SESA6085 – Advanced Aerospace Engineering Management

Lecture 1

2024-2025

Dr David Toal

Lecture Overview

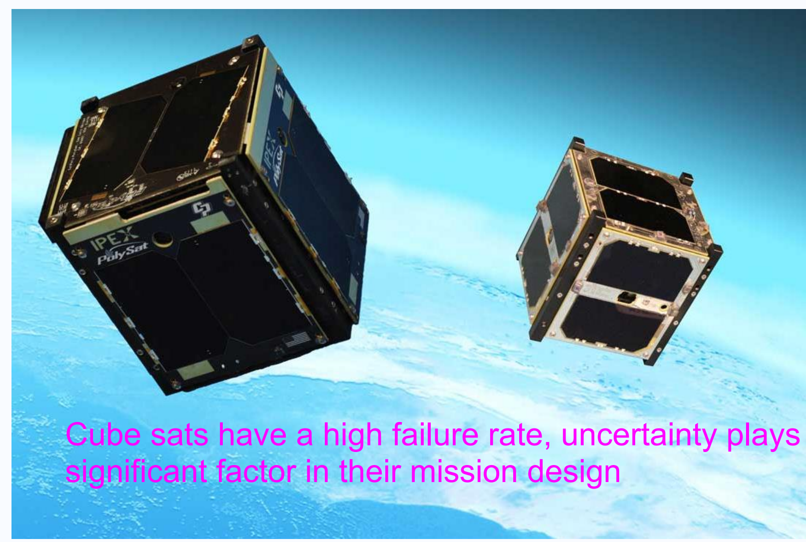
- Module information
  - Learning outcomes & topics
  - Assessment
  - Etc.
- Mathematical fundamentals
  - Notation
  - Probability

