Paper title

Developing and Delivering Complex Projects using Quantitative Risk Analysis

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Synopsis

Evidence based analysis by Independent Project Analysis, Inc. (IPA) in 2009 and PwC in 2012 showed that the dominant cause of major project failures in Australia has been poor management, especially of the development but also the execution.

One significant way to improve the success rate of Australian projects in the future is to model how likely the projects are to succeed using Monte Carlo Method simulation on carefully developed time/cost models.

This paper describes the proven use of Monte Carlo Method Risk Analysis and especially Integrated Cost & Schedule Risk Analysis (IRA) on a number of complex and mega projects with aggregate values exceeding $50 billion.

It starts by examining the development of the use of MCM simulation on projects and reasons why MCM simulation is viewed with scepticism by some.

The importance of the schedule to the rigor of the analysis is examined and some examples of success using SRA given, demonstrating the importance of interaction with the project team, whose input is essential for successful outcomes, often after several rounds of analysis and modification of inputs.

The paper then sets out the features of the IRA methodology and its application to major resource projects. It compares IRA with the traditional approach to risk analysis of projects, using separate Schedule Risk Analysis (SRA) on a summary schedule and passing a schedule contingency cost allowance to a subsequent Cost Risk Analysis (CRA). It carefully demonstrates the inherent shortcomings of the traditional separate SRA & CRA approach compared with IRA, based on sound technical reasons.

The paper concludes with a description of the competing demands of IRA for increasing model size with larger and more complex projects to produce model accuracy, versus the challenges of handling larger schedule and cost models and how the use of Quantitative Exclusion Analysis (QEA) provides the project team with real opportunities for optimising project risk to produce materially better project outcomes.

Contents

1. Addressing Australia's poor project performance

1.1 Poor Project Performance: diagnoses

On the evidence, Australia's record over the last 15-20 years in delivering large and complex projects is poor.

Independent Project Analysis, Inc. (IPA), reported (Young, 2009)[i] that 74% of completed Large and Technically Complex Projects assessed by IPA in Australia had been failures, mainly due to deficiencies or omissions during planning of the projects before they were approved for execution.

In late 2012, PricewaterhouseCoopers (PwC) reported[ii] that most projects failed to deliver at least some of their benefits and be completed within the planned time and cost limits and that over 90% of these failures were due to management failings rather than technical problems.

1.2 Focus on Project Quantitative Risk Analysis

Better project development and delivery performance depends on a wide range of factors. However, this paper concentrates on more effective use of Monte Carlo Method (MCM) simulation to model project development and delivery. It is intended to show that the effective use of quantitative risk analysis in projects has the potential to make a material difference to project outcomes, but that the modelling of projects using MCM is still an immature discipline with insufficient knowledge among practitioners about the requirements to deliver the most meaningful and useful results. The paper starts by looking at the history of the use of MCM to model project outcomes to explain the current state of knowledge and capabilities. It identifies Integrated Cost & Schedule Risk Analysis (IRA) as the goal for modelling project time and cost uncertainty, but notes the reasons for its use not being widespread. The reasons are examined then IRA methodology is compared with Serial Schedule Risk Analysis (SRA) to Cost Risk Analysis (CRA). Examples of successful use of Project QRA are given and the paper concludes with a detailed description of the use of IRA and the challenges to be overcome to use IRA effectively.

2. Monte Carlo Simulation: an emerging project management tool

2.1 History of Monte Carlo Method applied to Projects

The Monte Carlo Method (MCM) was developed out of the Manhattan Project to simulate random nuclear interactions, by Stanslaw Ulam and John von Neumann who named the method. Its methodology was developed in the late 1940s and early 1950s and broadened from nuclear physics to other areas of physics, physical chemistry and operations research.[iii]

The Method tends to follow the following process:

1. Define a domain of possible inputs;
2. Generate inputs randomly from a probability distribution over the domain;
3. Perform a deterministic computation using the inputs;
4. Repeat many times to cover most combinations of possible inputs
5. Aggregate the results[iv]

From Operations Research MCM was applied to PERT by RAND Corporation for the US Air Force in 1963.[v] This paper "Uses of Monte Carlo in PERT" introduced the concept of Criticality Index (probability that an activity will lie on a critical path). It also recognised the opportunity to use various probability distributions (beta, normal, triangular, uniform or discrete) in any combination. The paper demonstrated the superiority of the MCM over the PERT method. However, the limited computational power of then available computers (IBM 7090 was being used) and the use of an elaborate random number generation algorithm meant that most of the computational time was spent generating the random numbers. For a 200 activity network and 10,000 iterations, the running time was about 20 minutes to generate the project duration probability density function, its mean and variance and the criticality of each task. However, other project information was not made available.

In 1964, David Hertz wrote a much-cited paper "Risk Analysis in Capital Investment"[vi] which applied MCM to discounted cash flow calculations, defining the uncertainty and risks that may affect such calculations to produce probabilistic forecasts of return on investments. The RoI curve so produced described the Risk/Return curve, where higher returns were achieved with lower probabilities of success.

In 1970, Louis Pouliquen of the World Bank used MCM to assess 3 World Bank projects as case studies[vii], showing how risk assessment techniques could be used to evaluate them.

2.2 MCM Tools for Project Management

The majority of MCM software tools in use today for projects are add-ons to spreadsheets, such as @Risk by Palisade Corporation and Crystal Ball from Oracle Corporation. Both first became available in 1987 for use with Lotus 123 and subsequently migrated to Microsoft Excel when it became the dominant spreadsheet under Windows. Cost Risk Analysis (CRA) is performed on project estimates using such tools.

Schedule Risk Analysis (SRA) became available through several different pathways:

1. Linking the spreadsheet-based or other MCM tool calculating with a critical path engine application. Current examples include @Risk for Project, Full Monte (by Barbecana) and Risky Projects (by Intaver Institute), all of which use Microsoft Project as their input/output scheduling tool.
2. Purpose-built Critical Path software integrated with a MCM engine. Examples include Primavera Monte Carlo (no longer available) and Pertmaster (now Oracle's Primavera Risk Analysis).
3. Enterprise Risk Management Software Suites that include a Risk Management Database and CRA and SRA capable modules that interface with the Qualitative Risk Analysis database for mapping risk events into the MCM CRA and SRA models. Examples include Strategic Thought Group's Active Risk Manager (ARM - now owned by Sword Active Risk) and Risk Decisions' Predict!.

