

Schedule risk and contingency using @RISK and probabilistic analysis

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Appendix I – Useful references

Schedule risk and contingency using @RISK and probabilistic analysis

1 Introduction

1.1 Background

The percentage failure of projects and the number of project overruns is well documented. The Standish Group, for example, in their 2009 CHAOS report, which tracks project failure rates across a broad range of companies and industries, reported a marked decrease in project success rates. In particular:

- Only 32% of all projects were delivered on time, on budget, and with the required features and functions,
- 44% were 'challenged', i.e. they were late, over budget, and/or with less than the required features and functions,
- 24% 'failed' due to being cancelled or delivered and never used.

Previous reports had suggested that 56% of projects have cost overruns and 84% of projects have time overruns, implying that, on average, only 16% of projects are on time and only 44% achieve their budget. All in all, a poor record in anyone's terms and the situation seems to be getting worse.

The recession may account for some of the project cancellations but experienced project managers will probably recognise many of the common reasons for project failure, such as:

- Project goals are poorly defined, and outcomes are not identified in specific and measurable terms;
- Project plans lack sufficient detail, leading to insufficient time allocation and inadequate financial support and/or other resources;
- Key stakeholders do not "buy-in" and agree to provide adequate support;
- A risk analysis is not performed;
- The project scope expands uncontrollably - scope creep (lack of change control);
- Poor communication.

The UK Office of Government Commerce (OGC) and the National audit Office (NAO) provide a similar list for common reasons of project failure in Government, including:

- Lack of clear links between the project and the organisation's key strategic priorities, including agreed measures of success.
- Lack of clear senior management and Ministerial ownership and leadership.
- Lack of effective engagement with stakeholders.

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- Lack of skills and proven approach to project management and risk management.
- Too little attention to breaking development and implementation into manageable steps.
- Evaluation of proposals driven by initial price rather than long-term value for money (especially securing delivery of business benefits).
- Lack of understanding of, and contact with the supply industry at senior levels in the organisation.
- Lack of effective project team integration between clients, the supplier team and the supply chain.

As many of these problems are difficult to address in the short term, it is clear that project managers need some help in obtaining sufficient schedule and cost contingency to avoid overruns.

The purpose of this series of white papers is to suggest ways of using probabilistic analysis and Monte Carlo simulation so that managers can visualise and quantify the uncertainty in their projects and make thought-provoking predictions of the likelihood of being on-time and on-budget. With this new information, it will be possible to make more informed decisions about target dates, pricing, budgeting and risk management, as well as manage customer and stakeholder expectations more effectively.

Other planned papers in the project series include:

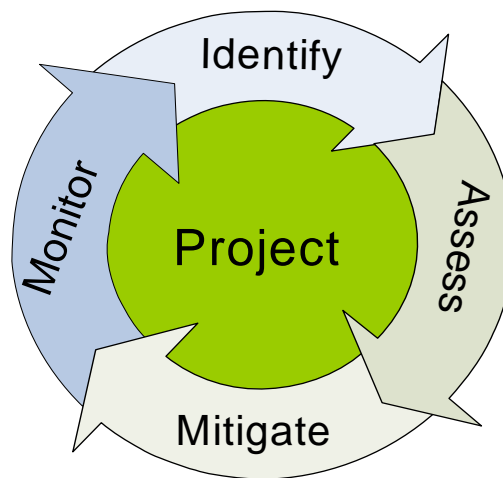
- Cost risk and contingency using @RISK and probabilistic analysis,
- Project progress evaluation using @RISK and probabilistic analysis.

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1.2 What is project risk analysis

Best practice project management, as advocated by leading methodologies provided by the Project Management Institute (PMI), the OGC (PRINCE2) and the Association of project managers (APM) involves carrying out a thorough analysis of potential risks as early and as regularly as possible, in order to determine the likelihood of specific risk-events occurring and, if they do, the magnitude of their impact on the project. Usually these events have negative consequences, such as delays or financial losses, but they could also have positive outcomes.

Perhaps more importantly, the process of regular and on-going risk analysis provides project managers with the opportunity to organise the development of contingency plans and funding, as well as manage the expectations of important stakeholders through formal and informal reporting mechanisms. Below is a typical overview of project risk management process:



The assessment stage of the process can be performed both qualitatively and quantitatively, with the latter attempting to assign numeric values to the probability and impact of each risk, either by using empirical data or by quantifying qualitative assessments such as 'high, medium or low' likelihood of occurrence, using a percentage, and a 3-point estimates (best case, most likely impact, worse case) for potential impact. A typical quantitative project risk analysis, usually developed in a spreadsheet and often referred to as a 'risk register', is shown in section 1.6.

Although very useful for prioritisation and contingency planning, there are several limitations to this 'deterministic' risk register approach, including:

- It considers only three discrete scenarios, ignoring hundreds or thousands of other combinations of outcomes.

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- It gives equal weight to each 3-point estimate. That is, no attempt is made to assess the likelihood of each outcome.
- Interdependence between risks, as well as their ultimate impact on the project plan's targets, is ignored, oversimplifying the model and reducing its usefulness.

1.3 What is probabilistic analysis & Monte Carlo Simulation

In Monte Carlo simulation, risk and uncertainty is represented by probability distributions which recognise that each value in a range of potential outcomes has its own probability of occurring. Probability distributions are therefore a much more realistic way of describing uncertainty in risk analysis. The most commonly used probability distributions are described in section 1.4.

During a Monte Carlo simulation (named after the famous casinos), values are sampled from the probability distributions hundreds or thousands of times and the spreadsheet or project plan recalculated each time. These recalculations allow us to graph the distribution of hundreds or thousands of potential scenarios. In this way, Monte Carlo simulation provides a much more useful view of what may happen for decision-making.

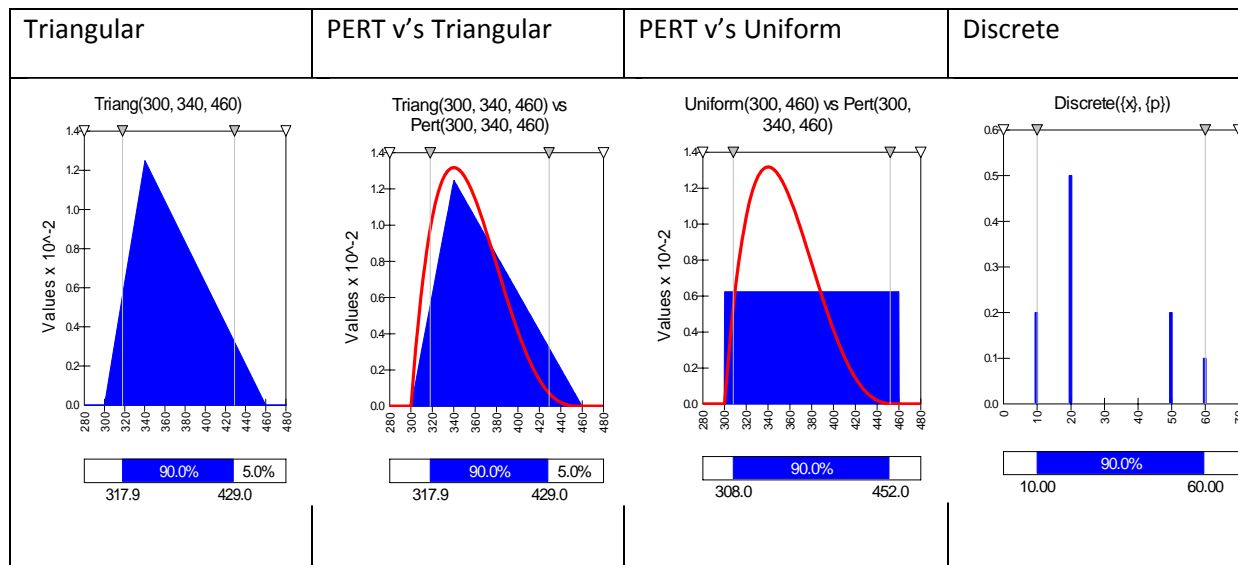
In summary, Monte Carlo simulation provides a number of advantages over 3-point deterministic analysis:

- Probabilistic analysis, showing not only what could happen, but how likely each outcome is.
- Graphical analysis. Due to the data a Monte Carlo simulation generates, it is easy to create graphs of different outcomes and their chances of occurrence. This is important for communicating findings to stakeholders.
- Sensitivity Analysis. Working with just three scenarios, deterministic analysis makes it difficult to see which risks impact the project outcomes most (e.g. completion dates and cost budgets). Monte Carlo simulation allows you to see which risks have the biggest effect on bottom-line results – very useful for allocating limited mitigation resources.
- Correlation of risks. It is important to represent real life interdependence so that when a particular risk occurs, the probability or impact of others goes up or down accordingly.