Module Overview

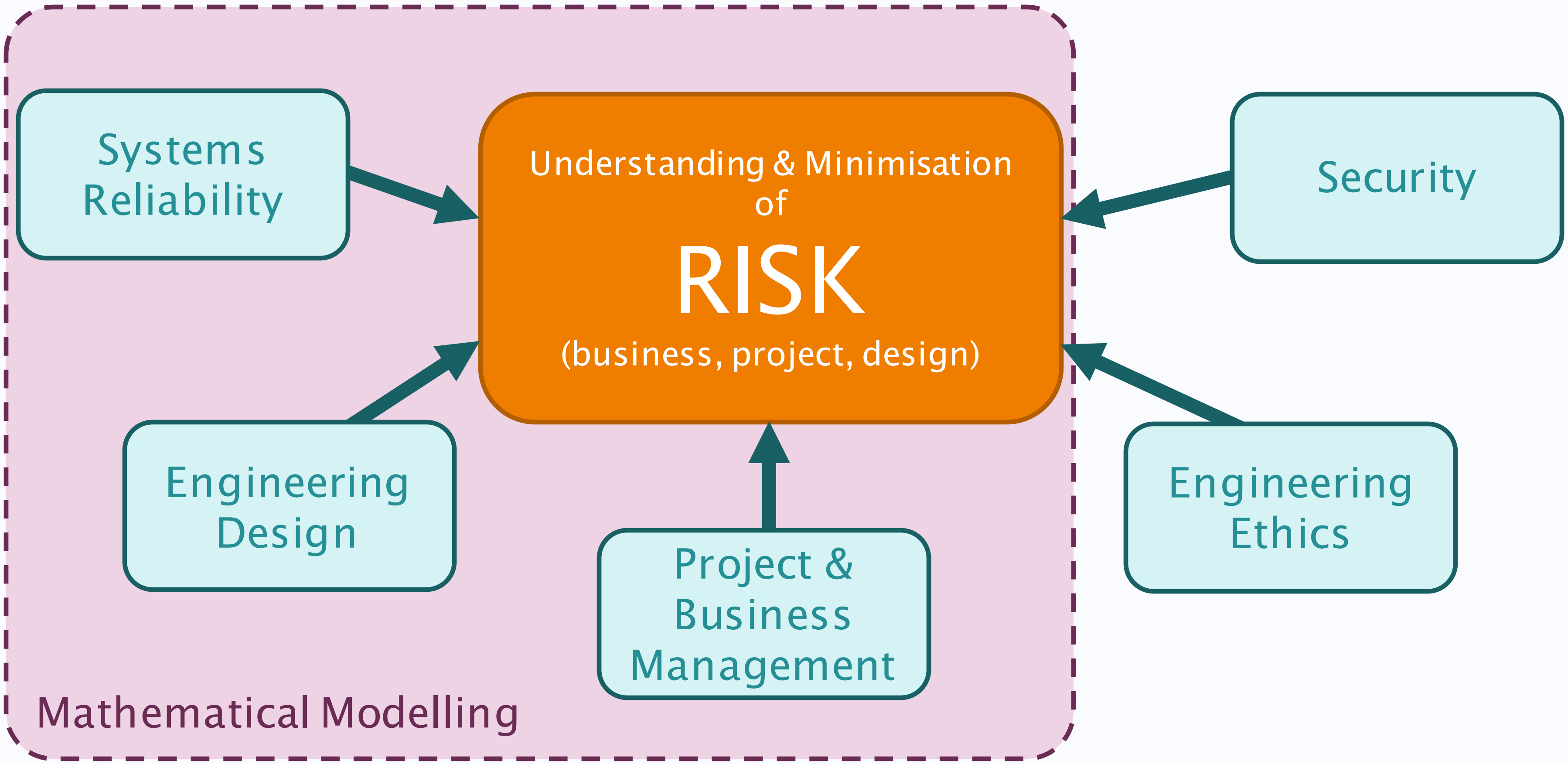
University of Southampton

Advanced Aerospace Engineering Management Uncertainty

Uncertainty?



SESA6085?


Systems Reliability
Understanding & Minimisation of
RISK
(business, project, design)
Security
Engineering Design
Project & Business Management
Engineering Ethics
Mathematical Modelling

Module Learning Outcomes

- The overall aim of this module is to enable students to effectively manage reliability, risk, uncertainty & security within a business or project while operating within an ethical and inclusive manner
- Having successfully completed the module, you will be able to demonstrate **knowledge and understanding** of:
  - Probability theory & statistical modelling and the role that this plays in engineering
  - Ethical practice within engineering
  - The role of inclusivity and diversity within engineering
  - The importance of risk and security within engineering

Module Learning Outcomes

- Having successfully completed this module, you will be **able** to:
  - Interpret the results of a model predicting reliability or uncertainty
  - Explain the working principles behind the methods covered throughout the module
  - Appreciate strengths and limitations of these techniques
  - Model and optimise the reliability of an engineering system
  - Manage uncertainty within a project management context
  - Model and manage uncertainty within engineering design

Overview of Topics

- Statistical Fundamentals for Management
  - Probability theory, rules & notation, sequence trees, Bayes' Theorem
  - Single & multi-variate PDFs and CDFs
  - Statistical model fitting, method of moments, least squares & maximum likelihood estimation (censored & uncensored)
  - Monte Carlo & Quasi-Monte Carlo analysis

Overview of Topics

- Systems Reliability Modelling
  - Series, parallel, m-out-of-n systems and balanced systems
  - Reliability block diagram analysis & decomposition
  - Active & inactive redundancy
  - Determining component importance
  - Fault tree analysis
  - Competing risk models
  - Load sharing systems
  - Optimal maintenance scheduling

Overview of Topics

- Management of Uncertainty, Risk & Security
  - Business continuity planning
  - Project risk modelling & management
  - Supply chain uncertainty and management
  - Task scheduling & resource planning
  - Designing for reliability (inc. FMEA)
  - Designing in the presence of uncertainty / robust design
  - Robust regularisation, aggregation & randomised techniques for robust design
  - Cyber security
  - Intellectual property management & export control
  - Concurrent & collaborative design processes