An exception to these is Booz Allen Hamilton's Polaris which was purpose designed as an integrated cost, schedule & risk event analyser, first used in NASA. It relied on Excel for inputs and did not include planning capabilities, which have since been added. A comparatively new arrival on the market, it is exceptionally fast, but its feature set is not as mature as for other products.

There is now widespread but not universal acceptance that MCM project assessment is a necessary part of evaluating projects before Financial Investment Decision (FID) and also during project execution, especially when problems arise. Known as Quantitative Risk Analysis, the use of MCM assessment of projects has traditionally broken into two types: Cost Risk Analysis and Schedule Risk Analysis.

Project management teams and especially those responsible for project controls recognise the linkage between time and cost in projects. The aphorism "Time is money" is an accepted principle in projects. However, this does not translate into the use of QRA to evaluate the related uncertainties of project duration and project cost simultaneously.

While it seems logical to combine CRA and SRA, there is considerable resistance to integrating cost & schedule risk analysis. We will now look at this dichotomy and the reasons for it.

3. What tends to Keep SRA and CRA Separate

Organisational and analytical factors have tended to keep SRA and CRA separate, as explained here.

3.1 Practitioners from different backgrounds

Estimators and cost controllers have traditionally come from the ranks of quantity surveyors and cost engineers, while project planners and schedulers have tended to emerge from the ranks of design and construction engineers. The first group is concerned with counting and quantities while the second group is more concerned with how things are put together.

Exponents of Cost Risk Analysis have tended to be skilled in estimating or financial analysis and comfortable with spreadsheets, but not project schedules.

This has carried through to the application of Monte Carlo simulation: Cost Risk Analysis tends to be performed by practitioners with estimating or cost control backgrounds, using spreadsheet based tools like @Risk and Crystal Ball. The practitioners may compile Trend Registers in which all uncertain items with cost impact are listed, including those driven by schedule. In the latter category, cost controllers assume some time rate of cost expenditure to forecast cost ranges in the Trend Register.

On the other hand, project planners who have transitioned into Schedule Risk Analysis tend to use Monte Carlo simulation tools built on project planning software. When costs have been included in such modelling, it has often been through working with resource-loaded schedules. Functionality for costs has not been as well-incorporated in such SRA tools, further deterring SRA practitioners from including costs in their analyses.

3.2 Different SRA and CRA tools hinder Integrated C&SRA

Consequently, CRAs tend to be performed by one set of practitioners using their favoured software and SRAs by another group of practitioners using different software. Even when the same analysts do both SRA and CRA, they commonly use different software due to the evolved specialisations.

4. MCM Scepticism

There are significant numbers of sceptics of the value of MCM simulation, due to their encountering poor or deliberately misleading usage of quantitative risk analysis in projects.

This is believed to be due to multiple factors:

- Lack of reliable published evidence that project quantitative risk analysis is helpful;
- Immaturity of the discipline of quantitative risk analysis in projects, resulting in a wide range of capabilities being offered in the market or practised within organisations, often producing results of little value, resulting in disillusionment with the idea of MCM being useful;
- Lack of understanding of what is required to produce high quality and reliable quantitative risk analyses in projects and thus an inability to specify the process adequately;
- Misuse of quantitative risk analysis by users who have deliberately skewed ranges to produce desired results, sometimes described by the slang term “cooking the books”.

These factors are discussed in more detail below.

4.1 Lack of published evidence of value of project quantitative risk analysis

Published information on the outcomes of project quantitative risk analyses or critically assessing the effectiveness of quantitative risk analysis techniques is hard to find.

A Working Paper published by RAND Corporation over ten years ago surveyed the use of quantitative risk analysis and management on the planning and execution of complex projects (Galway, February 2004[viii]). The survey found that there was a reasonable consensus on the need for and usefulness of project QRA but also that it is not well-understood, not well-integrated into project management and not easily explicable to senior decision makers. There is a lack of hard data on the accuracy of forecasting by quantitative risk analysis, despite the apparent widespread use of it on large and complex projects and the growth of computing power. This was ascribed to several reasons:

- The risk analysis community of practice is fragmented in nature, including academics, project professionals, risk consultants and software developments, making sharing of information harder.

- Projects change as they progress, outdating the results of QRA and calling into question the criteria for evaluating their effectiveness.
- Most projects are kept confidential and project owners and contractors are reluctant to share information about their progress or commercial outcomes. This is particularly applicable to high technology projects or those with an R&D component.
- Finding out about what quantitative risk analysis techniques work and what do not depends on publication of successes and failures and there is little incentive to do this, apart from the desire of the practitioners to have their successes recognised.
- Learning lessons from quantitative risk analyses on a project depends on a full report being prepared on the brief, inputs, assumptions and exclusions, analysis methodology, range results, rankings of drivers, actions arising and, after the actual results are in, recording the actuals for comparison. Unless the organisation takes Project Closeout seriously enough to fund such an exercise as part of a "Lessons Learned" Report, it is unlikely to happen, even if reports were prepared at the time of the risk analyses.

Other more recent papers provide listings of techniques without any evaluation of their effectiveness beyond opinions on their applicability. For example, "A Review of Quantitative Analysis Techniques for Construction Project Risk Management" (Thaheem et al, 2012)[ix]

A review more specifically focused on Oil & Gas "The Application of Quantitative Risk Analysis Techniques in the Oil and Gas Industry" (Hartke, 2012)[x] looks more incisively at quantitative risk analyses and the use of different types of Monte Carlo simulation at different stages of a project, envisaging use of CRA, SRA and even IRRA in assessing the probability distribution of the project's NPV and the value of identifying key risk drivers to mitigate risks. However, apart from stating that "investment projects in the oil and gas industry… offer an abundance of examples of successful application of risk analysis", Hartke provides no evidence of effectiveness in forecasting outcomes.

