SESA6085 – Advanced Aerospace Engineering Management

Lecture 16

2024-2025

Dr David Toal

Module Recap

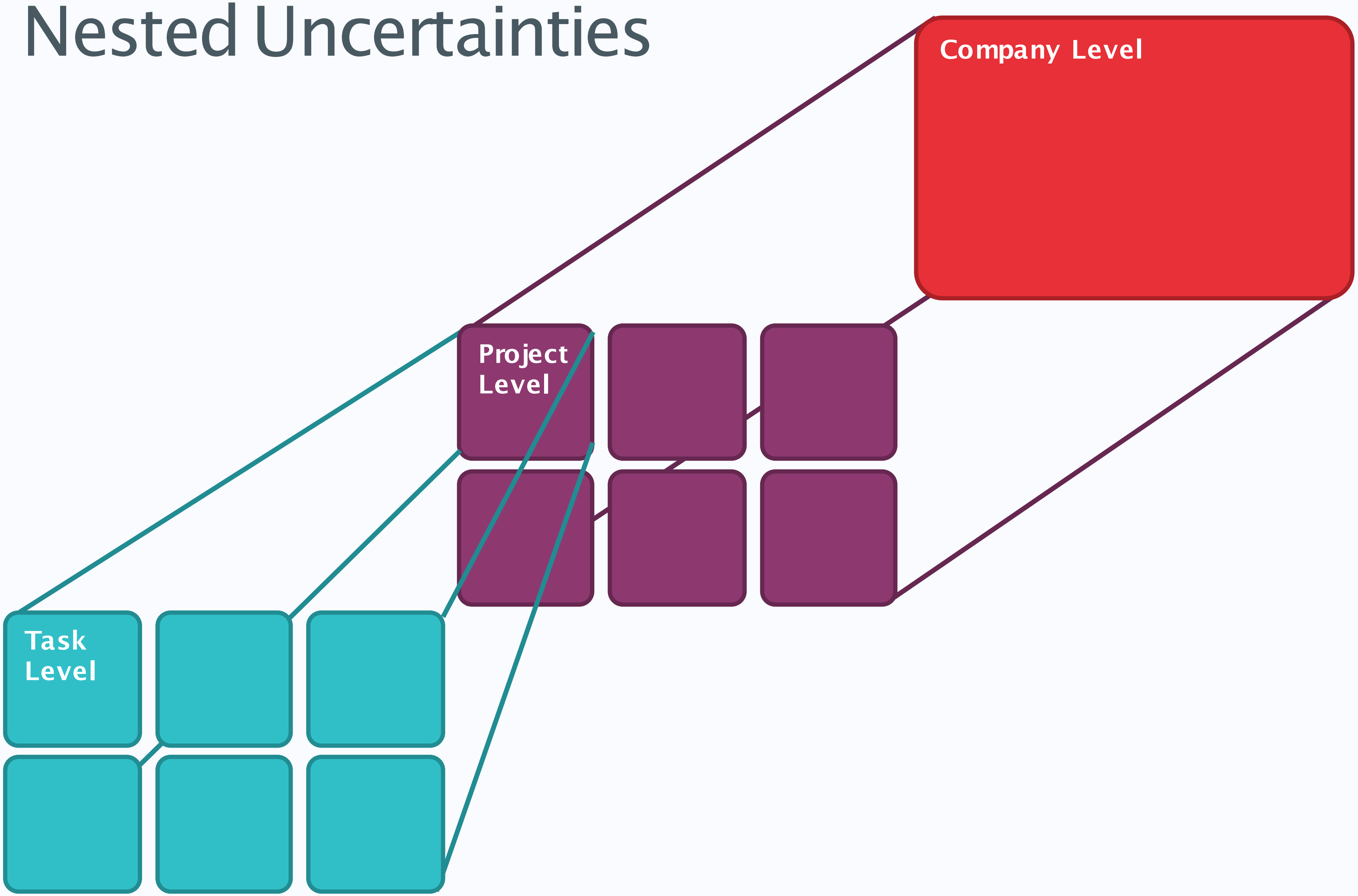
- Probability theory
- Capturing uncertainty e.g. PDFs
- The impact of uncertainty e.g. MC, RBD, FTA
- Design in the presence of uncertainty

Component & system level

- To date we've focused on component and/or system-level uncertainties primarily linked to performance or operation
- Of course, uncertainties are present throughout all aspects of a system's development

Nested Uncertainties

Nested Uncertainties



Over The Coming Weeks

- Having looked at uncertainties related to performance we will now move up the business hierarchy
  - Project uncertainties
  - Business uncertainties
- We will address:
  - The potential sources of uncertainties at these levels
  - The methods of capturing and modelling their impact
  - Decision-making based on such models
  - Mitigation against uncertainties

Project Uncertainty Management

An Overview

Risk vs. Uncertainty

- It's important to recognise the difference between risk and uncertainty

Uncertainty – lack of certainty

Risk – possible unfavourable outcomes

Opportunity – possible favourable outcomes

- We must remember the positives as well as the negatives!