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1.4 Probability Distributions

In project management, the most commonly used probability distributions are shown and described below:



Triangular – The user defines the minimum, most likely, and maximum impact of a risk or uncertainty, similar to the deterministic approach (in this case 300, 340 and 460 days respectively). However, the values around the most likely have a higher relative probability compared to those in the area around the minimum and maximum values. In fact, using his distribution, 90% of the probability (i.e. area of the triangle) is between 317.9 days and 429 days.

PERT (Project Evaluation and Review Technique) - Again, the user defines the minimum, most likely, and maximum impact of a risk or uncertainty, just like the triangular distribution. However, the values around the most likely are even more likely to occur as there is a built-in weighting of 4:1 towards the most likely value. This reflects the reality of a lot of project uncertainties, as many of them are partially within the control of the project team and therefore less likely to achieve their extreme values, as shown by the red line in the PERT v's Triangular diagram. Here, the PERT has a thinner 'tail' because it is inherently more 'confident' than the Triangular distribution.

Uniform – All values have an equal chance of occurring, and the user simply defines the minimum and maximum. This distribution is the least confident available and should be reserved for risks where users have 'no idea' of the potential impact. The PERT v's Uniform diagram shows quite dramatically how much thicker (and therefore uncertain) the Uniform tail is compared to a PERT. This is because no one is willing to estimate a 'most likely' value – always a sign of lack of confidence.

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Discrete – Here the user defines specific values that may occur and the likelihood of each one. In the diagram we have used 20% chance of 10 days, 50% chance of 20 days, 20% chance of 50 days and 10% chance of 60 days. The Monte Carlo simulation will therefore select these values in the same proportion during a simulation.

1.5 Scope/approach

For the purposes of this paper, we will use a simple project plan to develop a new engineering product, together with a list of 13 potential risks, typically found in a deterministic project risk register as shown below:

			Schedule impact (days)			
Risk	Impact	Probability	Min	Most Likely	Max	Mean
3rd party						
R1 - late customer requirement doc	Delayed start	50%	5	10	20	5.8
R2 - late customer acceptance plan	Delayed finish	10%	5	10	15	1.0
Quality Control risks						
R3 - inadequate customer requirements	Poor design/rework	10%	5	10	15	1.0
R4 - Design/solution QC	Rework design	20%	10	50	100	10.7
R5 - Ramp test QC fails	Rework design	10%	10	50	100	5.5
H&S risks						
R6 - Accident	Shut-down	1%	-	20	40	0.2
R7 - Pollution incident	Shut-down	1%	-	30	40	0.3
Technology risks						
R8 - Machine breakdown	Lost time	10%	2	10	15	0.9
R9 - Obsolescence	Early finish	1%	10	20	40	0.2
Commercial risks						
R10 - Supplier bankruptcy	Delays	10%	5	20	40	2.2
R11 - Customer bankruptcy	Project cancellation	5%	5	20	40	1.1
R12 - Law suit/penalties	Delays	10%	10	20	100	4.9
Weather risks						
R13 - Raw material delays	Delayed production	10%	5	20	40	2.2
Totals			72	290	605	35.2

In real life, a list such as this would be developed via workshop meetings and/or other sources such as project management methodologies which often provide lists of typical risks. A similar list has also been used for cost risk, discussed in separate white paper (Cost risk and contingency using @RISK and probabilistic analysis). In both cases, each risk event is broken down into two components – the probability of occurrence and the min/most likely/max impact if each risk occurs.

Schedule risk and contingency using @RISK and probabilistic analysis

Using Palisade's @RISK for Project, this white paper demonstrates how to calculate schedule/time risk and contingencies, using three steps:

- Entering probability and impact distributions for each risk, from the risk register above.
- Defining the outputs required and running a Monte Carlo simulation.
- Interpreting the results.

The model used assumes that the project is still in its very early days, with the project plan only drawn up at a high level for the purposes of a bid/tender or business case. Often, in the early stages of planning and during bids, the risk model comes before anyone has got around to planning in earnest. This is the time, however, when crucial risk management decisions have to be made and, indeed, when risk analysis can be at its most commercially advantageous.

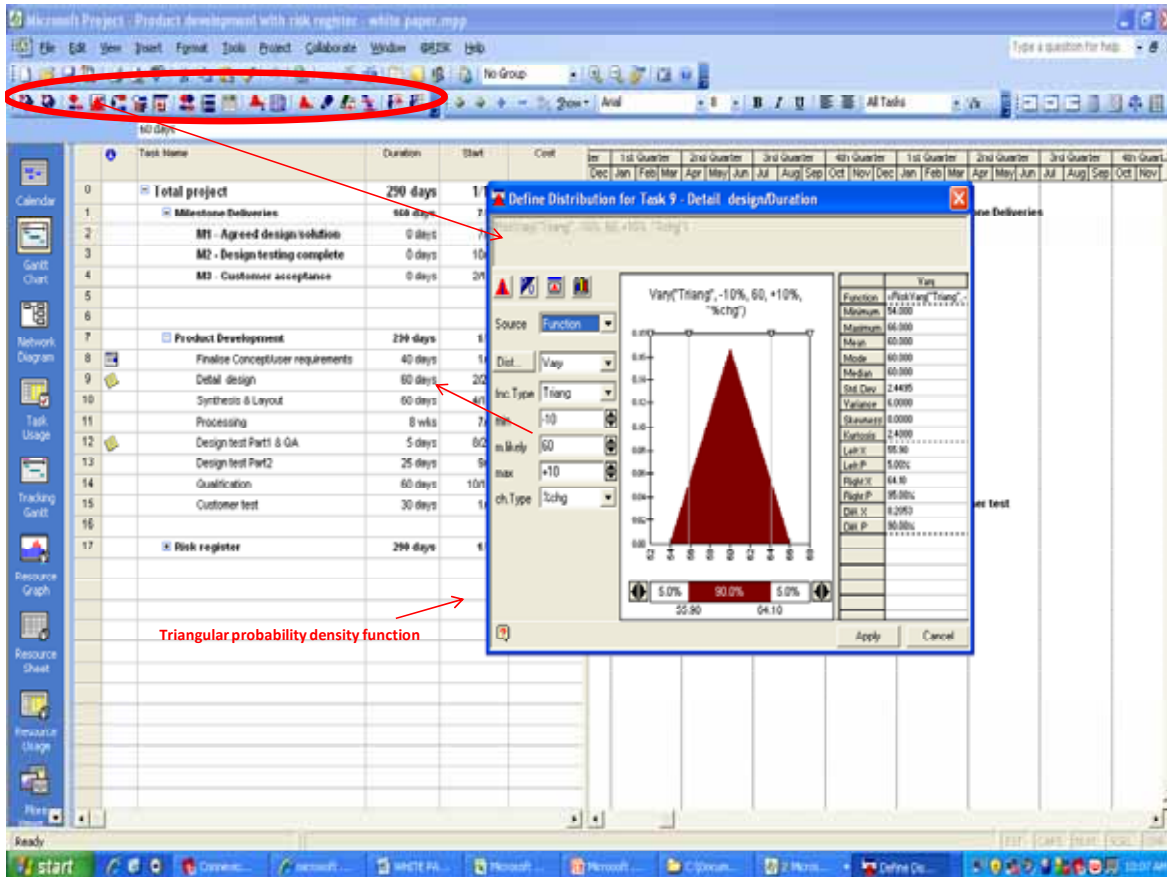
The White Paper entitled Project progress evaluation using @RISK and probabilistic analysis discuss how probability can be used to monitor the outturn during the project lifecycle and see if confidence is growing or deteriorating in the light of actual progress.

Note that although it is possible to model high level plans in Excel, rather than MS Project, the latter makes the process much easier because it will automatically work out the schedule depending on how tasks and activities are linked together. Using Excel involves having to write complex formula from scratch in order to model the relationships between tasks. In addition, MS Project allows you to added and cost project resources at the same time, and later, control actual work against the plan.

In either case, attempting at a high level plan, even if there is very little detail available, helps to focus and identify risks (and opportunities) more effectively.

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1.6 Overview of @RISK for Project



Triangular probability density function

Palisade's @RISK for Project is an 'add-in' for Microsoft Project, the well known planning tool. When the software is loaded, a new toolbar is provided in order to be able to add probability distributions to the single point estimates in your plan and run a Monte Carlo simulation.

The Monte Carlo algorithm takes samples within each distribution based on the density of probability implied by the shape and area. For example, the shape shown above implies that 90% of the samples should be taken between 55.9 and 64.1 days.

