risk team. Potential effects on project objectives for cost, time, quality, and scope are considered. Results of this effort help us to identify and focus our efforts on the significant risks to the project without overlooking any known element. All risks that are classified as yellow or red are subject to refinements for the estimates of likelihood and damage state. Probability of each risk event is determined from historical data, expert opinion, and subjective estimates from project staff. Some values of probability and consequence may themselves be uncertain, but this can be considered as well. Results of this step are crucial to the adequacy and validity of the risk assessment. We employ risk assessment techniques to capture subjective estimates of risk, identify internal biases, and reveal hidden risks. The results of Step 3 are summarized in a Risk Registry. Entries are ranked from highest risk to lowest. For the highest ranked risks, potential risk mitigation measures are identified and added to the Risk Registry. **Table 3** shows a sample Risk Registry for a simplified $20M roadway embankment project. More complex projects might have multiple pages of risk events. Compiling the Risk Registry as soon into the project as possible provides a valuable management and communication tool. The exercise of preparing the Risk Registry gets project people to think about what risks might impact the project and provides perspective on those risks that conceivably threaten the success of the project. The Risk Registry should be considered a working document that is frequently updated to reflect new information about the project.

Table 3: Example of Risk Registry for Highway Embankment Project

Event	Consequence	Likelihood	Risk	Mitigation Measure
Failure of soft soil foundation	Rework and delays cost $5,000,000	0.2	$1,000,000	Add strip drains to soft soil foundation to accelerate consolidation.
Fill materials fail specs	Use more distant and expensive borrow source at cost of $2,500,000	0.1	$250,000	Seek owner approval to accept marginal borrow materials.
Bad weather	Schedule delay costs $450,000	0.3	$150,000	Accelerate work to provide more float.
Earthwork subcontractor walks	Self perform work at additional cost of $600,000	0.05	$30,000	Increase retainage on sub.

This step is also used to identify opportunities to reduce cost. As there is uncertainty in the cost savings and probability for success, these are included as risk events with negative effects on the cost and schedule estimates, i.e. they reduce the cost and time to complete.

Step 4: Calculate Risks to Cost and Schedule and Rank Risks

Each project faces a unique set of risks with complex mathematical interactions between events, and their likelihoods and consequences. These interactions can be estimated by a numerical simulation model. This numerical model determines how the risks propagate through the project model to affect the estimated cost and completion time. Numerous simulations are completed to obtain a distribution of possible costs and schedules. The numerical model must be calibrated by testing it with repeated runs of known scenarios to remove any errors produced while assembling the model. The model must also be kept as simple as

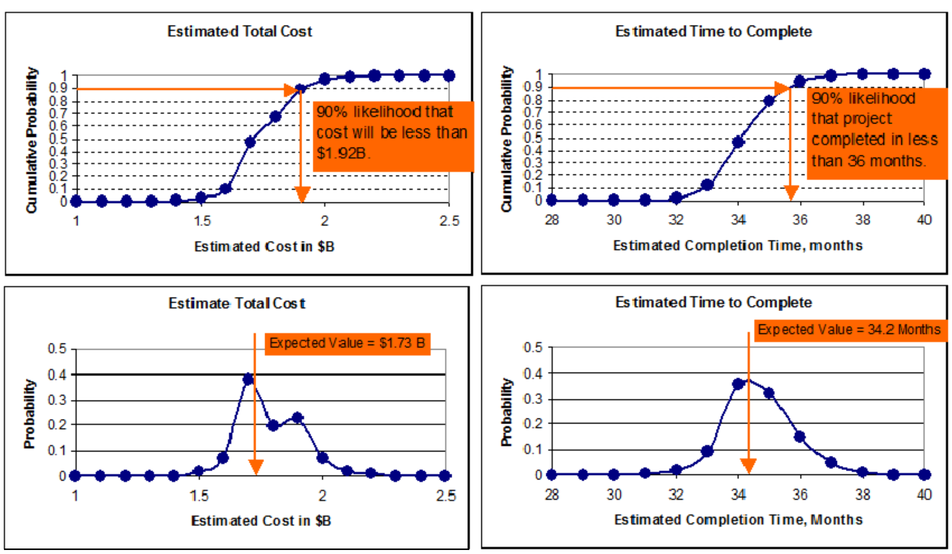


Figure 7: Uncertainty in Project Cost and Schedule

possible while still capturing the components of all components of risk that can potentially impact the project objectives.