Overview of Topics

- Engineering Ethics & Inclusivity
  - Ethical practice including, accuracy & rigor, honesty & integrity, responsible leadership and respect for life, law and the public good
  - Case studies in engineering ethics
  - Diversity & inclusion
  - Design for inclusivity

Timetable

- Three timetabled lecture theatre slots per week
  - Monday 12:00 – 13:00, 54/4011
  - Tuesday 15:00 – 16:00, 7/3009
  - Friday 15:00 – 16:00, 54/4011
- These slots will be split between formal lectures and tutorials
- “Tutorials” will include
  - Solutions to self-paced tutorial problems
  - Case studies
  - Revision

Slides, Blackboard & Recordings

- All slides will be made available on Blackboard
  - Tutorial slides will go live at the start of the tutorial session
- All lectures and tutorials will be recorded on Panopto
- Practice question workbook
  - Solutions considered during the tutorials
- Practice papers with solutions provided

- Please email me if you do not have Blackboard access!
  - djjt@soton.ac.uk

Module Assessment

- Final written exam – 80%
  - 2 hours (TBC November)
  - Questions can be from any topic covered in the module
- Coursework – 20%
  - Based on the techniques taught throughout the module
  - Mix of analytical and practical tasks
  - Individual work to be submitted via e-assignments:
  - On time (2 weeks) - 12th November – 26th November
  - Properly, clearly, and neatly documented
  - Including any code/scripts/spreadsheets as an appendix

Software

- There is no requirement to use a particular piece of software to solve any of the coursework problems
- Use whatever you are comfortable with
  - Excel, Matlab, Python etc. are all acceptable
- Upload any scripts, code, spreadsheets etc. with any submissions
- The goal is to get the correct solution using the correct methodology not assess your coding skills

Textbooks

- Elsayed, E., “Reliability Engineering” (2nd Edition), ISBN: 978-1-118-13719-2 (e-book available)
- O’Connor, P., “Practical Reliability Engineering (4th Edition)”, ISBN: 978-0470844632 (e-book available)
- Crowder, Kimber & Sweeting, “Statistical Analysis of Reliability Data”, ISBN: 978-0412594809
- Soong, T.T., “Fundamentals of Probability and Statistics for Engineers”, ISBN: 978-0470868133 (e-book available)
- Chapman, C. and Ward, S. “How to Manage Project Opportunity and Risk: Why uncertainty management can be a much better approach than risk management”, ISBN: 978-1-119-96666-1 (e-book available)

Textbooks

- Pinto, J.K., “Project management - Achieving competitive advantage”, ISBN: 978-1292269146 (e-book available)
- Laudon K.C. and Laudon J.P, “Management Information Systems: Managing the Digital Firm”, ISBN: 978-9332548909 1 (e-book available)
- Christopher, M., “Logistics & supply chain management”, ISBN: 978-1-292-08379-7
- Royal Academy of Engineering, “Engineering ethics in practice: a guide for engineers”, ISBN: 1-903496-74-8

- N.B. You do not need to purchase these but for those interested they should all be available from the library in print or digital

Contact Details

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- Office Hours: By appointment

Questions?

Mathematical Fundamentals

Definition of Probability

1. If an event can occur in N equally likely ways, and if the event with attribute A can happen in n of these ways, then the probability of A occurring is

$$\boxed{P(A) = \frac{n}{N}}$$

Covers events of equal probability e.g. dice

2. If an event with attribute A occurs n times out of N experiments, as N becomes large, the probability of event A approaches

$$\boxed{P(A) = \lim_{N \to \infty} \left(\frac{n}{N} \right)}$$

Typically encountered in quality control & reliability i.e. out of 100 items tested 30 are defective, P(A) =0.3

