Nalcor Energy – Lower Churchill Project

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LOWER CHURCHILL PROJECT

Lower Churchill Project – Project Execution Risk & Uncertainty Management Guidelines

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NEWFOUNDLAND and LABRADOR HYDRO

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TABLE OF CONTENTS

1.0 PURPOSE

The purpose of this guidance document is to describe and detail the methodology that will be used for effective project execution risk management during the planning and execution phases of the Lower Churchill Project (LCP).

2.0 SCOPE

LCP has decided to implement a formal project risk management system to encourage the Lower Churchill Project Management Team (LCPMT) to look ahead, seek opportunities and avoid/mitigate problems before they arise. We believe that successful project risk management promotes early risk awareness and risk monitoring that is vital to a project's success.

The Lower Churchill Project is dedicated to a proactive program of risk management to:

- Identify and analyze risks and uncertainties which have potential safety, environmental, operational, cost, schedule or reputation implications on the LCP;
- Utilize knowledge of these risks and uncertainties to facilitate more effective decision making by removing uncertainty;
- Timely and cost effectively respond to these risks in order to control their potential adverse impact on the LCP.

To achieve the lowest cost of risk, the LCP will be adopting a multi-dimensional strategy for managing risks to include technical, operational, contractual, risk financing, and risk retention considerations.

The scope of this document is:

- To explain the chosen methodology for identifying, evaluating, responding and monitoring risks and uncertainties during the planning and execution of the LCP; and
- To introduce the risk and uncertainty management tools to be used to implement the LCP risk management program.

Note that this methodology does not replace:

- Any process or techniques currently utilized by the LCP OHS function for evaluating safety in design and operations related risks of an asset (i.e. HAZOPs, JHA's, Safety Case, etc.); or
- Responsibilities of NLH corporate risk management function with respect to understanding financial exposure for developing corporate insurance programs.

3.0 RESPONSIBILITIES

Project Manager

- Accountable to ensure that project risk assessment is carried out for each project phase in support of effective decision making. The Project Manager will assign this responsibility to the Project Services Manager, which brings with it ownership and responsibility for ensuring implementation.

Project Services Manager

- Responsible for design of a risk management program within the LCP and ensuring that resources are identified and deployed to allow for the program's implementation.

Risk Management Coordinator

- Ensure general team awareness and understanding of the purpose and application of these Guidelines.
- Ensure project risk management activities are conducted in accordance with these guidelines.
- Establish and maintain the LCP Risk Register.
- Stewardship of the risk response plans and must ensure that all necessary actions are implemented.
- Ensure that these Guidelines are updated to reflect all lessons learned in the spirit of continuous improvement.
- Coordinate and communicate outcomes of risk sessions and project risk management updates.

LCP Team

- Embrace the project risk and uncertainty management tactics described in these Guidelines. All LCP team members are responsible for risk identification.

4.0 ABBREVIATONS

CDF	Cumulative Distribution Function
CPM	Critical Path Method
ETA	Event Tree Analysis
DRT	Discipline Risk Team
EV	Expected Value
LCP	Lower Churchill Project
LCPMT	Lower Churchill Project Management Team
PDF	Probability Density Function
PRC	Project Risk Coordinator
QRA	Quantitative Risk Assessment
RF	Risk Facilitator
WBS	Work Breakdown Structure

5.0 DEFINITIONS

Accident	The actual realization of a hazardous event that may, depending on the circumstances, cause personal injury, loss of equipment, damage to assets, monetary loss and/or delay in schedule.
Allowance	Costs added to the base estimate, based on experience, to cover foreseen but not fully defined elements.
Base Estimate	Represents the most likely outcome (time or cost) if everything on the project happens exactly in accordance with the given information and assumptions on which the estimate was based and includes allowance. The Base Estimate does not include any provisions for resolution of risks or uncertainties.
Consequence	The potential effect or impact a given risk event or uncertainty will have on a project objective including both negative effects for threats and positive effects for opportunities.
Consequence Modeling	An evaluation of the effects resulting from potential incident events and what their impacts may be on the desired outcome.
Contingency	Provision made for variations to the basis of an estimate of time or cost that are likely to occur, and that cannot be specifically identified at the time the estimate is prepared. Contingency is not meant to cover scope changes or extraordinary random events.
Decision Tree	A graphical representation of a problem describing chance events and decisions in sequential order and showing all possible outcomes. Events “branch” from their predecessors, making the final model look like a tree. Traditionally, decision trees begin with a decision node.
Event Tree Analysis	A technique that starts from a single initiating event and maps each possible sequence of subsequent actions, leading to a number of possible outcomes (desirable or undesirable and with varying consequences).
Frequency	The number of occurrences of an event per unit of time.
Hazard	A physical situation that has the potential of causing harm, or has negative project time and cost implications.
Mitigation Measures	Measures to reduce the effect of a risk by eliminating the risk completely, making it less likely to occur or by reducing its consequences.
Monte Carlo Simulation	A method where the distribution of all possible outcomes of an event (i.e. total time, total cost or frequency of occurrence) is generated by analyzing a model many times, each time using input values randomly selected from the probability

	distributions of the components making up the model.
Opportunity	A risk that may affect the project in a positive manner if the risk occurs.
Project	Includes all project phases from feasibility through to commissioning and start-up of the asset.
Qualitative Risk Assessment	Evaluation of the amount of risk in a project by non-numerical means.
Quantitative Risk Assessment	Evaluation of the amount of risk in a project by numerical means.
Risk	An uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives
Risk Analysis	The systematic approach followed to identify and evaluate risks in a qualitative and/or quantitative based approach.
Risk Criteria	Guidelines to indicate whether certain risks are acceptable, or some other judgment about their significance.
Risk Facilitator	The person heading the brainstorming sessions in the main risk updates. The risk facilitator has a general process and method knowledge connected to project risk management.
Risk Monitoring	Corresponds to the development of risk actions as well as responding to the risks revealed in the risk analysis.
Risk Register	A database or register of the identified project risks / critical areas.
Severity Level	A measure of the impact or consequence on project objective.
Threat	A risk that may affect the project in a negative manner if the risk occurs.
Uncertainty	The difference/gap between the information needed in order to make a certain decision and the available information.

Probability Terms

Cumulative Distribution Function	A plot of cumulative probability values as a smooth curve.
Cumulative Frequency	The number of data points falling in all classes up to the current class.
Cumulative Probability	For any particular "k" value of a parameter, this is the probability that all values will be less than "k".
Exclusions	Unanticipated, unpredictable random events (may include political events and scope changes).
Expected Value	For a probability distribution, the same as its mean – it is the

	weighted average of all possible values, and it is usually taken as the best guess for the distribution.
Frequency	Number of data points in each class, or the number of times an event occurs per unit time.
Histogram	A plot of the variable magnitude in the form of blocks representing each variable class.
Mode	The value of a variable that has the highest probability level.
Probability	The likelihood of occurrence of a risk event or uncertainty.
Probability Density Function	A plot of probability values as a smooth curve.
P10	The value that separates the smallest 10% of all values from the largest 90% (the 10th percentile).
P50	The value that separates the smallest 50% of all values from the largest 50% (the 50th percentile).
P90	The value that separates the smallest 90% of all values from the largest 10% (the 90th percentile).
Random Variable	Any parameter that has a PDF or a CDF defined for it – typically, random variables are used to describe future events whose outcomes are uncertain
Relative Frequency	Relative number of data points in each class, expressed as a % of the total number, or the fraction of times an event occurs

Statistical Terms

Mean	For sampled data, the sum of all sample values divided by the number of values.
Median	For sampled data, re-arranging data from smallest to largest and selecting the middle.
Standard Deviation	Is a measure of how widely dispersed the values are in a distribution and is equal to the square root of the variance.
Variance	The variance is a measure of how widely dispersed the values are in a distribution, and thus is an indication of the "risk" of the distribution. It is calculated as the average of the squared deviations about the mean. The variance gives disproportionate weight to "outliers", values that are far away from the mean. The variance is the square of the standard deviation.

