Crossing the CASM

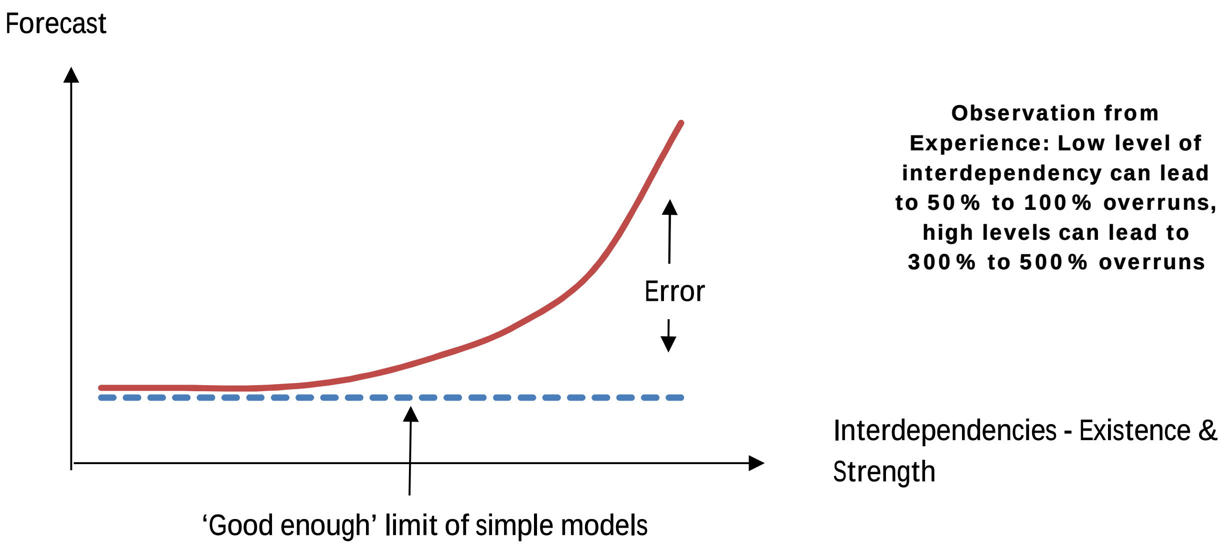
A framework for managing complexity in Risk Management and Forecasting

CASM FRAMEWORK

Executive Summary

The most common forecasting methodologies (including those embodied in Enterprise Risk Management systems) do not consider the impact of interrelationships between risks. This results in highly optimistic forecasts with serious financial, reputation and governance consequences. This paper briefly outlines how CASM can provide you with a minimal effort basis for taking steps to avoid these problems in your organisation.

Widespread evidence and experience informs that assuming risks as independent and unconnected leads to highly optimistic results. Conceptually the size of the error rises exponentially with the existence and strength of interdependencies:



CASM provides a framework for thinking about interdependence based on commonly accepted definitions of cause, risk and effect:

- **Cause Association is where risks have root *causes* in common, meaning they are more likely to happen or not happen together.**
- **Where the *effects* of risks are interlinked by some System or Mechanism there can be combined effects and outcomes should the risks occur.**

The framework is supported by a Monte Carlo based tool that can, with minimal effort, recalculate a forecast to incorporate the effects of basic interdependence to provide more realistic forecasts. It is recommended that this is undertaken as an absolute minimum or as an initial step prior to the use of other techniques.

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Introduction

It is widely recognised that there is a problem with projects overspending, over running and / or not delivering on anticipated benefits. There are multiple reasons for the unrealistic forecasting that lies behind these problems including:

- **Unconscious bias and human psychological phenomena – for example ‘Anchoring’ where there is a reluctance to move away from the first estimate even if wrong**
- **Deliberate bias – for example depressing risk allowances to secure funding**
- **Cultural influences, such as pressures to downplay risk**
- **Ambiguity about objectives, a lack of plans**
- **A lack of time and input to the Risk Management and forecasting process**
- **Shortfalls in knowledge, leading to a reduction in the quality of the data input to models**
- **Poor methodology, where the computational methodology used to calculate the forecast is not appropriate for the project characteristics, in particular a failure to appreciate complexity in from of interdependencies between risks**

This paper and the CASM framework is focussed only on the final factor – the calculation methodology. For a successful forecasting environment all relevant areas would need to be addressed.

This paper and the CASM framework have their origins in Project Risk. However, the concepts are transferrable to Operational and Strategic contexts. The paper assumes an understanding of common Risk Management & forecasting practices as well as the Monte Carlo analysis method (for those requiring a refresher there is an explanation in Appendix A of the Monte Carlo method). In Appendix C there is a high level summary of current practice.

Throughout the paper wherever the term ‘Risk’ is used it should be interpreted in a broad term, encompassing risks events, opportunities/upside risk, uncertainty, variability and so on.

About the CASM Framework

The framework has been developed by Stephen Cresswell, an independent Risk Management Consultant with Into Risk Limited, drawing on 15 years of industry experience. Inspiration for the framework has come from the assignments undertaken, research and observations on a wide range of projects at all stages of delivery. The framework development has benefitted greatly from the observations and feedback from clients, colleagues, unofficial mentors and competitors.

The Framework has been developed in response to the following needs:

- **Not including the effects of interdependencies is one of the reasons why forecasts can be so badly wrong – therefore these phenomena need to be addressed.**
- **Current modelling practices for including interdependencies are prohibitively onerous and time consuming – something more efficient is required.**
- **Current modelling concepts are difficult to communicate and not transparent to stakeholders and non-experts. Something explainable and accessible is needed.**
- **Organisations have already invested considerable sums in training, Enterprise Risk Management systems and so on. Therefore, solutions ideally need to build upon what is already in place.**

The Framework is of course a simplification of reality (as all models are). The aim is not perfection but improvement. The Framework is positioned between the 'one size fits all' approach of common practice and the onerous requirements of developing fully bespoke models.

Resources can be downloaded from www.casm-framework.com. Users can download the CASM Monte Carlo analysis tools and other materials (all graphs shown in this paper are outputs from the tool).