Project Uncertainty Management

- What is project uncertainty management?
- Process by which uncertainty is:
  - Captured
  - Understood – sources and impact
  - Used to make decisions – mitigate risk or exploit opportunity
- This applies to:
  - Project management – creating of specific assets
  - Operations management – managing for business as usual
  - Corporate management – changes to corporate strategy & ensuring appropriate governance
- All of which are interlinked e.g. project management is driven by corporate decisions and strategy

Uncertainty Types

- Uncertainty can generally be divided into four main types
  - Not dissimilar to our definitions of uncertainty types in design

1. Ambiguity uncertainty
   - Lack of complete/perfect knowledge e.g. specification, data etc.
   - Can be reduced/resolved over time
2. Inherent variability
   - Always happens but the degree is variable e.g. inflation
3. Event uncertainty
   - Events that may or may not happen
4. Systemic uncertainty
   - Dependencies and complex relationships (feedback or feed-forward) e.g. link between material price and labour

Project Uncertainty Management

PUMPs

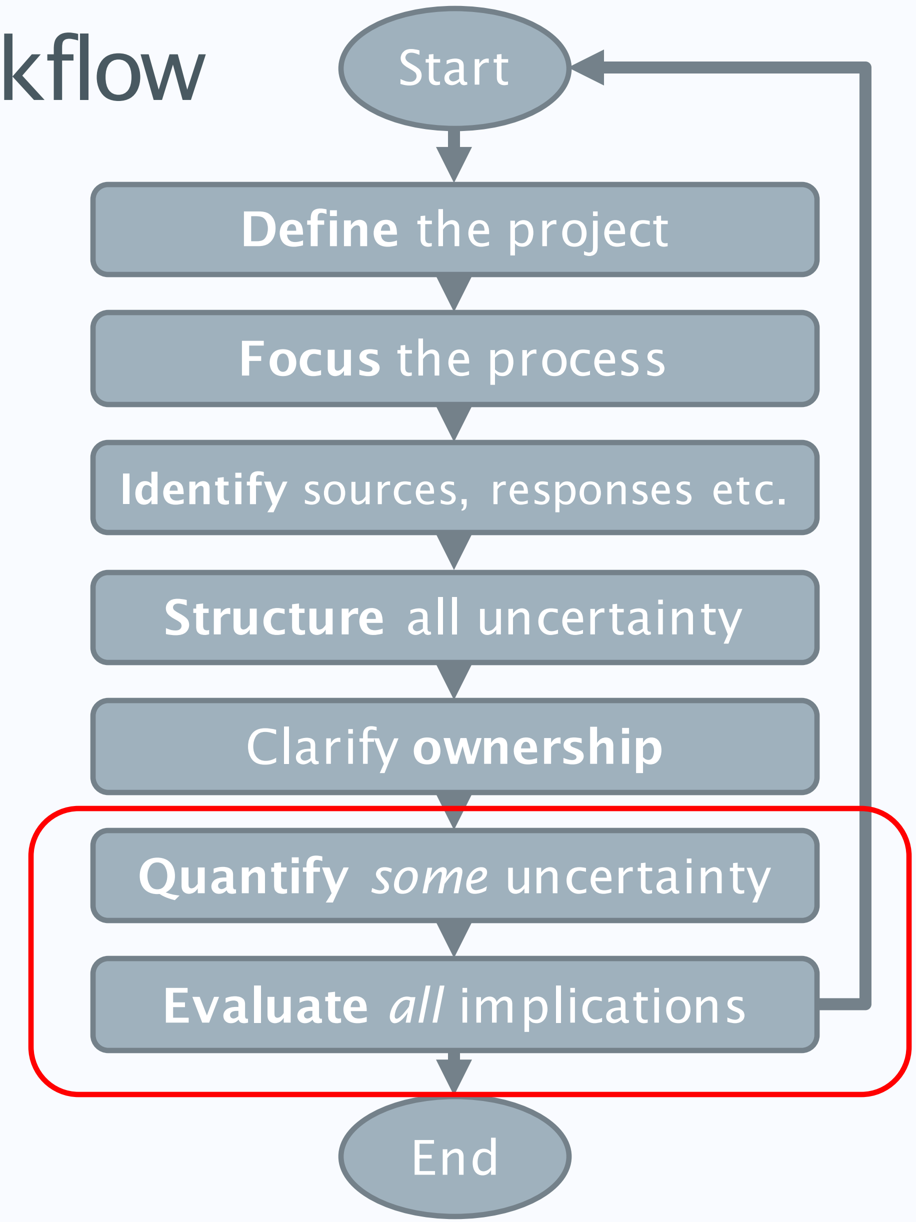
PUMPs

- PUMPs – Performance Uncertainty Management Processes
  - Offers a framework to capture uncertainties, determine their impact, help make decisions and identify opportunities
- This is an evolution of the PERT (Programme Evaluation & Review Technique) framework you would have been introduced to in FEEG2006
  - PUMPs embeds stochastic processes in PERT including Monte Carlo analysis
  - Includes decision branches, sensitivity diagrams, recognises the role of documentation etc.

PUMP Overview

- Iterative process comprising of seven linked phases
- Can be performed at any point in a project's lifecycle
  - Conceptualisation
  - Planning
  - Execution & delivery
  - Ultilisation
- Should ideally start at the project's conceptualisation and be repeated throughout each stage
- The process can be started later in the project
  - But the full benefits will not be realised

PUMP Workflow



We will focus on steps 6 & 7

Common Tasks

- There are five common tasks to all seven PUMP phases:
  - Document – record text, tables, diagrams etc.
  - Verify – ensure that all providers of information agree and highlight where this is not possible
  - Assess – evaluate the analysis to date and ensure it is fit for purpose
  - Report – release documentation and present findings
  - Fit for purpose iteration control – ask, "are the current deliverables fit for purpose?"
- Tasks also tend to focus around the seven Ws
  - **W**ho, **W**hy, **W**hat, **W**hichway, **W**herewithal, **W**hen, **W**here