6.0 PROJECT RISK MANAGEMENT

In any project venture or corporation management has the responsibility to make formal judgment and appropriate decisions that will lead that organization to successfully achieve its stated goals. In the ideal world, these decisions are made with total certainty. However, we do not live in an ideal world, where all the required information is available for making the right decision, and where the outcome of the decision can be predicted with a high degree of confidence. Thus decisions are taken without complete information, and therefore give rise to some degree of *uncertainty* in the outcome.

The goal of project risk management is to identify project risks (contributing to uncertainty) and develop strategies which either significantly reduce them or take steps to avoid them altogether. At the same time, steps should be taken to maximize associated opportunities that are identified. Thus it can be stated that Project Risk Management is the process of identifying, assessing, and responding to project risks throughout the life cycle of a project in an effort to maximize the likelihood of achieving the project's objectives. The value of early project risk management is illustrated in Figure 6.1.

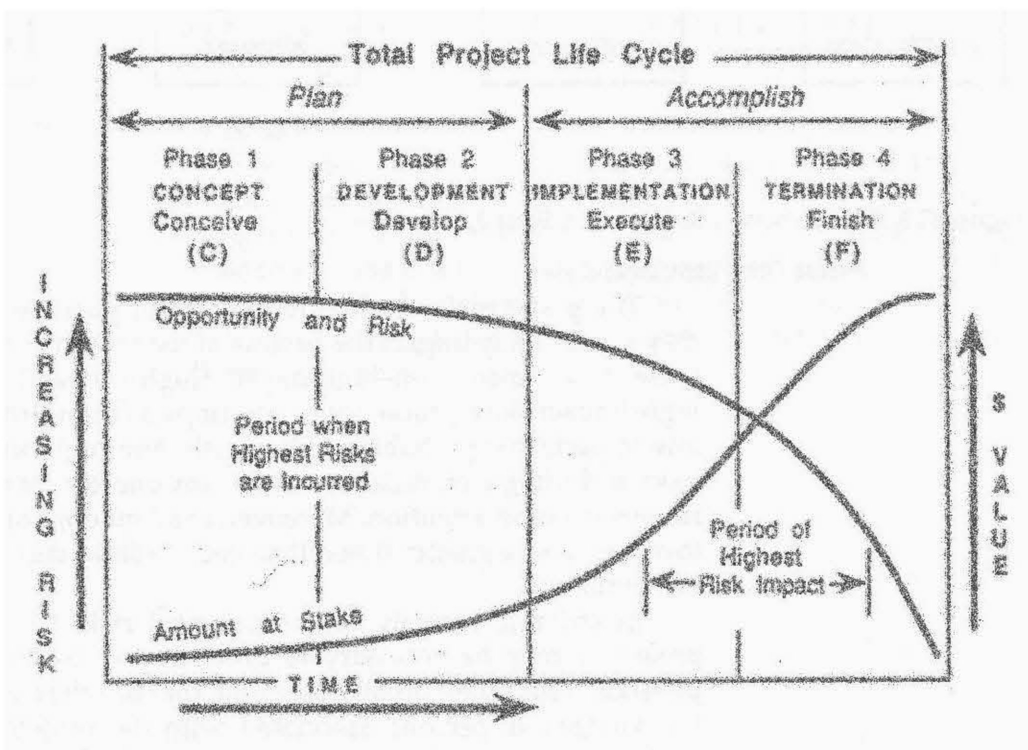


Figure 6.1: Opportunity and Risk – Trade-off against Value (Source: PMI PMBOK)

In the context of project cost and schedule, risk management may be further described as the process used to manage the risk of occurrence of unfavorable events creating project cost and schedule overruns during the execution of a project.

Project risk management provides a mechanism by which the Project Management Team can:

- Realistically set reasonable cost and schedule contingencies;
- Estimate the probability of cost overruns and schedule delays;
- Estimate the probability that the projected cost and schedule targets will be achieved;
- Understand the accuracy of the targeted cost estimate or schedule; and
- Ensure that the project team identifies both project risks and opportunities, and implements a plan to mitigate risks and realize opportunities.

6.1 Implementing a Project Risk Management Process

The goal of a Project Risk Management Program is to gain competitive advantage by increasing the return on investment from the project by allowing for informed decision making by removing uncertainty. To accomplish this goal, the Project Risk Management Program must achieve the following objectives:

1. Reduce project costs and duration by:
   - Eliminating the use of hidden contingencies;
   - Reducing the required contingency through effective risk mitigation; and
   - Improving team communication on the subject of project risks and uncertainty by fostering open communication on the subject.

2. Increase the probability of success by:
   - Identifying and mitigating risks in all phases of the project; and
   - Providing a method to manage risk as effectively as other project variables such as safety, cost, schedule, and quality.

3. Improve corporate investment performance through application of decision-making tools and for better information for optimizing project risk and return.

6.2 Phases of Project Risk Management Program

There are several phases within a Project Risk Management Program:

- Phase 1 – Risk Management Planning
- Phase 2 – Risk Identification
- Phase 3 – Risk Analysis
- Phase 4 – Risk Response Planning
- Phase 5 – Risk Monitoring and Control

Figure 6.2 illustrates how these phases interrelate to form the overall Project Risk Management Program. Although shown as discrete, individual steps, there is considerable overlap among stages. In addition, some stages may be repeated during the life of a project.