4.2 Scepticism toward Quantitative Risk Analyses

Experience of the author with various clients has revealed mistrust of the validity and reliability of QRA, due in many cases to prior experience of poor or misleading analyses.

This is particularly pronounced toward CRAs among the financial community. It seems clear that these have been misused in the past to produce favourable forecasts.

The author's own experience of intervention by clients to produce desired outcomes is exemplified by the following (for which the practitioner's only protection apart from declining to do the work is to be explicit in listing input assumptions and exclusions):

(i) A tender specification for a naval defence contract called for a SRA to be submitted with the tender to demonstrate the bid was achievable – Client SRA inputs were adjusted until they gave the "right" answer;

(ii) A CRA for a petrochemical plant was required to be kept below $450m and input ranges were constrained with this in mind. (Some years later the plant was completed for a cost that was more than double this limit…)

(iii) A major construction contractor carefully adjusted the inputs to an LNG design & construct SRA requested by the client during the tender process so that the contract period planned by the contractor was equivalent to a P51. (This contract period was considered by an LNG plant construction expert on the client's team to be around a realistic P80. The contract was to include a sliding scale bonus for early completion and penalty for late completion.)

These examples are outweighed by many more engagements where no such influence was apparent.

4.3 Immaturity of QRA Discipline leads to poor specifications and performance

Because knowledge is poor of what are the necessary and desirable ingredients of effective QRAs, especially involving SRA, specifications for QRAs are rarely prescriptive concerning methodology and where they are, it is usually to specify particular software tools.

The situation described in the 2004 RAND Working Paper remains relatively unchanged in the author's experience:

There is a lack of available evidence of successful methodologies and techniques – the practitioner has to rely on:

- Limited useful reference books – see for example both excellent books by Hulett: "Practical Schedule Risk Analysis" (2009)[xi] and "Integrated Cost-Schedule Risk Analysis" (2011)[xii]
- Discussions on specialist forums, such as the following on LinkedIn (most of which require application for admission, which is not unreasonably withheld):
  - Schedule and Cost Risk Analysis
  - Oracle Primavera Risk Analysis (PertMaster)
  - Oracle's Primavera Risk Analysis - a subgroup of Primavera
  - Monte Carlo Simulation and Risk Modelling
  - Mining risk and uncertainty analysis

While contributors to these forums include many of the most knowledgeable and skilled practitioners, there is understandable reluctance to share commercially sensitive evidence of QRA performance, due to client confidentiality, but also to protect the business interests of the practitioners.

Requirements to perform QRAs usually do not specify the methodology, presumably because:

(i) Organisations may not know how to specify what is required;

(ii) Industry is not risk-mature enough to know definitively what are the best techniques; and

(iii) There is a dearth of data on QRA performance in forecasting project outcomes.

5. Importance of schedule to rigor of analysis

SRA is often used to model the probability of a project achieving its key milestone dates. The reliability of this forecasting is dependent on how well that schedule model represents the project. There are a number of contributors to the effectiveness of the schedule model as a representation of the project. Here are some important ones.

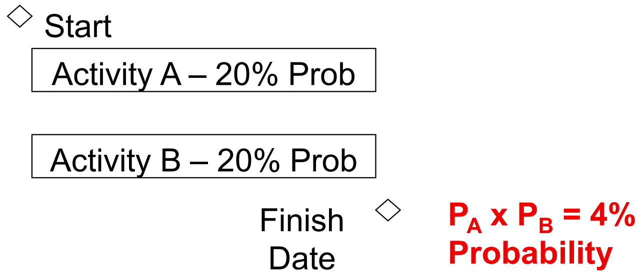
5.1 Represents the project scope and strategy

The schedule must include all the project scope that affects the project timing. It must also describe the implementation of that scope in the logic of the schedule as it is intended to be performed or the schedule will not behave as the project can be expected to perform in execution.

5.2 Allows for the complexity of the schedule logic

All but the simplest project plans consist of multiple logic pathways that necessarily converge through milestone logic nodes leading to project completion. The probability of completing a given logic node milestone by the planned date is the determined by the probabilities of each pathway to that convergent node. How those probabilities are related to each other can be illustrated by the following example. Two identical activities are to be performed in parallel using identical but separate resources. If the probability of each activity A & B being completed by the planned finish date is 20%, what is the probability of both being completed by that date?

Figure 1: Merge Bias Effect of converging parallel logic



As shown above the probability of both tasks A & B being completed by the planned finish date is the product of the probabilities of each path being finished by that date. This is analogous to the probability of throwing two dice and getting the same value on each.

It is known as the Merge Bias Effect (MBE) and explains why it becomes progressively harder to complete a project on time as more converging parallel logic paths overlap. It is also a reason for it being hard to complete complex projects on time, due to the convergence of many parallel logic strands.

So when a project is delayed in starting, one effect is to reduce the probability of each logic pathway being completed by the planned date. Due to the MBE, the reduction in probability is not linear with time delayed but geometric, due to the probability of timely completion being the product of all converging probabilities.

The MBE is an important reason why, wherever possible, the project schedule should be used for SRA rather than a summary schedule. The "hard wired logic" of the project schedule forms the logic framework of the project strategy. If that is summarised and logic nodes removed, the reduction in MBE restraint on the schedule will allow a summary SRA model to show that earlier completion of the project can be achieved than is actually possible.

5.3 Allows for the uncertainty of activity durations

The duration of a task is rarely able to be known exactly. In most cases, it is more like being asked how long it takes to travel from home to work each day. Because it is a regularly repeated activity, most people are likely to answer in a way similar to the following:

"If it is a fine day when most people are away on holidays, it only takes me 20 minutes. In winter, when the weather is bad and everyone is trying to get to work, it may take 50 minutes. If there is an accident or the road is being repaired, it can take 75 minutes. Most of the time it takes about 30 minutes."