Adopting a philosophy of accessibility, the CASM framework business model is 'free to use / pay for support'. The development of the tools, materials and website is cross funded by paid consultancy advice on the CASM component of assignments.

The framework has been used on a number of high value projects. A citable example is for the UK's Network Rail, where the framework was used on a large value portfolio of rail infrastructure projects as part of the Sir Peter Hendy review:

> ***"Alternate Risk Evaluation Model. During this review, a revised modelling technique, Cause Association Modelling (CAM), has been applied to better reflect actual experience of risk. This results in an increase in contingency"***
>
> **https://www.networkrail.co.uk/Hendy-review/**

What makes a good forecast?

A good forecast should feature the following:

- **The mean / Expected Value of the forecast should be approximately right (good enough)**
- **How the outcome might vary from the mean should be right (variance)– i.e. the overall range with upper and lower limits (it should also convey any interesting characteristics)**
- **It should reference the decision making context. For instance, this might be the risk around the following:**

  - **Targets – is the target too aggressive or not challenging enough?**
  - **Expectations – do these support profitability or 'worthwhileness'?**
  - **Commitments – the risk of missing commitment levels that have unacceptable implications for the organisation**

Many forecasts are bad because they are not incorporating the effects of interdependencies between the components. Experience informs that when these dependency phenomena are overlooked actual costs can be between 50% and 500% greater than forecast. The importance of these omissions cannot be overstated: many forecasts are setting expectations of profitability & worthwhileness whilst a more robust forecasts would warn that outcomes are likely to be unacceptable.

CASM – Conceptual Model

Though not normally explicitly stated or acknowledged; most Risk Management processes and associated forecasts consider risks as independent and isolated. This includes the quantification of the risk, where the probability and or impact or each item is assessed assuming it is the only risk. Working with commonly understood concepts of cause, risk and effect a typical risk register can be represented as follows:

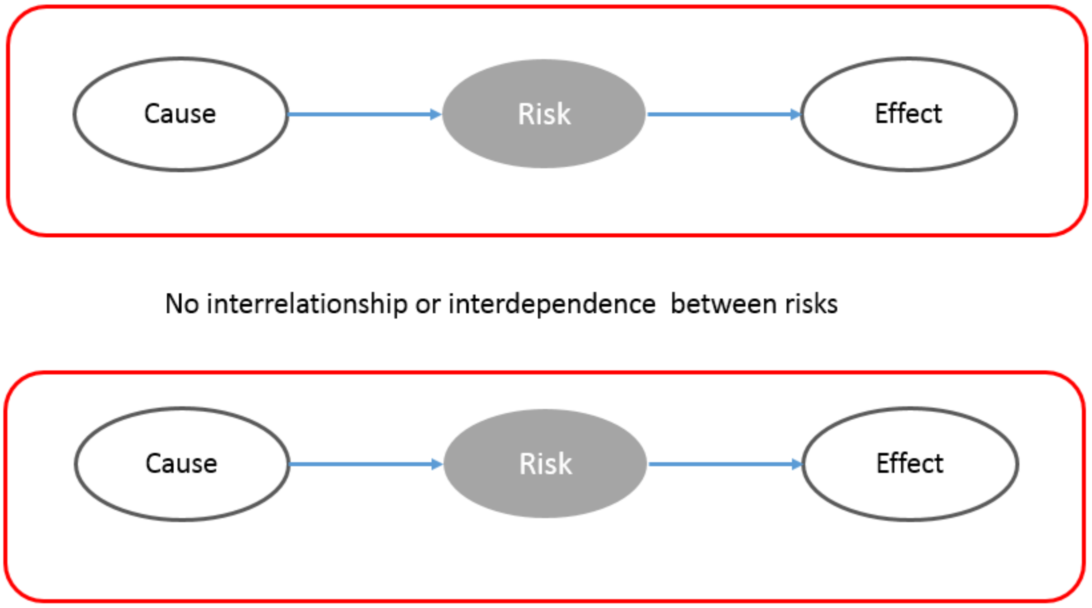


Diagram 1 – Independent Risks

In the CASM framework risks can be interconnected or interpendent via their causes and/or effects. These interdependances are defined in two main categories as follows:

Cause Association – Where risks, opportunities and uncertainties have common root *causes*, they are more likely to happen or not happen together. This can have a positive and negative effect on the forecast.

Systems & Mechanisms – The *effects* of risks, opportunities and uncertainties may be linked by underlying mechanisms; if they are realised in combination the overall outcome is changed. This can also have positive and negative effects