Probability Rules & Notation

1. The probability of obtaining an outcome *A* is denoted by *P(A)*

2. The *joint* probability that both *A* ***and*** *B* occur is denoted by *P(AB)*

3. The probability that either *A* ***or*** *B* occurs is denoted by *P(A+B)*

4. The *conditional* probability of obtaining outcome *A*, *given that B has already occurred*, is denoted by $P(A|B)$

Probability Rules & Notation

5. The probability of the complement, i.e. *A not* occurring is

$$P(\overline{A}) = 1 - P(A)$$

6. If and only if events *A* and *B* are *statistically independent (s-independent)*, then *P(A)* is unrelated to whether or not *B* occurs, and vice versa

$$P(A \mid B) = P(A \mid \overline{B}) = P(A)$$

$$P(B \mid A) = P(B \mid \overline{A}) = P(B)$$

Probability Rules & Notation

7. The *joint* probability of occurrence of two *s-independent* events *A* and *B* is the product of individual probabilities:

$$P(AB) = P(A)\,P(B)$$

- This is also called the *product rule* or *series rule*.
- Example: The probability of getting two 6's by throwing a set of die.

$$P(6 \text{ and } 6) = P(6)\,P(6) = \frac{1}{6} \times \frac{1}{6} = \frac{1}{36}$$

Probability Rules & Notation

8. If event A and B are *s-dependent*, then

$$P(AB) = P(A)\,P(B \mid A) = P(B)\,P(A \mid B)$$

- If $P(A) \neq 0$

$$P(B \mid A) = \frac{P(AB)}{P(A)}$$

Probability Rules & Notation

- Consider a pack of 52 playing cards
- What is the probability of picking a queen then a jack without replacing the queen?

$$P(A) = {}^{4}\!/_{52}$$

$$P(B \mid A) = {}^{4}\!/_{51}$$

$$P(AB) = P(A)\,P(B \mid A) = {}^{4}\!/_{52} \times {}^{4}\!/_{51} = {}^{16}\!/_{2652}$$

Probability Rules & Notation

9. The probability of events A or B occurring is:

$$P(A+B)=P(A)+P(B)-P(AB)$$

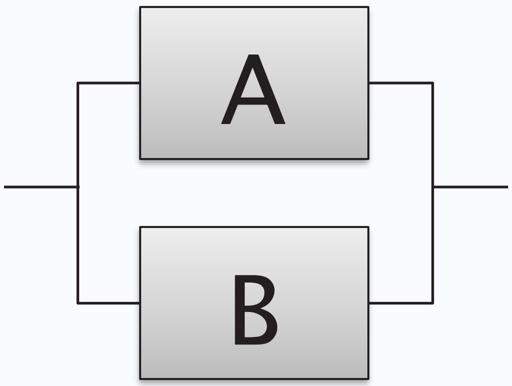
10. The probability of *A* or *B* occurring, if *A* and *B* are *s-independent*, the above equation simplifies to

$$P(A+B)=P(A)+P(B)-P(A)P(B)$$

Consider now the derivation of this equation using the example of a double redundant system

Dual redundant system

- In this system either *A* or *B*, or *A* and *B* must work for the system to work. If we denote success probability as P_s and failure probability as $P_f = 1 - P_s$



$$P_f = P(\overline{A})P(\overline{B})$$

$$P_f = [1 - P(A)][1 - P(B)] = 1 - P(A) - P(B) + P(A)P(B)$$

$$P_s = 1 - P_f = P(A + B) = P(A) + P(B) - P(A)P(B)$$

Probability Rules & Notation

11. If the events *A* and *B* are mutually exclusive (*A* and *B* cannot occur simultaneously), then

$$P(AB) = 0$$

$$P(A+B) = P(A) + P(B) - \underbrace{P(AB)}_{=0}$$

$$P(A+B) = P(A) + P(B)$$

Probability Rules & Notation

- A perfect 12 sided dice has the numbers 1 to 12 printed on it. What is the probability of getting a number *less than* 5
- All of the events are mutually exclusive e.g. you can't role a 1 and a 2