Project plans contain hundreds or even thousands of activities like this. But deterministic project planning only allows one duration value for each task. The project planners cannot represent the inherent uncertainty of each task in their single duration values. MCM simulation enables the full uncertainty of an activity to be modelled.

5.4 Allows for risk events

The above discussion of the variability of the time required to get to work from home referred to the occasional traffic accident or road repair or malfunctioning traffic lights. Each of these is a Risk Event that has a low probability of occurrence, but in a project with thousands of activities, some risk events are virtually certain of happening. It is therefore essential to take risk events into account in planning such projects, to increase the resilience of the project, not only to such "known unknowns" that are identified and managed in the project risk register, but also to the inevitable "unknown unknowns" that occur in almost all projects and for which projects require a buffer of time and cost contingency.

Projects that are planned with no allowance for risk events have no protection against unplanned threats to the project objectives. This can be seen as naïve optimism.

MCM simulation of the project can be broadened to allow for risk events as well as range uncertainties. The significant risks, both threats and opportunities with schedule impacts in the project risk register can be mapped into the MCM model of the project and their effects taken into account through the product of their probabilities and impacts. By assessing the schedule impacts of the risk events as three-point distributions, the uncertainty of the risk events can be allowed for both in their probabilities of occurrence and their impacts if they do occur.

5.5 Allows for weather uncertainty

For construction projects, it can be very important to model weather events and uncertainties separately from schedule logic because weather risk is often strongly seasonal with the project activities moving around in time over the weather backdrop. The impacts of weather are often not modelled well in deterministic planning and estimating. Historical weather data can be analysed and seasonal probability distributions modelled in MCM simulations to take account of complex weather effects such as:

- Variability of weather causing random fluctuating downtime due to wind or rain year-round;
- Seasonal weather events such as hurricanes or cyclones; and
- Weather windows of uncertain start and finish times such as winter freeze and thaw cycles, monsoons and wet seasons.

6. Examples of success using SRA

The following examples illustrate the collaborative and iterative nature of the QRA process and the accuracy that can be achieved due to the rigor of the process.

6.1 Australian LNG Train Completion to RFSU

The project was about 5 months from planned plant startup and the client was concerned that the schedule was slipping each week. The current completion schedule of ~2,700 tasks was converted to an hourly schedule to provide more granularity for the hundreds of 1-3 day remaining duration tasks. Duration ranges were obtained by interviews with the various discipline superintendents.

Several SRA iterations were required, using cruciality tornado diagrams to identify schedule drivers and twice remove delaying equipment not necessary for startup (a flare awaiting a missing part; a let-down gas turbine with a faulty bearing) until the schedule was driven by the main remaining work, to complete installation of the refrigerant modules. The third simulation for plant RFSU was within 3 days of the actual RFSU by the client's criteria.

6.2 Middle Eastern LNG Train Completion to RFSU

About 4 months from planned startup, the project owner was concerned completion would be late as contractor progress was slipping and shipment of LNG in the month after planned startup was in doubt. The construction schedule was high-level and did not show systems to enable handover linkages to be made to the detailed and consistent commissioning schedule.

The final steps before construction handover included pipeline pressure testing, which enabled "pseudo tasks" to be created between the data date and the forecast final test pack pressure test date for each system, extracted from a testing database. The ~1,000 remaining tasks schedule was also converted to hours to increase ranging granularity. Conservative ranging assumptions based on experience to date were made for System Mechanical Completion and Intermediate RFSU Punch Listing and Clearing (MCPL & IRFSUPL) tasks when Owner's Team and Contractor discipline supervisors met to range the schedule.

Initial SRA results were considered pessimistic so further changes were made to the schedule to add an air blowing nightshift and reduce pessimism in the MCPL & IRFSUPL tasks. Optimistic and pessimistic scenarios were modelled. These reduced the probabilistic dates, but the cruciality tornado diagram showed the Punchlist & Clearing tasks were driving. The Commissioning Manager then refined the punch list clearing logic, replacing the single 15 day task with one 5 day punch listing owner task and three categories of clearing tasks by the contractor: A – Must clear for system MC (5 days), B – Clear in parallel with commissioning work by IRFSU (10 days), C – Clear after startup (20 days). Ranges were assigned pro-rata. These changes were made to all systems and added to the previous changes. These brought the deterministic date back within the contractual date of 31Oct. Results from the progressive analyses are shown below:

Table 1: RFSU Dates from SRA Analyses

	Deterministic	P50	P80
Initial Analysis	08Nov	14Dec	20Dec
Conservative Scenario	07Nov	07Dec	12Dec
Optimistic Scenario	07Nov	29Nov	04Dec
Refined Punch Clearing	**31Oct**	**14Nov**	**19Nov**

The final report recommended tracking actual performance versus the refined P3 schedule. An email was later received showing RFSU was signed off on 13Nov, the day before the refined P50 date.

6.3 Oil Refinery Enhancement Project

About 4 months into an EPC contract to enhance the quality of diesel produced from an Australian refinery, a SRA was commissioned by the project owner through the EPC contractor. The project schedule of about 700 activities was being used to manage engineering, procurement, construction and commissioning. The first intermediate milestone whose timing was to be forecast was “95% Engineering Completed”, about 4 months after the start of the engagement, along with later milestones and the project completion. After a day spent ranging the schedule durations with the Chief Planner and the Project Manager, analysis was performed and a report submitted. The analysis showed the following for “95% Engineering Completed”:

Planned Date – 16Sep; P50 - 26Oct; P90 - 5Nov.

After the report was submitted the client requested a meeting to review the results, accompanied by the EPC contractor stakeholders. The client Project Director was very scathing about the 95% EC milestone forecast, stating that he was negotiating with the EPC Contractor to bring that date forward but the SRA was forecasting it would finish at least a month late. The fact that the forecast was based on the EPC Contractor’s own duration ranges and schedule did not deflect the Project Director from “shooting the messenger” and stating that the report was not credible. Yet, in mid-November, the author was called in to perform another SRA due to delays to procured pressure vessels from Korea. In the course of collecting the new inputs and ranges, the author learned that the 95% EC milestone had actually been achieved on 5Nov, the P90 date. The author was engaged two more times on the project after the initial work.

