ATEQ Consulting

A Model Based Approach to System of Systems Risk Management and its Application to CAS Planning

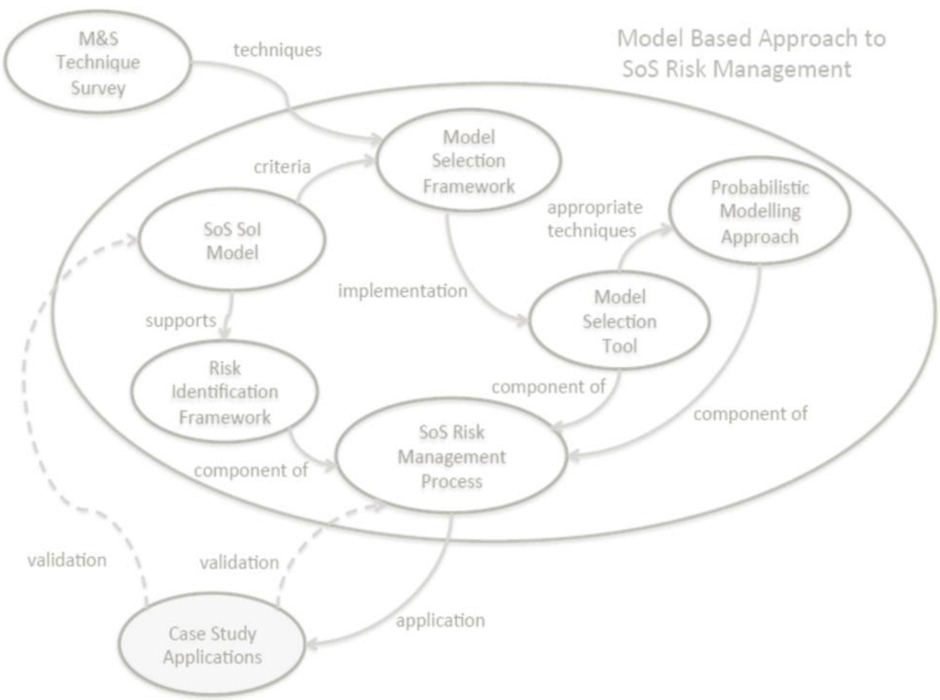
Andy Kinder

UKAS MANAGEMENT SYSTEMS
0003

FS 643969
ISO 9001:2015

Content

- Motivation
- What is Risk?
- SoS Risk Management
- Model Based Approach
- CAS Case Study
- Conclusions



Motivation

System of Systems (SoS) Engineering (SoSE) is an emerging sub-discipline of which Risk Management is a critical, but immature, element

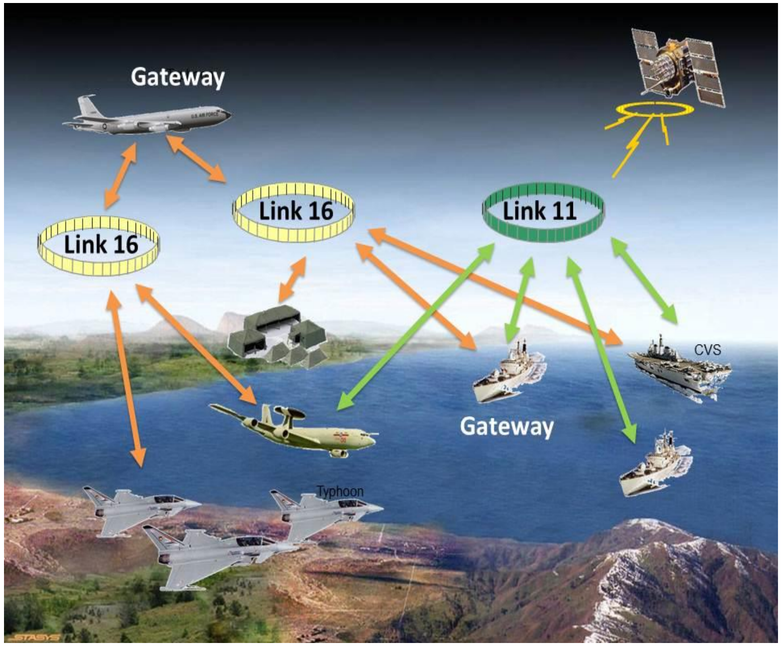
Likelihood of risk is typically determined through qualitative approaches - results are subjective

Traditional Systems

- Tools and methodologies are available to address defined problems
- System boundaries are fixed
- Expected behaviour is known
- Scoping these problems and the associated risks is relatively straightforward

System of Systems

- "A SoS is a system which results from the coupling of a number of constituent systems at some point in their life cycles" (Brook, 2016)
- Boundary is not necessarily static
- Component systems may not all be identified
- Behaviour is emergent
- Therefore new tools and methodologies are required



ATEQ Consulting

What is Risk?