  - **W**hichway – how will plans in each stage deliver
  - **W**herewithal – what resources are needed

1. Project Definition Phase

- This phase provides the basic foundation for everything following
  - If this is flawed then so is all subsequent analysis
  - Don’t build your house on sand!
- Comprises two different but coupled tasks
- Consolidation
  - Gathering and integration of existing information about the project & its management in a suitable form
- Elaborate & resolve
  - Filling in the gaps uncovered during the consolidation process and resolving any inconsistencies
- Deliverable for this phase is a clear unambiguous shared understanding of the project and its management

2. Focus

- This phase is concerned with adapting the generic PUMP process to the specific project of interest
- Within a project the opportunities for uncertainty management are considerable, pervasive and diverse
  - There is potential to be sucked into a black hole of uncertainty management
- The aim in the focus phase is to achieve "clarity efficiency"
  - A cost-effective use of uncertainty management resources
- The focus phase comprises of a number of modes
  - Process scoping
  - Process planning
- Delivers a clear unambiguous plan of the PUMP application

3. Identify Uncertainty Sources

- The PUMP approach aims to identify both sources of uncertainty and the corresponding response options simultaneously
  - Unidentified responses are themselves a potential source of uncertainty
- Responses can be reactive or preventative depending on the consequences of the source of uncertainty
- The identification process is highly iterative in nature
- Depending on the objectives of the PUMP the identification phase is tailored accordingly in the previous focus phase
  - Responses are important to shape contingency plans etc.
  - Unbiased performance estimations require close attention to uncertainties

3. Identify Uncertainty Sources

- Identification phase is a top-down process related to each PUMP objective
- The process begins by defining which objectives are important now
  - Remember the PUMP is applied repeatedly throughout the project lifecycle – priorities may change

4. Structure Uncertainties

- This phase is primarily concerned with completing the qualitative analysis
- The aims are:
  - To improve the understanding of the relative importance of different sources
  - Explore relevant interactions
  - Test any implicit or explicit assumptions made in previous phases
- This can lead to:
  - A refinement of response options and perhaps the development of new responses
  - More effective forms of analysis