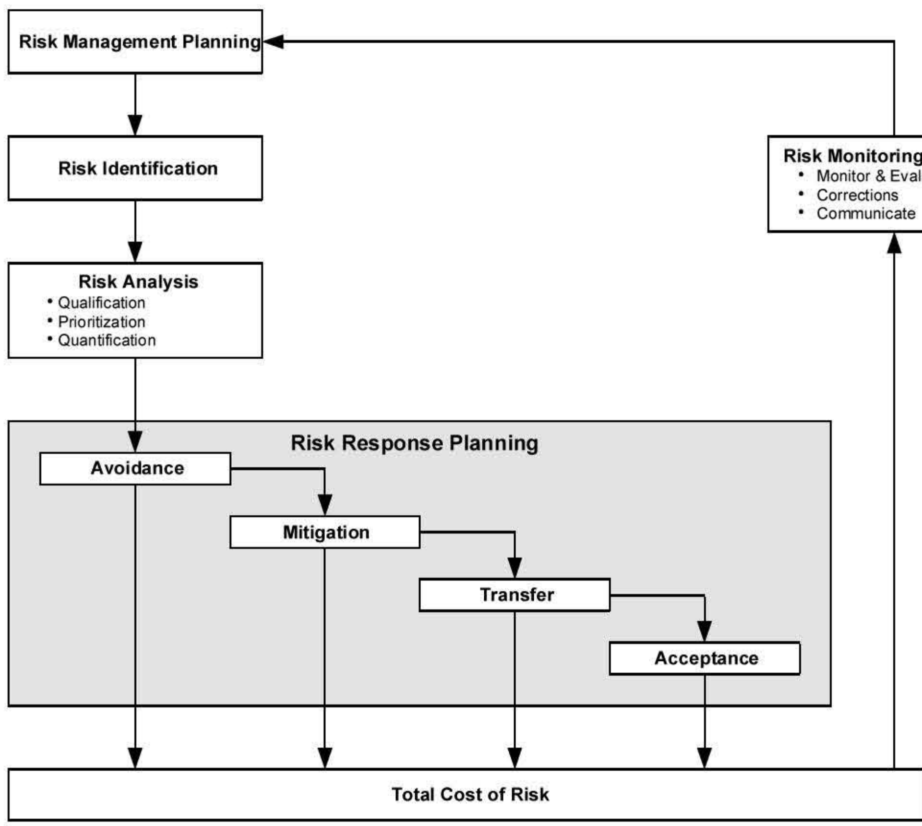
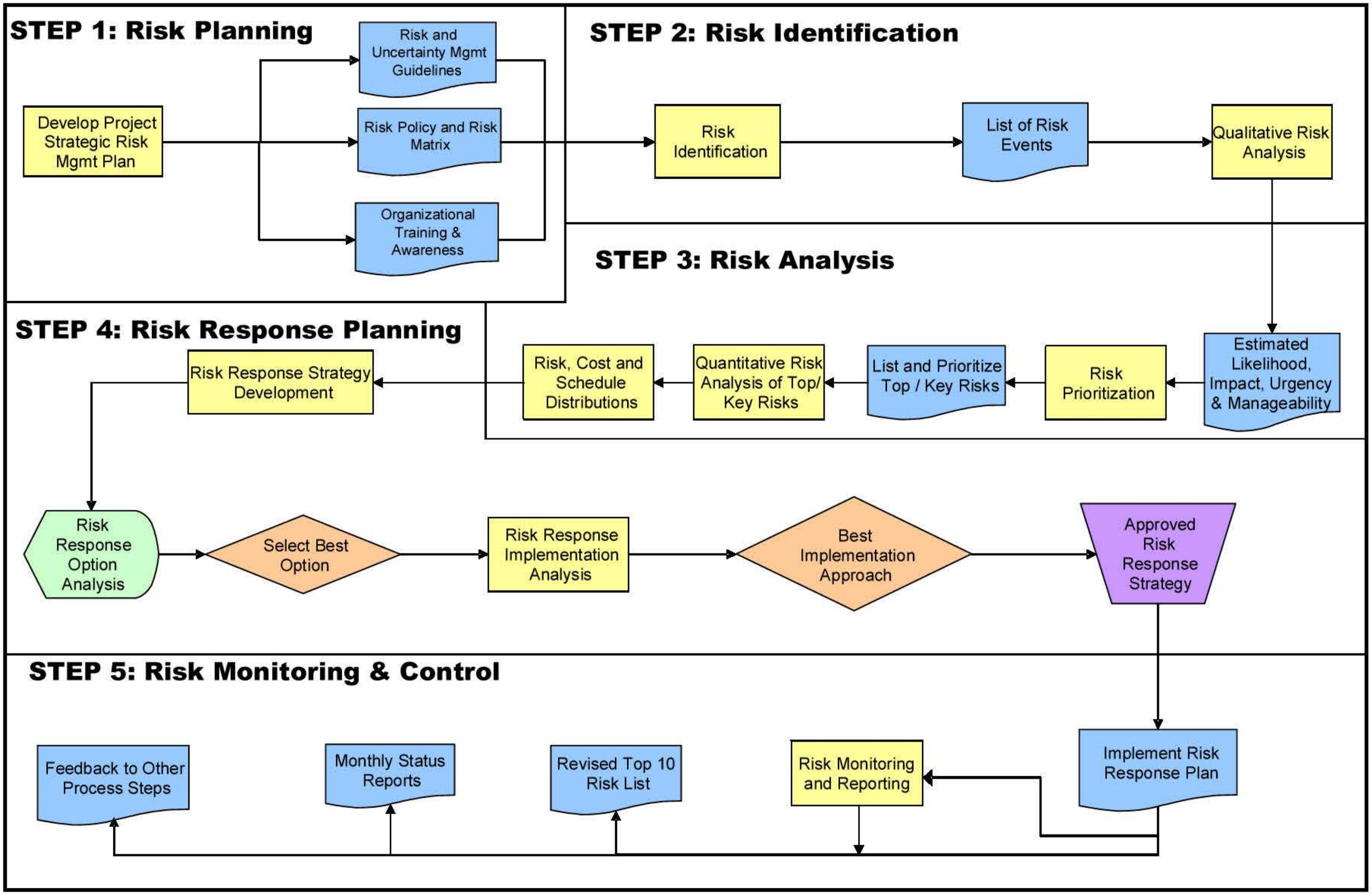


Figure 6.2: Project Risk Management Model (Source: PMI PMBOK)

Utilizing this "generic" process, the LCP risk management program will include a number of discrete steps within each of these five phases as illustrated in Figure 6.3.

Figure 6.3: LCP Risk Management Program



6.3 Risk Management Planning

During this phase of the Project Risk Management Program, the following are the areas of focus:

- Define the project risk management philosophy;
- Draft and seek management endorsement of the Project Risk and Uncertainty Management Policy;
- Staff the position of the Risk Management Coordinator;
- Define the type of risk to be included in the Project Risk Management Program (i.e. those risks that have a potential detrimental impact on safety, environment, capital cost, project schedule, product quality and corporate image / reputation);
- Define the general risk management approach for the project;
- Determine whether the risk analysis will be a qualitative or quantitative based approach;
- Define the risk reporting requirements (i.e. documentation deliverables).

The preferred manner to carry out a risk assessment is to convene a facilitated project team workshop (facilitated by the Risk Facilitator) with key project participants contributing and exchanging information.

6.4 Risk Identification

Risk Identification involves determining which risks might affect the project's desired outcome. Risk identification is an on-going and iterative process, with the first iteration being performed by the project team, the second being completed by the project team and key stakeholders, while the later iterations may be completed by an external or non-project team. It is recommended to have separate focus on threats and opportunities when identifying risks because experience shows that this dual approach increases the focus on the opportunity part.

The primary objectives of Risk Identification may be summarized as follows:

- Encourage open dialogue about risks among project participants to foster team building and a spirit of success;
- Obtain the input of all project participants about their perception of risks;
- Identify and categorize project risks; and
- Provide a basis for the follow-on activities namely risk assessment, evaluation and mitigation.

One technique used to quickly identify a large number of project risks and opportunities is the convening of a risk workshop. Participants in the workshop should include key members of the owner and contractor project teams, and particularly those responsible for preparing the cost estimate and schedule. Another technique often utilized is to conduct separate interviews with project team members, after which the risk analyst runs a simulation program and calculates the results. Experience suggests that having the key members of the owner and contractor teams participate together in a workshop with a neutral facilitator has the following advantages:

- The workshop format provides a much richer discussion of risks and their potential impact on cost and schedule;
- Open discussion provides a means to establish a "balance" between optimistic and pessimistic opinions;
- The discussion provides a way to calibrate the level of the base estimates of cost and duration so that everyone understands what is in the estimate and what must be covered by contingency -this avoids the frequent "double dipping" of estimate allowances on top of which contingency is applied;
- The entire team has a sense of ownership of the resulting cost and schedule contingency levels;
- The entire team collaborates on using the results of the risk analysis to generate a Risk Mitigation Plan to which they are all committed;
- Results can often be generated in a single day, depending on the size and complexity of the project; and
- Communications channels are established and open dialogue is encouraged throughout all project phases.

Executing a risk identification workshop may be accomplished most efficiently using a experienced 3rd Party Risk Facilitator providing the team with the Project Scope Statement, Work Breakdown Structure (WBS) and Risk Categories (risk that may affect the project for better or worse can be identified and organized into risk categories) and having the team develop risks for each WBS areas for using each of the Risk Categories. Such categories could include:

- *Technical, Quality or Performance Risks* – Such as reliance on unproven or complex technology, unrealistic performance goals, changes to the technology used or to industry standards during the project.
- *Project Interface Risks* – Such as project organization / structure, contractual arrangements, project management tools and expertise.
- *Organizational Risks* – Such as cost, time and scope activities that are internally inconsistent, lack of prioritization of projects, and inadequacy or interruption of funding.
- *External Risks* – Such as availability of skilled labor, regulatory and certification, delivery of critical equipment, and weather.
- *Site-Related Risks* – Such as environmental, geotechnical and geological.

As Risk Identification is an on-going activity, the LCP Team will be encouraged to identify risks and uncertainties continuously by using the Risk Identification Form similar to that shown in Figure 6.4. Each risk statement should be clearly described in order to make it possible to split the risk into probability and consequence in the risk evaluation phase. The risk statements should be specific and not too general in order to avoid losing important information. Identified risks perceived not relevant for the project should not be included in the risk register once they have been fully discussed with the originator.

