Modelling of cost distributions for Monte Carlo simulation

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Scope of the work

A cost estimate for a space mission is requested since the very beginning of the design, often during a phase 0 or a feasibility study. At that moment, the uncertainties about the design, trades-off, activities duration and deployable resources and other unforeseen events might add up to 30%-40% on top of the estimate or even more. Therefore, a risk analysis becomes mandatory to get a reasonable estimate that covers all the aspects not necessarily accounted by the cost model.

The MoCA (Monte Carlo Analysis) risk tool developed in the ESA TEC-SYC (cost engineering section), performs a Monte Carlo simulation to compute the overall cost risk for a space mission, by converting every deterministic cost estimate into probability distribution matching correlation constraints between all those variables.

Object of this presentation is to explain how the conversion process has been built and what are the main driving parameters.

Source of uncertainties

Margin needs to be added to the cost estimate to account for:

Technical risks: risk associated with the evolution of the design and the production of the system of interest affecting the level of performance necessary to meet the stakeholder expectations and technical requirements. Technical risk is affected by: ambiguous/unstable requirements, non-completed trade-off analysis, needed of additional design iterations, etc.

Programmatic Risk**:** This is the risk associated with action or inaction from inside or outside the project, over which the project manager has partial or not at all control, but which may have significant impact on the project itself. These impacts may manifest themselves in terms of schedule delay or direct increase of the cost. Programmatic risk is affected by: optimistic planning (schedule not enough detailed depending on the complexity/interfaces of the project, no margin included, no identification of critical path), GEO return Constraint (impacting the supplier selection and industrial setup), import/export control, partner agreements with other domestic or foreign organizations, industrial contractor restructuring, product obsolescence, external organizational changes, etc.

Risk Drivers 1/3

Technology Readiness Level (TRL), from 1 to 9 or equivalently the product categories (A,B,C,D) to identify the technological maturity of the relevant item.

Design maturity (DM) of the equipment, subsystem or the overall system (to identify the manpower effort to reach the full ready to flight):

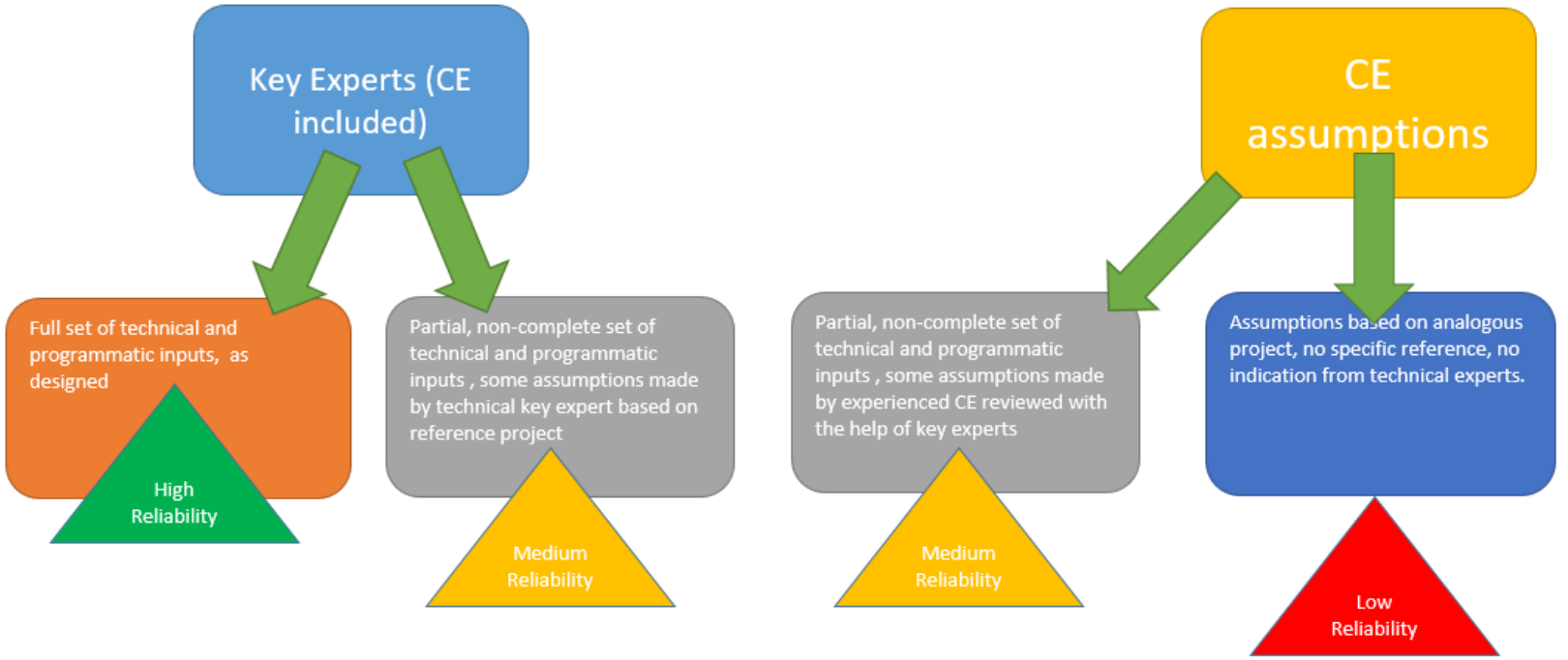
- Off-the-shelf (OTS)
- Minor modification
- Major modification
- New design
- New development