$$P(1) = P(2) = P(3) = P(4) = \frac{1}{12}$$

$$P(<5) = P(1) + P(2) + P(3) + P(4) = \frac{1}{3}$$

Probability Rules & Notation

12. If multiple, mutually exclusive probabilities of outcomes B_i jointly give the probability of outcome A, then

$$P(A) = \sum_i P(AB_i) = \sum_i P(A \mid B_i) P(B_i)$$

Missile Launch Example 1

- The reliability of a missile is 0.85. If two missiles are fired, what is the probability of at least one hit? (Assume s-independence of missile hits)
- Let's call the event 'first missile hits' A, and the event 'second missile hits' B

$$P(A) = P(B) = 0.85$$

$$P(\overline{A}) = P(\overline{B}) = 0.15$$

Missile Launch Example 1 – Solution 1

- There are four possible outcomes

$$\underbrace{AB,\ A\overline{B},\ \overline{A}B}_{\text{In these instances at least one missile hits}},\ \overline{A}\,\overline{B}$$

- The probability of both missing is

$$P\left(\overline{A}\,\overline{B}\right) = P\left(\overline{A}\right)P\left(\overline{B}\right) = (0.15)\times(0.15) = 0.0225$$

- The probability of at least one hit is

$$P_s = 1 - P\left(\overline{A}\,\overline{B}\right) = 1 - 0.0225 = 0.9775$$

Missile Launch Example 1 – Solution 2

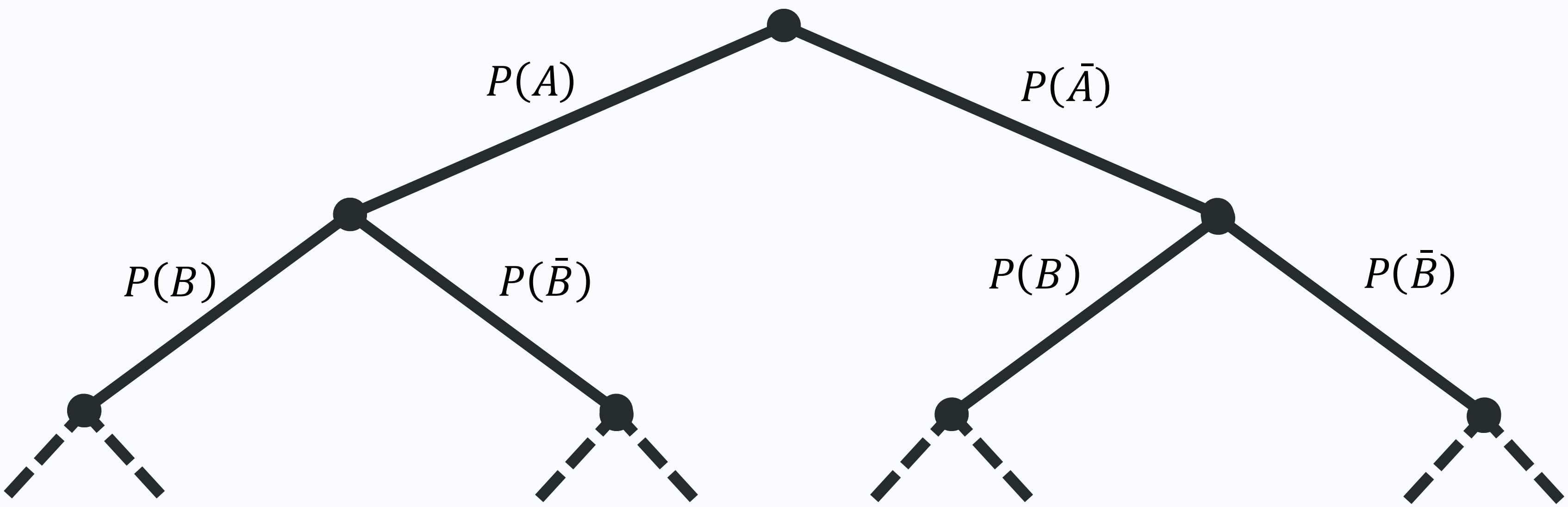
- Alternatively, we can also directly use the following equation