It is recommended that the originator should consult with the Risk Management Coordinator regarding guidance of how to complete this Form. These forms should be signed by the originator and forwarded to the Project Risk Coordinator for logging within the overall LCP Risk Register as illustrated in Figure 6.5.

Figure 6.4 LCP Risk Identification Form

Lower Churchill Project

Risk Identification Form

Date:

WBS Ref No:

Risk Reference No.:

Risk Group:

Risk Name:

Risk Description:

Risk Ranking: (reference Project Execution Risk and Uncertainty Ranking Matrix

Probability of Occurrence (Likelihood)	☐ Intangible	☐ Rare	☐ Unlikely	☐ Possible	☐ Probable	☐ Almost Certain
Potential Consequence on Project Objective						
People (OHS)	☐ None	☐ Insignificant	☐ Minor	☐ Moderate	☐ Major	☐ Catastrophic
Environmental (Physical)	☐ None	☐ Insignificant	☐ Minor	☐ Moderate	☐ Major	☐ Catastrophic
Capital Cost	☐ None	☐ Insignificant	☐ Minor	☐ Moderate	☐ Major	☐ Catastrophic
First Power Target Date	☐ None	☐ Insignificant	☐ Minor	☐ Moderate	☐ Major	☐ Catastrophic
Product Quality	☐ None	☐ Insignificant	☐ Minor	☐ Moderate	☐ Major	☐ Catastrophic
Reputation / Image	☐ None	☐ Insignificant	☐ Minor	☐ Moderate	☐ Major	☐ Catastrophic
Urgency	☐ Very Low	☐ Low	☐ Moderate	☐ High	☐ Extreme	
Manageability	☐ Easy	☐ Manageable	☐ Hard	☐ Complex	☐ Extremely Difficult	

Notes (including source of data):

Recovery Actions:

Mitigation Actions:

Originator & Discipline:

Location & Contact Details:

Figure 6.5: LCP Risk Register Template

Lower Churchill Project

Risk and Opportunity Register

Note: Likelihood of Occurrence and Potential Consequence is prior to risk response plans.

Item	Opportunity or Threat	Status	Bin	Risk or Opportunity Description	Project Phase	Date Logged	Likelihood of Occurrence (A)	Potential Consequence on Project Success Criteria (B)							Urgency (C)	Manageability (D)	Risk Priority Setting = (A) x (B) x (C) x (D)	Risk Treatment Strategy	Potential Risk or Opportunity Response Plan	Mitigation Status	Residual Risk Provision							Risk Owner	Action	Action Due Date	Action Status
																					CAPEX			Schedule							
								People	Environment	Capital Cost	First Power Target Date	Quality	Reputation	(B) Max Severity							Minimum	Most-Likely	Maximum	Minimum	Most-Likely	Maximum	Comments (if any)				
	THREAT	OPEN		Poor stakeholder management leads to lack of communication of project status.	PHASE 2		Unlikely	None	Moderate	Minor	Minor	Major	Catastrophic	5	Extreme	Extremely Difficult	250	Avoidance													
	THREAT	OPEN		Failure of Main Bearing on Turbine	PHASE 3		Almost Certain	Insignificant	Insignificant	Minor	Moderate	Catastrophic	Minor	5	Moderate	Complex	300	Transfer													
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6.5 Risk Analysis

The purpose of this phase of the Project Risk Management Program is to evaluate the risks and opportunities identified in terms of both their potential likelihood of occurrence (probability) and their severity level or impact/consequence on one of the project's six objectives (i.e. people/health & safety, environment, capital cost, schedule/first power target date, operational reliability/quality, and reputation/image). The categories for likelihood of occurrence and potential impact/consequence are detailed in Tables 6.1 and Table 6.2. Identified risks and opportunities as contained in the LCP risk register are first analyzed utilizing qualitative techniques as a first pass in order to set priorities. Then the top prioritized 50 to 100 risks are further analyzed using more detailed techniques, known as quantitative risk analysis.

Table 6.1: Risk Likelihood Ranking Criteria

Likelihood	***Ranking***
Intangible	0
Rare	1
Unlikely	2
Possible	3
Probable	4
Almost Certain	5

Table 6.2: Risk Impact/Consequence Ranking Criteria

Impact/Consequence	***Ranking***
None	0
Insignificant	1
Minor	2
Moderate	3
Major	4
Catastrophic	5

6.5.1 Qualitative Risk Analysis

The first step in the qualitative risk assessment approach is to logically group the identified risk according to LCP Risk Register, which is shown in Figure 6.5.

A Qualitative Risk Assessment Matrix based-approach (reference LCP Doc. # MSD-RI-002) is then utilized to categorize and assign risk ratings (very low, low, moderate, high and very high) to identified risks based on combining the probability of occurrence with the consequence of impact (Risk = Probability x Consequence). The Project Execution Risk and Uncertainty Ranking Matrix provides a tool for evaluation of these risks and opportunities specifically in the context of the LCP. The results from evaluation of each risk or opportunity should be noted in the relevant fields of the LCP Risk Register. Similarly, the urgency of responding to a risk or opportunity risk and manageability of the risk are qualitatively assessed for each identified risk or opportunity and ranked as shown in Tables 6.3 and Table 6.4.

Table 6.3: Risk Urgency Ranking Criteria

Urgency	***Ranking***
Very Low	1
Low	2
Moderate	3
High	4
Extreme	5

Table 6.4: Risk Manageability Ranking Criteria

Manageability	***Ranking***
Easy	1
Manageable	2
Hard	3
Complex	4
Extremely Difficult	5

The rankings for each of the risks and opportunity using these four indicators noted above (i.e. Likelihood, Impact/Consequence, Urgency, and Manageability), when combined, provide a risk level ranging from low to extreme. Risks identified as extreme will require implementation of a risk transfer, reduction or elimination strategy to reduce the risk exposure level and/or the risk will need to be brought to the attention of the LCP Gatekeeper. All other levels of risk will require implementation of an appropriate risk transfer, mitigation, avoidance or acceptance strategy and will require appropriate actions and approvals within LCPMT.

The outputs from this Qualitative Risk Analysis will include:

A. <u>List of Prioritized Risks</u> – All risks and opportunities will be assigned a priority setting.

B. <u>Overall Risk Ranking for the Project</u> – Risk ranking may indicate the overall risk position of a project relative to other projects by comparing the risk scores. It can be used to assign personnel or other resources to projects with different risk rankings, to make a benefit-cost analysis decision about the project, or to support a recommendation for project initiation, continuation or cancellation at a Gate decision.

C. List of Risks for Additional Analysis and Management – Using the prioritized risk listing the key risks requiring further analysis through techniques such as Quantitative Risk Analysis will be easily identifiable.

6.2.4 Quantitative Risk Analysis

The purpose of the Quantitative Risk Analysis (QRA) phase is to analyze numerically the probability of each risk and its consequence on project objectives, as well as the extent of overall project risk. This process uses techniques such as decision analysis and Monte Carlo Simulation (reference Appendix A for background information on technique) to:

- Define the probability of achieving a specific project objective;
- Quantify the risk exposure for the project, and determine the cost and schedule contingency required for the total project as well as for each cost and schedule element (including defining the cost and duration cumulative probability curves);
- Identify risks requiring the most attention by quantifying their relative contribution to the overall project risk; and
- Establish the basis for the Risk Mitigation Plan and Project Estimate Contingency recommendations.

Inputs into Quantitative Risk Analysis

Inputs into a Quantitative Risk Analysis include:

- List of prioritized risks from the Qualitative Risk Analysis;
- Expert judgment on the subject matter from resources within or outside the project team;
- Historical information on previous projects with similar scopes; and
- Assumptions utilized.