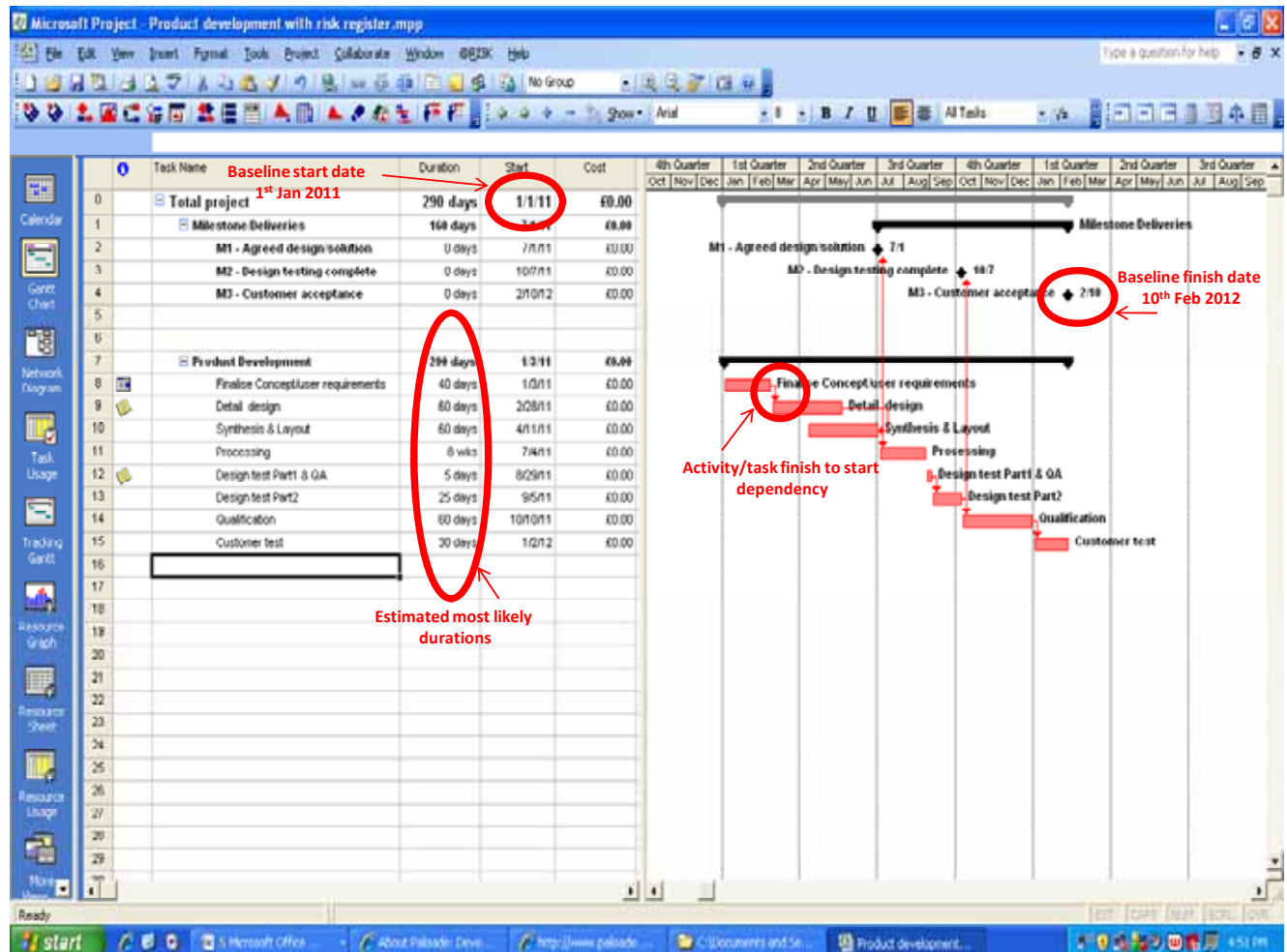
Each time a sample is taken, it is entered into the plan so that MS Project can recalculate the finish date. Consequently, if we run 1000 iterations we will obtain 1000 potential finish dates, along with a distribution of where most of them lie. The narrower the distribution of finish dates, the more confident the outlook; the wider the distribution, the more uncertain the outlook.

As we shall see, this information is extremely useful for quoting acceptable finish dates and setting internal targets and contingencies.

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2 Quantifying schedule risk and contingency

2.1 Overview of risk model



The plan we have used to demonstrate probability analysis is an early, high level decision-making plan, consisting of the key activities, linked together using simple finish-to-start dependencies. There are also three milestone-deliverables which are shown at the top of the plan:

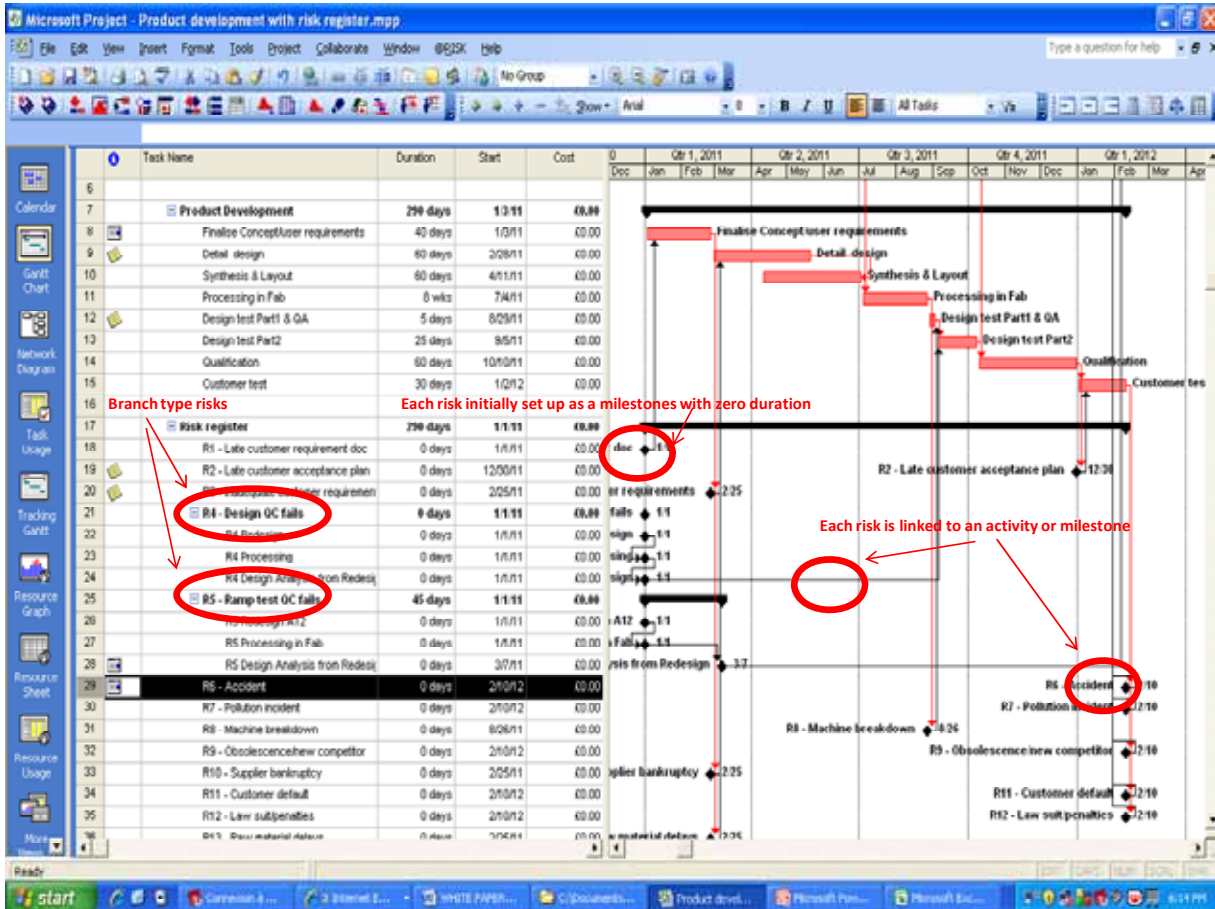
- Agreed design/solution,
- Design testing complete,
- Customer acceptance.

In real life, these milestones would most likely be linked to some sort of contractual payment.

Schedule risk and contingency using @RISK and probabilistic analysis

Starting on 1st January 2011, the high-level finish date is predicted to be 10th February 2012 using single point estimates. Often this is known as the baseline plan.

In order to add risk and uncertainty, the process advocated here is to leave the original estimates untouched and to model the risk register described in section 1.5 in a separate section of the plan, as shown below. This helps avoid double-counting and forces people to be more specific about uncertainties, rather than describing them as vague concerns or possibly 'padding'.



Using standard Microsoft Project functionality, risks 1 to 13 have been entered as tasks with zero duration, like milestones, and using the same description as the risk register. The risks 'milestones' have then been linked to the activities or project milestones affected using standard Microsoft project finish-start dependency links.

The @RISK modelling for Risks 1-3 and 8-13 is described in section 2.2.1.

For risks 4 and 5 (both quality control risks), a different type modelling has been used called probabilistic branching, as described in section 2.2.2. This technique introduces additional activities into the plan if the quality control risk occurs and the design fails to meet technical requirements.