$$P(A+B)=P(A)+P(B)-P(A)P(B)$$

$$P(A+B)=0.85+0.85-0.85^2=0.9775$$

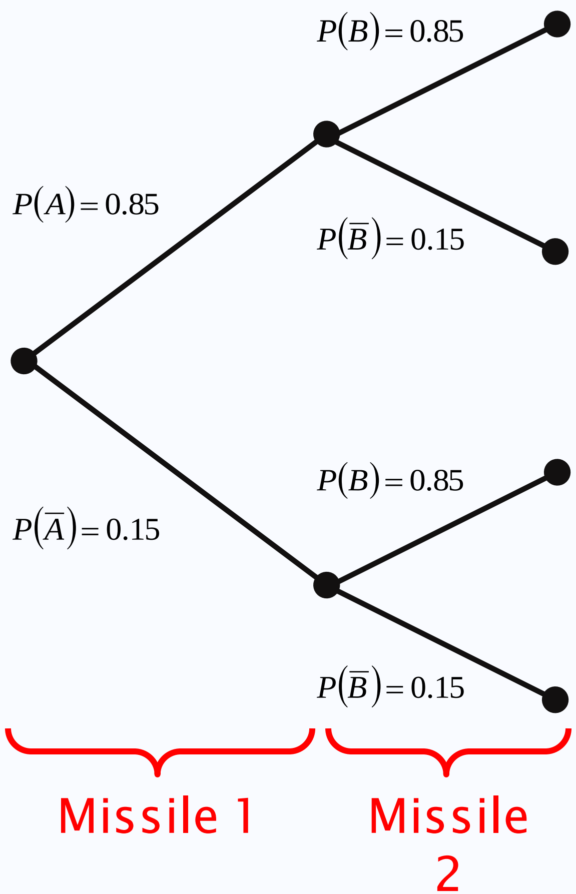
Sequence Tree Diagrams

- Offer a simple way of visualising interactions in order to calculate overall probabilities



- Final probabilities can be calculated by summing together the relevant final leaves

Missile Launch Example 1 – Solution 3



$$P(AB) = P(A)P(B) = 0.85 \times 0.85 = 0.7225$$

$$P(A\overline{B}) = P(A)P(\overline{B}) = 0.85 \times 0.15 = 0.1275$$

$$P(\overline{A}B) = P(\overline{A})P(B) = 0.15 \times 0.85 = 0.1275$$

$$P(\overline{A}\,\overline{B}) = P(\overline{A})P(\overline{B}) = 0.15 \times 0.15 = 0.0225$$

$$\boxed{P_s = P(AB) + P(A\overline{B}) + P(\overline{A}B) = 0.9775}$$

Missile Launch Example 2

- Now assume that the missile hits in Example 1 are not s-independent.
- If the first missile fails, the probability that the second will also fail is 0.2 (not 0.15 as in Example 1)
- If the first missile hits, the hit probability of the second missile is still 0.85
- What is the probability of at least one hit?

Missile Launch Example 2 – Solution 1

- Given

$$P(A) = 0.85$$

$$P(B \mid A) = 0.85$$

$$P(\overline{B} \mid A) = 0.15$$

$$P(\overline{B} \mid \overline{A}) = 0.20$$

$$P(B \mid \overline{A}) = 0.80$$

- The probability of at least one hit is

$$P(AB) + P(\overline{A}B) + P(A\overline{B})$$

Missile Launch Example 2 – Solution 1

- Since there is no effect of the first hit on the events of the second missile (hit or miss)

$$P(AB) = P(A)P(B) = 0.85 \times 0.85 = 0.7225$$
$$P(A\overline{B}) = P(A)P(\overline{B}) = 0.85 \times 0.15 = 0.1275$$

- However, there is an s-dependency between the first miss and the second hit. Therefore

$$P(\overline{A}B) = P(\overline{A})P(B \mid \overline{A}) = 0.15 \times 0.80 = 0.12$$

