Integrated Systems Understanding using Bayesian Networks: Measuring the Effectiveness of a Weapon System

Pretoria

Defence, Peace, Safety & Security

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Summary

- Modelling of Complex Systems
  - System-of-systems
  - Independent research
  - Lack of whole systems view
- Approach: Causality
  - Derive causal relationships from combinations of knowledge and data
  - Improve understanding of system behaviour
- Causal Inference
  - Identify sensitive variables in the system
  - Identify interdependencies between sub-systems
  - Predict the effects of actions and policies
  - Evaluate explanations for observed events and scenarios
  - Support decisions

Research Case Study: Measure the effectiveness of the FSG Weapon System

- Weapon system onboard Corvettes
- System-of systems:
  - designation radar
  - tracking radar
  - electro-optical tracking sensor
  - combat management system
  - missile system.
- Define, measure and quantify *being effective*

Approach: Causal Modelling

- Cause-and-effect relationships between system variables
- Introduce realistic scenario variables such as ‘natural environment’
- Quantify the cause-and-effect relationships
- Evaluate the weapon system behaviour and performance

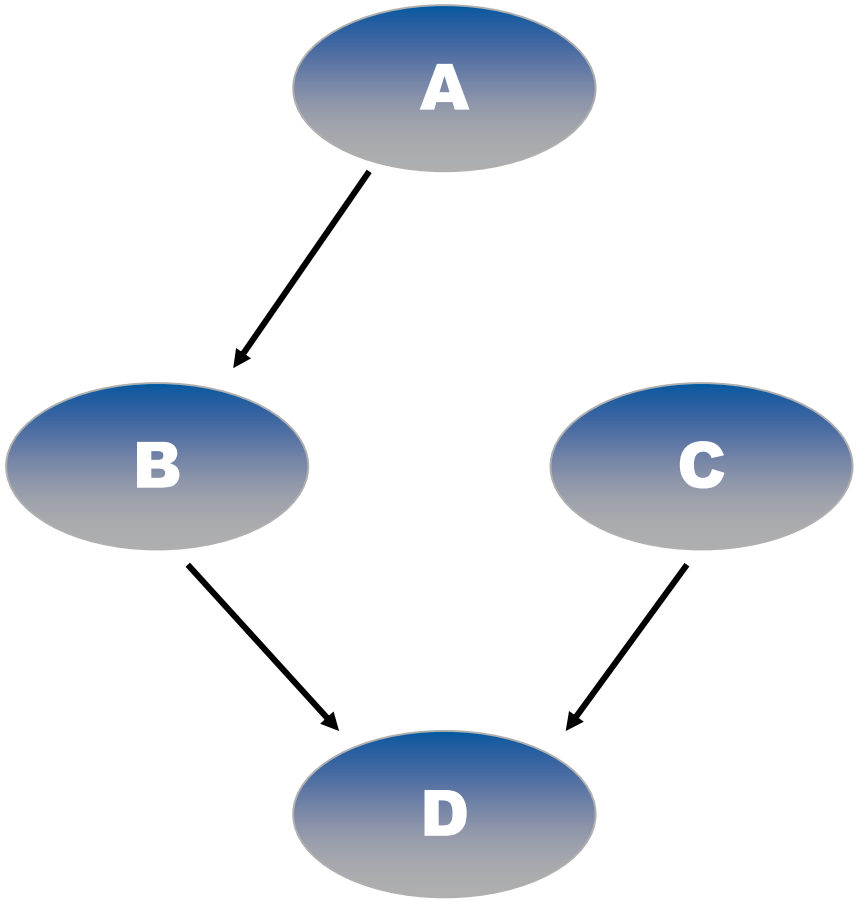
- Graphical Notation: represents causality
- Probabilities: represents causal inference

Bayesian Networks: A marriage of graphs and probabilities

- Causal Graph
  - Diagonal Acyclic Graph (DAG)
    - Nodes (represents variables)
    - Arrows (represents causal links between variables)