7. Integrated Cost & Schedule Risk Analysis (IRA)

Cost Risk Analyses (CRAs) and Schedule Risk Analyses (SRAs) have been performed for many years. But integrating cost and schedule risk analyses into one analysis is not fully accepted in the project quantitative risk analysis community, partly due to differences in the origins of the species of personnel performing CRAs versus SRAs and partly due to perceived limitations in software tools.

Consequently it is worth setting out the reasons why cost and schedule uncertainties and risks should be analysed together and what the best practice process looks like.

Note that this section of the paper makes extensive use of an article by the author and a colleague published in our April 2014 Newsletter “RiskIntegral”.[xiii]

7.1 Definition of Integrated Cost & Schedule Risk Analysis

Integrated Cost & Schedule Risk Analysis (IRA) is the Monte Carlo Method simulation of a project using a schedule representation of the project overlaid by a cost estimate or control budget of the project and with treated risk events with cost and schedule impacts appropriately mapped into the cost-loaded schedule. All significant sources of time and cost uncertainty are incorporated into the model and simultaneous cost and schedule uncertainty distributions are calculated by the simulation, together with cost and schedule driver sensitivities.

7.2 The IRA Process

It is assumed that this process is being performed in the latter stages of a Feasibility Study prior to Financial Investment Decision (FID) when well-developed detailed schedule, estimate and risk register are available. This does not preclude the process being performed at other times, including during pre-feasibility or after execution has started, but if so, the inputs are likely to differ.

7.2.1 Starting with the schedule

IRA starts with the project schedule. As noted earlier, for maximum realism, the schedule should represent the project strategy and how the project is to be executed. The schedule should include sufficient detail to reveal the critical and near-critical paths of the project. It should also retain the characteristic complexity of the project to ensure that the Merge Bias Effect (MBE) realistically constrains the potential for early completion. For major and complex projects including construction, the schedule used to organise and control the overall project without becoming too detailed and unwieldy is often referred to as the Level 3 Integrated Master Control Schedule. This is usually a good basis for an IRA model.

7.2.2 Summarising the estimate

The project estimate is overlaid on the project schedule in a series of hammock activities (tasks that change in duration according to the durations of the tasks to which they are linked without taking part in critical path calculations). The estimate / control budget may consist of thousands of line items. The goal is to set up the cost breakdown structure so that it aligns with the schedule breakdown structure and enables costs to be summarised to differentiate between significantly different risk profiles; for example, in costing of equipment and materials packages, separating procurement and fabrication from construction.

7.2.3 Splitting fixed and variable costs

The line item costs are a mixture of variable (time-dependent) and fixed (time-independent) costs, all of which are uncertain at the start of the project. The proportions (“splits”) of fixed and variable costs must be accurately known or estimated for each line item so that the summarised variable costs, when spread over the applicable groups of tasks in the schedule can vary realistically due to duration changes. Variable costs can vary due to task duration changes and also due to uncertainty in their rates. For example, labour and equipment hire rates may be uncertain at the start of the project.

7.2.4 Ranging and Reviewing the Uncertainty and Risk Inputs

Subject Matter Experts (SMEs) can provide range and rate inputs to workshops or interviews to develop consensus inputs for the IRA model schedule and cost ranges. In addition, risk events from the project risk registers with time and cost impacts incorporate the known risks that could affect the project goals. The risk events could be opportunities or threats and could affect multiple activities in the project. They may also be mapped into the cost-loaded schedule as risk factors that affect groups of activities to reflect such things as productivity, quantity uncertainty or market conditions.

7.2.5 Correlation: a necessary input

Correlation models are developed to ensure that groups of activities and resources that behave in related ways are represented realistically in the IRA model. This extends to risk factors that vary in related ways, such as productivity risk factors for different disciplines. Correlation inputs are essential instructions to the MCM modelling tool that correct the inherent assumption of complete independence between all inputs and enable the model to forecast realistic probabilistic spreads of schedule and cost.

7.2.6 Building the IRA model

The IRA model is built from:

- the carefully reviewed and technically corrected schedule;
- overlaid by the summarised estimate;
- inputting the schedule and cost ranges;
- schedule and cost correlation models;
- mapping in the treated cost and schedule impact risk events and risk factors; and
- assigning the probabilistic weather calendars (usually derived from historical weather data) to the appropriate construction tasks where the project involves weather-exposed construction.

7.2.7 Integrated analysis

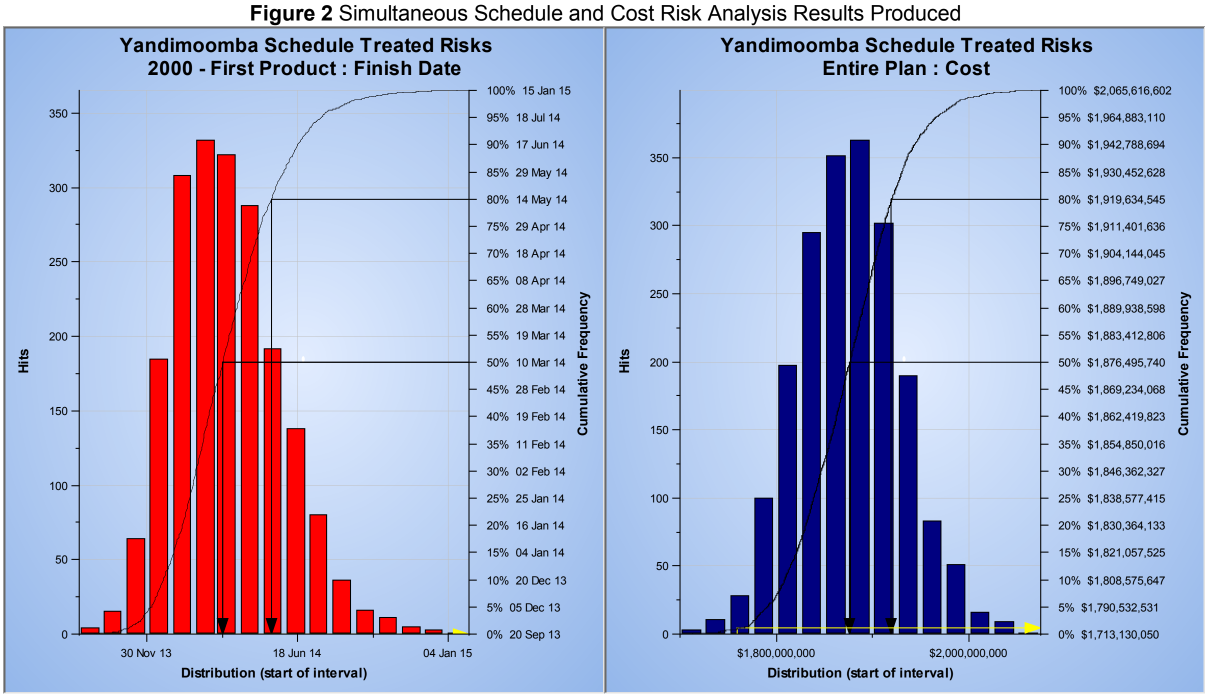
The analysis is usually performed at least twice and sometimes three or more times, depending on the complexity of the model and how far the client wants to go in optimising the risk profile of the IRA model and thus the project. The key point is that changes to inputs to the model depend on the wishes of the project team in reviewing the results and what the sensitivity rankings reveal about the schedule drivers and the underlying logic in particular.