Tools and Techniques used in a Quantitative Risk Analysis

- Interviewing – Used to quantify the probability and consequence of risks to project objectives. A risk interview with key project stakeholders and subject-matter experts may be the first step in quantifying risks. *It is important to emphasize that the quality of output from the risk assessment is directly dependant on the quality of input received during the interviewing stage, hence the importance of getting high quality input during risk interviews.* Information gathered during the interview process depends on the type of probability distributions that will be utilized. For instance, information would be gathered on the optimistic (low), pessimistic (high), and the most likely scenarios if triangular distributions are used, or on mean and standard deviation for the normal and log normal distributions (reference Appendix C for further details on distribution types). The Project Risk Coordinator with the Risk

Facilitator may elect to utilize a large workshop setting rather than individual interviews to conduct the risk assessment for a project.

- Sensitivity Analysis – Sensitivity analysis helps to determine which risk has the most potential impact on the project. It examines the extent to which the uncertainty of each project element affects the objective being examined when all other uncertain elements are held at their baseline values.
- Decision Tree Analysis – A decision analysis is usually structured as a decision tree. The decision tree is a diagram that describes a decision under consideration and the implications of choosing one or another of the available alternatives. It incorporates the probabilities of risks and the costs or rewards of each logical path of events and future decisions. Solving the decision tree indicates which decision yields the greatest expected value to the decision-maker when all the uncertain implications, costs, rewards, and subsequent decisions are quantified.
- Simulation – Monte Carlo simulation is generally the preferred way to translate the uncertainties specified at a detailed level into their potential impact on objectives that are expressed at the level of the total project. We will use Monte Carlo simulation as a QRA tool to achieve these objectives, utilizing off-the-shelf software packages such as *Pertmaster Professional* + *@Risk*, as described in Appendix B. The output from the Monte Carlo simulation will indicate which cost or schedule elements require the most contingency, and which risk categories contributed the most to contingency. This information will be used in the Risk Mitigation Plan.

  Where possible, the Monte Carlo simulation should be run during the same meeting during which Risk Identification and Assessment were done. Failing this, it should be run at the end of the day and overnight, such that the results can be presented while the team is still assembled. The meeting participants can then proceed directly to develop the Risk Mitigation Plan.

Outputs of Quantitative Risk Analysis

The outputs from a Quantitative Risk Analysis may be grouped as follows:

A. Prioritized List of Quantified Risks – This list of risks includes those that pose the greatest threat or present the greatest opportunity to the project together with a measure of their impact.

B. Probabilistic Impact of the Project – Forecasts of potential project schedule and cost results listing the probable completion dates or project duration and costs with their associated confidence levels.

C. Probability of Achieving the Cost and Schedule Objectives – The probability of achieving the project objectives under the current plan and with the current knowledge of the risks facing the project can be estimated using quantitative risks.

D. Cost and Schedule Contingency Recommendations – Recommendations for carrying capital cost contingency and first power schedule contingency will be made by taking the results of the Monte Carlo simulation analysis. Contingency recommendations will be made to the LCP Gatekeeper by the Project Manager with the results of this investigation.

E. Trends in QRA Results – As the analysis is repeated, a trend of results may become apparent.

6.6 Risk Response Planning

The main purpose of risk response planning is to generate:

- Options and determine actions to enhance opportunities and reduce threats to a project's objectives;
- Alarm signals for the project key risks that could give a pre-warning that a risk is likely to become an event;
- Contingency plan which outlines how to react if a specific risk occurs (optional); and
- Unknown risk event plan which is a generic plan outlining how to handle any occurrence of unidentified risks.

To be successful, risk response planning must be appropriate to the severity of the risk, cost effective in meeting the challenge, timely, realistic within the project context, agreed upon by all parties involved, and owned by the most appropriate LCPMT member (i.e. Risk Owner). The Project Risk Coordinator has the overall responsibility for the stewardship of the risk response plans and must ensure that all necessary actions are implemented.

Risk Response Types

There are four basic response types:

1. Avoidance – eliminate the specific threat, usually by eliminating the risk cause. Can be achieved by finding an alternative approach or different route to reach the end objective of the project.

2. Mitigation (or Abatement) – reduce the probability and / or consequence of an adverse risk event to an acceptable threshold:
    - *Reducing* the probability of risk occurrence;
    - *Minimize* the consequence if the risk occurs; and

3. Transference (or Allocation) – seeking to shift the consequence of a risk to a third party together with ownership of the response (e.g. insurance). This does not eliminate the risk, however reduces exposure of the project.

4. Acceptance (or Retention) – accept the consequences of the risk (i.e. live with it – run the risk, include cost and schedule contingency).

Each risk action should be evaluated with respect to other key project risks in order to avoid unplanned remedial effects elsewhere in the project. Should remedial effects on other risks become evident, the chosen risk action should provide the most optimum effect on most risks.

Outputs from Risk Response Planning

A. Updated Risk Register – Outputs from the risk response planning phase should include a detailed Risk Register (as shown in Figure 5.4) that includes a detailed description of the risk; the action planned to mitigate the risk; the action date; the responsible person; and an indication of the magnitude of the risk (from either qualitative or quantitative risk analysis).

B. Contingency Plan – A contingency plan should be developed to deal with risks should they not be able to be avoided, mitigated, transferred or accepted. The contingency plan should include an assessment by the LCPMT of the cost and schedule contingency required by the project to reduce the risk of overruns of project objectives.

6.7 Risk Monitoring and Control

Risk monitoring and control is the process of keeping track of the identified risks, monitoring residual risks and identifying new risks, ensuring the execution of risk plans, and evaluating their effectiveness in reducing risks.

Specific actions to be undertaken during the Risk Monitoring and Control phase include:

- Continuous follow-up of Project Key Risks – The Project Risk Coordinator should follow-up the risk with the appropriate Risk Owner until all risk actions on the Project Risk Register are closed and the risk level is low (including contractor and supplier key risks). The project key risks should be followed-up on a regular basis in project meetings and should be on the agenda on regular Project Management Team meetings.

- Continuous update of the Project Risk Register – This data-gathering of the project risks should reflect the present risk status of the project and should as a minimum include:
    - All identified risks, open and closed, including responsible person for addressing the risk;
    - Risk identification date and planned closed date;
    - Risk level (probability x consequence x urgency x manageability);
    - Risk actions, including responsible person for addressing the risk;
    - Status risk actions (open or closed); and
    - Alarm signals.

- Communication on the Status of Key Risks – Top prioritized or key risks will be reported on a regular basis in a manner that fosters continuous awareness by all levels of the LCPMT. Cost and schedule impacts will be included in regular reporting and change control processes.

- Initiation of Contingency Plans – Contingency plans implemented as required. Any changes made to contingency plans during the life of the project must be coordinated with Project Controls to ensure that the necessary contingencies (i.e. cost, schedule, etc.) remain up-to-date.

Risk management is an on-going and continuous activity through-out the lifecycle of any Project following the Plan-Do-Check-Act cycle (see Figure 6.6 below). Following the implementation of risk response planning and continual monitoring or key risks, identification of additional risks will be on-going simultaneously, while risks that were once deemed manageable or non-urgent at a particular point or phase of a project may now be deemed urgent and / or unmanageable. Thus this process is continual, requiring both informal and formal risk reviews, workshops and various levels of risk analysis throughout the duration of the Project to help facilitate effective and timely decision making.

