QRA Model with Probabilistic Parameters and Its Application for Road Tunnels

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Contents

Background

➢ Background

- ✓ A risk criteria is deemed *required* for *tunnel >240 m* in Singapore (*the Road Traffic Act, 2005*)
- ✓ EU Directive shows that the *risk assessment* is compulsory for *every* road tunnel in Europe *(EU Directive, 2004)*
- ✓ A project *quantitative risk assessment of road tunnels* collaborated with LTA

Background

- Input parameters
  - ✓ Frequency of fire in tunnel *(no fire record in CTE since it was officially open in 1989)*
  - ✓ Probability of fire detection system fails to work
  - ✓ Probability of tunnel ventilation system fails to work
  - ✓ Air velocity when tunnel ventilation fails to work
  - ✓ Evacuate time when fire detection system fails to work
  - ✓ ……

Uncertainty is an unavoidable element affecting outputs of the model!

Background

- How to represent uncertainties?
  - ✓ Probability theory (pdf)
  - ✓ Fuzzy theory (membership function)
  - ✓ Evidence theory
  - ✓ Uncertainty theory
  - ✓ ……

Background

- Literature review and objective
  - ✓ Huang et al. (2000) initially considered the fuzzy parameters in event tree analysis
  - ✓ Baraldi and Zio (2008) took the uncertainty propagation in event tree analysis into consideration
  - ✓ This paper will deal with the uncertainty propagation in quantitative risk assessment

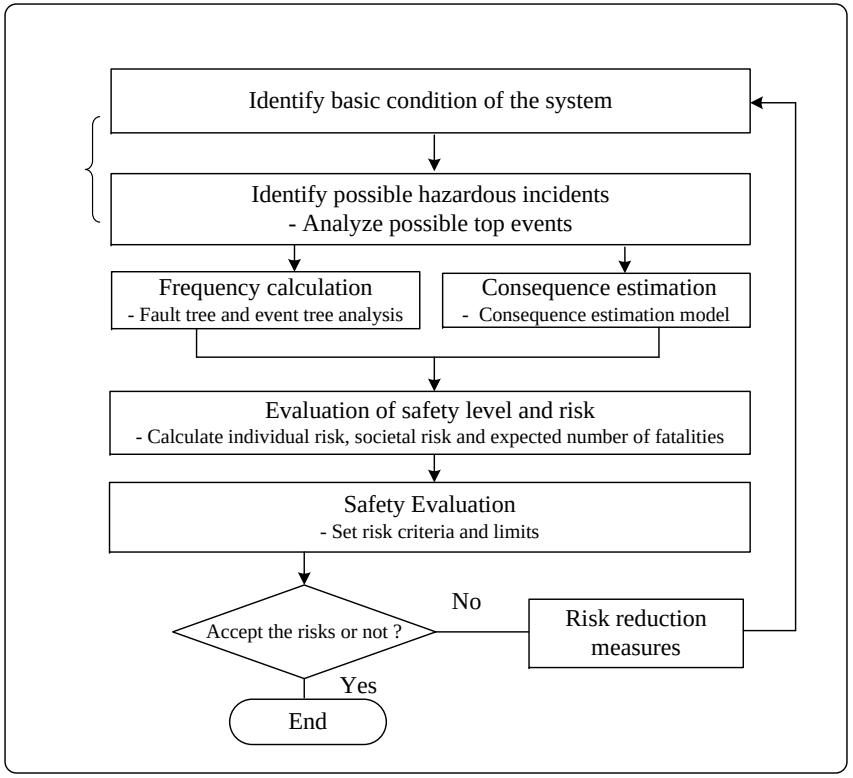
Contents

QRA Model Review

- Introduction
  - ✓Use reliability and statistics to engineering design
  - ✓Proposed by US Atomic Energy Commission for evaluating the safety level of nuclear power plant *(US Atomic Energy Commission, 1957)*
  - ✓To assess the safety level of hazardous installations such as road tunnel, nuclear power plant, work zone, and etc.