7.3 The benefits of IRA

IRA enables the simultaneous analysis of probabilistic schedule and cost distributions for IRA models incorporating all known and possible sources of time and cost uncertainty, such as shown in the example distributions below. It reflects the project reality that “time is money”.

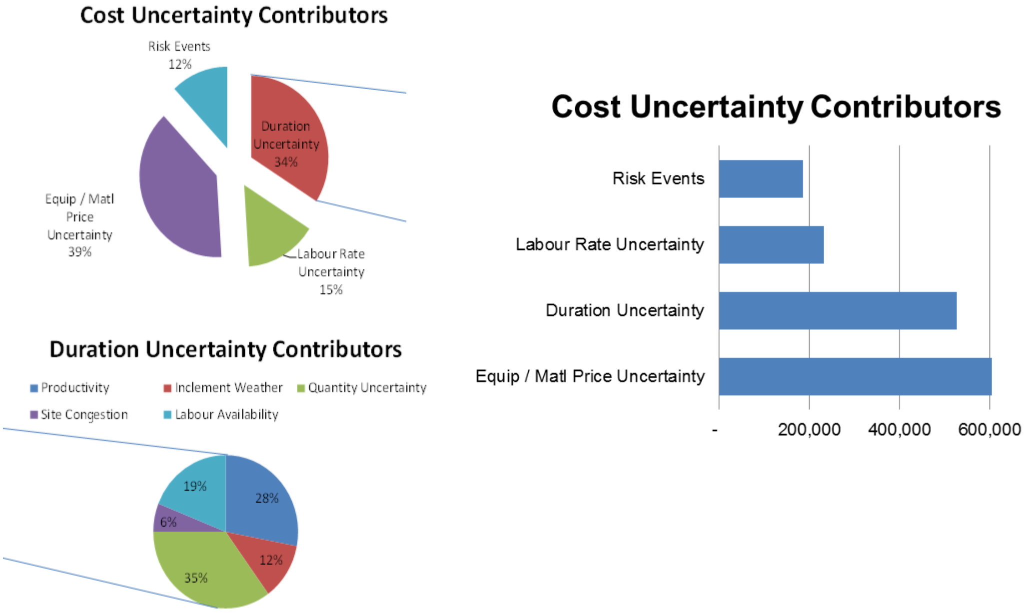
By modelling all time and cost uncertainties together, IRA enables the analysis to calculate the cost consequences of schedule changes based on where and when they occur in each iteration and thus probabilistically from the complete simulation.

Figure 2 Simultaneous Schedule and Cost Risk Analysis Results Produced



In addition, IRA enables the quantification and ranking of all driving sources of uncertainty in the IRA model, providing insight into the what, why, and how of assessing model behaviours and outputs. This is done by a technique that can be called Quantitative Exclusion Analysis (QEA), which entails the systematic removal of classes of uncertainty or individual tasks or costs or groups of tasks or costs. A full simulation without each class, group or individual contributor enables the effect of the missing element to be measured by difference at selected probability levels. This provides valuable information on the priorities to assign to optimising project schedule and/or cost risk. Examples are shown below of the results of QEA, graphically expressed:

Figure 3 Ranked Classes of Cost and Schedule Uncertainty by QEA



More detailed analyses are possible, down to individual tasks, cost line items and risk events if needed to understand project risk better and optimise it: IRA provides the means to do it.

7.4 The challenges of IRA

IRA has pitfalls that must be avoided to produce reliable results. These include:

- The schedule and estimate must be aligned (produced on the same set of assumptions) for the combined analysis to be valid. For example if the schedule assumes a different sequence or rate of performing work from the estimate, the analysis will be wrong.
- Obtaining accurate splits between cost types - time-dependent (variable) and time-independent (fixed).
- Avoiding "double-dipping" between duration and cost ranges versus risk events or risk factors
- Spreading the costs correctly over the rights groups of activities to represent the true time-variability of the costs.
- Dealing with mismatches in level of detail between the estimate and the schedule, such as where the estimate does not split out procurement costs from installation costs, preventing different risk profiles from being measured and differentiated.

7.5 Megaprojects exacerbate the challenges of IRA

IRA modelling done well is a demanding environment, especially for mega projects (capex >$1bn). Large L3 Integrated Master Control Schedules and large complex estimates are to be expected.

The bigger the project the more difficult the task of developing a well-structured and responsive schedule that is technically acceptable for SRA and IRA. In addition, ensuring that the project scope is fully and properly represented is another challenge of increasing difficulty as the project grows in size.