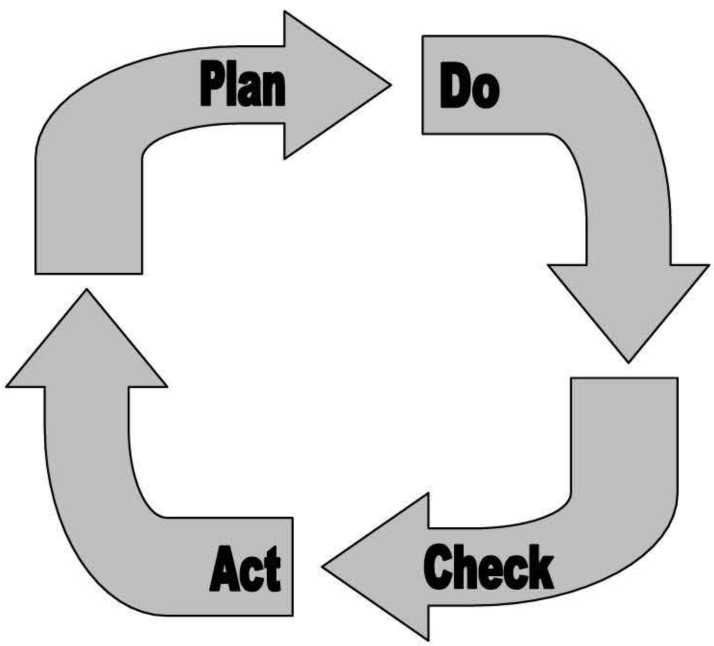

Figure 6.6: The Plan-Do-Check-Act Cycle

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APPENDIX A: Monte Carlo Simulation

What is Monte Carlo simulation?

Monte Carlo simulation was developed for the Manhattan Project during World War II as a means of modeling when inputs consist of statistical distributions rather than single values. When we use scheduling software, such as *Microsoft Project* or *Primavera*, we perform the calculations associated with project duration, critical path, etc just once. When we use software, such as *Pertmaster,* to run a risk assessment, we are going to perform these calculations thousands of times. Let's look at a single iteration and see how it is performed, but first of all, we have to look at how risk analysis software handles the distributions we have entered.

Cumulative Distribution Functions

When constructing risk models, distributions are entered as Probability Density Functions (PDFs). The risk analysis software takes the PDFs that we enter (triangular distributions in most cases) and converts them to *cumulative distribution function* (CDF) curves by summing them from p = 0 to p =1.0, as shown in Figure A1, which shows the CDF curve for the triangular distribution shown in Figure A1. Note that the y-axis starts at 0.0 and extends to 1.0, and the x-axis starts at the most optimistic completion time and extends to the most pessimistic time.

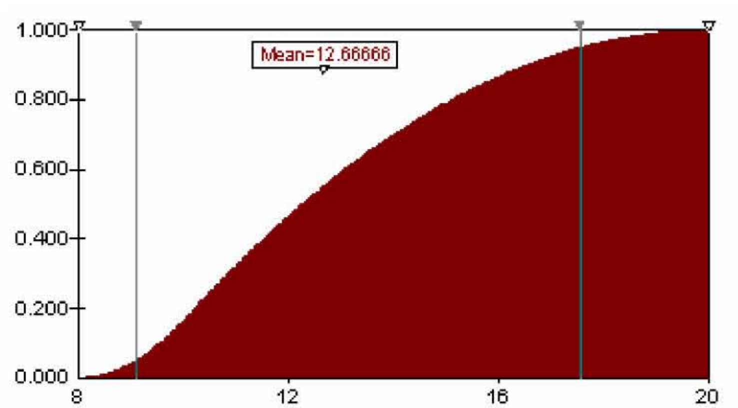

Figure A1: Cumulative Distribution Function (CDF) curve for a triangular distribution.

A Single Iteration

Now that all of our distributions have been converted to CDFs we are ready to undertake the first iteration. How can we perform calculations on ranges of numbers? The simple answer is that we don't. Instead, we sample from the CDFs. To do this we select a random number between 0 and 1 and enter the Y-axis of the CDF and read the equivalent value from the X-axis, as shown in Figure A2. In this example, the random number generated is 0.76 and results in a value on the x-axis of 12.5, which we can use in our calculations. This process is repeated using the same random number for each distribution in our model, giving us single values that we can use to calculate the project duration, critical path, etc.

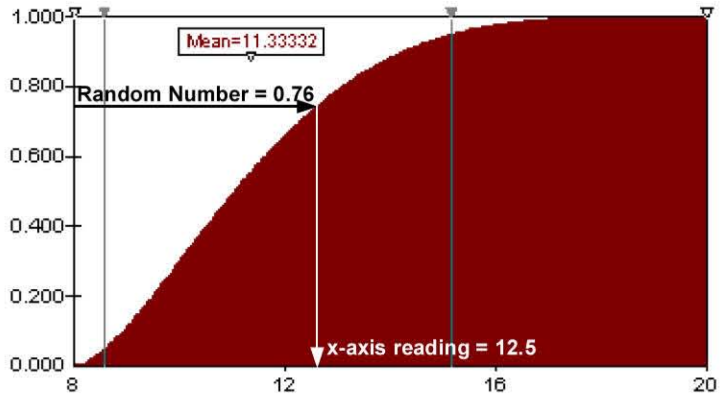

Figure A2: The Y-axis (which extends from 0.0 to 1.0) was entered with the random number generated for this run (0.76) to obtain the corresponding number from the x-axis (12.5) for use in our model.

Running the Complete Simulation

To begin another run, we have the computer select another random number and repeat the process described above. This time the numbers we obtain from the curves will be different because the random number we obtain will probably be different from the first one we used. Thus, when we calculate the total project time and the critical path, we are likely to get a different result from the first run.

We repeat this process enough times – usually 1,000 to 10,000 times – until we get enough estimates of project completion date and critical path to provide reasonably accurate statistics. We can now look at the distribution of these results, usually by means of a histogram that shows how they are distributed, as shown in Figure B4 in Appendix B. In this manner we can show our management the likely distribution of completion times and costs instead of reporting a single value of project time and cost.

Monte Carlo Simulation on a Project's Cost and Schedule Expectations

To conduct a Quantitative Risk Analysis of project schedule and cost overruns, we can undertake a Monte Carlo Simulation of the project using risk analysis software, such as *Pertmaster Professional + @Risk.*

The general steps in Monte Carlo simulation are as follows:

1. Simplified Cost and Schedule models and prepared for the Project.

2. Cost and Schedule Risk Assessment Matrices listing the potential ranges for each risk are prepared in a spreadsheet format.

3. Risks are correlated to help build a model that best reflects the implications of risks on the project.

4. The Monte Carlo software is set up to operate on each cell in the matrix that contains a range. This setup requires that a type of probability distribution be selected. Most software provides a selection of distributions. A triangular distribution is recommended as it more closely reflects the variation in typical project data. In the triangular distribution, a straight-line relationship is assumed between the minimum value (at which the probability is zero), up to the most likely value (at which the probability is greatest), and from the most likely value down to the maximum value (at which the probability is zero).

5. The Monte Carlo software is then triggered to run the simulation. At this point the software produces the frequency distribution curve for total project cost and duration. It does this by using the probability distributions in each cell of the Risk Assessment Matrix together with a random number generator to simulate thousands (recommend at least 6000) of possible outcomes of the project. When these values are analyzed, the result is the desired frequency distribution.

6. The output of the simulation is presented in graphical format. From this information, contingency, accuracy and other decision – support information can be gained.

APPENDIX B: Monte Carlo Simulation using Pertmaster Professional Software

Importing a Project Schedule into Pertmaster Software

The LCP is employing the Critical Path Method (CPM) extensively for project planning and execution, while *Primavera* is being utilized as the schedule management software.

Once *Pertmaster* has been installed and started up, you can import an existing *Primavera* schedule in its native format, or develop a project schedule from scratch within *Pertmaster*.

Replacing Single Number Estimates with Distributions

Once the plan is opened in *Pertmaster*, we click on the task where we wish to convert the time estimate to a distribution and obtain the drop-down box shown in Figure B1. Note that the "**Risks**" tab has been clicked, showing the various forms of risk that may be entered. Activate "**Duration Risk**" for this cell by clicking the "**Risk On**" box in the "**Duration**" tab. We get the display shown in Figure B2, showing both the distribution type (triangular) and the most optimistic, most likely and most pessimistic times for task completion. You can experiment with changing these numbers and distribution type and see the effect on the risk criteria.