- Causal Inference
  - Need the joint probability distribution of variables in DAG
  - Without independence assumption, the joint probability distribution grows exponentially
  - Graphs facilitate decomposition of large distribution functions: conditional independence assumption

$$P(x_1,...,x_n)$$



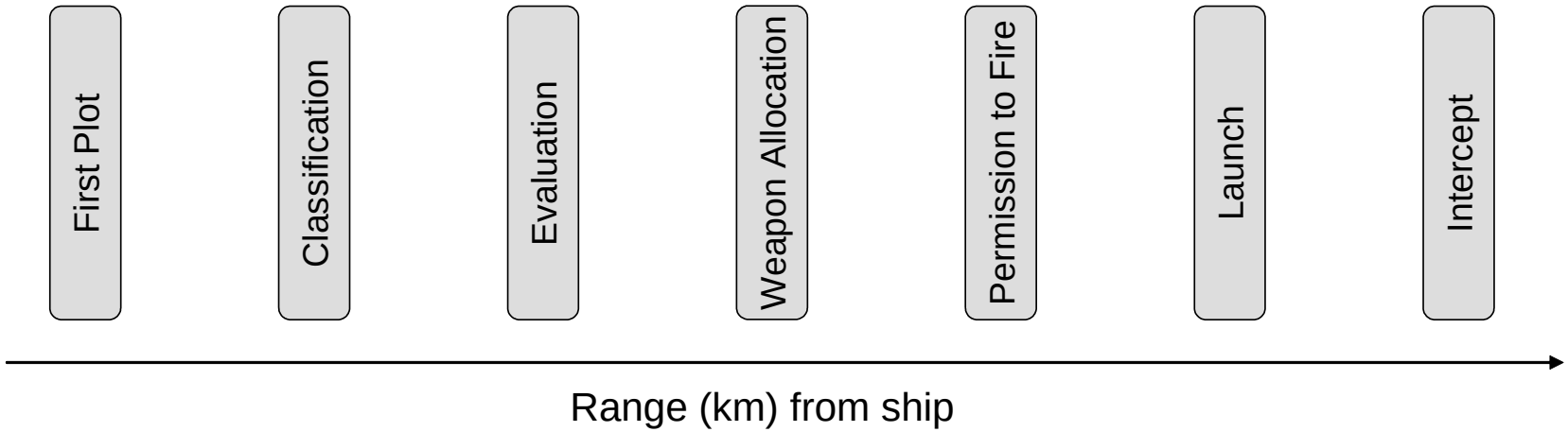
The FSG System Model

A Timeline Approach

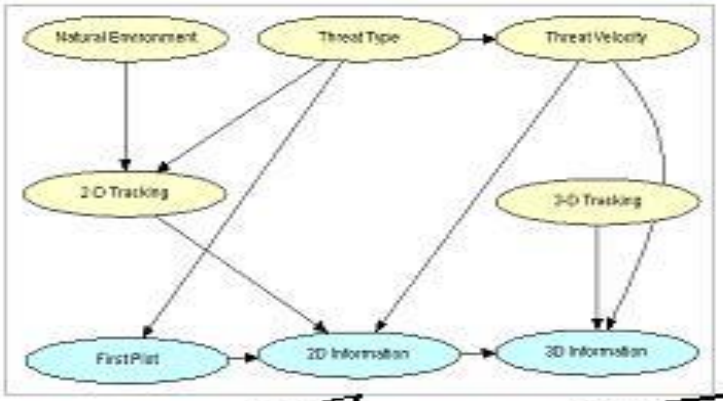
our future through science

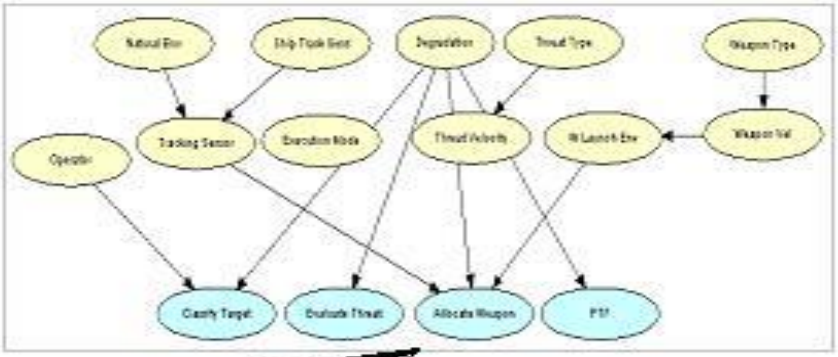
Engagement Timeline

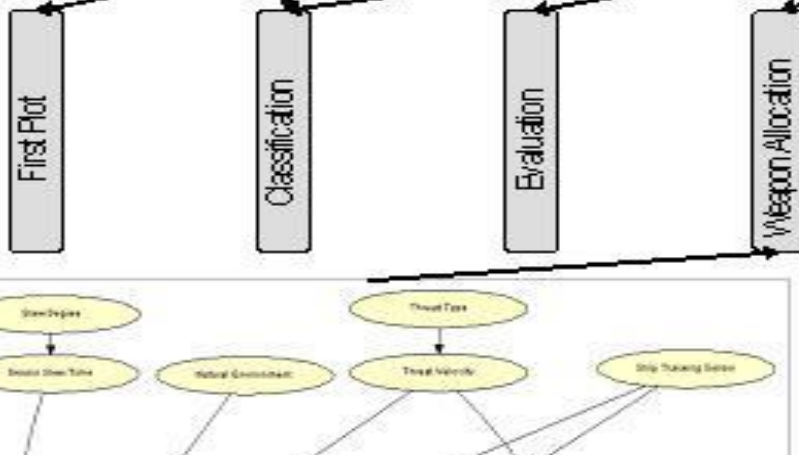
- Utilise causal dependencies along the engagement timeline
  - Sequence of Events
  - Measuring Unit: time (seconds) translated to range (km)
  - Did the intercept happen in-time (or far enough from the ship) not to endanger the ship?