The TRL is directly linked to the DM

Risk Drivers 2/3

Degree of reliability on the performed cost estimate.

It depends on the source and quality of inputs that have been used to run the cost estimate.

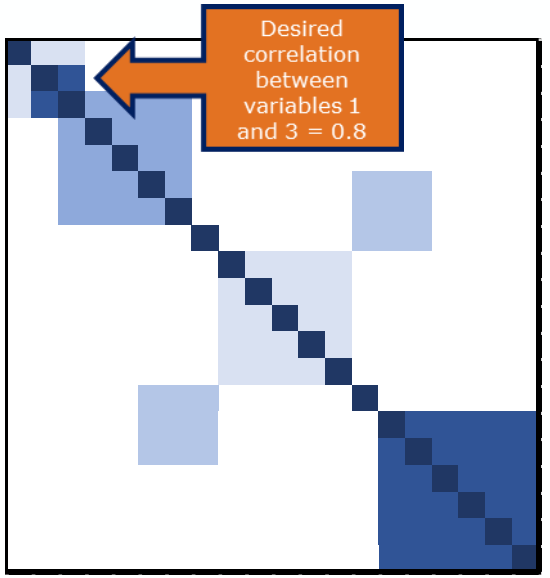


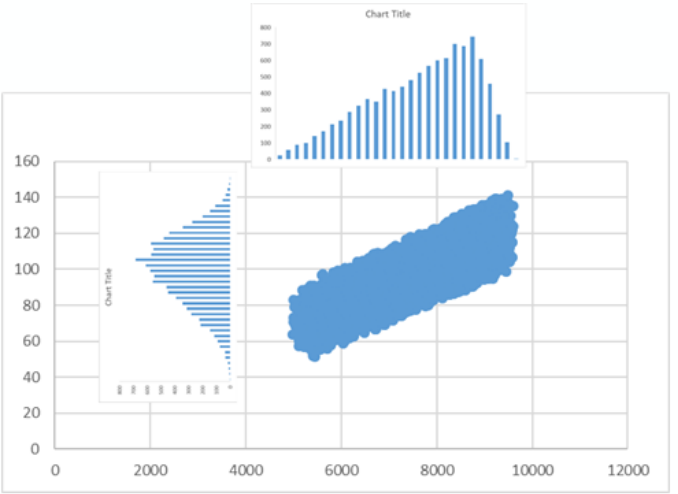
Risk Drivers 3/3

Correlation between every cost item, indicating how the risk of cost growing of one item impacts others (HW and activity).

By default correlation set to 0.2 for every cost variable (*reference Correlations in Cost Risk Analysis Presented at 2006 Annual SCEA Conference, Raymond P. Covert (technical director at MCR, LLC)*

Customisation of correlation matrix structure might be implemented according to specific case.





Estimated Correlation =0.8036

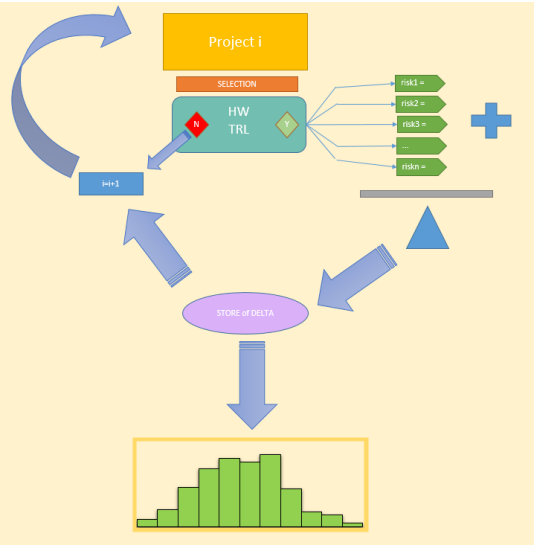
Data analysis 1/2

List of HW and manpower main risks split by grade of TRL or DM (industrial and ESA data):

- Change of requirements
- Additional design iteration
- Additional reviews
- Additional tests
- Additional MAIT procedures