5. Ownership

- This phase attempts to ensure that every relevant source/response has an appropriate owner
  - Develops a basic plan for relationship and contracting strategy which aligns with the objectives of the parties involved
  - Distinguishes between sources/responses the project owner wants responsibility and those to sub-contract
  - Allocates responsibility for uncertainty management to a named individual
  - Approval of allocations of responsibility controlled by other parties
  - Tests the robustness of the overall approach

PUMP – Phase 6

Quantification

Quantification

- Phase 6 aims to provide probability estimates of uncertainty associated with:
  - Previously identified sources of uncertainty
  - Their associated response options
- These estimates can be associated with e.g.
  - Costs
  - Duration
  - Or other measurable performance criteria identified earlier in the PUMP
- They form the basis of future decision-making and aim to shape the project to be resilient to risk and/or exploit opportunities

Quantification

- The quantification phase involves two modes of analysis
  - The sizing of sources of uncertainty in probabilistic terms - first pass analysis
  - Refining earlier quantification of uncertainty – subsequent passes
- Normally multiple passes to quantify uncertainty are required
- To be effective we want this phase to be clarity efficient
  - Achieve clarity in terms of the objectives of the PUMP but in an efficient manner
  - Minimise time on minor uncertainty sources to spend more time on important sources of uncertainty
  - Recall our previous phases ranked sources based on an initial qualitative assessment to enable us to focus better in this phase

Quantification

- Some approaches to risk management use non-numeric approaches to define the likelihood of an event
- These use labels such as “low”, “medium” and “high”
  - i.e. a qualitative assessment
- The classic example of this is the probability-impact grid (PIG)
  - Where have you seen this before?

Probability-Impact Grid (PIG)

- Recall the risk assessment template (see FEEG3003)…

LIKELIHOOD					
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
	1	2	3	4	5
			IMPACT		

Likelihood	
1	Rare e.g. 1 in 100,000 chance or higher
2	Unlikely e.g. 1 in 10,000 chance or higher
3	Possible e.g. 1 in 1,000 chance or higher
4	Likely e.g. 1 in 100 chance or higher
5	Very Likely e.g. 1 in 10 chance or higher

Impact		Health & Safety
1	Trivial - insignificant	Very minor injuries e.g. slight bruising
2	Minor	Injuries or illness e.g. small cut or abrasion which require basic first aid treatment even in self-administered.
3	Moderate	Injuries or illness e.g. strain or sprain requiring first aid or medical support.
4	Major	Injuries or illness e.g. broken bone requiring medical support >24 hours and time off work >4 weeks.
5	Severe – extremely significant	Fatality or multiple serious injuries or illness requiring hospital admission or significant time off work.

Probability-Impact Grid (PIG)

- What's the issue with such an approach?
  - Requires a very simple characterisation of risk – falls short of our desire for a minimum level of clarity
  - The definitions of the terms used may not be clear – risk in qualitative terms means different things to different people – perhaps linked to how risk-averse their personality is
  - It's simple and therefore attractive which might discourage putting more effort into a more meaningful/useful quantification of risk
- The risk assessment is something of a halfway house – not completely qualitative or quantitative
  - Note the probabilities associated with the likelihood definitions

Qualitative Approach Illustration

- You are a project manager on an aircraft assembly line. You've been asked to assess the likelihood that an aircraft will be delivered late to the customer.
- How would you assess this likelihood?
  - An unfair question given the lack of context but let's roll with it…

1. Rare
2. Unlikely
3. Possible
4. Likely
5. Very likely

- N.B. I've used the definitions from the risk assessment template but I've deliberately removed the probabilities

Qualitative Approach Illustration

- This is a rather contrived example but it illustrates
  - Not everyone has the same definition of these qualitative terms
  - Not all risks are considered (lack of structure)
  - Context is lost when defining likelihoods
  - Unknown what factors played into the definition of risk and likelihood
- Consider a follow-up question to the same problem
  - What is the likely financial penalty the company will have to pay to the customer for the late delivery?
  - Can a qualitative approach help us answer this?

Quantification

- Uncertainty quantification in the PUMP framework aims to produce a probabilistic definition of uncertainty
  - Thereby avoiding the ambiguity associated with a qualitative approach
  - Producing a more meaningful and useful assessment
- The use of data is central to this philosophy
  - Something we should all be familiar with having considered reliability modelling!