The numerical model of risk is run through numerous simulations using the likelihoods and consequences obtained from our work with the project staff. **Figure 7** illustrates a typical result. In addition to the expected cost and completion time that comes from conventional estimating procedures, the risk assessment indicates how the uncertainties may affect the estimated cost and completion time. One of the most useful results from the risk assessment is the information to examine the likelihood that the cost will exceed a certain amount or that the schedule will overrun a certain date. Figure 7 illustrates how this is done. The example shows a 90% chance that the cost will not exceed $1.92B and a 90% chance that the schedule will not exceed 36 months.

The simulations are repeated with probabilities for each major risk set to zero to determine the relative contributions of each major source of risk to uncertainty in estimated total cost and estimated time to complete.

Step 5: Review Results with Client Team

Results from Step 4 are presented to and reviewed with the Client Team. Results include the contribution of each risk event to the uncertainty in estimated project cost and completion time. The purpose of this review is to reconsider the risk assessment components on the computed results to ensure that the information being used is complete, consistent, and meaningful. This activity also helps us develop the most effective ways to summarize and present the results of our risk assessment in ways that are most useful to the Project team and Owner's management. This review also identifies any changes required to the risk model and the risk information.

We revise the risk model based on the outcome of client review and rerun it to prepare the revised risk assessment. We draft a written report that documents the procedures we used, the data we obtained, and the results of the risk analysis. We provide recommendations for future actions to incorporate this risk assessment into an overall risk management plan for the project.

"Don't let anything move up there while we're down here cutting off these piles ."

Step 6. Identify Key Risk Indicators

This step identifies which key components of risk can be measured in real time to provide early warning of unexpected behavior so consequences can be mitigated. These KRIs are then monitored with a WEB-based information management system that provides key players with an up-to-date summation of the status of the project's risk elements. Useful measurements include monitoring of key cost and schedule elements, monitoring of markets for price changes, monitoring productivity levels as the job progresses and monitoring of sensors that detect whether risky events are developing.

Step 7. Monitor Key Risk Indicators

KRIs are monitored and assessed as often as necessary to maximize benefits of active risk management. Geocomp provides WEB-based tools to monitor KRIs on the project in real time and provide warnings whenever a KRI exceeds a present warning value. These tools include the ability to monitor subsurface movements, vibrations and noise, performance of critical equipment as well as schedule and cost indices to give key staff immediate information on the principal components of operational risk for the project.

"Hey guys, I found a fish here."

Step 8. Invoke Mitigation Measures When Warranted

Potential mitigation measures were identified in Step 3. Step 7 monitors KRIs to identify emerging risks at the earliest possible time. This step invokes the appropriate mitigation measure at the time that minimizes impact on cost and schedule.

Step 9. Update Probabilistic Cost and Schedule Estimates with New Information

Periodic updates of the risk assessment are prepared and reviewed with the project risk management team. Risk updates should be an item on the project meeting agenda just like safety, schedule, budget, etc. All results of ARM are documented so effectiveness and benefits to the project can be assessed at the end of the project and reviewed with the risk management team and the key project players.

Step 10. Keep Management Informed of Risk Status in Real Time

Active risk management requires early action to recognize and mitigate emerging risks at earliest possible time. Management must be informed and proactive in the risk management activities. Geocomp uses a project web page to display current information on the project's risk profile. Our system also provides alert messages to the management team as soon as a significant change occurs in the project's risk profile. Monthly summary reports are provided on the current status and project risk.

Client Benefits

Active Risk Management provides the project team with complete information on the risks they face in an understandable format – cost and schedule at risk. It identifies the uncertainties and potential events that create the most risk to the project and develops ways to minimize these uncertainties on final project cost and schedule. This not only helps team members to make informed decisions, but also to monitor the progress of risk management efforts over the duration of the project.

Active Risk Management provides clients with a continual assessment of their risk profile and how it is changing as the project progresses. Active Risk Management identifies specific actions that can be used to alter events and reduce consequences; thereby preventing unexpected and costly events. Active Risk Management seeks to contain and control the many costs that result from unexpected and uncontrolled events. The result can be savings that are many times the cost of the risk management effort.

Implementation

Our experience shows that the project's best interests are served when key participants take a proactive approach to minimizing the occurrence of unexpected events and controlling the consequences of undesirable performance. Our experience using Active Risk Management concepts on significant projects around the world has shown that this methodology is best applied by whoever has the most at risk in a project's successful outcome. In conventional design-bid-build projects, we believe Active Risk Management fits well into a part of the CM's role. In design-build projects where risk is successfully shifted to the DB team, the best results from Active Risk Management are achieved when the DB Risk Management team applies the ARM™ process.