QRA Model Review

➢ Procedure



QRA Model Review

- Input and output of the model
  - ✓Input parameters
    - Probability of fire detection system fails to work
    - Probability of tunnel ventilation system fails to work
    - Air velocity when tunnel ventilation fails to work
    - Evacuate time when fire detection system fails to work
    - ……
  - ✓Output
    - Frequency and consequence of each particular scenario
    - Risk index (societal risk and expected number of fatalities)

QRA Model Review

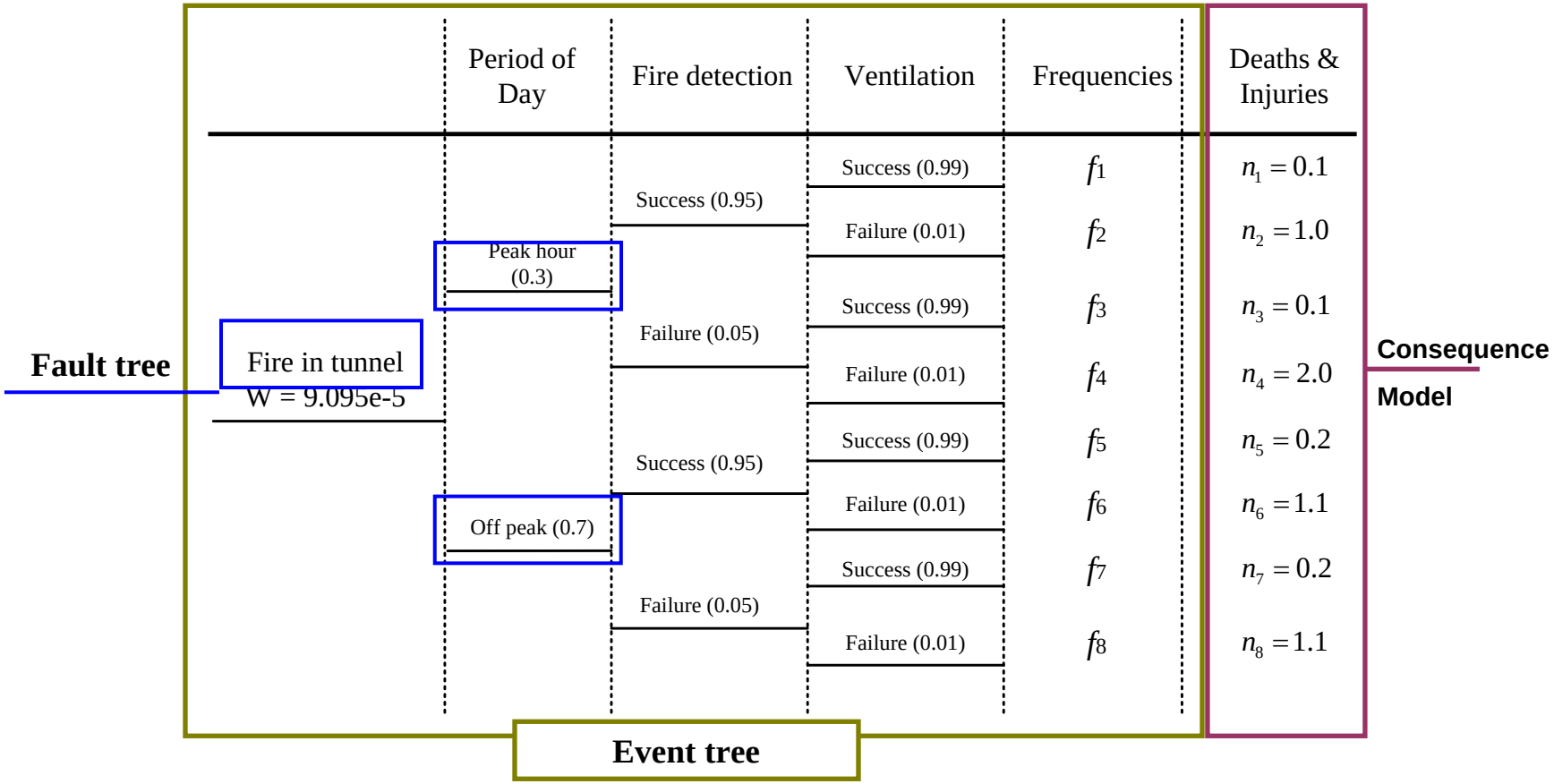
- Top events
  - ✓Depends on expert judgment and historical record
  - ✓Trigger the event tree
- Fault tree
  - ✓Estimate the frequency of top event
  - ✓Present all possible causes rendering a single event

QRA Model Review

- Event tree
  - ✓All the possible scenarios
  - ✓Different frequencies and consequences
  - ✓Example road tunnel