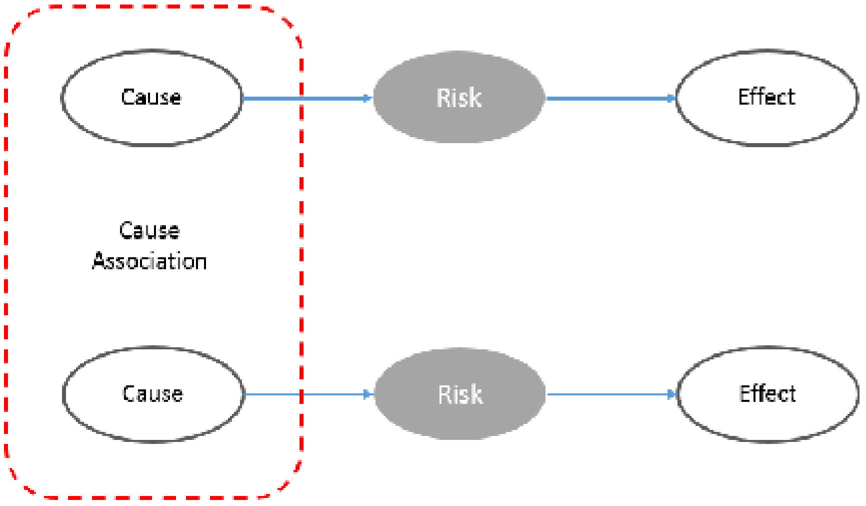


Diagram 2 – Risks with causal interrelationship

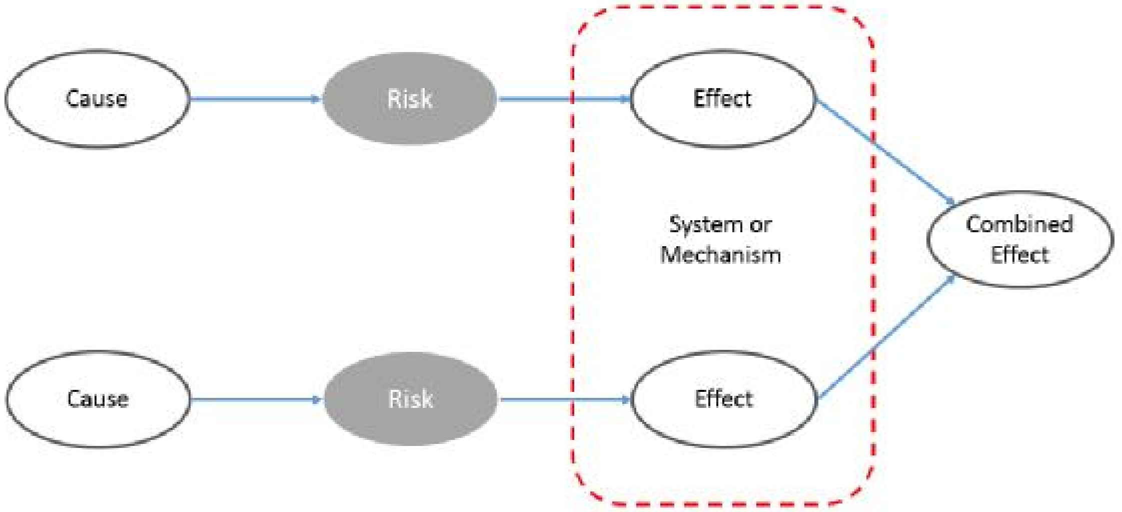


Diagram 3 – Two risks with an 'effect side' interelationship

Impact of Complexity on Forecasts

The following is a worked example, based on experience with real projects, which illustrates why it is important to consider the interrelationships between components when calculating the EV/mean. Consider the simple example of software development project where a significant proportion of the development is to take place overseas. The planned cost for the development work is £1.2m. The following risks have also been identified in a register:

Ref	Risk Description	Prob.	Impact	P*I
a)	Additional subsystem required to integrate with legacy system	20%	£500,000	£100,000
b)	Additional development time may be required to achieve speed performance criteria	30%	£600,000	£180,000
c)	Performance of offshore development team. It may be necessary to bring the work back in-house where developers are 50% more expensive. [Impact represents 50% increase in base cost]	25%	£600,000	£150,000
			Total	£430,000

Table 1 – Identified Risks

On the basis of the calculation above, the figure of £430k is taken to the board as the mean risk value and the recommended provision against risk for the project. However, each risk has been treated as independent; leading to the risk exposure being understated for the following reasons:

- **If the offshoring arrangement doesn't work (Risk C), then the additional cost of the in house development team means the impact values of risks A & B will rise by 50%. This is because the in house team will undertake the emerging works from risks A & B, whereas the original quantification was based on the offshore team undertaking it.**
- **If risks A and/or B occur it will place more demands on the performance of the offshore team and increase the likelihood that the development work has to be brought back in house Risk C. In this case it has been assessed that if either Risk A or Risk B occurs then the likelihood of Risk C will increase to 50%. If both A and B occur, then Risk C is a certainty.**

Using a 'probability tree' calculation, based on the above data a more realistic mean value in this example is £601k. The workings supporting this conclusion are shown in Appendix D. Whilst probability trees are a simple and very useful tool combining both cause and effect interactions, they can become unwieldy when larger number of inputs are used. The author regards 20 inputs as a practical upper limit and prefers 7. To work with larger numbers of inputs a different technique is required and this is where the CASM approach can provide an effective solution.

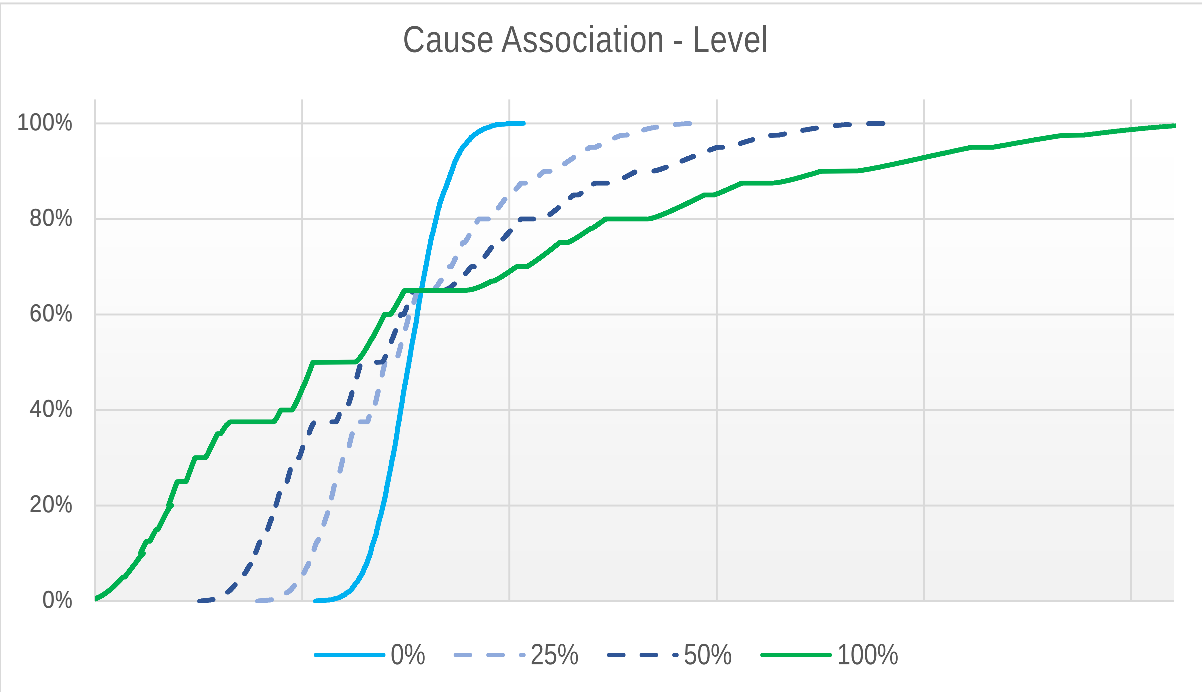
Cause Association Method

The Cause Association Method (CAM) is a way of modelling the implications of causal links between inputs. It has been designed to be efficient to model and easy to explain. The steps in the method are as follows:

- **Create two 'bounds' for the result:**
  - **a Monte Carlo result based on 0% causal dependence**
  - **a Monte Carlo result based on 100% causal dependence**
- **Specify the Cause Association Level - a number between 0% and 100%**
- **Using the Cause Association level, interpolate between the two bounds to provide the final answer**

[An explanation of the Monte Carlo method and an example of a 0% and 100% Cause Associated results output tables can be found in the appendices]

The diagram below shows an S-Curve in which the 0%, 100% and two interpolated curves for 25% and 50% Cause Association levels are shown.



Graph 1 – S Curves for Monte 0% to 100% Curves

[The horizontal levels in the 100% curve are caused by multiple large risks of the same likelihood]

Systems Mechanisms Methods

The Systems Mechanisms Method is based on modifications to the Monte Carlo data tables and results to incorporate the effect-side interdependencies. These modifications take place after the Monte Carlo simulation has been run. This is different from the normal approach to incorporating secondary impacts where a bespoke model is created, to which the Monte Carlo inputs are then applied. The Systems Mechanisms Method is best explained through example with the following mechanisms (there are others).

Overlay

A good example of the overlay method is project prolongation costs (time related management and other costs if the project is delayed, or to pay for responses that mitigate against time impacts – e.g. additional resources). If modelled as an isolated item, then the risk can occur independently of any other of the risks on the project. In fact, it is usually more realistic to say that if no risks occur then there will be no prolongation, whereas if all other risks occur at their fullest extent then the prolongation will be at its maximum value.

Worked Forecast Example including an Overlay

The table below shows how the CASM forecast is build up together with an independent forecast for comparison. This is based on real project data (a version of the CASM Monte Carlo Tool pre-populated with these inputs can be downloaded from the website).

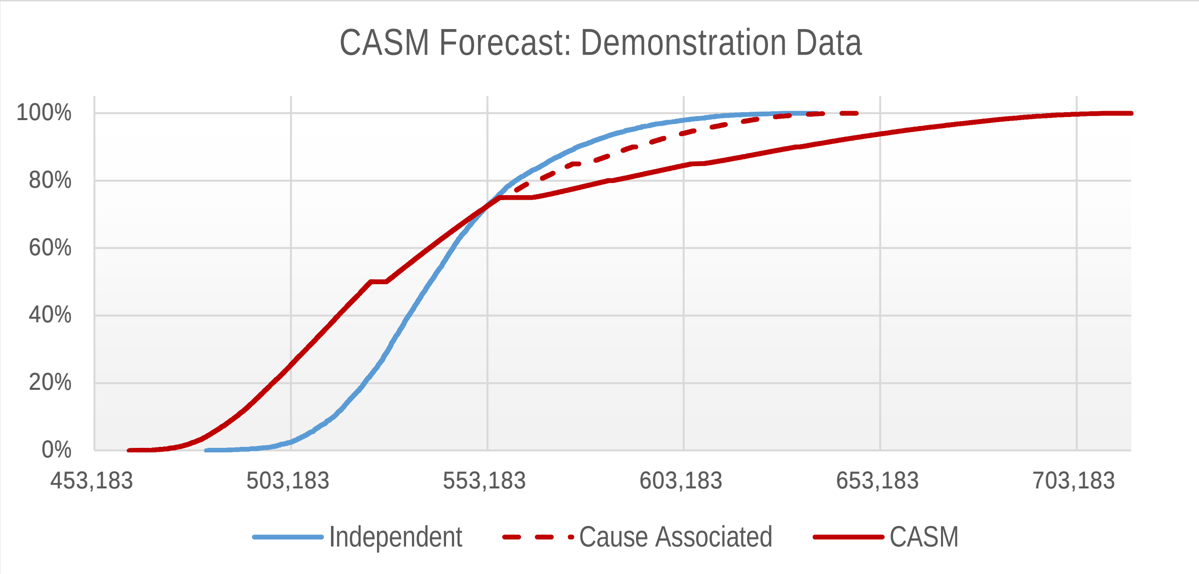
	CASM Forecast Build Up					
Percentile	0% Cause Associated (a)	100% Cause Associated (b)	50% Cause Associated (c)	Overlay for Mechanisms (d)	CASM Forecast (e)	Fully Independent Forecast
0%	476,074	447,884	461,979	0	461,979	481,617
20%	518,433	478,610	498,521	0	498,521	521,879
50%	532,683	514,286	523,484	0	523,484	538,697
80%	546,882	582,525	564,704	19,268	583,972	560,357
90%	554,569	625,807	590,188	41,589	631,777	576,127
100%	595,404	698,764	647,084	70,000	717,084	637,086
Mean	532,962	532,962	532,962	9,125	542,087	542,087

Table 2 – Build-**up** of a CASM forecast

Notes

- Columns a and b are the 0% and 100% Cause Associated Monte Carlo simulations
- Column c is the interpolated results. As 50% a Cause Association level has been specified this is the mid-point between a and b
- The prolongation type risks have been split out and incorporated into the result as an overlay

- **The 0% CA simulation does not include the prolongation items, hence the lower mean value**