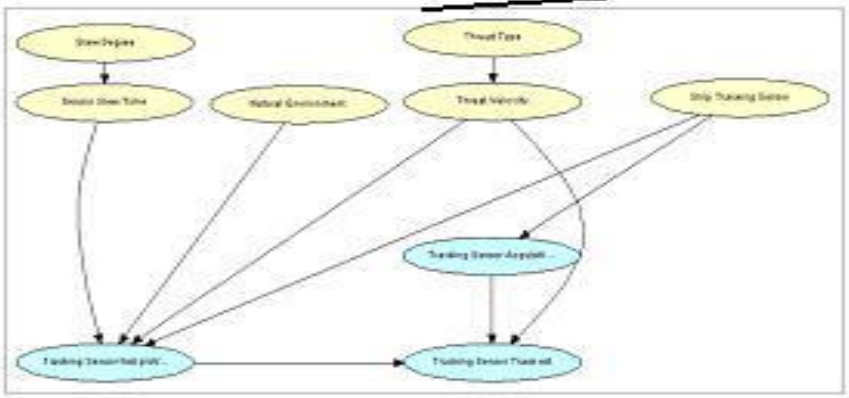


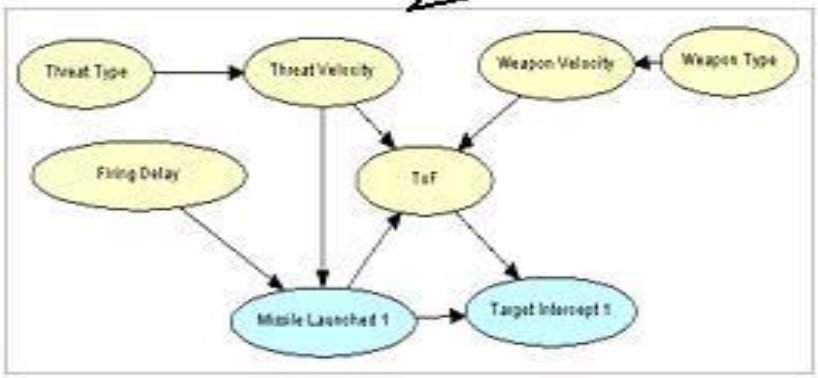
The Causal Structure





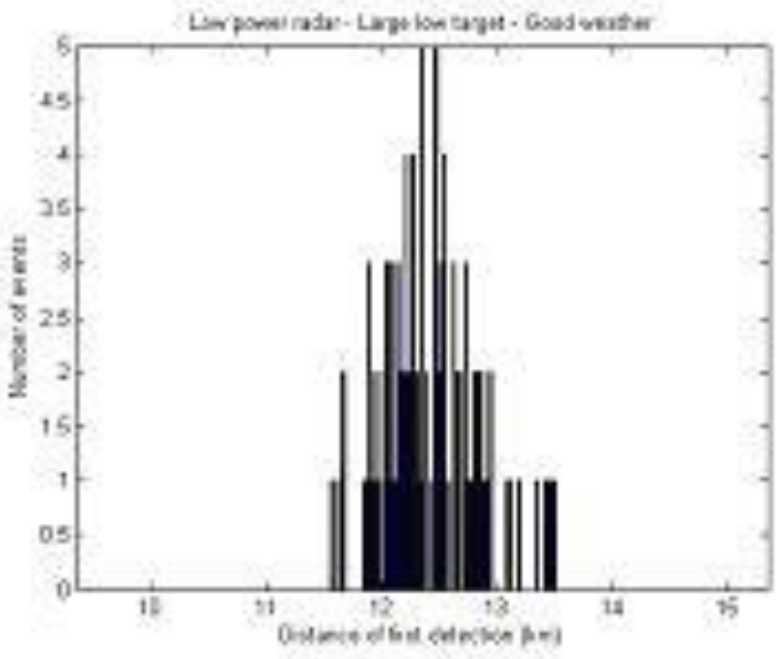




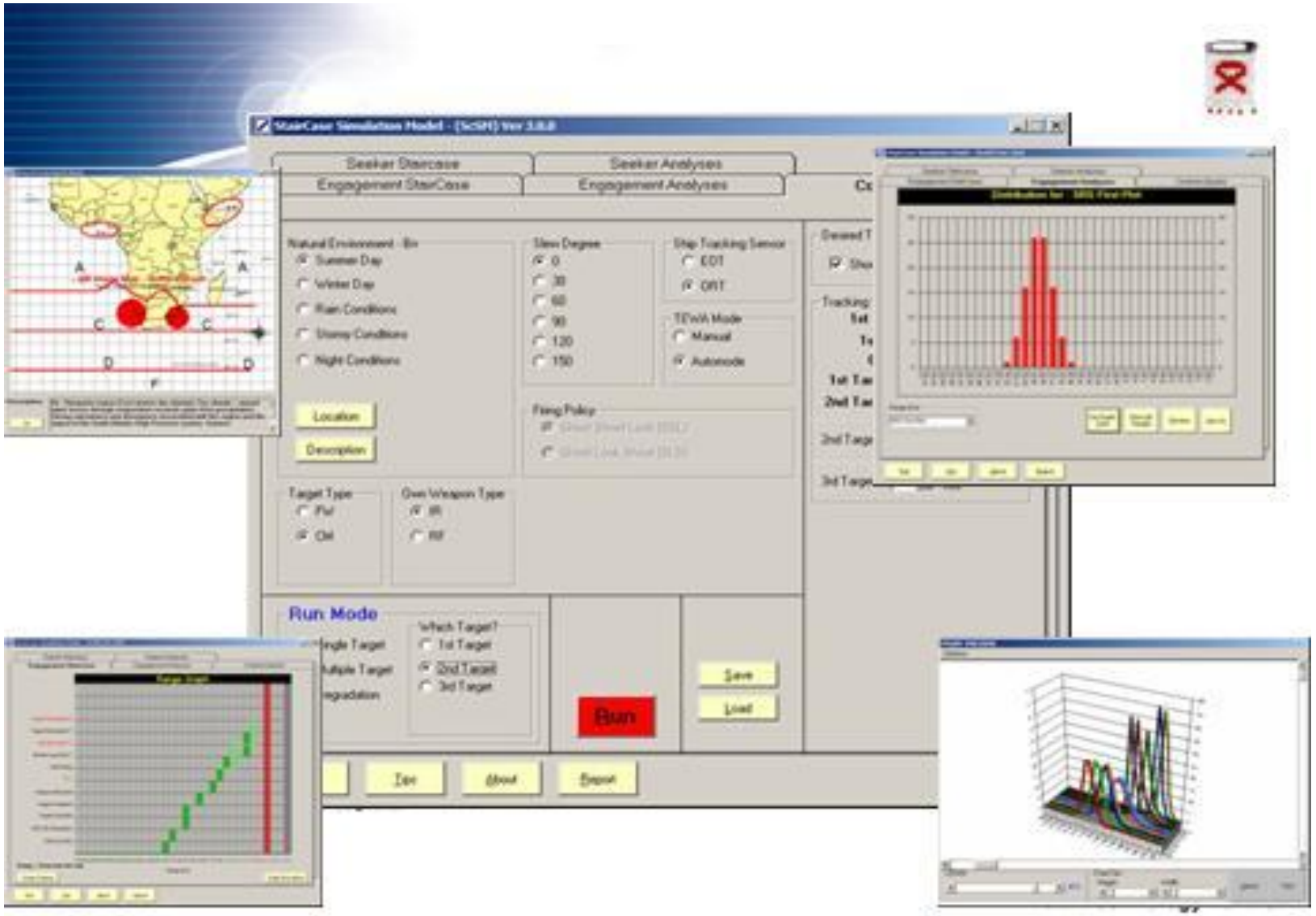


Quantification of the Model

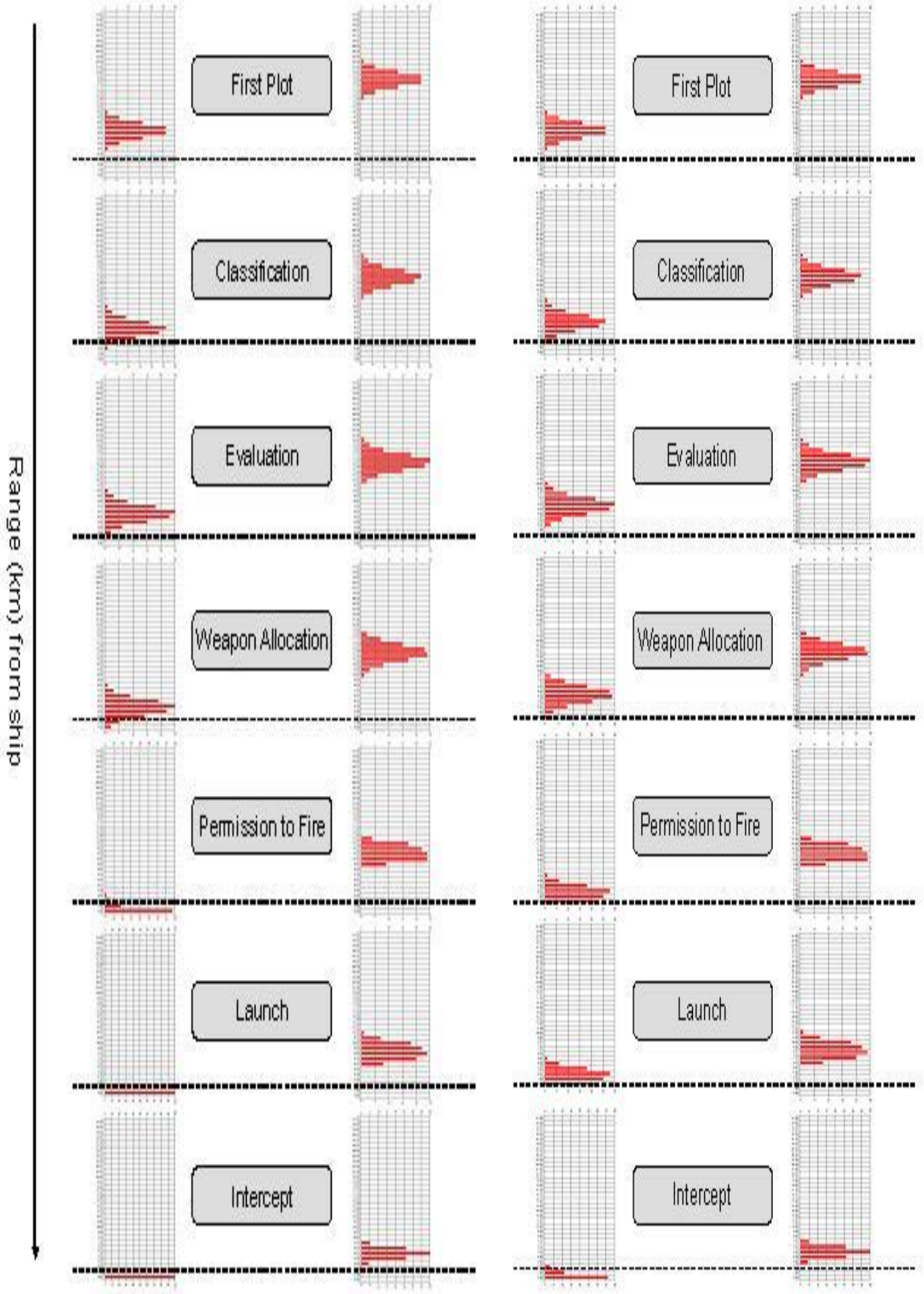
- Expert Knowledge
- Results from Monte Carlo simulations



The Integrated Model



Results


First Plot
Classification
Evaluation
Weapon Allocation
Permission to Fire
Launch
Intercept
First Plot
Classification
Evaluation
Weapon Allocation
Permission to Fire
Launch
Intercept
Range (km) from ship

Conclusions

- Benefits
  - Tacit Knowledge – Explicit Knowledge
  - Model that represents the *knowledge about the system* rather than the system itself
  - Shared understanding of the system
  - *What-if* capability
- Shortcomings
  - No feedback loops
  - Lack of understanding of aggregation of uncertainty