QRA Model Review

- Event Tree for road tunnels

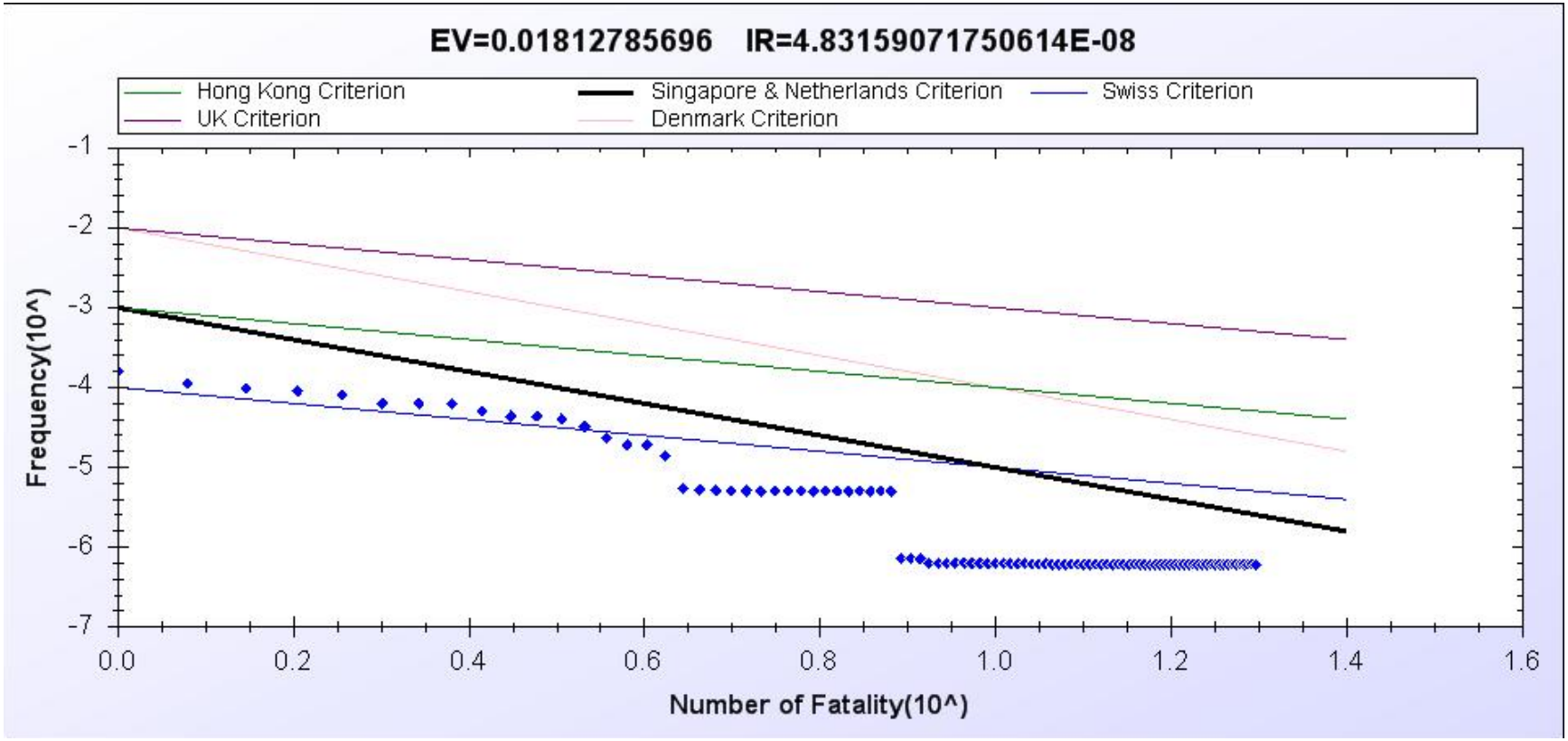


QRA Model Review

- Risk Index
  - ✓Expected number of fatalities
  - ✓Societal risk
    - Relationship between the frequency and number of people suffering from a specified level of harm from a top event
    - Represented by F/N curve
      - ✓ F: likelihood of N or more fatalities (frequency)
      - ✓ N: number of fatalities
    - Widely used in risk assessment for hazardous installations