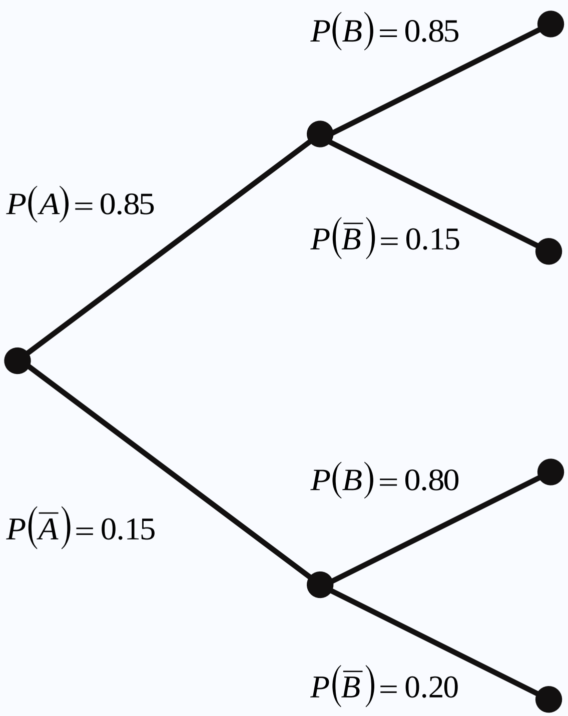
Missile Launch Example 2 – Solution 1

- The probability of at least one hit is therefore the sum of these probabilities

$$P(AB)+P(\overline{A}B)+P(A\overline{B})=0.7225+0.1275+0.12=0.97$$

Missile Launch Example 2 – Solution 2

- Once again we can also use a sequence tree diagram



Two hits : $P(AB) = P(A)P(B) = 0.85 \times 0.85 = 0.7225$

One hit : $P(A\bar{B}) = P(A)P(\bar{B}) = 0.85 \times 0.15 = 0.1275$

One hit : $P(\bar{A}B) = P(\bar{A})P(B) = 0.15 \times 0.80 = 0.12$

No hit : $P(\bar{A}\bar{B}) = P(\bar{A})P(\bar{B}) = 0.15 \times 0.20 = 0.03$

$$\boxed{P_s = P(AB) + P(A\bar{B}) + P(\bar{A}B) = 0.97}$$

Probability Rules & Notation

- Recall that if event A and B are *s-dependent*, then

$$P(AB) = P(A)\,P(B \mid A) = P(B)\,P(A \mid B)$$

- And $P(A) \neq 0$

$$P(B \mid A) = \frac{P(AB)}{P(A)}$$

Baye's Theorem – Simple Form

- Rearranging this part of the formula

$$P(A)P(B|A) = P(B)P(A|B)$$

- Gives

$$\boxed{P(A|B) = \frac{P(B|A)P(A)}{P(B)}}$$

- If $P(B) \neq 0$

This is a simple form of Bayes' Theorem

Baye's Theorem – Generalised Form

- The probability of event B can be expressed as

$$P(B) = \sum_j P(B|A_j)P(A_j)$$

- Leading to the generalized form of Baye's Theorem

$$\boxed{P(A_i|B) = \frac{P(B|A_i)P(A_i)}{\sum_j P(B|A_j)P(A_j)}}$$

- Where A_j is the jth event affecting the event B

Baye's Theorem – Binary Partitions

- When the probability of event B depends on the probability of event A happening and not happening, the generalised Bayes' theorem simplifies to

$$\boxed{P(A|B) = \frac{P(B|A)P(A)}{P(B|A)P(A) + P(B|\bar{A})P(\bar{A})}}$$

Applications of Baye's Theorem

- Baye's Theorem is an important result in probability mathematics and has a number of wide-ranging applications
  - Defining overlapping regions of probability density functions
  - Applying priors to the parameters defining probability density functions during their construction etc.

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