Quantification

- The key steps in this phase include:
  1. Ordering of uncertainty sources in terms of importance
  2. Clarifying associated conditions for these uncertainties e.g. this will only happen if…
  3. Data or elicitation is used to size the uncertainty e.g. produce a PDF
  4. Refine sizing e.g., alternative PDF definitions, management of elicitation, clarification of relationships between objective data and subjective probabilities
  5. Repeat steps 2-4 for each uncertainty in the list updating priorities if necessary are more information comes to light

Elicitation

Sizing Sources

- As noted, source sizing can be with data or without data
- A data-based approach should be familiar territory
  - Gather the data together
  - Fit an appropriate PDF to this data e.g. rectangular, triangular, normal, Beta etc.
  - Use the resulting PDF and associated parameters within our model
- What about without data?
- How can we create/define an appropriate PDF without data?
  - Elicitation!

A Simple Scenario Approach

- What follows is a simple approach to elicitation based on a set of defined scenarios

1. Pessimistic outcome scenario
   - Locate the pessimistic end of the range of possible outcomes
   - Effectively defining our point at which 10% or 90% will exceed depending on the case e.g. point at which 10% of costs will exceed
2. Optimistic outcome scenario
   - Estimate a complementary optimistic outcome
   - Perceived chance of being exceeded by 90% or 10% e.g. point at which 90% of costs will exceed

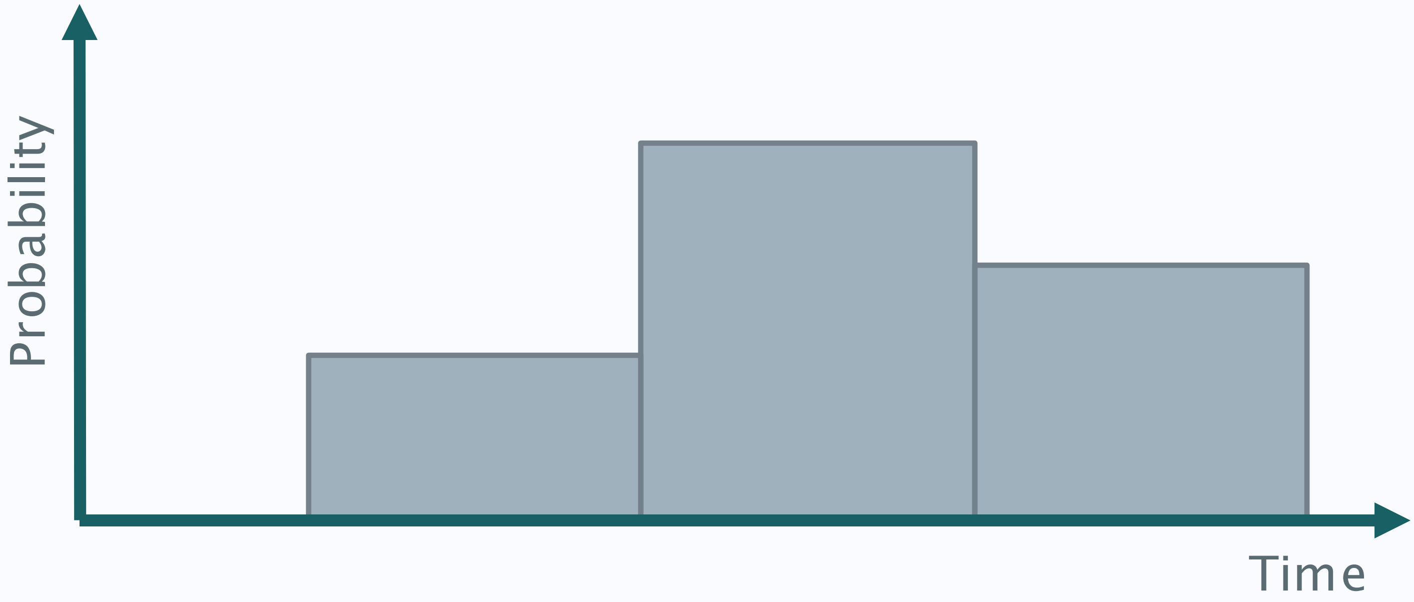
A Simple Scenario Approach

3. Intermediate outcome scenarios
   - Is one interval sufficient or are more required?
   - If more are required, define values for intermediate scenarios
   - Ensure distances between each pairs of adjacent scenario values are equal
   - Assign probabilities to each interval