QRA Model Review

- Societal risk



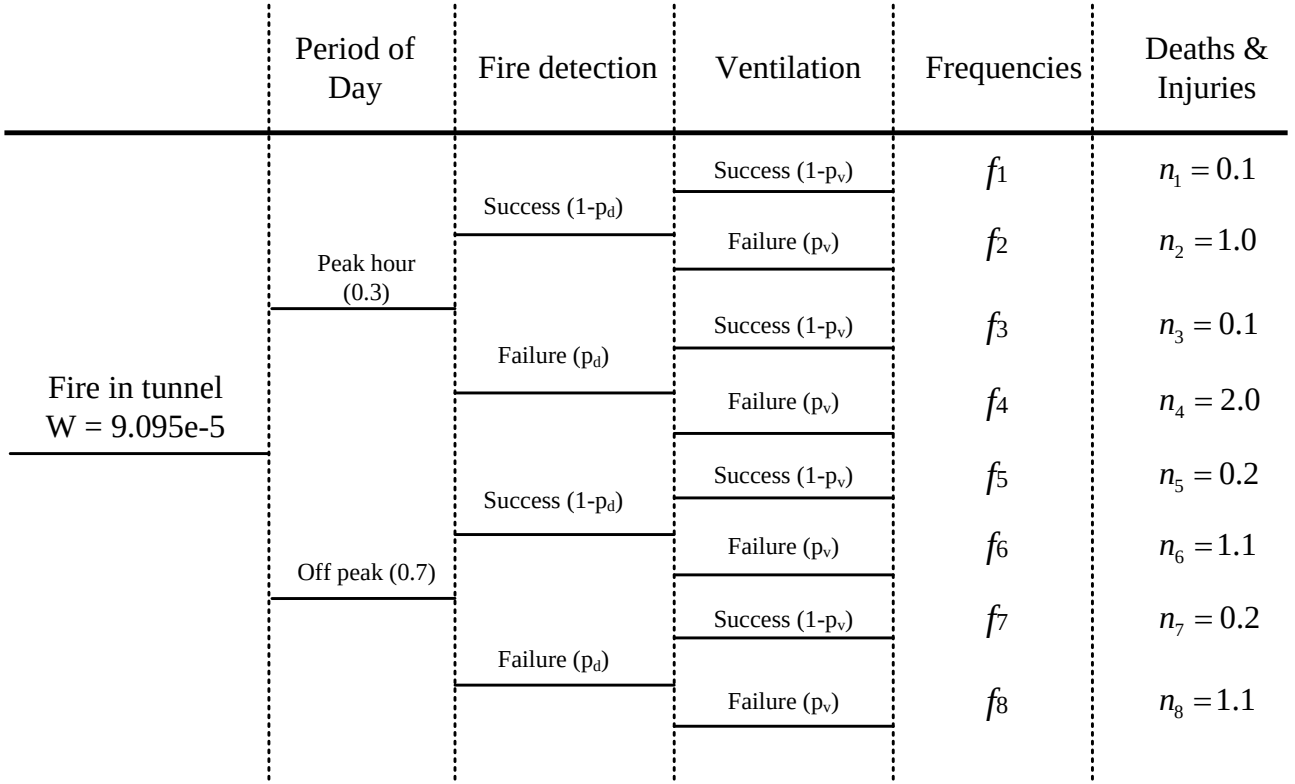
Contents

QRA with Uncertain Parameters

- Probabilistic Parameters
  - ✓Event tree parameters
  - ✓Fault tree parameters
  - ✓Consequence parameters

QRA with Uncertain Parameters

- Example



QRA with Uncertain Parameters

- Methodology (Monte Carlo Simulation)
  - ✓ Step 1: sample the *ith* realization of the probabilistic variable vector
  - ✓ Step 2: compute the frequencies and fatalities for the *ith* realization
  - ✓ Step 3: return to step 1 and repeat
  - ✓ Step 4: stop when all the realizations are computed

The number of fatalities and frequencies of each scenario are uncertain variables which has n realizations