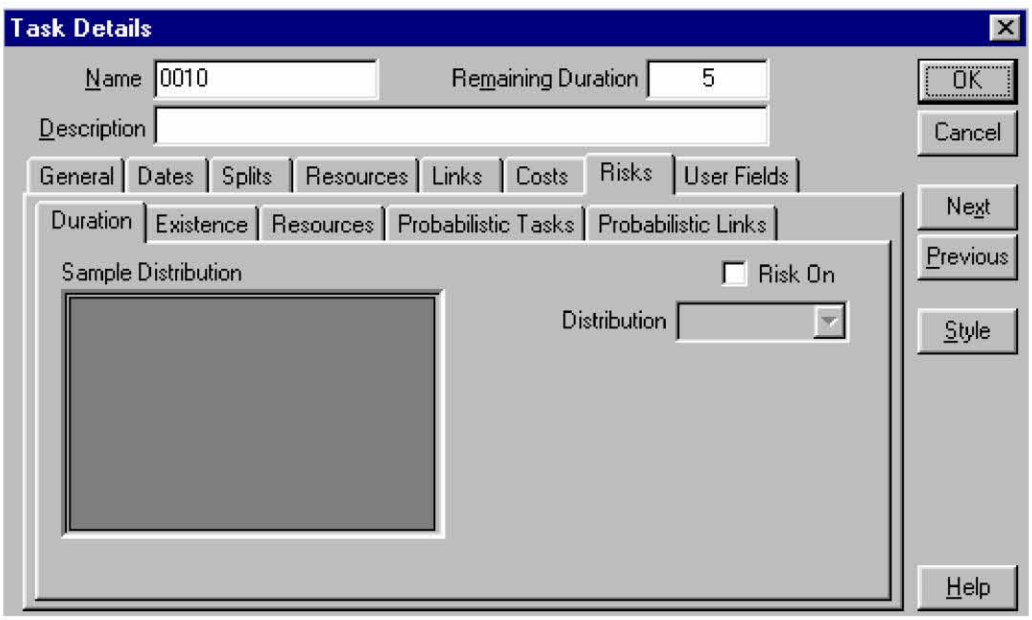

Figure B1: Drop-down Task Details box, with "**Risks**" tab displayed.

We can repeat this process for each task where we wish to specify a probability distribution, or we can click on the drop-down Risk Menu and specify "**Duration Quick Risk**". This provides a nominal triangular distribution for all task duration. When you have finished this, click on "**Run Risk Analysis**" on the same drop-down menu and you will see the drop-down box shown in Figure B3.

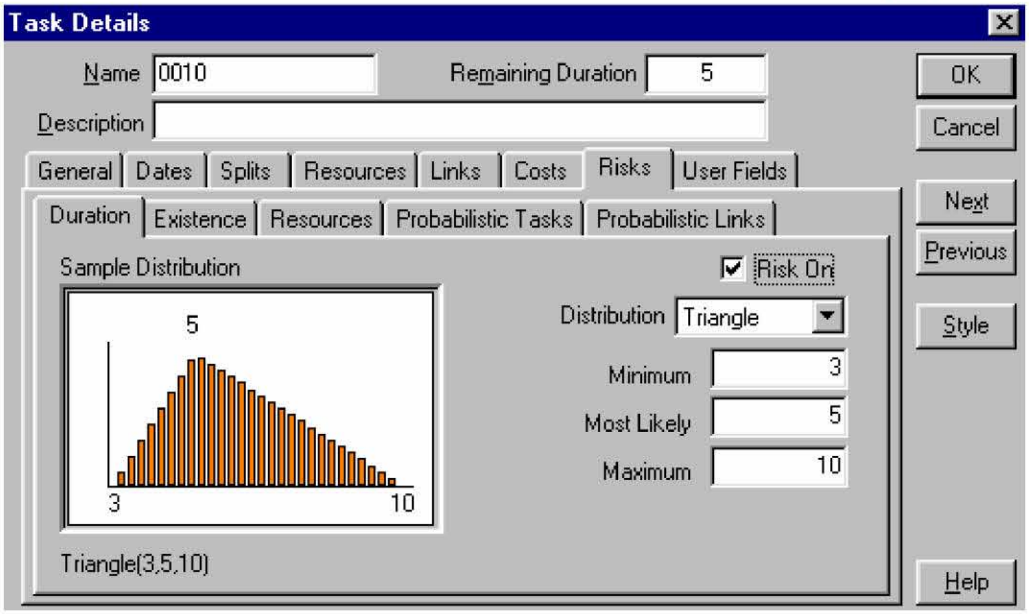

Figure B2: Drop-down Task details box showing "**Duration Risk**" when "**Risk On**" has been clicked.

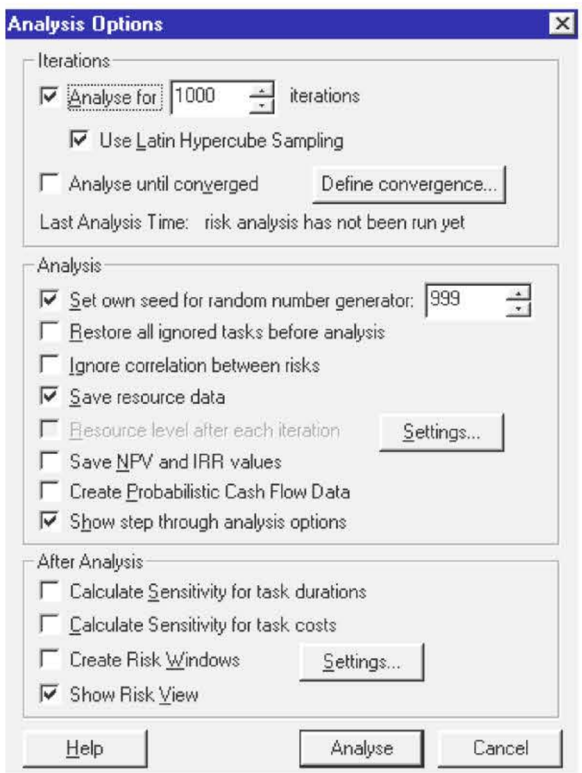

Figure B3: Risk Analysis drop-down menu box. Note that the number of iterations (or runs) has been set to 1000.

Adding Probabilistic Branching and Chance Incidents to the Model

In some cases, it will be desirable to add probabilistic branching to the model to simulate accidental occurrence or equipment malfunction. To do this, add each possible branch to the Gantt Diagram, then open the risk tab on the common predecessor and click on "**Probabilistic Branching**" and click the turn "**Risk On**" button. You can then specify the probability of each branch occurring. Note that the total must add up to 100%. When you run the model, the software will choose a random number in order to decide which event will occur during each iteration, based on the probability of occurrence you have specified.

You can also specify the probability that the task will occur by clicking on the "**Existence**" tab and adding the probability.

Including Costs in the Risk Model

Costs per Unit Time (CN)

These are costs that increase proportionally with the length of the task. To include such costs in your model, you must first specify a resource. This can be done by clicking on the "**Resource Box**" on the **Plan** menu. Name the resource CN and add a value of $1. The loading should be set to "**normal**" for this type of resource.

Where this type of cost is to be specified for a task, double-click on the task and add the name of the resource and the number of units.

Spread Costs (CS)

These are lump sum costs that are not time-dependent. To include such costs in your model, you must first specify a resource. This is done by clicking on the "**Resource Box**" on the **Plan** menu. Name the resource CS and add a value of $1. The loading should be set to "spread" for this type of resource.

Where this type of cost is to be specified for a task, double-click on the task and add the name of the resource and the number of units.

Resource Leveling

In situations where the resources to undertake a project are limited, the resources in the model should be leveled following each iteration to obtain an accurate picture of resource demands. *Pertmaster* is capable of doing this, although it slows the model down.