Graph 2 – S Curve for Project with Prolongation

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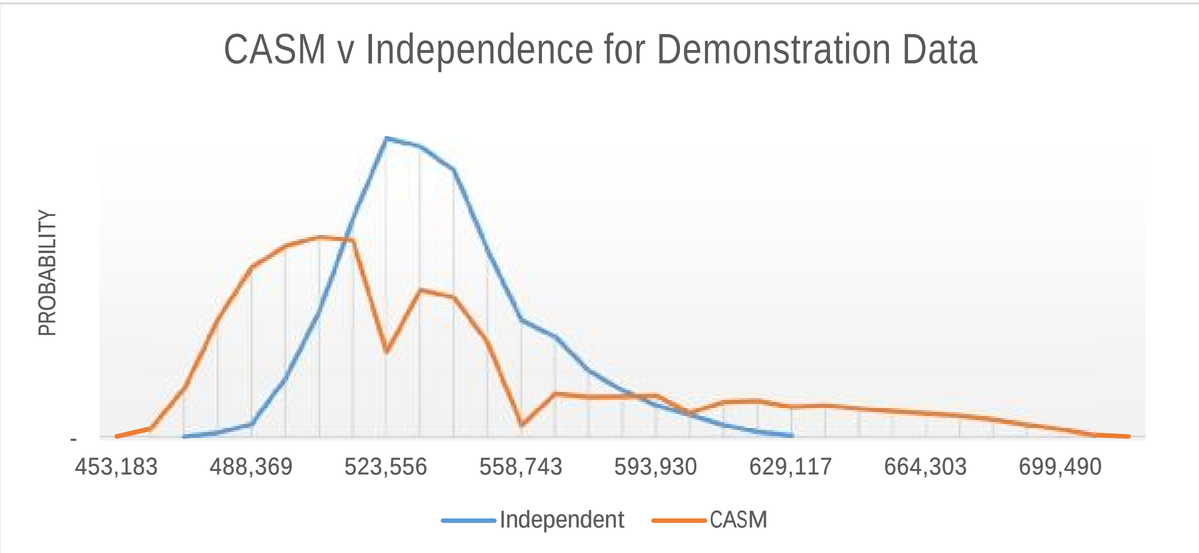


Graph 3 – Comparative Probability Independent & CASM Forecasts

Looking at the probability density in the graphs above the CASM forecast has a much broader range of results and is left skewed with a long tail. The CASM forecast is predicting a much better chance the project will be on or near budget, but that if things go wrong costs could be greater than anticipated.

To understand the ramifications of the characteristics of the forecasts, they should be referenced against the organisations view points on risk and reward. Suppose that this is a bid and will represent the Company’s single largest contract. The CASM forecast (or another competent complexity inclusive forecast) compared to the independent forecast could give rise to very different decisions:

- One corporate view is that if costs were to rise beyond £600m this would be an unacceptable and dangerous outcome, resulting in severe financial and other consequences:
  - With the independent forecast there is a circa 98% confidence that this will not happen (or 2% that it will)
  - The CASM forecast however gives only around 85% confidence that this will not occur (or 15% that it will)
- Another corporate view is that if the costs were to be less than £500m the additional profits would pay for investments that further the Company’s strategic ambition:
  - With the independent forecast there is a less than 2% change this will happen
  - The CASM forecast gives around a 20% confidence that this would be achieved

Using the CASM Monte Carlo Tool

The CASM Monte Carlo tool was used to produce the worked example above. This is an Excel spreadsheet with the Monte Carlo capability offered on a free to use / pay for support model. The steps to produce the CASM forecast were as follows:

1. All the usual steps were taken as the client would to produce the independent forecast. Basically, Identification and quantification of event type risks and opportunities with quantification of ‘estimation uncertainty’ for the planned works. These were copied and pasted to the tool.

2. A Cause Association Level was specified:

Cause Association Parameters

CA Level %	50%

3. **On the risk register the prolongation type risks were flagged. Adding the code :Overlay: in the title / description indicates to the tool that they should be incorporated as an overlay:**

ID	Title	Prol	Min	Most	Max
006	Extended close out period for Programme :overlay:	25%	2,000	5,000	20,000
007	Unrecoverable delay: e.g. a critical schedule milestone cannot be maintained. :overlay:	25%	5,000		50,000

4. **The model was then run and the report produced (< 30 seconds).**

Other Systems / Mechanisms

Multiplicative Effects

This is principally in situations in which if a risk (or opportunity) occurs it impacts not only on the planned costs but also the impact costs of other risks. From the earlier example of an IT project where the in-house developers are more expensive than those sourced offshore; the Monte Carlo results tables are modified so that if Risk C occurs then the impacts of Risk A and B are increased by 50%.

These changes can be made manually in the tables, however there is another tool available on the website that automates this process. The tool can also incorporate ranges – for instance if the cost increase was a variable between 30 and 50%.

Capping

The Monte Carlo results can also be modified so that the combined impact of two or more risks are capped at a certain level. An example of this is the concurrent effect of project delays, where if two delays occur the combined effect is simply that of the largest. These changes can also be made to the data tables via an automated routine. This looks at the total of the values of the risks to be capped and then reduces their values on a pro rata basis such that the combined value does not exceed the cap.

Summary – Systems Mechanisms

The advantage of the SMM approach is that modifications can be classified and automated in the interest of speed, transparency and reduction in error; these are trade-offs against the specific nature and granularity achievable with a bespoke model. There are also practical limitations on the number of modifications that can be made whilst maintaining transparency and traceability.

CASM Trees

To refine forecasts, it is possible to breakdown the forecast into associated areas. This breakdown might be by discipline, area, organisation etc. The results from the sub analyses can then be combined using CASM principles. The sub analyses can also be the outputs of other types of models including bespoke analyses.

A CASM Tree tool can be downloaded from the website that facilitates the amalgamation of sub inputs into an overall results.