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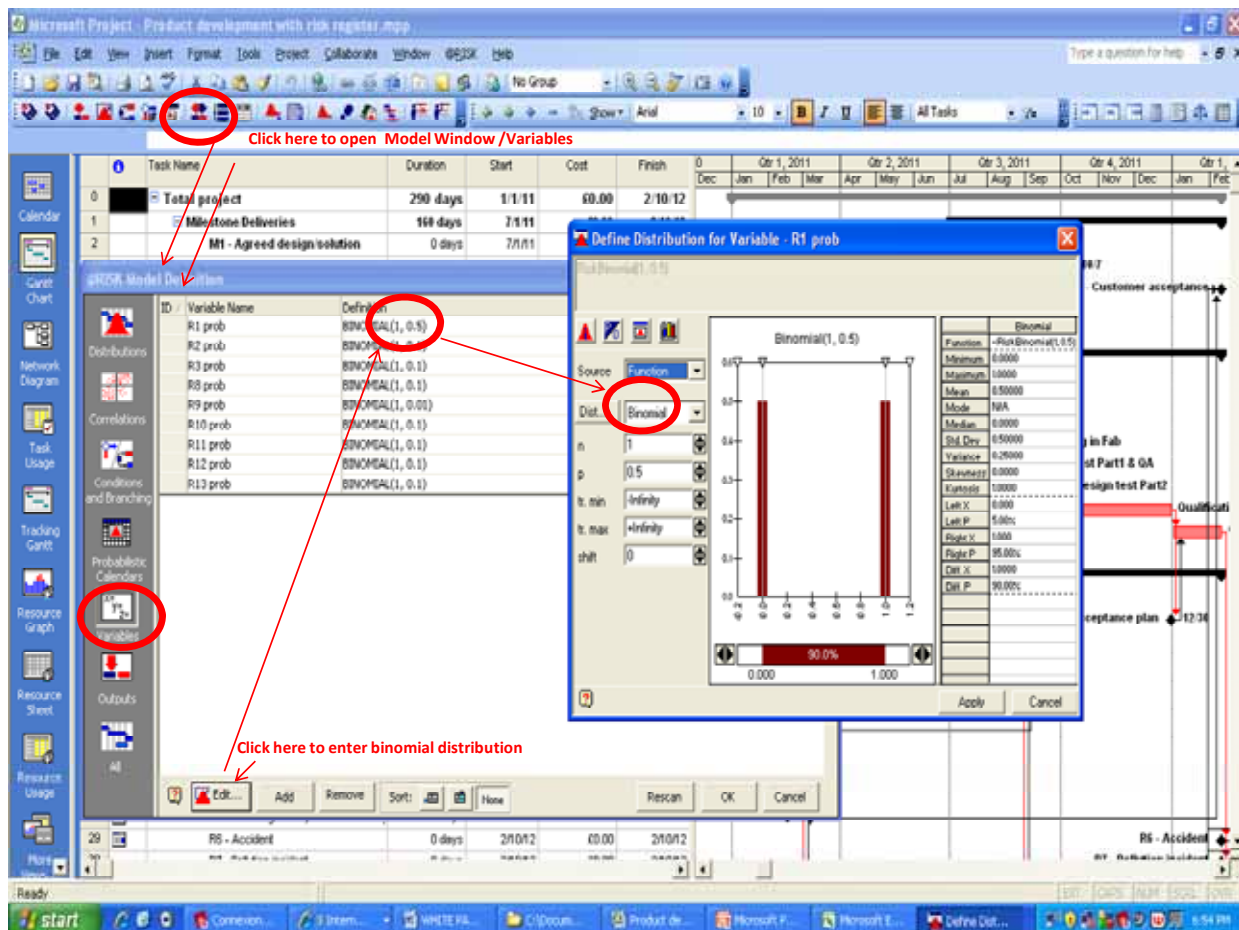
2.2 Step 1 - enter probability distributions

Three techniques have been used for modelling the risk register:

- RISK/IF statements containing the probability distributions for each risk's occurrence and impact;
- Probabilistic branches for modelling uncertainty around quality control (getting it right first time);
- Simple discrete distributions for modelling the very unlikely and least known risks with discrete values.

2.2.1 RISK/IF statements

The RISK/IF function in @RISK for Project has been used 9 of the risk register risks. Firstly, the probabilities of occurrence have been entered as 'variables' in the model definition window using binomial distributions, as below:



The variable names have been abbreviated to 'R1 prob', 'R2 prob', etc and the binomial distributions will return either a zero or one during the Monte Carlo simulation, described later.

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Having entered the probability of occurrence for each of the 9 risks, a RISK/IF statement for each risk needs to be set up to link the Monte Carlo simulation samples '1' to a probability distribution for the impact, as below:

The screenshot displays the Microsoft Project interface with a Gantt chart and a Risk register. A dialog box titled "Define Distribution for Task 18 - R1 - Late customer requirement doc/R1..." is open, showing a Triangular distribution with parameters (5, 10, 20). The distribution is visualized as a red triangle on a graph. The "Define Distribution" dialog box includes a "Source" dropdown set to "Triang", a "Dist..." dropdown set to "Triang", and input fields for "min" (5), "m. likely" (10), and "t. max" (20). The "Shift" field is set to 0. The "Triang(5, 10, 20)" distribution is shown on a graph with a peak at 10. The "Define Distribution" dialog box also includes a "Trans" table with the following data:

Function	Value
Minimum	5.0000
Maximum	20.0000
Mean	10.617
Mode	10.000
Median	9.545
Std. Dev.	3.880
Variance	15.054
Skewness	0.3554
Kurtosis	-2.4000
Left X	4.34
Left P	5.00%
Right X	17.26
Right P	95.00%
Dist. X	10.0000
Dist. P	90.00%

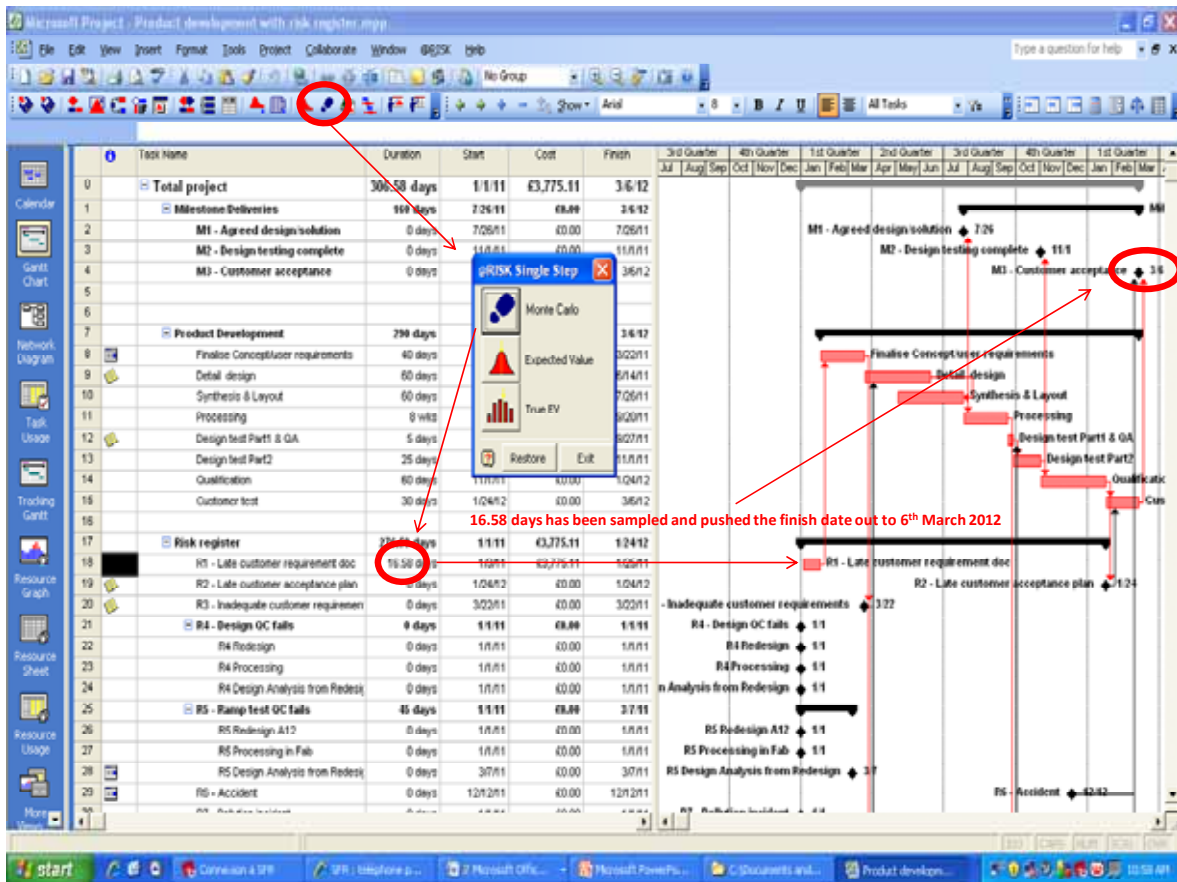
The Risk register shows the following data:

Task Name	Duration	Start	Cost
R1 - Late customer requirement doc	0 days	1/8/11	60.00
R2 - Late customer acceptance plan	0 days	12/0/11	60.00
R3 - Inadequate customer requirements	0 days	2/25/11	60.00
R4 - Design QC fails	9 days	1/1/11	60.00
R4 Redesign	0 days	1/8/11	60.00
R4 Processing	0 days	1/8/11	60.00
R4 Design Analysis from Redest.	0 days	1/8/11	60.00
R5 - Ramp test QC fails	45 days	1/1/11	60.00
R5 Redesign A12	0 days	1/8/11	60.00
R5 Processing in Fab	0 days	1/8/11	60.00
R5 Design Analysis from Redest.	0 days	3/7/11	60.00
R6 - Accident	0 days	2/10/12	60.00

Here, the RISK/IF statements reads – 'If Variable 'R1 prob = 1', then the probability distribution for the duration of 'R1 – Late customer requirements' is a Triangular distribution of minimum 5 days, most likely 10 days and maximum 15 days'.