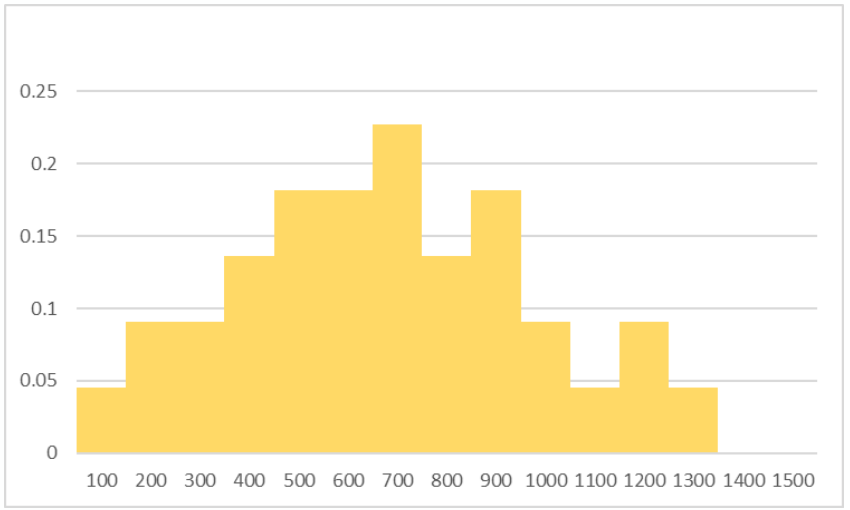
Cost evaluation of risks by endorsing industrial risk estimate (cross validation by using bottom up cost estimate)

Storage of deltas and building of the full cost distribution (e.g. Maximum Likelihood Estimator (MLE) method)



Data analysis 2/2

Observations yi:



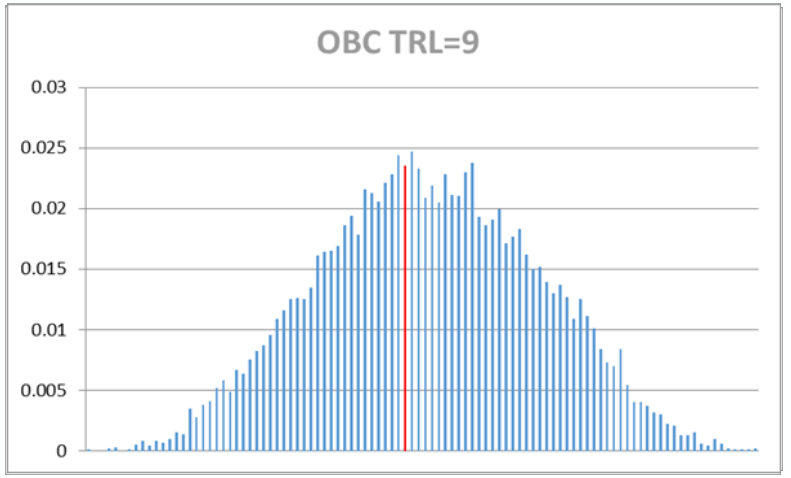
MLE is a method for estimating population parameters (such as the mean and variance for Normal, etc.) from sample data such that the probability (likelihood) of obtaining the observed data is maximized

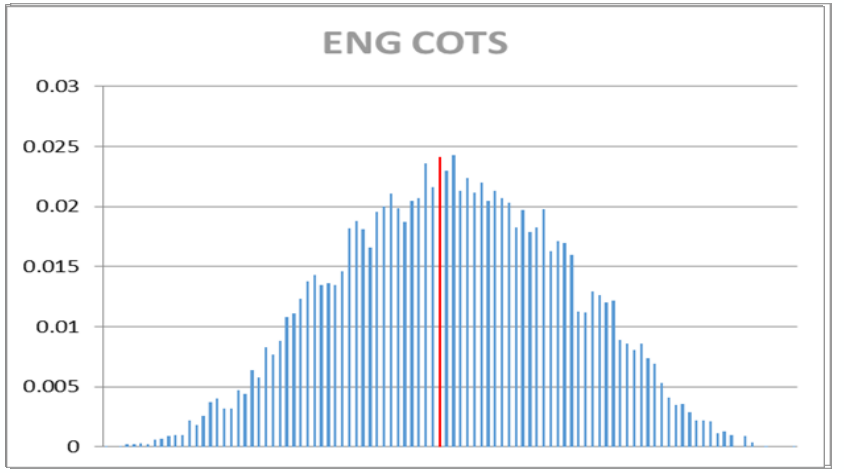
$$\max_{\beta} \left\{ \prod_{i} p(y_i|\beta) \right\}$$

How risk drivers impact cost distribution 1/3

The TRL and the DM impact the ratio between the point estimate and the average value of the distribution.