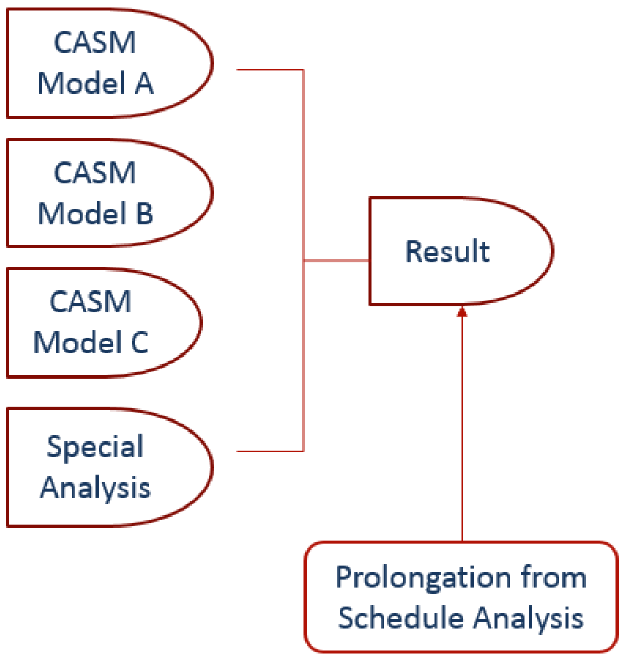
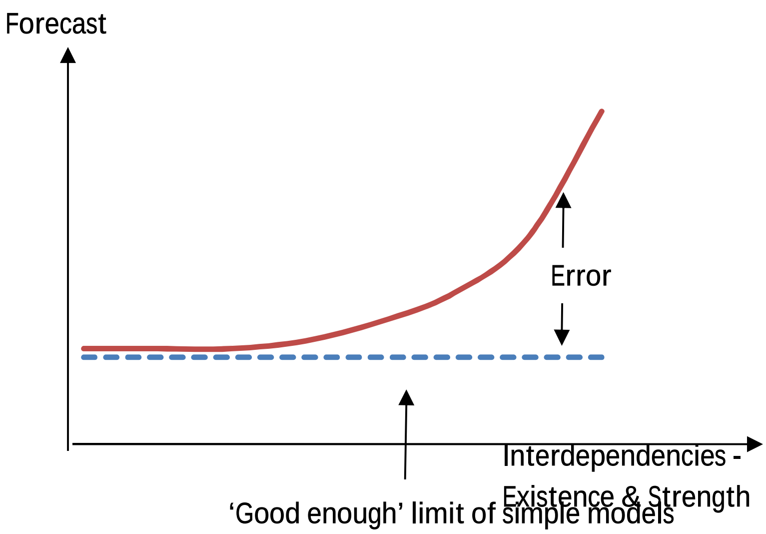


Diagram 4 – CASM Tree Illustration

Conclusion & Recommendations

Where independence between inputs is low or not present, then simple methods of risk quantification may be adequate. In many situations assuming independence inappropriately is an over simplification that introduces large errors and puts project objectives at risk. This error will nearly always be significant, and the greater the presence of interdependencies the larger that error will be. Experience suggests that the error rises exponentially with the presence and strength of both, as shown conceptually in the graph below:



Observation from Experience: Low level of interdependency can lead to 50% to 100% overruns, high levels can lead to 300% to 500% overruns

Diagram 5 – Error Exponentially Increases with Interdependencies

This conclusion should not be interpreted as a reason to abandon established risk management techniques and processes – the opposite is the case; the benefit of the actions in the risk register may be of a much greater value than indicated. From a management and mitigation perspective it may be more effective to manage root causes and systemic mechanisms than the identified risks and uncertainties.

Key Recommendations:

1) **Any forecasting exercise (including those embedded within ERM systems) should consider the presence and implications of interdependencies at least qualitatively, and this should become part of the identification process (and "second nature").**

2) **Where independence is assumed it should be explicitly stated why this is the case. It is safer to assume interdependence initially and then revise in light of new information that supports moving away from this (if it exists).**

3) **Where complexity in the form of interdependence is identified it should be modelled with an appropriate methodology. There are many ways in which this can be done of which the CASM Framework and tools are just one. The different methods have different applications and trade-offs between effort and outputs. It will always be better to use one technique or another rather than none.**

4) **Where a Monte Carlo cost analysis has been undertaken in which independence has been inappropriately assumed, re-computation with the CASM tool and a CA coefficient should be seen as a minimum. The effort to do this compared with the effort required to identify and quantify the inputs is trivial. With only slightly more effort the results can be refined by splitting out the 'overlay' type inputs**

5) **Selecting the Cause Association level can be a quandary for those not experienced in modelling dependency. The recommendation here is that as a starting point 50% Cause Association level is used as a minimum for the majority of circumstances. Other valid approaches include:**

   a) **Assuming a 75% Cause Association level starting point, for instance in a highly interconnected programme of works.**
   b) **Assuming a 100% Cause Association level initially and then modify downwards if justification to do so is found.**

   It should be noted that if considering Cause Association level then a 100% level may be give optimistic results if there are Systems Mechanisms / 'Knock on' impacts that should have been modelled.

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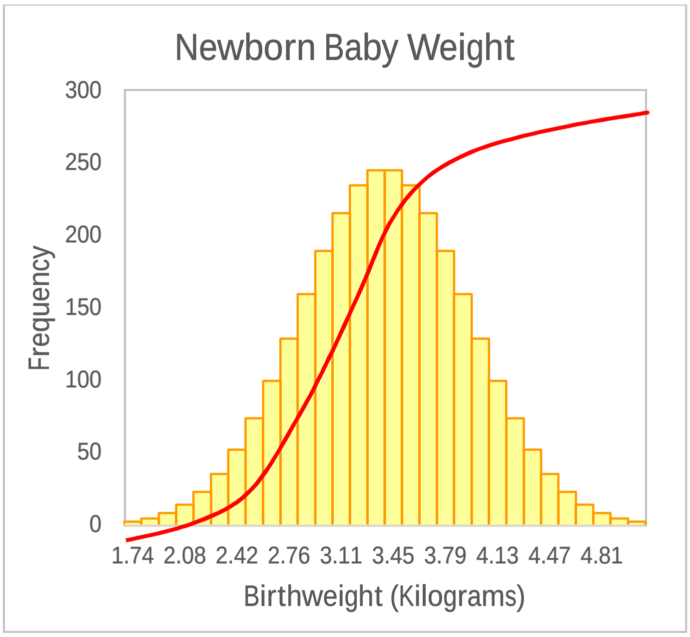
Appendix A – Monte Carlo Analysis Method

Here the Monte Carlo method is explained by analogy. Most people will be familiar with basic statistical methods used to capture the characteristics of a sample group. The bar chart below shows the distribution of weights of new born babies:



From the graph we can see what the most likely baby weight is and what the biggest and smallest babies weigh. Also shown is an 's curve', which shows the percentage of babies that are at or less than each weight level.