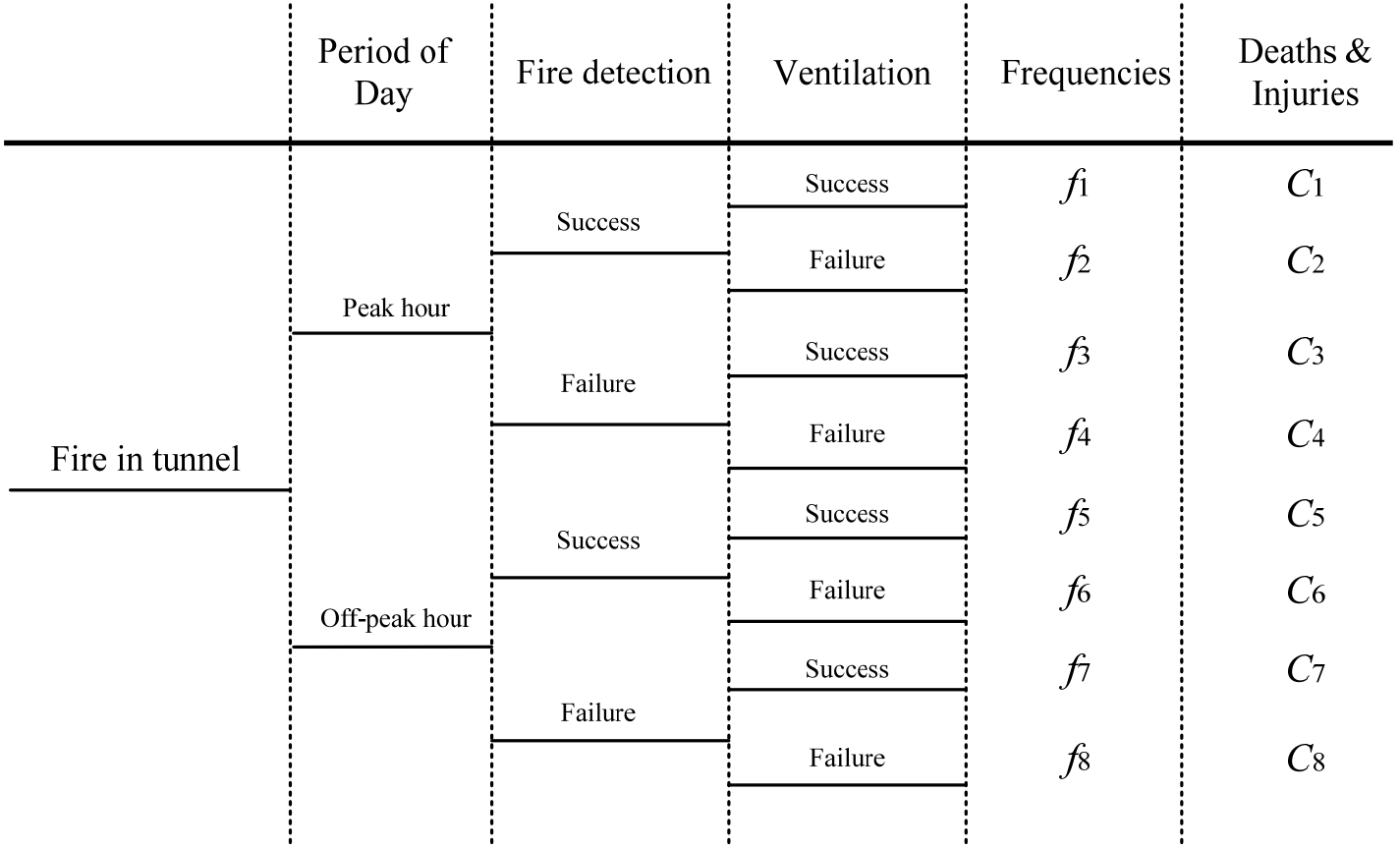
QRA with Uncertain Parameters

- Risk indices
  - ✓ Expected number of fatalities (Uncertain variables)
  - ✓ Societal risk
    - Each realization has a societal risk

Contents

Application for Road Tunnels

- Event tree structure

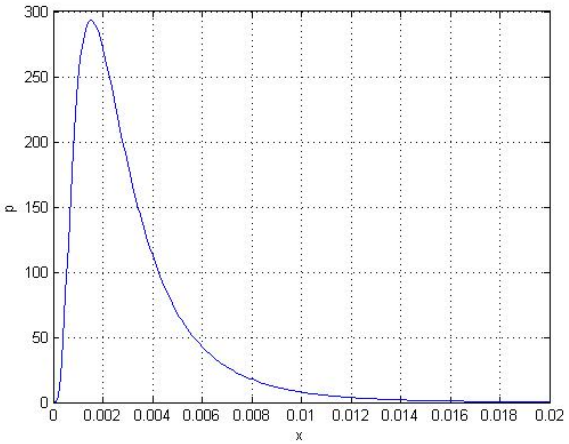


Application for Road Tunnels

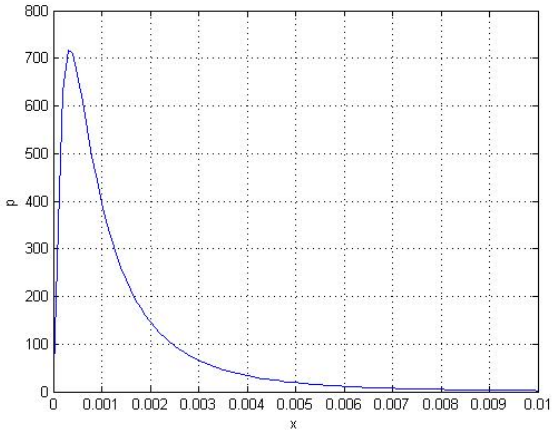
- Probabilistic parameters
  - ✓Probability of fire detection working normally
  - ✓Probability of ventilation system working normally
  - ✓Evacuate time when fire detection works normally
  - ✓Evacuate time when fire detection fails to work
  - ✓Air velocity when ventilation system fails to work
  - ✓Air velocity when ventilation system works normally
  - ✓……