The lower is the value of the TRL/DM the more steps (reviews, test, design iterations) are needed to go through in order to make the item/system ready to flight

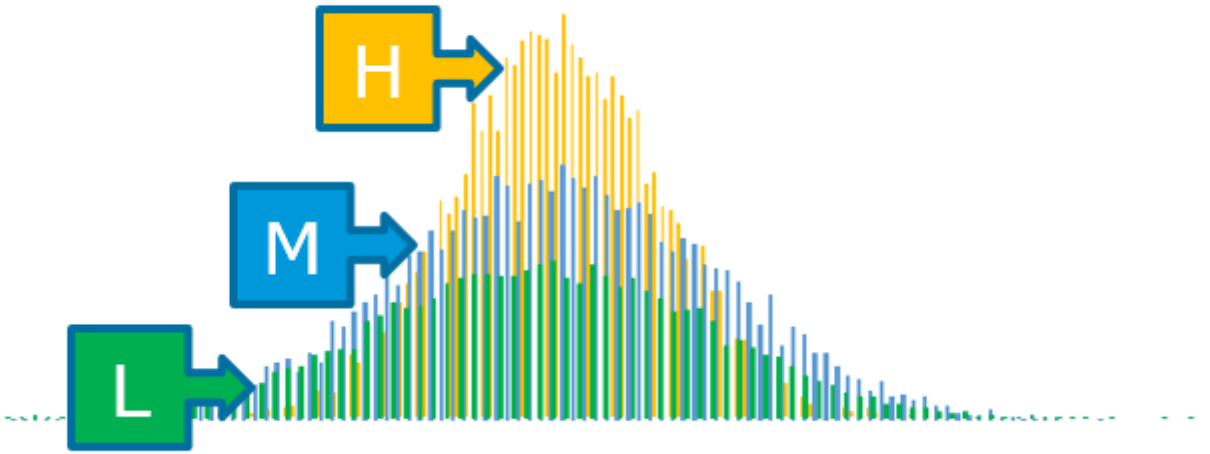




How risk drivers impact cost distribution 2/3

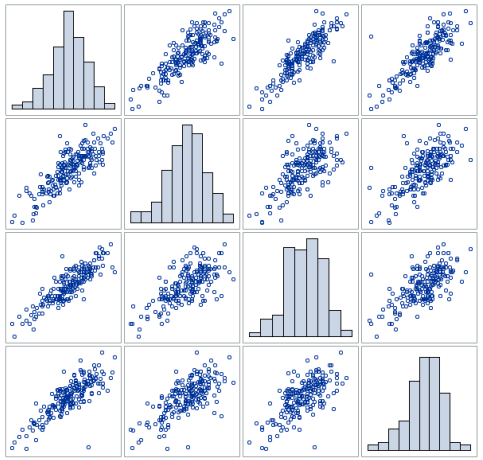
Reliability on the inputs used to perform the cost estimate impacts the standard deviation of the input distribution, measure of the amount of variation or dispersion of a set of values.

Low reliability on the inputs will increase the admissible range of allowed values.



How risk drivers impact cost distribution 3/3

The effect of the correlation on the overall cost distribution is impacting the confidence level of the total distribution.



$$\mu = \sum_{k=1}^{n} \mu_k$$

$$\sigma = \sqrt{[\sigma][C][\sigma]^T} \leq \sum_{k=1}^{n} \sigma_k$$

The total standard deviation is always less than the sum of its constituent's standard deviation when the correlation between these elements are less than 1.
the steepness of the cost S-curve, and therefore the confidence level, is determined by the standard deviation, the impact of correlation will be reflected in the confidence level.

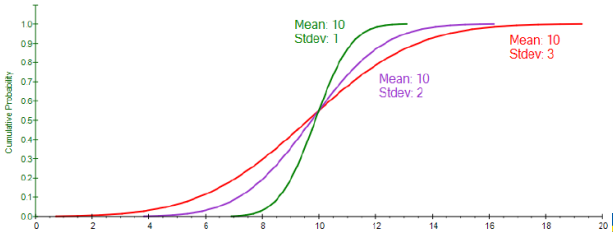


Figure 5. CDFs of Three Normal Distributions (Identical Means, Different Standard Deviations)

Conclusions

Reliability on the distribution estimation has been validated by using the risk analysis tool in many different projects at any stage (pre-feasibility, preliminary or advanced design etc..) and comparing the cost growth with cost at completion.

The importance of increasing the number of cases/observations is crucial to improve the degree of accuracy of the distributions in terms of their parameters

Next step is also to investigate in a more deep details correlation between cost variables, especially between HW equipment cost and cost of manpower at system or instrument level, exploring different matrix correlation structures for each type of mission and maturity design status.