In a forecasting environment, such as forecasting the cost of a project, there may be no sample group of similar historic projects which can be analysed. The Monte Carlo method is used to create this sample group.

The sample group is created in a data table – a part of which is shown below, In the table below each row represents one sample (referred to as an iteration) and each column on the right represents an input. The columns are populated in accordance with what has been quantified, but in a randomised way. So if a risk has been assessed as a 10% chance of £100 and there are 1,000 samples/iterations then 100 cells in that column will be populated with £100.

A value for each row is then calculated, in this case by adding the values in the row (Simple Addition). The sample group is then used to create the bar chart and s curve in the same was as for the babies.

Iteration	Total	1 - Risk A - Additional Subsystem	2 - Risk B - Speed Criteria	3 - Risk C - Offshore brought back in House
1	0	0	0	0
2	600	0	600	0
3	600	0	0	600
4	0	0	0	0
5	0	0	0	0
6	600	0	0	600
7	500	500	0	0
8	600	0	600	0
9	0	0	0	0
10	0	0	0	0
11	500	500	0	0
12	500	500	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	1700	500	600	600
17	0	0	0	0
18	1200	0	600	600
19	1200	0	600	600
20	500	500	0	0
21	600	0	600	0
22	600	0	0	600
23	0	0	0	0
24	0	0	0	0
25	600	0	600	0
26	0	0	0	0
27	600	0	600	0
28	0	0	0	0
29	1200	0	600	600
30	600	0	600	0

X1,000 iterations

Appendix B – 100% Cause Associated Monte Carlo Table

Iteration	Total	1 - Planned project cost	1 - Risk A - Additional Subsystem	2 - Risk B - Speed Criteria	3 - Risk C - Offshore brought back in House
1	1,100	1,100	0	0	0
2	1,114	1,114	0	0	0
3	1,120	1,120	0	0	0
4	1,125	1,125	0	0	0
5	1,128	1,128	0	0	0
6	1,132	1,132	0	0	0
7	1,135	1,135	0	0	0
8	1,138	1,138	0	0	0
9	1,140	1,140	0	0	0
10	1,143	1,143	0	0	0
11	1,145	1,145	0	0	0
12	1,147	1,147	0	0	0
13	1,149	1,149	0	0	0
14	1,151	1,151	0	0	0
15	1,153	1,153	0	0	0
65	1,216	1,216	0	0	0
66	1,217	1,217	0	0	0
67	1,218	1,218	0	0	0
68	1,220	1,220	0	0	0
69	1,221	1,221	0	0	0
70	1,222	1,222	0	0	0
71	1,823	1,223	0	600	0
72	1,825	1,225	0	600	0
73	1,826	1,226	0	600	0
74	1,828	1,228	0	600	0
75	1,829	1,229	0	600	0
76	2,030	1,230	0	600	200
77	2,090	1,232	0	600	258
78	2,115	1,233	0	600	282
79	2,135	1,235	0	600	300
80	2,152	1,236	0	600	315
81	2,667	1,238	500	600	329
82	2,681	1,240	500	600	341
83	2,694	1,241	500	600	353
84	2,706	1,243	500	600	363
85	2,718	1,245	500	600	373
86	2,729	1,247	500	600	383
87	2,740	1,249	500	600	391

Appendix C – Risk and forecasting methods

The evolution or maturity of risk management within an organisation might be simplified in the following list. All of these will depend on definition; some will consider risk only as covering 'events' to which a probability can be attached and that have a downside/negative. A broader definition will include upside risk events (opportunities) and uncertainty associated with planned works. A better definition still will also encompass uncertainty of all forms including that arising from ambiguity, culture, capability and knowledge.

1. **Managing Risk Qualitatively**

   Managing risks 'qualitatively' usually means:

   - **Documenting the 'qualities' of the risk, typically where a risk means an event that may or may not happen and usually listed in a risk register. The qualities include the reasons why the risk is considered to exist and what the consequences might be should it occur – these are expressed descriptively.**
   - **Action plans, responses and mitigations will also be captured.**
   - **The risks may be prioritised using a Probability Impact Matrix where probabilities and impacts are evaluated against a Very Low, Low, Medium, High, Very High scale. For some the use of these matrices defines qualitative risk.**
   - **Risk Management might or might not also encompass opportunities/ upside risk**

   Compared to doing nothing Managing Risk qualitatively is a good decision. The author recounts the experience of undertaking a project risk workshop that used an exclusively qualitative process. One of the risks identified related to the potentially inaccuracy of an existing survey and it was agreed that a new survey would be carried out. However, the project team were trying to stick to the schedule so the survey was not undertaken. The risk became reality and the resulting rework was valued at €10 - 15 million whilst the survey cost €5k - 10k. The survey had to be undertaken anyway as part of the rework – the schedule was also blown.

   Note that Qualitative Risk Management / Assessment is not a forecasting methodology.

2. **Assessing Risk Quantitatively**

The identified risk items can also be assessed quantitatively – for instance it might be judged that a risk has a 10% chance of happening and if it does happen the costs will be £15,000. Quantifying risk in this way can also be a good decision compared to a qualitative only process – even if no further calculation is done. In the example from the authors experience – it is easy to see that knowing the quantification of the impact might have led to the project team thinking twice about not undertaking the surveys. The act of quantification can reduce the scope for ambiguity and mis-interpretation.

Quantifying risk alone is not generally a forecasting methodology – further calculation is required.

3. **Forecasting the Cost of Risk using Risk = Probability x Impact**

The quantified values can be used to calculate the mean value of the risk by multiplying Probability by Impact; in the example above 10% x £15,000 = £1,500. The mathematical term for this calculation of the mean value is 'Expected Value / EV'. This definition does not sit well with common language, where it might be reasonable to 'expect' the value of this risk that has 90% chance of not happening to be zero. The mean values can be used to prioritise the risks with the highest Expected Value items receiving the most management attention.