After entering the nine RISK/IF statements, it is possible to test that they are working by clicking on the single step button with the footprint icon. When 1 is selected in any of binomial variables, a value for impact will be entered into the relevant duration field and thence into the project schedule where all the standard MS Project functionality will take effect, as shown below:

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16.58 days delay has been sampled when Risk 1 occurred, causing the first task in the original plan to move to right. As a result, the end date has moved from 10th February to 6th March.

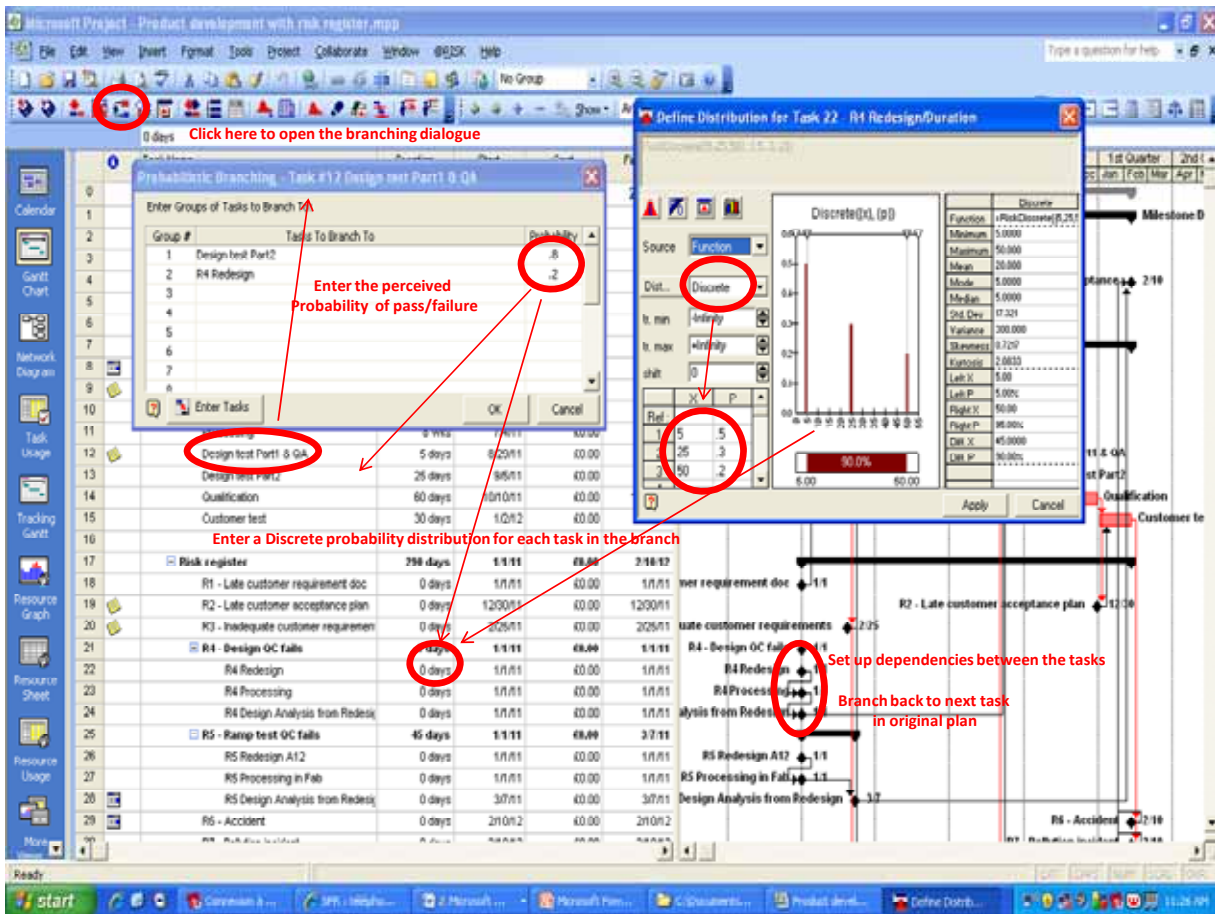
Later, when the Monte Carlo simulation is run, we obtain hundreds/thousands of potential outcomes, giving a useful probability distribution for decision-making (see section 2.4).

2.2.2 Probabilistic branches

This technique is similar to RISK/IF but allows you to branch the project plan (probabilistically) to a separate sequence of tasks, each with their own duration and uncertainty.

The probabilistic branch is entered in the original plan at the task where a branch may occur, and directed to the first task in the new branch/sequence of work, held in the risk register section, as below:

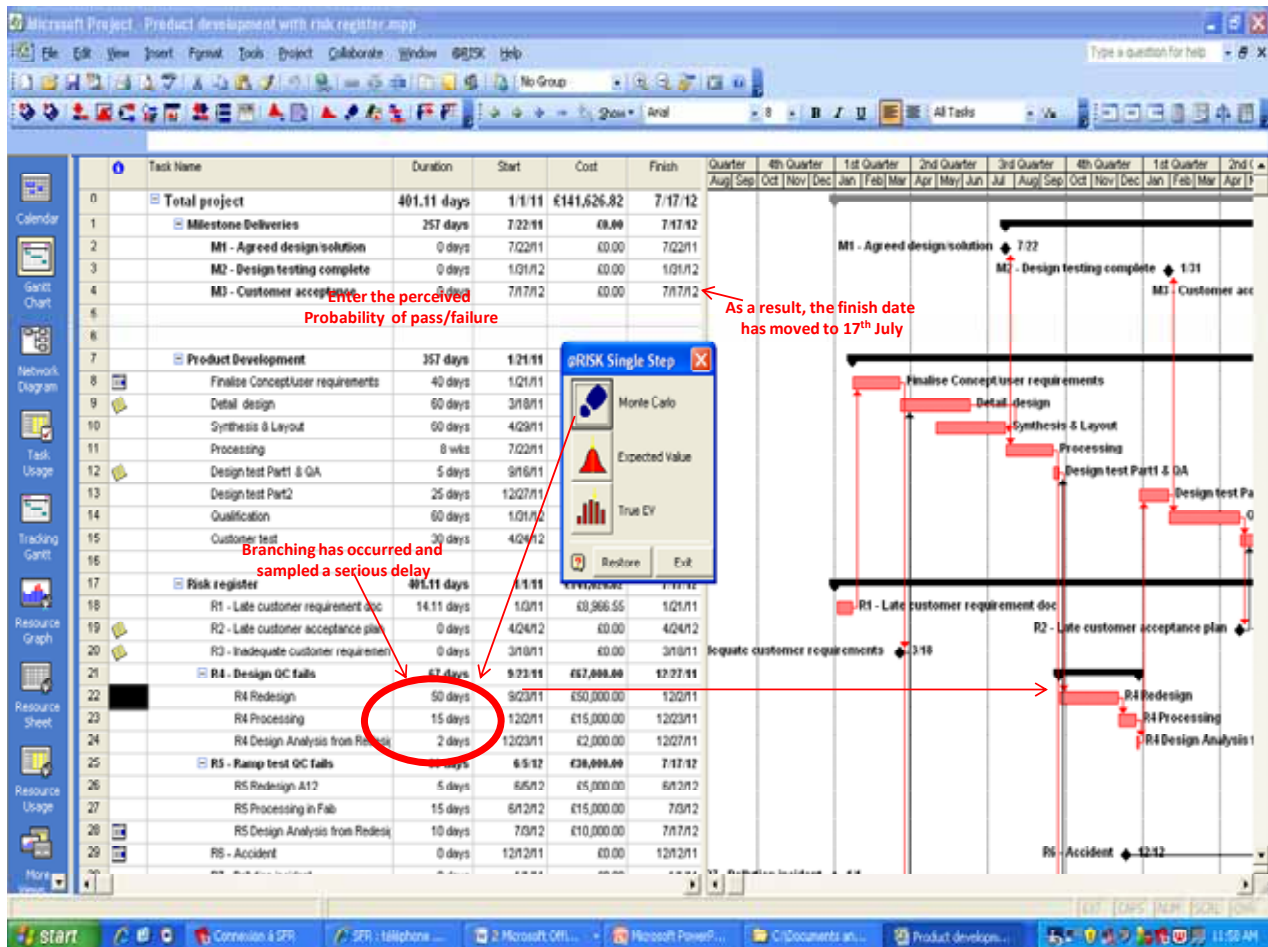
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According to risk 4 (R4), the project team currently thinks that there is a 20% chance that design quality standards may not be met, perhaps because of concerns over the requirement or lack of knowledge in the area. The probabilistic branch dialogue enters a @RISK function so that during a simulation the project plan jumps to the R4 redesign task for 20% of the iterations. At the same time, a discrete distribution will sample 3 potential redesign duration values (5 days, 25 days and 50 days) using respective probabilities of 50%, 30% and 20%. A discrete distribution has also been set up on the other tasks in the R4 branch sequence.