Already noted is the need for the complexity of the project to be adequately represented in the schedule model to ensure the MBE is appropriately represented. As the size of the IRA model increases, the effects of the Central Limit Theorem become more significant and the importance and difficulty of adequately correlating the IRA model increase.

Weather may be a major uncertainty factor for projects including construction. Being able to input the probabilistic weather calendars and model the weather realistically in all its complexity is another demanding IRA modelling element that becomes more challenging as the model size increases. But for some projects weather may be the dominant risk that must be modelled and only IRA provides the means to measure and rank the cost consequences reliably.

As the scale of the IRA model increases, the difficulty of measuring meaningful and accurate risk driver information also increases. This is because the increasingly sophisticated correlation models distort the use of correlation sensitivities as risk outputs from the analyses to rank the drivers of schedule completion and schedule cost. The correlation models behave as undeclared independent variables to bias the crucialities and cost sensitivities, making the use of QEA vital for realistic ranking of risk drivers of the IRA model.

8. What is wrong with Serial SRA to CRA

Where the decision has been made to perform combined schedule and cost risk analyses, analyses usually will be conducted separately, often by different personnel or contractors. The assessed SRA contingency allowance is fed into the CRA as a “schedule risk allowance” using an assumed “cost burn rate” over the contingency period.

A significant problem with this approach is that it makes no allowance for when and where schedule changes occur, nor the reasons for the changes.

8.1 Flawed Assumptions

Consider the following scenario:

A schedule risk analysis reveals that 30 days of contingency are required in addition to the planned duration to be 90% confident of achieving project completion on time. It also reveals that the bulk of the duration uncertainty for the project is distributed across its construction phase. The results of the schedule risk analysis are then input to the cost risk analysis at an assumed cash burn rate of $1 million dollars a day based on the conservative assumption of peak construction manning levels.

There are three clear issues which we will identify as the ‘when’, ‘where’, and ‘why’ of the traditional approach to combining cost and schedule risk which fail to accurately characterise the true project uncertainty:

8.1.1 When

The first issue relating to the combining of separate cost and schedule risk analyses lies in the assumed cash burn rate per day. For the example above, because the bulk of the duration uncertainty was identified as coming from the construction phase, the assumed cash burn rate per day was calculated based on peak construction manning levels. However, this assumption is overly pessimistic, as only a proportion of the construction period will actually run at peak manning levels. What if delay occurred before all contractors had been mobilized to site? The capital cost impact of the delay would understandably be significantly reduced. Similarly, critical path delays affecting pre-execution engineering or approvals would have drastically different cost impact profiles. The calculated cost of delay is clearly dependent on when the delay occurs.

8.1.2 Where

The second issue relates to where in the program a delay occurs. It is likely that the schedule will consist of multiple parallel paths of tasks that ultimately converge on one completion milestone (either directly or through other connected tasks). Some of these paths will be dominant in determining the completion date of the project, occurring frequently on the critical path, whereas others will not. It is entirely possible for a chain of tasks to be significantly delayed, but never impact on the overall project critical path. However, even though they’re not impacting on the end date of the project, prolongation costs will still be incurred associated with the delays, due to longer use of hired equipment, labour, etc. Calculating the cost of a schedule allowance based on delay to project completion fails to account for these non-critical delay cost uncertainties.

8.1.3 What / Why / How

The final issue with the traditional approach to cost and schedule risk analysis deals with why a particular answer was given, what was driving it, and the assumptions and methodology of how it was derived. Separate cost and schedule risk analyses will almost always have different assumptions that underlie their inputs. A cost risk analysis that draws from the result of a schedule risk analysis must take account of the schedule assumptions underlying the schedule answers to accurately portray forecast cost of delay over-runs.

Further, because the schedule is analysed separately from cost, the visibility of individual schedule elements as drivers of delay cost is lost. We can indeed attribute a certain amount of cost contingency requirement to schedule, but why it is required, what drives it, and how it has been derived is very difficult to express through such a methodology.

8.2 The latest version of serial SRA & CRA

A more sophisticated serial SRA/CRA approach is described by Yuri Raydugin in his useful recent book "Project Risk Management"[xiv]. By this method a project duration probability distribution from a SRA is transferred into a matching CRA, representing the project variable cost uncertainty.

All other cost line items in the CRA represent fixed cost uncertainties and risks, and exclude variable costs. While this approach provides a variable cost probability distribution, it is still based on an assumed rate of expenditure of variable cost per unit time and divorces the schedule drivers from the cost drivers.

The approach also advocates using a highly summarised schedule (<100 tasks), ignoring the importance of the Merge Bias Effect in producing realistic schedule forecasts.

8.3 Summary comparison of IRA with Serial SRA to CRA

The comparison between IRA and serial SRA/CRA can be summarised in the following table:

Table 2 IRA versus Serial SRA/CRA

Integrated Cost & Schedule Risk Analysis (IRA)	Schedule Risk Analysis (SRA) to Cost Risk Analysis (CRA)
More rigorous if done correctly	Less rigorous
Harder to do correctly	Easier to perform
Can provide key driver information, unifying schedule and cost drivers in one ranking as influences on project cost	Cannot reveal cost consequences of schedule delays – schedule drivers are separate from cost drivers

The practicality of IRA depends on being able to handle large scale inputs and analysis of large models in a timely and accurate way. Increasingly, practitioners and the tools to do this are appearing. Apart from PRA, Booz Allen Hamilton's Polaris is becoming increasingly capable and is significantly faster than PRA. Other contenders include Intaver Institute's RiskyProject and Barbecana's Full Monte, along with Deltek's Acumen Risk.