It is also possible to calculate an overall 'Cost of Risk' by adding the mean/EV of each risk. We call this method <u>'Simple Addition'</u> and the result can be used to inform a risk budget or contingency levels. Using such an approach can also be a good decision compared to relying solely on experience based 'rules of thumb' or guesswork to set contingency levels which might otherwise go unchallenged. Note that with the Simple Addition calculation an assumption is made that all inputs are independent of each other.

4. **Forecasting Cost of Risk using Monte Carlo with Simple Addition**

A limitation of the Expected Value calculation is it gives no insight into the variability associated with the risk or opportunity. The following risks all have exactly the same EV but have very different characteristics and would be responded to in different ways:

- 100% of £1,500 = £1,500 EV
- 10% of £15,000 = £1,500 EV
- 1% of £150,000 = £1,500 EV

Monte Carlo is a methodology for working with ranges of values where the results are expressed also expressed as a range of values. (the Monte Carlo method is explained in Appendix A). Most commonly the Monte Carlo method for cost is used in conjunction with Simple Addition: within the modelling the overall cost of risk for each risk is simply the sum of all risks. This is the most common method for CoR forecasts using Monte Carlo, it is the standard output from a number of Enterprise

Risk Management systems and it is very straightforward to put together a basic template if using an Excel based Monte Carlo 'Add in'.

This methodology provides insight into variability and is 'good enough' in many circumstances.

5. **Forecasting Cost of Risk using Monte Carlo and factoring in Complexity**

Complexity in this context means the interrelationship between risks – either as common root causes or knock on impacts should the risks materialise. As outlined in the paper, where complexity of this type exists but is not modelled serious errors can arise. Using common approaches, the time, effort and skill involved in producing realistic forecasts in this type of this are typically much greater than the methods outlined above.

The most common ways of producing forecasts in these circumstances are through the use of Monte Carlo software and a bespoke model for example in a spreadsheet. To incorporate the relationships between the impacts of these risks (knock on impacts) it is necessary to codify these in the model. The level of effort to produce a bespoke model will of course be dependent on the circumstances and the level of detail which the analyst is working to. The more complex the model the greater the potential for 'spreadsheet risk', which should not be underestimated. The examples on the EU Spreadsheet Risk Group's website are worth reading http://www.eusprig.org/horror-stories.htm.

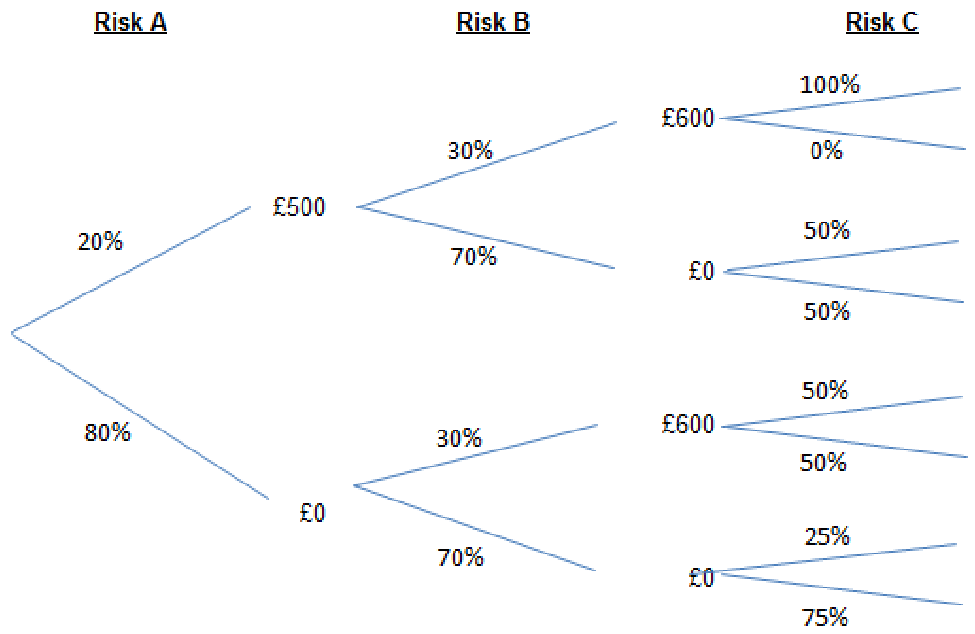
To incorporate the effect of common root causes most Monte Carlo packages would need a 'correlation' matrix to be completed. This specifies the strength of the relationship between all the inputs to the model. A matrix might look as follows:

	Input 1	Input 2	Input 3	Input 4	Input 5
Input 6	50%	50%	0%	0%	0%
Input 5	25%	35%	35%	0%	
Input 4	95%	50%	0%		
Input 3	0%	0%			
Input 2	0%				

As the number of inputs rises the number of relationships that need to be specified can quickly become onerous and unmanageable. For instance, in a forecast with 30 inputs there will be around 450 relationships to be specified – when modelling risks the probability and impact are usually separate inputs so potentially this relates to only 15 risks.

It should also be noted that the mathematics behind correlation matrices is complex (the example above for instance would not be workable). The use of matrices can also slow down models so they take many hours to run.

Appendix D – Probability Tree Calculations



		Prob	Impact	P*I
£1,150	(a)	6%	£2,250	£135
£0		0%	£1,100	£0
£850	(b)	7%	£1,350	£95
£0		7%	£500	£35
£900	(c)	12%	£1,500	£180
£0		12%	£600	£72
£600	(d)	14%	£600	£84
£0		42%	£0	£0
			Total	**£601**

Notes

1) **The probability and impact of each 'path' is found by multiplying the probabilities and adding the impacts.**
Impact of A & B are added to base cost, which is then multiplied by 50% to reflect cost of bringing work in house [(£500 + £600 + £1,200) x 50%]
Impact of A is added to base cost, which is then multiplied by 50% to reflect cost of bringing work in house [(£500 + £1,200) x 50%]
Impact of B is added to base cost, which is then multiplied by 50% to reflect cost of bringing work in house [(£600 + £1,200) x 50%]
Base cost is multiplied by 50% to reflect cost of bringing work in house [(£600 + £1,200) x 50%