The ISO Guide relating to risk management vocabulary defines risk as;

- *"the effect of uncertainty on objectives"*

a deviation from the expected — positive and/or negative

deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood

Perception of Risk

Risk is frequently determined as a subjective estimate of likelihood, utilising experience of an individual or team

Affect heuristic

- assessment of risk is related to the perceived "goodness" or "badness" of an activity

Conspiracy of optimism

- likelihood or impact of a risk may be underestimated due to financial, managerial or political pressures

System of Systems Risk Management

- **Identification of SoS objectives and the identification of the risks that threaten the achievement of those objectives**
- **Minor individual program risks could be major risks to the SoS**
- **Significant system risks may have little or no impact on the SoS functionality**
- **May be risk to a set of SoS objectives which are not risks to the constituent systems**

DoD. Systems Engineering Guide for Systems of Systems

Why a Model Based Approach?

- **A SoS is inherently complex**
- **Risks typically quantified through subjective expert opinion**
- **Derived from a mental model of the problem**
- **Human processing of problems involving five variables is at “chance level”**

Halford, Graeme S., et al. "How many variables can humans process?"

Model Based Approach – a caveat

- All models are wrong, but some are useful
- Models are abstractions and simplifications
- Over reliance on poorly tested models, based on false assumptions, providing the illusion of a sophisticated risk management method is the “worst” case
- “Best” case to be the use of proven, quantitative models

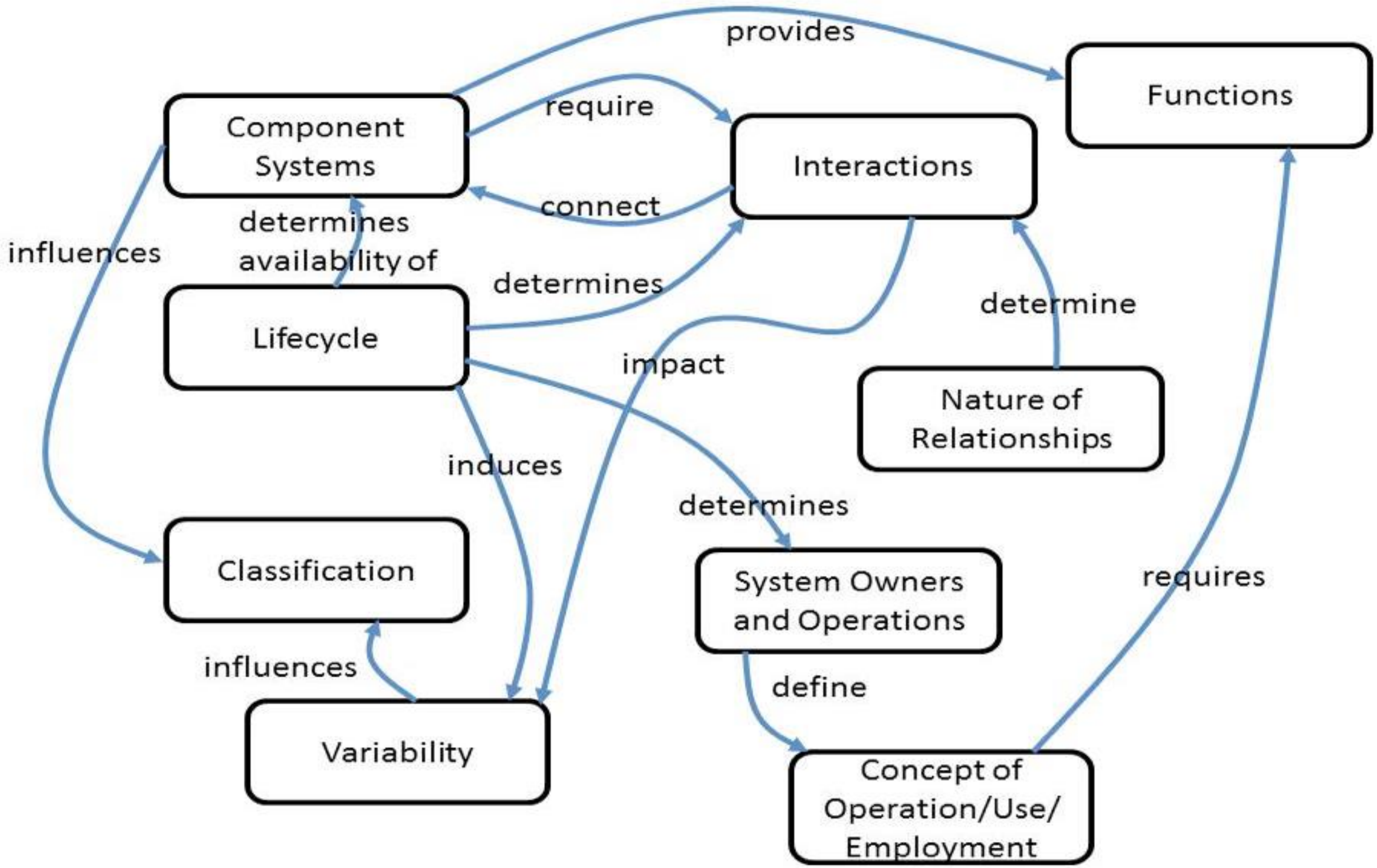
Box, G. E. P., and Draper, N. R., Empirical Model Building and Response Surfaces
Hubbard, Douglas W. The failure of risk management: why it's broken and how to fix it