9. Examples of Use of IRA

9.1 Coal Seam Gas LNG Project Forecasts

As part of performing SRAs for the Santos GLNG project before Financial Investment Decision (FID), the author was required to prepare and analyse an integrated schedule of all work leading up to FID and then through the Execution Phase, the Upstream field development, the Pipeline, LNG Plant and Port work to First LNG Cargo. At the time of preparation of the integrated schedule (Data Date 18Dec09), FID was scheduled to occur at the beginning of September 2010 and First Cargo to occur at the end of July 2014. A modified Level 1 Integrated Project Schedule of 410 activities was developed using summary schedules for all the above aspects of the work. A more detailed schedule was impractical because of time pressures. 25 meetings, workshops and review sessions were held over a month covering all aspects of the project scope and including risk register reviews. 27 risk

events were mapped into the integrated schedule. Duration correlation was applied to various groups of tasks in the SRA model, at around 50-60%.
FID occurred in January 2011.
At the time of writing this paper, First Cargo was forecast to occur "in 2015".
The comparison of planned, probabilistic and actual/current forecast dates was as follows:

Table 3 Planned, Forecast & Actual GLNG Dates

Milestone	Planned	P50	P90	Actual/ Current Forecast
FID	2Sep10	21Dec10	15Apr11	Jan11
First LNG Cargo	31Jul14	20May15	29Sep15	"2015"

An IRA was performed for the whole project in late 2010, simultaneously analysing probabilistic dates and costs for the whole project. The report was included in the FID Data Room for the GLNG partners. Further IRA work continues to be done by RIMPL for GLNG on Upstream FEED projects.

9.2 Talisman Energy PNG O&G Exploration 2013/14[xv]

Talisman Energy (TE), a Canadian based Oil & Gas Exploration and production company has been exploring for natural gas and condensate in the Western Province of Papua New Guinea (PNG) since 2009, aiming to develop an LNG project. In the extremely challenging environment of marshy or steep and unstable terrain, heavy rain, low cloud, mandatory use of supply river boats, helicopters and long logistics chains, deterministic planning and estimating proved unworkably optimistic over the first couple of years.

RIMPL offered IRA for risk-based forecasting of time and cost outcomes. TE's Operations VP took the creative approach of breaking exploration down into "Unit Operations": "Seismic Surveys", "Seismic Interpretation", "Drilling Site Preparation", "Drilling Rig Move and Assembly" and "Drilling". Generic Schedules for each of these stages (except Seismic Interpretation and Rig Move) were developed, along with estimates. Duration and cost ranges and risk events were workshopped for each Unit Operation. IRA models were produced and adapted as real seismic campaigns and drilling projects were proposed. Examples of rig moves and drilling and recent seismic campaigns are shown below. The rig moves were planned and estimated deterministically while the drilling and seismic campaigns were forecast and budgeted probabilistically. The differences in outcomes between rig moves and drilling, particularly financially, are significant.

Table 4 Planned/Forecast vs. Actual Rig Move & Drilling Duration & Cost Outcomes

Kupio-1 Well

	Rig Move (Un-risked)		Act/Plan	Drilling (Risked)		Act/Plan	Actual
	Plan	Actual	%	Plan	Actual	%	cf Forecast
Total Days	21d	40d	***190%***	51d	53.8d	**105%**	P87
Total Cost	$5.79m	$7.90m	***136%***	$16.2m	$15.4m	**95%**	P45

Manta-1 Well

	Rig Move (Un-risked)		Act/Plan	Drilling (Risked)		Act/Plan
	Plan	Actual	%	Plan	Actual	%
Total Days	35d	45d	***129%***	31d	29.5d	**95%**
Total Cost	$8.23m	$9.63m	***117%***	$10.2m	$9.7m	**95%**

The seismic planning and estimating were based on probabilistic forecasting. In both cases, the actual survey costs were slightly higher than planned, but still within capital governance tolerances. Durations in both cases were higher than planned P90 values:

Table 5 Planned vs. Actual Seismic Surveys Duration & Cost Outcomes

Southern Blocks

	Seismic Survey		Act/Plan
	Plan	Actual	%
Total Days	152d	168d	**111%**
Total Cost	$39.5m	$39.8m	**101%**

PPL 239 (Highlands 2013)

	Seismic Survey		Act/Plan
	Plan	Actual	%
Total Days	69d	80d	**116%**
Total Cost	$15.1m	$15.9m	**105%**

RIMPL continues to perform IRAs for Talisman Energy for their PNG exploration program.

10. Conclusions

1. There is a clear need for the methodology for the development and delivery of major and complex Australian projects to be materially improved, given the poor success rate achieved over the last couple of decades.
2. A significant step forward would be achieved by improving the quality of performance of a key tool for assessing the riskiness of such projects: Quantitative Risk Analysis using MCM simulation.
3. This paper has shown that the most realistic version of QRA developed so far for forecasting project time and cost outcomes is Integrated Cost & Schedule Risk Analysis (IRA).
4. While IRA has its limitations and challenges to perform well, particularly for megaprojects, it is useful where:
    - It is being used on projects that have enough similarities to others previously completed that sufficient informed expert opinion is available to provide consensus time and cost range and risk information; and
    - It is being used at a stage of project development where enough definition is available for meaningful QRA to be performed, particularly Schedule Risk Analysis.
5. The quality of results produced from IRAs depends, like project success, on a number of elements being done well:
    - The practitioners performing the work must be capable and experienced and using good tools.
    - The inputs to the analysis – schedule, estimate and risk register – must be technically good and aligned to each other.
    - The project / study team and other stakeholders must be capable and experienced so that the schedule and cost ranges and reviewed risks are built on well-founded, consensus values.
6. IRA methodology has a rigorous foundation based on using the Integrated Master Control Schedule (IMCS) or suitably equivalent comprehensive and technically acceptable project schedule.
7. All IRA inputs are transparent and auditable, available for review with the final report. If any attempt is made to manipulate or distort the results, the inputs causing the distortion should be explicitly reported in the Assumptions and Exclusions section of the report or be auditable from the analysis inputs.
8. Use of IRA is scalable: it has been used on projects of only a few million dollars up to billions of dollars.
9. Overruns or failures of complex major and mega projects are not inevitable; using IRA the probability of project success can be materially improved through identification and optimisation of the major risk drivers of the project.
10. Project owners, managers and contractors need to improve their understanding of best practice MCM simulation so that they can specify its use effectively and understand how best to utilise its value, seventy years after its initial development and more than fifty years after the first demonstration of its potential for optimising project risk.

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