- Beginning with extremes and working in is an effective way of limiting bias – people tend to underestimate uncertainty
- Keep the scenarios simple where possible
- Assigning fixed probabilities to each interval results in a rectangular histogram approach
  - Can be quite effective at determining expected values

A Simple Scenario Approach

- A simple example…



- Remember this is a PDF so all the usual PDF requirements should apply e.g. $\int f(x)\,dx = 1$

Other PDFs

- The simple scenario-based approach results in a set of rectangular distribution functions defining the overall PDF
- There is, of course, no reason why the values resulting from the elicitation cannot be used to fit other PDFs
- However…
  - Care should be taken to ensure the PDF is appropriate e.g. the tails of a normal distribution
  - The assumption that a more complex PDF equals more precision is not necessarily true e.g. due to inappropriate assumptions
  - Distribution parameters should not be directly elicited e.g. “what do you think the local standard deviation in rainfall is?

Other PDFs

- The triangular distribution can be popular in these circumstances
  - Covers a finite range
  - Middle is more likely
  - Can have some skewness
  - Is relatively transparent compared to other distributions
- Max and min bounds can be elicited, or perhaps more appropriate 10% & 90% values

Other Methods of Elicitation

- Fractile methods
  - Expert is elicited to define a CDF
  - 0%, 50%, 100% values defined initially
  - Divide the two intervals in two i.e. 25% and 75% values
  - Keep sub-dividing as required and fit a smooth curve to the resulting CDF

PUMP – Phase 7

Evaluation

Evaluation

- This phase is at the core of being able to understand the implications of uncertainty
- The PDFs that have been sized in the quantification phase are now combined
- This is then used to inform decision making
- This phase, therefore, includes the presentation & interpretation of results
- All of this is bearing in mind the objectives, assumptions, conditions etc. identified as part of earlier phases of the PUMP

Evaluation

- The main stages include…
  1. Defining an appropriate starting point based on source dependencies
  2. Specifying dependence between sources
  3. Combining sources using mathematical operators
  4. Presenting the results of the model
  5. Diagnosing the implications of these results

Specifying Dependence & Combining Subsets

- Together these are the two key tasks
- This can be a simple set of mathematical operations e.g. consider the combined costs of two items A & B

Cost (£k), C_A or C_B	Probability
8	0.2
10	0.5
12	0.3

Cost (£k), $C_A + C_B$	Computation	Probability
16	0.2×0.2	0.04
18	$0.2 \times 0.5 + 0.5 \times 0.2$	0.20
20	$0.2 \times 0.3 + 0.5 \times 0.5 + 0.3 \times 0.2$	0.37
22	$0.5 \times 0.3 + 0.3 \times 0.5$	0.30
24	0.3×0.3	0.09

Specifying Dependence & Combining Subsets

- However, things are rarely so simple
  - Multiple uncertainty sources combining
  - Multiple different PDF definitions
- This leads us to computational approaches
- How might we solve such problems?
  - Monte Carlo methods!!
- The uncertainty models we've just described are very similar in form to our fault trees
  - An objective decomposed into constituent parts described by a PDF
  - The same modelling processes can therefore be applied here

Independence Assumptions

- We've assumed up to this point that the PDFs are independent
- However, as we saw with our reliability modelling this may not always be the case
- E.g. If the costs of items A and B in the previous example are perfectly correlated then the resulting total cost probability is very different