Below is a single sample/step example to show the effect of one sample on the end date. Note that it is important to link the last task in the branch sequence back to the original plan so that it is correctly added into the schedule.

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In this sample, the branch has occurred and sampled 50 days for R4 redesign, a serious delay which has pushed out the finish date to 17th July 2012.

Using this technique allows you to model, at the same time, both the uncertainty in passing a quality test and the uncertainty in how long it will take to correct the design.

Probabilistic branches are also very useful for modelling contingency plans should a specific event occur – a common requirement in project plans.

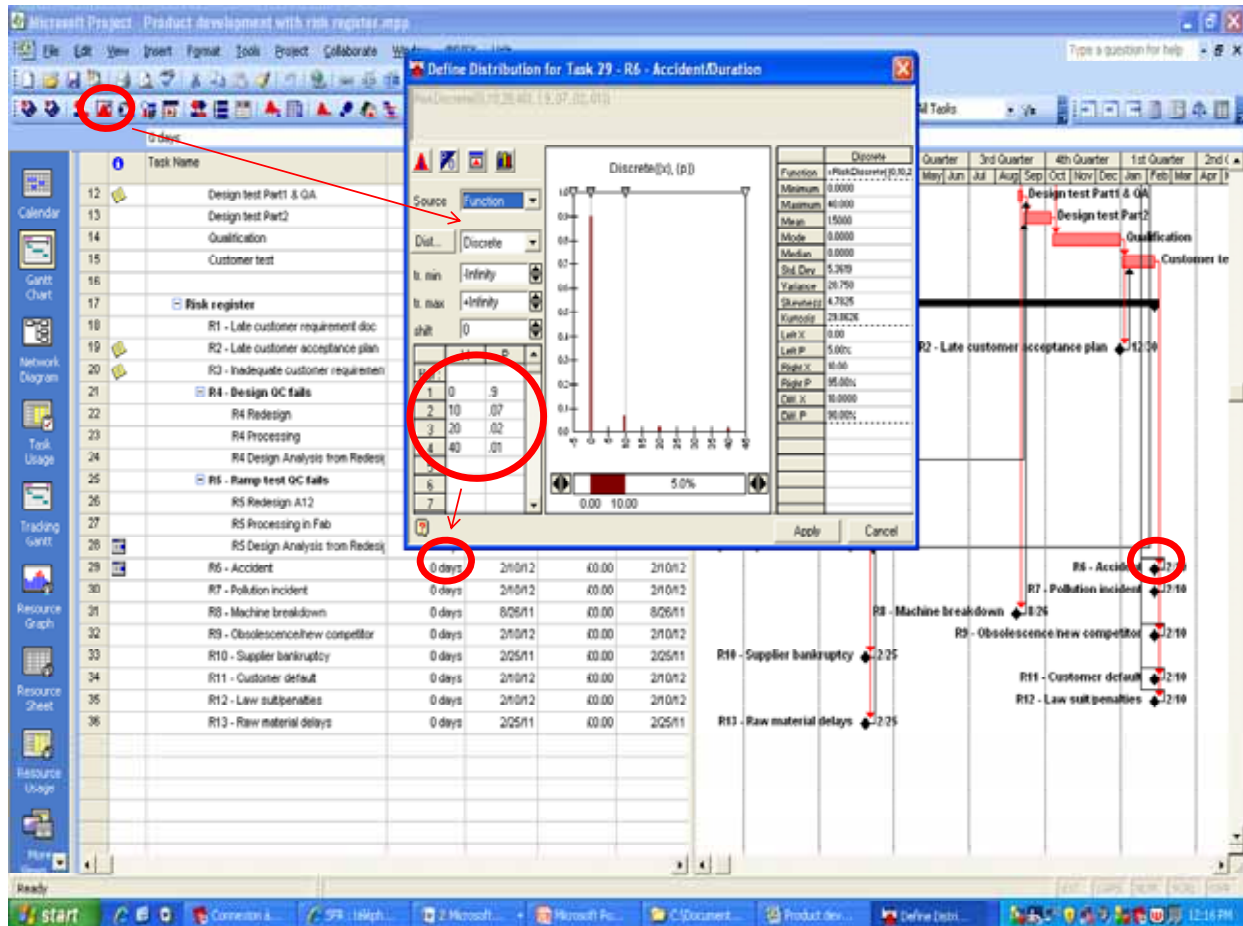
2.2.3 Simple discrete distributions

Simple discrete distributions are an alternative to the rather more complex RISK/IF statements, described earlier. However, by definition, they only allow discrete values for the impact of a risk, rather than a range of uncertainty such as a Triangular distribution.

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In this model, the discrete distribution technique has been used for risks 6 and 7, as they are the least likely, least well known risks in the risk register and involve accidents and pollution control.

Risk 6 (Accident), for example has been set up as follows:

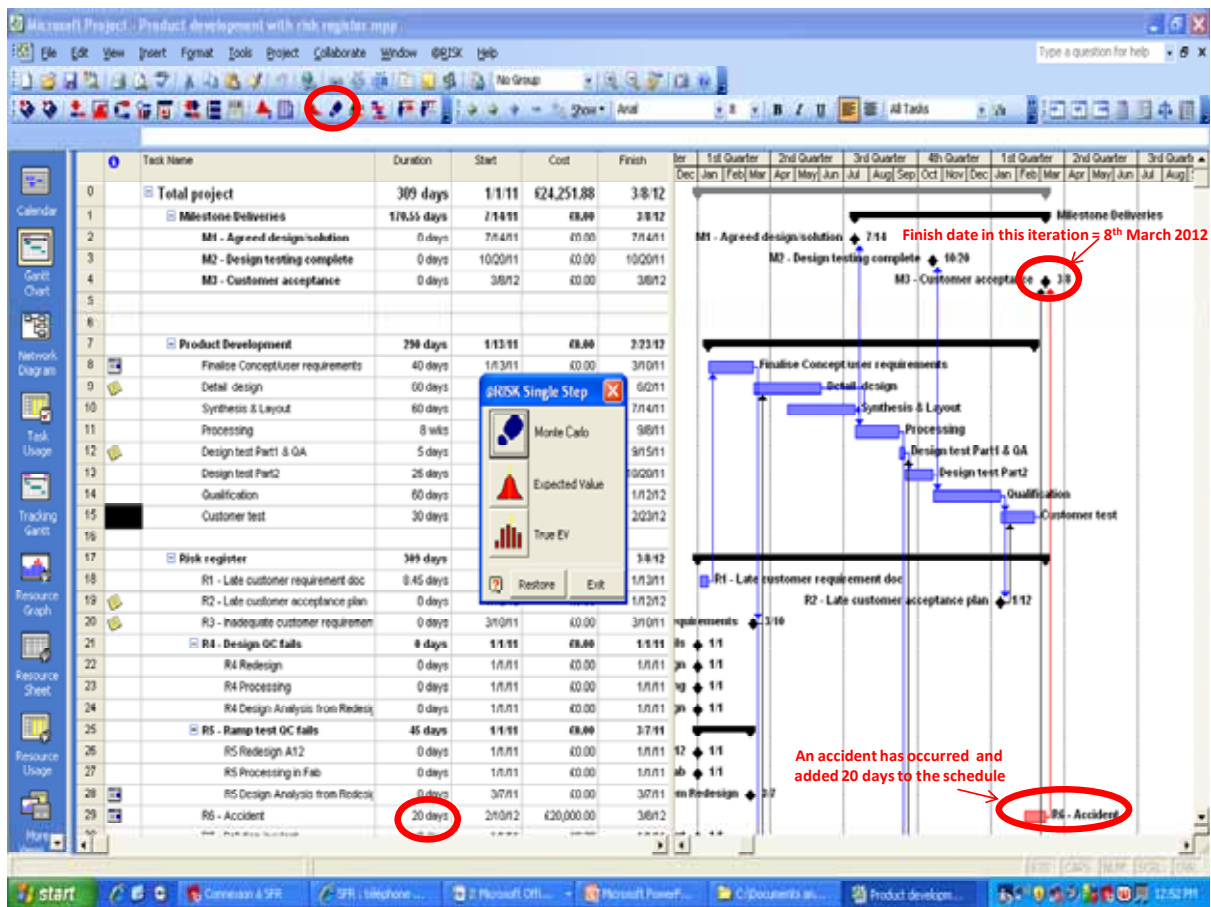


Here, the probability of zero delay due to accidents is thought to be 90%. However, there is a 7% chance of 10 days delay, 2% chance of 20 days delay and 1% chance of 40 days delay.