Application for Road Tunnels

- Probabilistic parameters



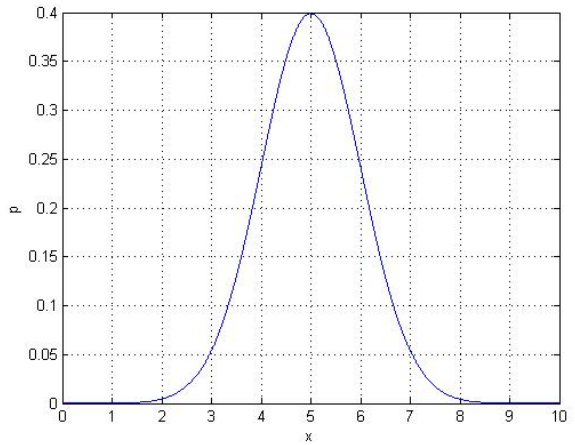
Detection failure rate pdf



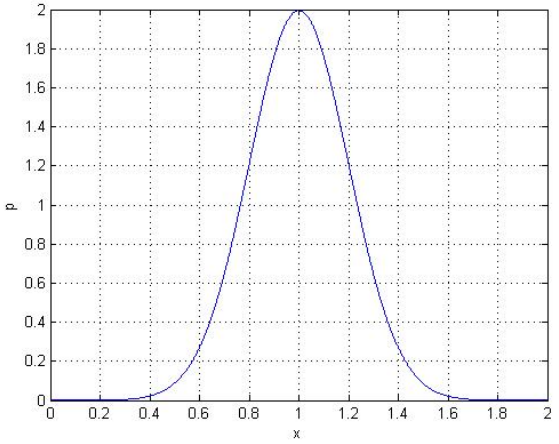
Ventilation failure rate pdf

Application for Road Tunnels

- Probabilistic parameters



Air velocity (ventilation normal)



Air velocity (ventilation failure)

Application for Road Tunnels

- Frequency estimation model

$$f_j^{(i)} = \prod_{k=1}^{K} P\left(E_k \middle| S_j\right)$$

- Consequence estimation model

$$F_{o_2} = \frac{t}{e^{8.13-0.54(20.9-X_{o_2})}}$$

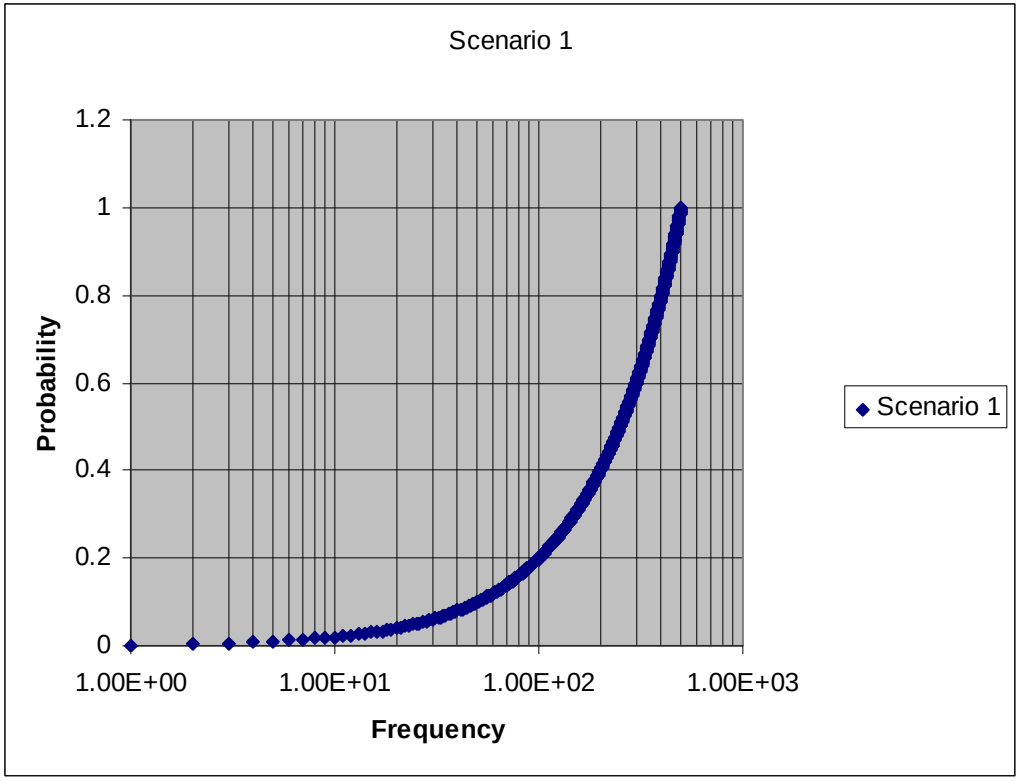
$$F_{CO} = \frac{K\left(X_{CO}{}^{1.036}\right)t}{D}$$