Cost (£k), C_A or C_B	Probability
16	0.2
20	0.5
24	0.3

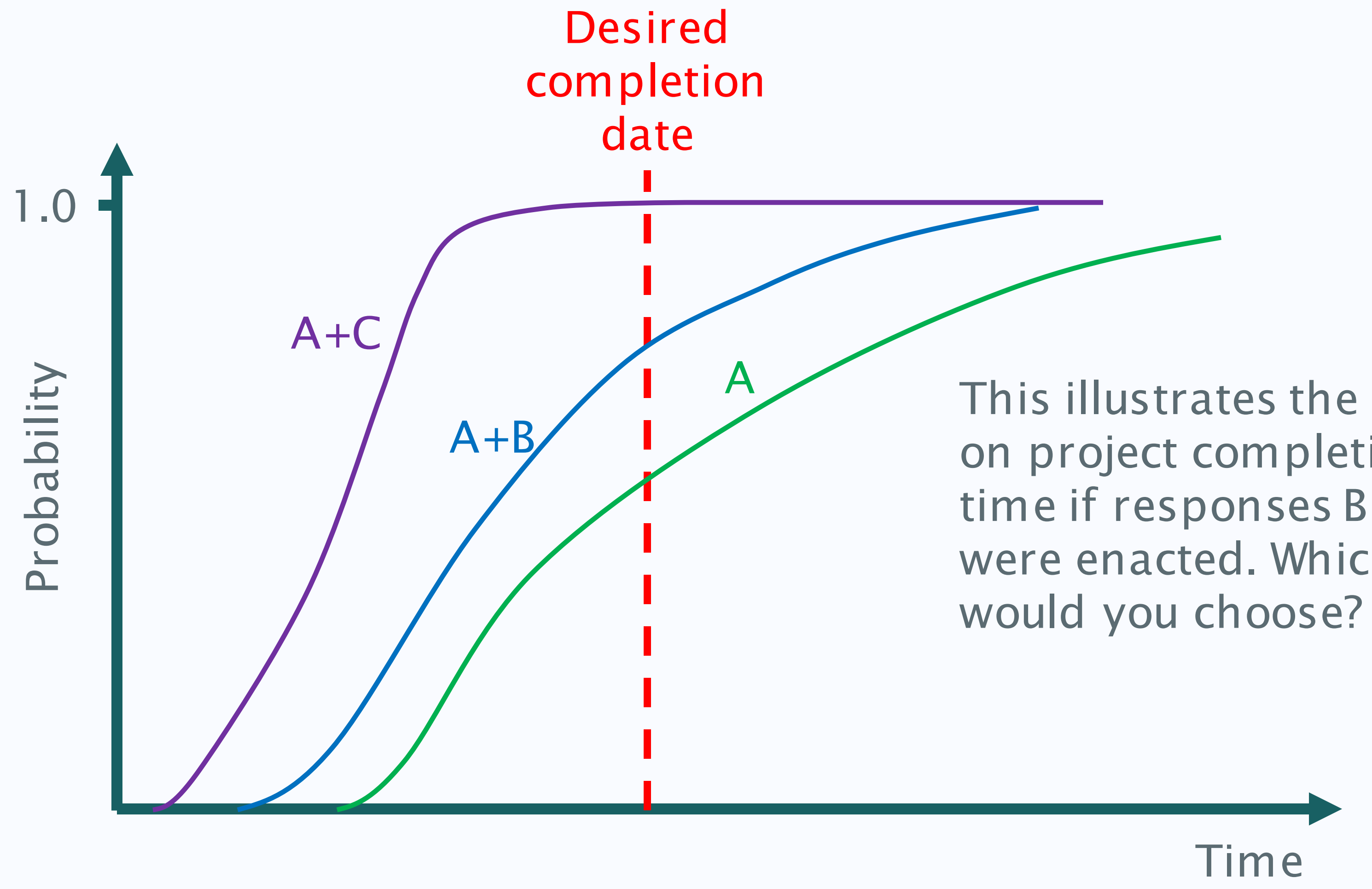
Independence Assumptions

- It's therefore important that any assumptions of independence are identified and challenged
- Within Monte Carlo simulations a coefficient of correlation (or percentage dependence) can be defined
  - 0-1 vs. 0% to 100%
  - Define a linear association between two variables
- Multi-variate distributions may also be appropriate
  - But perhaps introduce elicitation problems
- Breaking down a source further may lead to common initial sources which drive the fundamental correlation
  - E.g. the cost of item A and B could be decomposed into material cost and other costs, where the material cost may be a common PDF

Portraying Effects

- A key output of a PUMP is the presentation or portrayal of the effects of uncertainty
  - This is key in the eventual decision-making process
- This includes tables etc. but figures/diagrams are very important
- Sensitivity diagrams are a useful way of illustrating the cumulative effect of issues/uncertainties
  - Permit different scenarios to be tested
  - Help with decision making

Sensitivity Diagrams



This illustrates the impact on project completion time if responses B or C were enacted. Which would you choose?

Conclusions

- The PUMP framework offers a way in which uncertainty can be captured, quantified, evaluated and its implications determined
- The mathematical foundations of the analysis are very similar to those used in reliability modelling
  - In some respects they are a lot simpler
- However, now we are dealing with situations where data is perhaps not ubiquitous
  - Techniques like elicitation are key
  - Don't forget elicitation can also be effective in reliability modelling!
- We will look at some examples of this type of analysis in future sessions

University of Southampton