Also, as an accident can occur at anytime during the schedule, the risk has been linked to final milestone (M3) so that it impacts the finish date if it occurs.

Below is an example of the effect if the discrete distribution samples a positive number:

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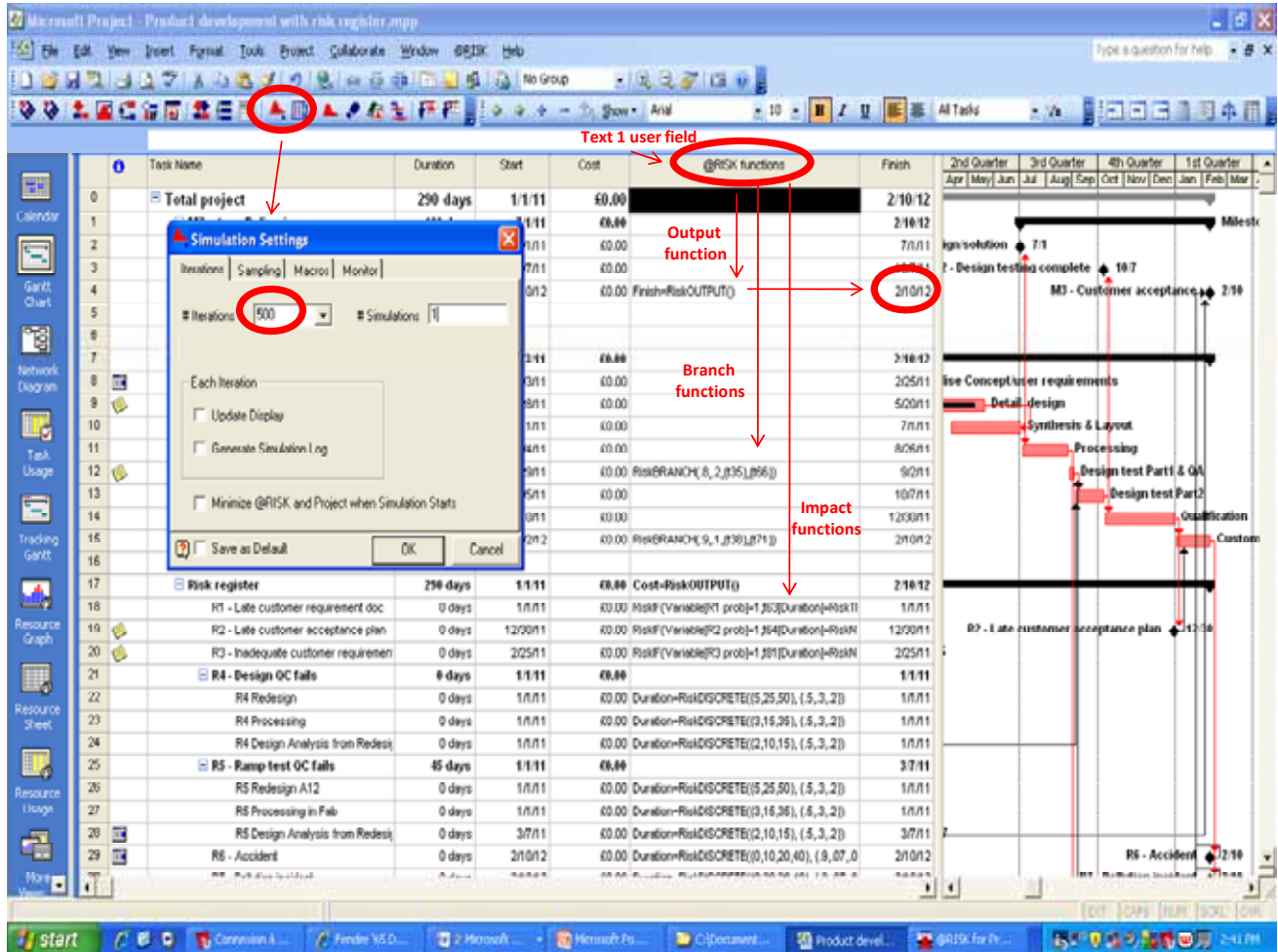
Here, the discrete distribution for Risk 6 (Accident) has sampled 20 days delay, causing the finish date to move to 8th March 2012. If the discrete distribution had sampled zero (90% probability), there would have been no effect on the schedule.

2.2.4 Correlation

For simplicity, correlation has been excluded from this model and will be discussed in a separate White Paper. In reality, there is usually significant correlation between risks in projects since if one thing goes well or badly, other things tend to follow suit. As a result, the effect of correlation tends to increase the overall uncertainty in a project and this should be taken into account when interpreting the results in section 2.4.

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2.3 Step 2 - define outputs and run the simulation



Once the probability distributions for the risks have been entered, the sequence of actions is:

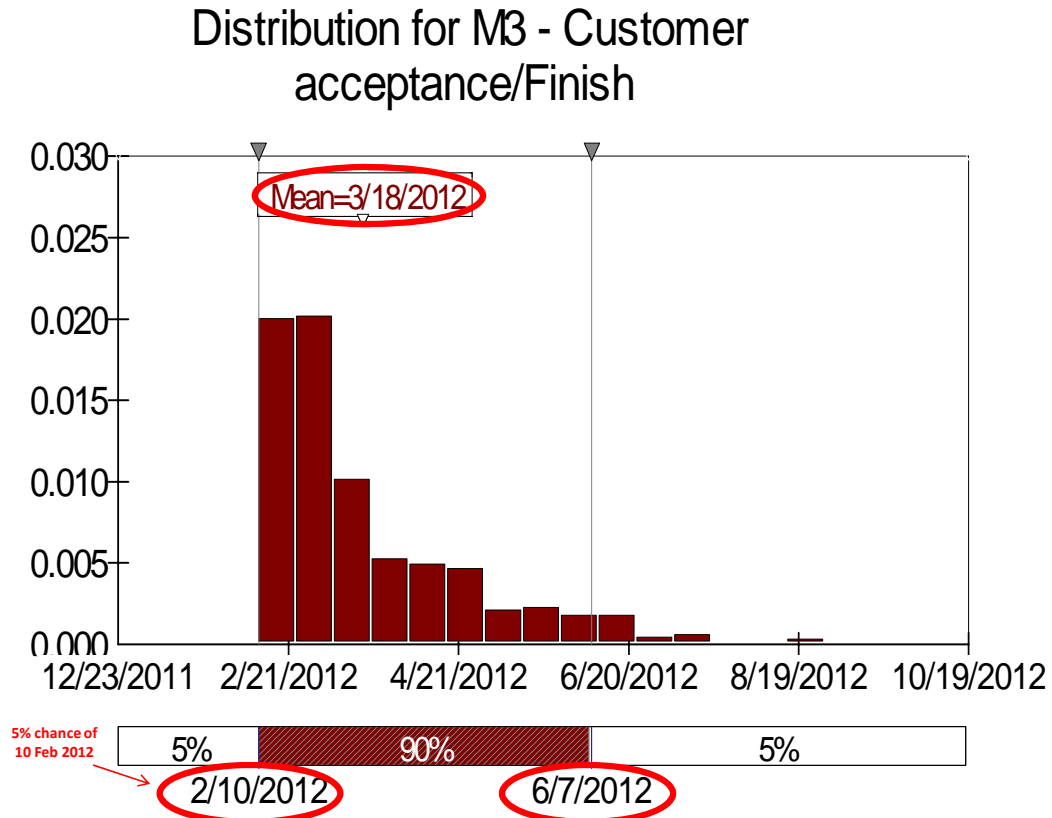
- Add the output(s) – in this case the M3 finish date. This tells @RISK what we want to track.
- Enter the number of iteration (samples) to take during the simulation – in this case 500 has been used
- Run the simulation.

By inserting the Text 1 user field as a column in the View, you can see where the @RISK functions are held in MS Project. You can also double-check everything by clicking the single sample footprint to see all the functions are working as expected.

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2.4 Step 3 - interpret the results

2.4.1 Histogram of probability density



One of the most important graphs obtained from @RISK is a histogram of simulation results, as shown above, where the 500 calculated finish dates are contained in bins, allowing us to see where the values occur most often. In this case, 90% of the simulation scenarios (i.e. 450 of them) ended with a finish date between 10th February and 7th June.

The first thing to notice is that, given the current perception of risk, there is only a 5% chance of meeting the baseline date of 10th February 2012. Indeed, the average or mean outcome is 18th March. Also the shape of the finish date probability distribution is distinctly lognormal (skewed) with a small possibility of an extremely late outcome – 5% chance of being greater than 7th June (i.e. 4 months late).

If correlation had been added into the model, no doubt these results would have been worse.