Running the Risk Assessment Simulation Model

Once model development has been completed, run the model by clicking on the "**Run Model**" box on the "**Risk**" drop-down menu. You will be prompted to enter the number of iterations, or number of times the model is to be run. Once this has been done, click "**Analyze**" and a box will appear that will allow you to step through the model one iteration at a time. You can watch the Gantt chart change as the model selects different task duration and probabilistic branches and calculates different critical paths for each iteration. Once the model is behaving as expected, you can click on the "**Continue**" button, which will cause the run to proceed automatically, or the "**Complete**" box, which will cause the runs to finish quickly.

More iteration will be required in order to produce accuracy if the model is complex or if probabilistic branching is used. Often iterations will take time to complete where the project is complex or resource leveling is conducted after each iteration, so there is a practical side to the number of iterations to use.

Simulation Model Outputs

Once the runs have been completed, the Risk Report Window will automatically appear, showing the project completion date histogram and cumulative curve. You can select the percentage probability on the Y-axis and the graph will show the equivalent completion date, as shown in Figure B4. Other curves are also available by clicking on the View dropdown menu.

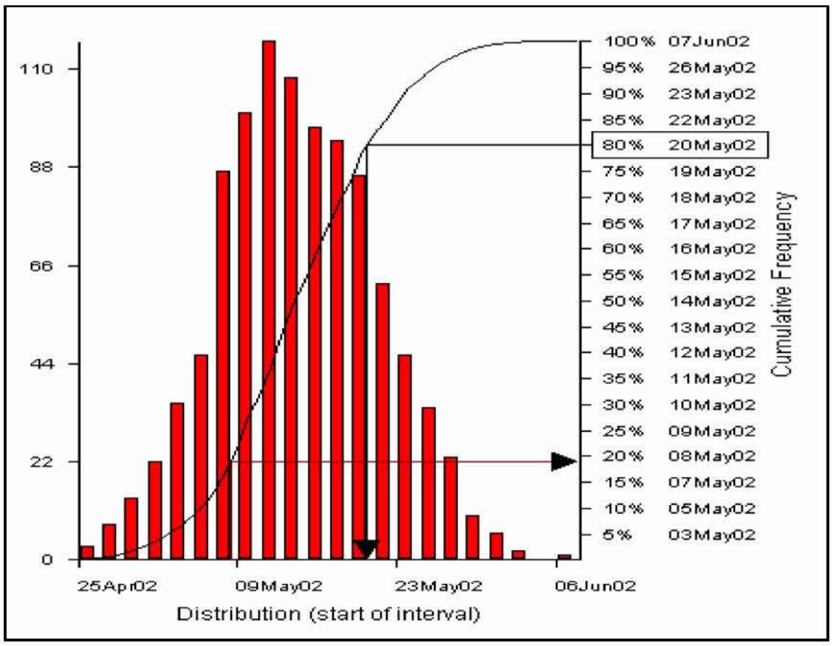

Figure B4: Output from the Monte Carlo model in the form of a histogram showing the distribution of project completion times, together with a curve showing cumulative probability of completion.

Task Criticality

When a project has several parallel tasks, the critical path may change with each iteration of the model. In this situation, we cannot report with certainty what the critical path will be for the project. Instead, we report ***task criticality***, indicating the number of times that the task appeared on the critical path, expressed as a percentage of the total runs. This enables us to assess each potential critical path and potentially control the actual critical path during project execution. The criticality index is always calculated during a risk analysis.

Task Crucially

Crucially is calculated from the Duration Sensitivity and the Criticality Index, as follows:

Crucially = Duration Sensitivity x Criticality Index

Crucially combines the benefits of sensitivity and criticality index to produce a measure of how likely a task is to affect project duration. Combining the criticality index with sensitivity removes the random sensitivity values that can occur with tasks that are not always on the critical path. To generate Crucially values, choose Run Risk Analysis from the Risk Menu. Ensure the "**Calculate Sensitivity for task duration**" box is checked. This is required as Crucially uses sensitivity in its calculation. Click "**Analyze**". At the end of the analysis you will see the Sensitivity being calculated. To display Task Crucially, add the column "**Risk - Duration Crucially**" to the Gantt chart.

Project Contingency

Referring to Figure B4, if we were to report project completion time as the 50% probability completion time, May 14, we can also report project contingency as the difference between, say, the 80% completion time and the 50% completion time. That is May 20 – May 14 = 6 days. This same approach can be used for cost contingency.

APPENDIX C: Probability Distributions

The Triangular Distribution

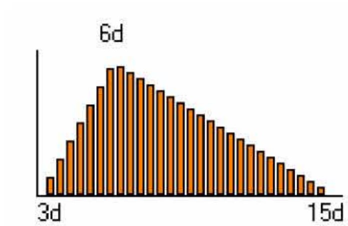

Figure C1: Triangular Distribution – Triangular distribution can be skewed to the left (optimistic), the right (pessimistic) or can be symmetrical (neutral).

The Triangular distribution is the most commonly used distribution for modeling expert opinion. It is defined by its minimum, most likely and maximum values.

The mean and standard deviation of the Triangular distribution are equally sensitive to all three parameters. Many models involve variables for which it is fairly easy to estimate the minimum and most likely values. But for others the maximum is almost unbounded and could be enormous, for example, in estimations of cost and time to complete some task. In situations where the maximum is difficult to determine, the Triangular Distribution is not usually appropriate since it will depend a great deal on how the estimation of the maximum is approached. For example, if the maximum is assumed to be the absolutely largest possible value, the risk analysis output will have a far larger mean and standard deviation than if the maximum is assumed to be a “practical” maximum by the estimating experts.

The Triangular Distribution is often considered to be appropriate where little is known about the variable outside an approximate estimate of its minimum, most likely and maximum values. On the other hand, its sharp, very localized peak and straight lines produce a very definite and unusual (and very unnatural) shape, which conflicts with the assumption of little knowledge of the variable.

The BetaPERT Distribution

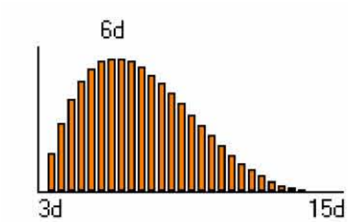

Figure C2: BetaPERT Distribution

The BetaPERT Distribution gets its name because it uses the same assumption about the mean as PERT networks and because it is a version of Beta distribution. It requires the same three parameters as the Triangular Distribution, namely minimum (3 days), most likely (6 days) and maximum (15 days).

The mean for the PERT Distribution is four times more sensitive to the most likely value than to the minimum and maximum values, as compared with the Triangular Distribution where the mean is equally sensitive to each parameter. The PERT Distribution therefore does not suffer to the same extent the potential systematic bias problems of the Triangular Distribution, that is, in producing too great a value for the mean of the risk analysis results where the maximum for the distribution is very large. The standard deviation of a PERT Distribution is also less sensitive to the estimate of the extremes.

The Uniform Distribution

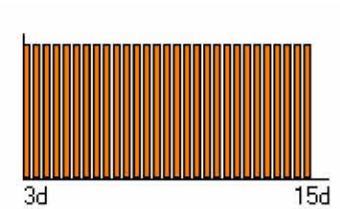

Figure C3: Uniform Distribution

The Uniform Distribution is generally a very poor model of expert opinion since all values within its range have equal probability density, with the density falling sharply to zero at the minimum and maximum in an unnatural way.

The Uniform Distribution does, however, have several uses:

- To highlight or exaggerate the fact that little is known about the variable;
- To model circular variables (like the direction of wind from 0 to 360 degrees); and other specific problems;
- To produce spider sensitivity plots.

The Discrete Distribution

The Discrete Distribution is an array of the possible values of the variable "x" each with probability weightings "p". The "p" values do not have to add up to unity as the software will normalize them automatically. It is actually often useful just to consider the ratio of likelihood of the difference values and not to worry about the actual probability values.

The discrete distribution has three distinct uses;

- to model a discrete variable (i.e. a variable that may take one or two or more distinct values;
- to model a variable that may be affected by an uncertain event; this is known as conditional branching; and
- to combine two or more conflicting expert opinions.