$$F_{DH} = F_{DH}(t,T) = t / e^{(5.1849-0.0273T)}$$

$$F_{co_2} = \frac{t}{e^{6.1523-0.5189*X_{co_2}}}$$

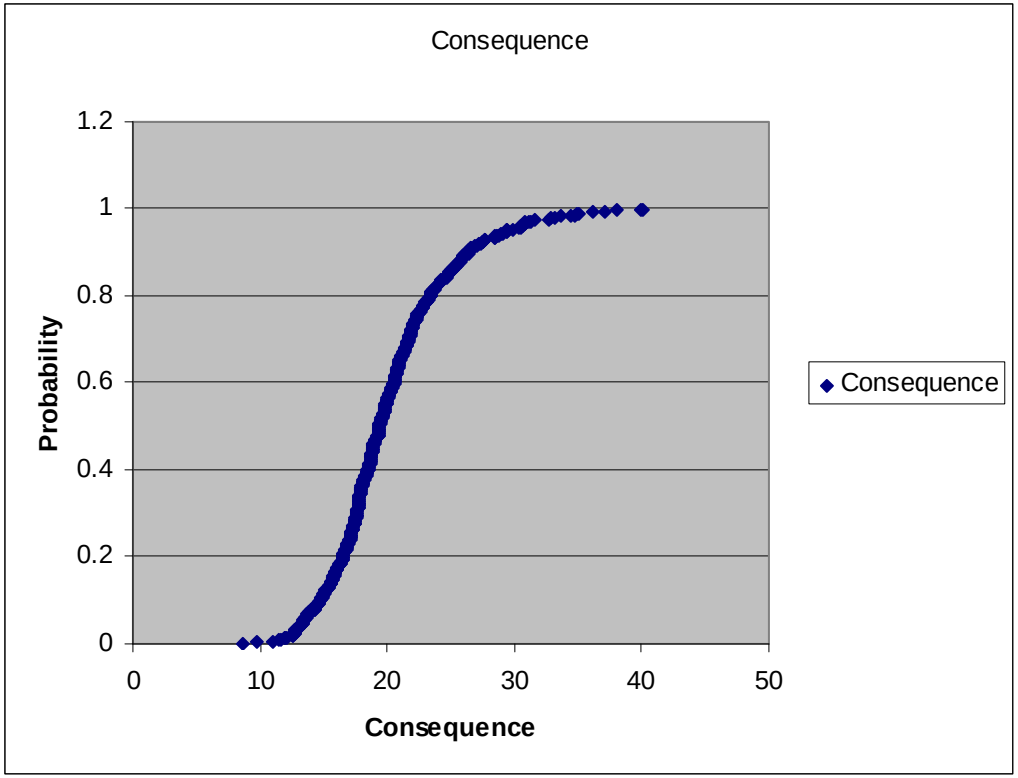
Application for Road Tunnels

- Frequencies of Scenario 1



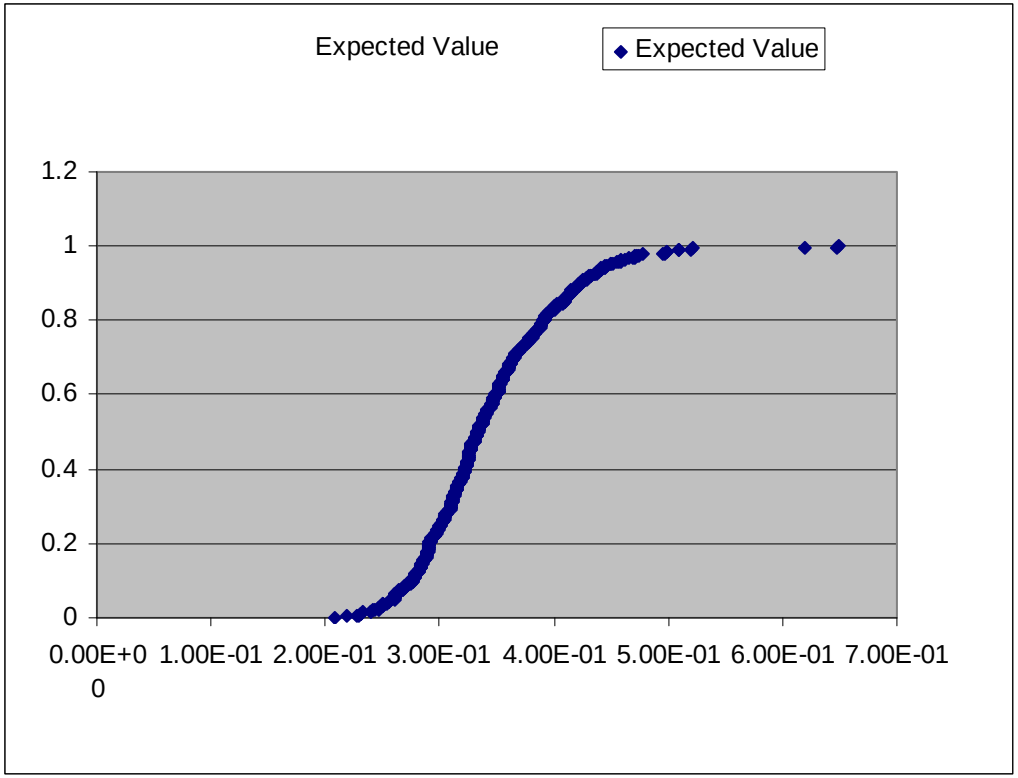
Application for Road Tunnels

- Consequences of Scenario 1



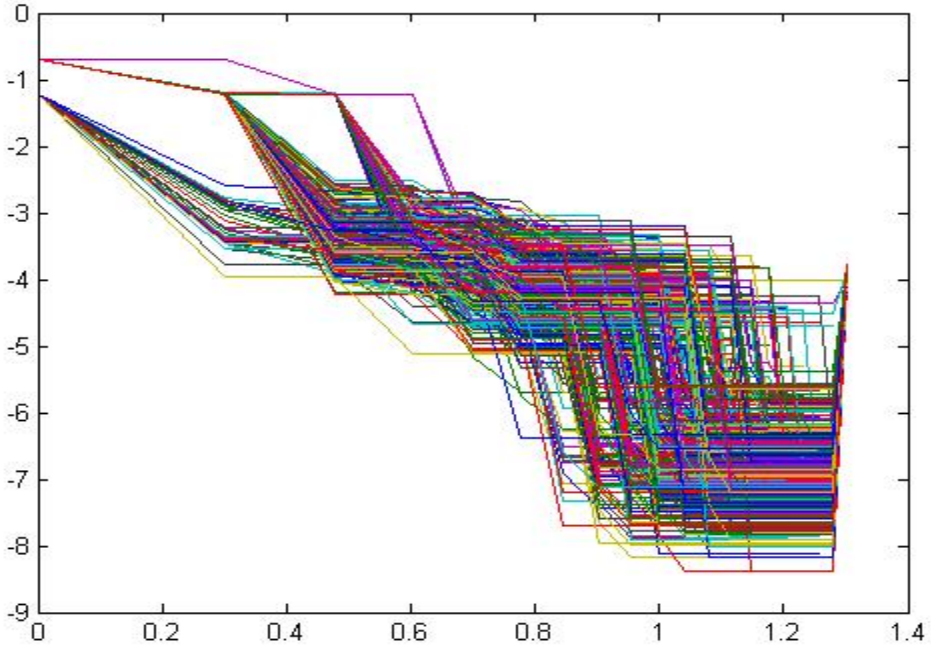
Application for Road Tunnels

- Expected Number of Fatalities



Application for Road Tunnels

- Societal risk



Contents

Conclusion and Future work

- Conclusion
  - ✓Proposed an approach to take the variability of parameters into account
  - ✓Apply the new model to road tunnel in Singapore
  - ✓Propose the risk index for new model

Conclusion and Future work

- Future Work
  - ✓Degree of uncertainty
  - ✓Fuzzy or uncertainty
  - ✓Risk deduction
  - ✓Uncertainty deduction