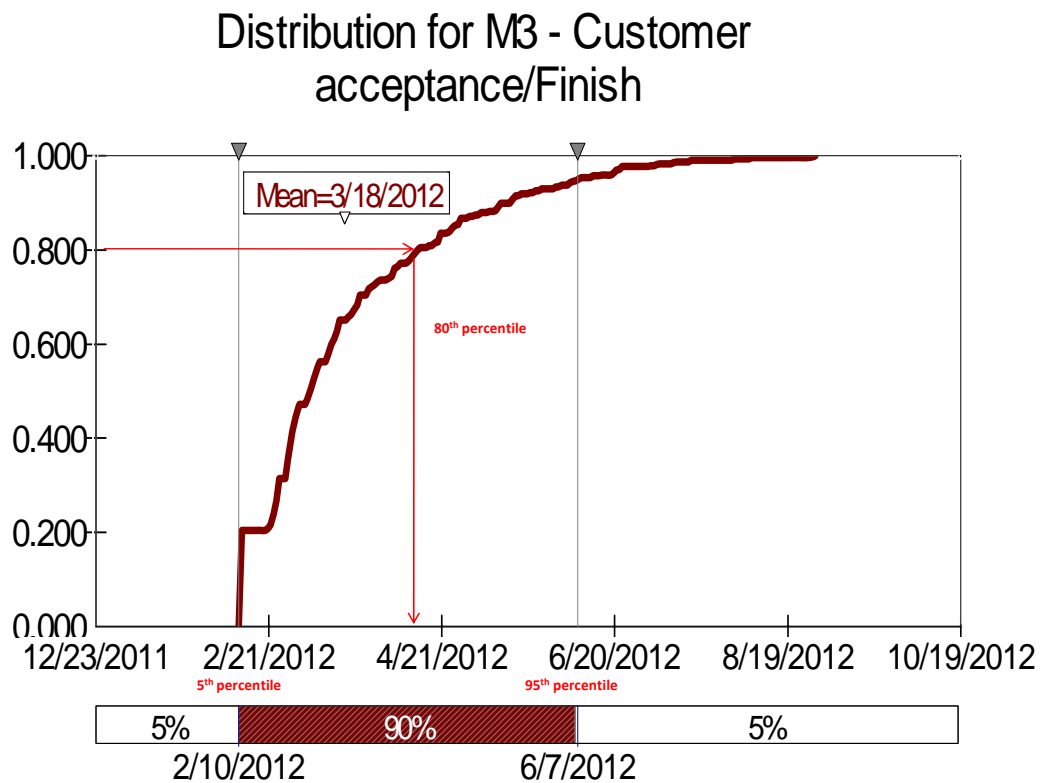
How much schedule contingency should be made?

Given the level of risk, one would be prudent not to quote below the 80th percentile, setting an internal target around the 50th percentile, as shown in the next section.

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2.4.2 Cumulative probability density

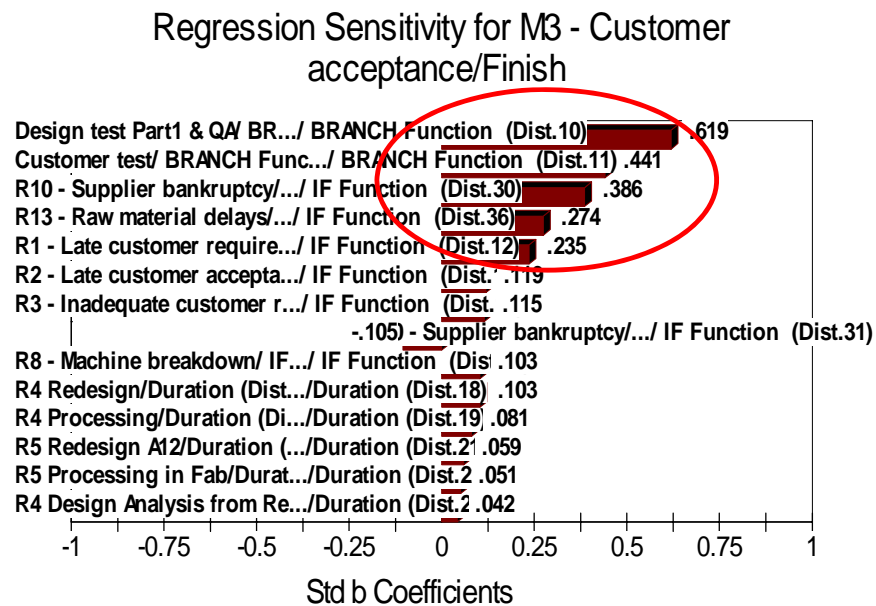
Here, 80% of the 500 simulations were less than or equal to 10 April, a contingency buffer of two months later than the original baseline date.



As a buffer of 2 months is probably an unacceptable contingency, something must be done about mitigating the risk. This is where the Tornado graph (described in the next section) becomes so useful.

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2.4.3 Sensitivity/exposure analysis - Tornado graph



Although this Tornado graph should ideally be improved before presentation to management, it quickly tells us which risks are causing most of the uncertainty or exposure in the high level plan.

In particular, something needs to be done about:

- Passing the design part 1 test,
- Organizing and meeting the customer's acceptance test criteria,
- Supplier bankruptcy,
- Raw material delays.

All the other risks are relatively inconsequential and can be dealt with by normal project management contingency plans.

The top four risks, however, are exceptional and the project manager can now use this probability analysis to argue the case for appropriate actions to be taken, possibly involving significant expenditure and a reduced margin.

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3 Benefits

Many project managers already carry out risk reviews and use them to develop mitigation and contingency plans. So what is the added value of probabilistic analysis?

The obvious 'hard benefit' is that project management can calculate the probability of an outcome. This is an extremely powerful and persuasive measure, since we all use probability in our everyday communication and decision-making. It is also a very valuable sales aid for quotations and budgets.

However, there are also some important 'soft' benefits surrounding the core competencies for a successful project manager, as shown below:

Core competency	Benefits of probability analysis
Understanding the problem, solution and scope	The very fact that a plan has been drawn up even when the details are unknown helps to define the problem, solution and scope. Focused risk management, using probability analysis, also helps to 'shape' the strategy/solution more effectively and demonstrates a deeper understanding to important stakeholders.
Working with and leading people	Talking through the uncertainties and activities brings consensus and understanding amongst the project team and other stakeholders, and shows leadership.
Planning and controlling the work	One of the key outcomes of probabilistic analysis, and in particular sensitivity analysis, is a better quality plan with a perceived higher probability of success.
Managing stakeholders	An effective project manager needs to manage the expectations of all stakeholders – customers, management, project team, staff, financiers, 3 rd parties, etc. Probabilistic analysis demonstrates leadership and coordination, and provides powerful arguments for additional resources and time.

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4 Conclusion

Risk is a very personal matter and can sometimes seem to be questioning the competence of colleagues and individuals. As a result, it is important to be prepared for some negative reactions since there is a common tendency in projects to 'think positive' and say 'it won't be allowed to take any longer', even though this is usually wishful thinking. Often, by the time people discover they are heading for an overrun, there is little or no chance of getting new resources quickly enough to make a difference.

Another common concern is subjectivity, with people forgetting that, by definition, all estimates are subjective, and notoriously inaccurate! However, once the benefit of probabilistic analysis and working in ranges is understood, it is surprising how quickly people want to extend the idea to all their single point estimates and reduce any padding or over-optimism.

Before introducing probabilistic analysis, therefore, it is worth getting the support of senior management to help you get it off the ground. This might mean some sort of selling exercise, perhaps using the theme of improved customer confidence, particularly with regard to schedules, where lost time equals money in terms of benefits or revenues.

Indeed, making significant schedule risk improvements can also involve some quite controversial decisions, such as:

- Changing the technical solution to something that can be achieved more quickly and possibly at more cost;
- Adding more resources to complete tasks more quickly;
- Running more tasks in parallel, usually resulting in a larger project team, additional cost and communication problems.

Difficult decisions and recommendations, such as these, will therefore be much more convincing with the aid of probabilistic analysis.

Schedule risk and contingency using @RISK and probabilistic analysis

APPENDIX 1 – Useful references

Books and documents:

Grey, S, *Practical Risk Assessment for Project Management*. John Wiley & Sons Ltd

ISBN 0 471 93979 X

Klastorin, E, *Project Management Tool and Trade-Off*. John Wiley & Sons, Inc

USA ISBN 0-471-41384-4

Project Risk Analysis and Management (PRAM) Guide. Association of Project Management

ISBN 0 9531590 0 0

Rees, M, *Financial Modelling in Practice*. John Wiley & Sons Ltd

ISBN 978-0-470-99744-4 (H/B)

Websites:

The Standish Group - www.standishgroup.com

The Office of Government Commerce - www.ogc.gov.uk

The Association of Project Management - www.apm.org.uk

The Project Management Institute - www.pmi.org

Microsoft Project White Papers – www.microsoft.com/project/en/us/white-papers.aspx

Palisade Corporation's @RISK for Project – www.palisade.com/riskproject/