The System of Systems Risk Model

A modelling approach has been developed to reflect the holistic nature of SoS Risk

- Allows the interaction of risks to be modelled and enables the integration of heterogeneous modelling techniques
- Ensures the use of methods appropriate to individual risk characteristics, as opposed to a ‘one size fits all’ approach

SoS Risk Identification

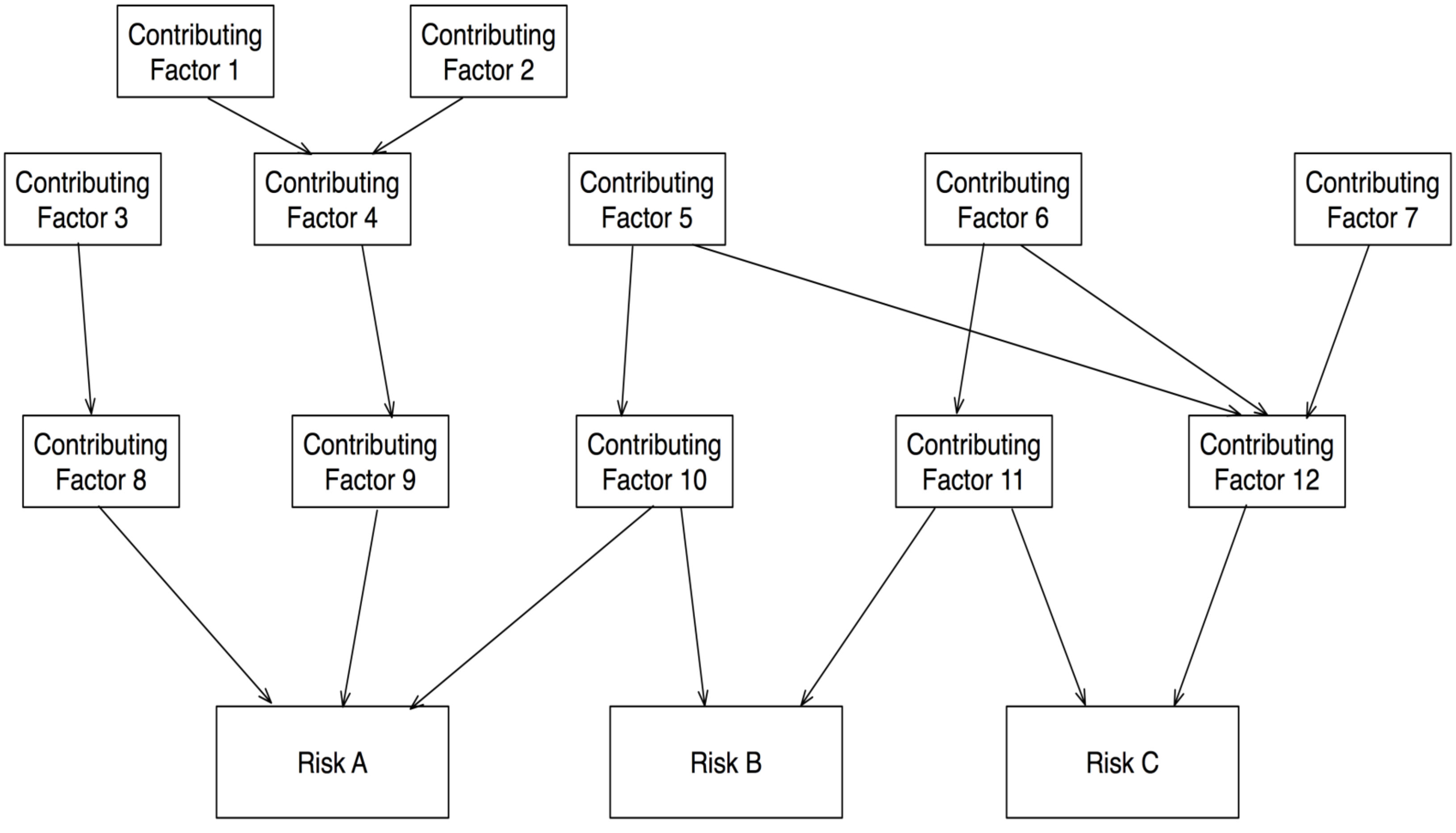


Kinder, A.; Barot, V.; Henshaw, M.; Siemieniuch, C., "System of Systems: “Defining the system of interest”

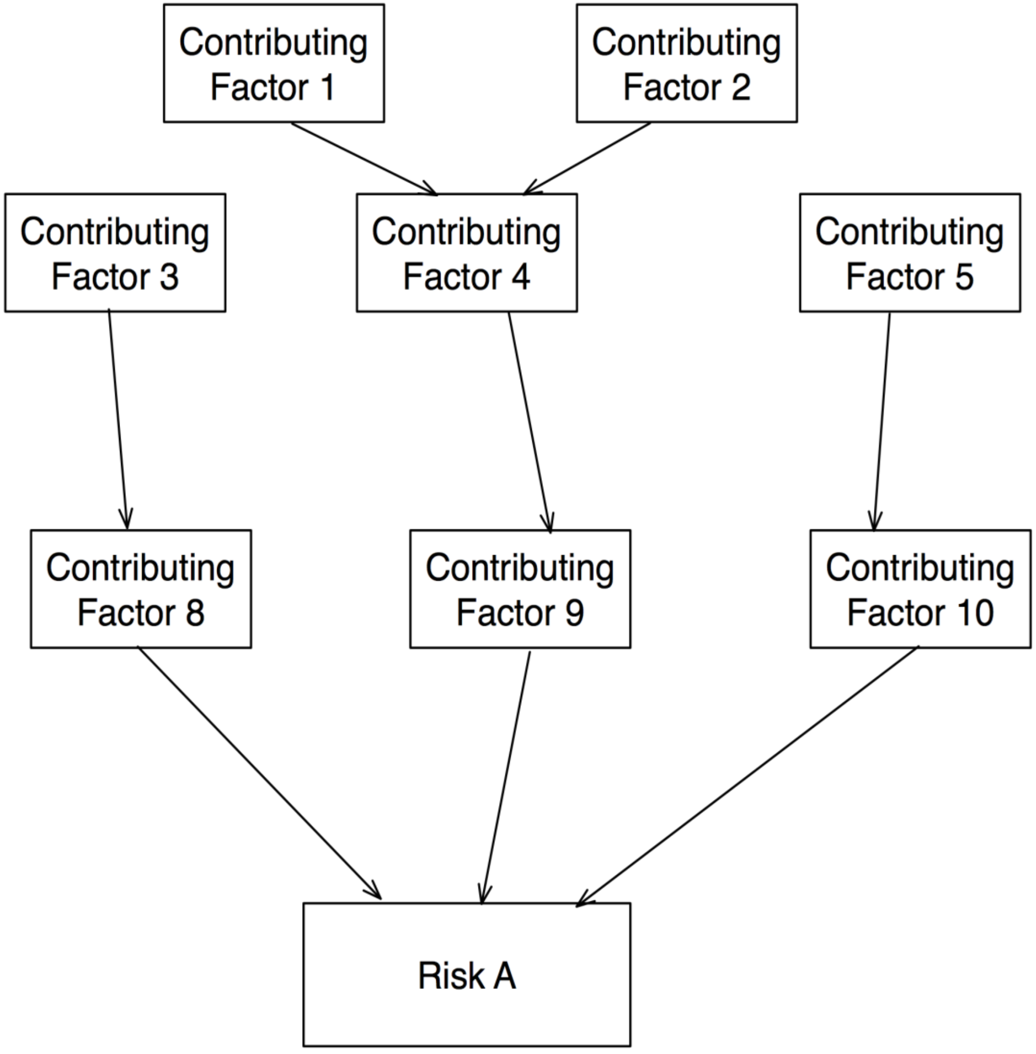
Risk Identification

SoS Dimension	Hazard	Control	Opportunity
Component Systems	Emergent behaviour inhibits purpose	System immaturity System unavailability	Emergent behaviour enhances purpose
Interactions	N/A	Misclassification	N/A
Lifecycle	Poor interoperability Bandwidth insufficient	Poor interoperability interrupts command and control	Bandwidth can support additional interaction medium
Variability	Failure dependent on a single node	Hierarchical command structure inhibits agility	Agility increased
Classification	Immaturity of component systems	Lack of coordination	Lifecycles of component systems align
Functions	SoS instability	Instability inhibits control	High agility
Systems Owners and Operations	Functions not available	Ownership of function not defined	Additional functionality exists
Concept of Operation	Lack of co-operation	Lack of management authority	High level of co-operation
Nature of Relationships	Concept of operation not supported	No clear concept of operation	Adaptable for changing concept of operation

Causal Network



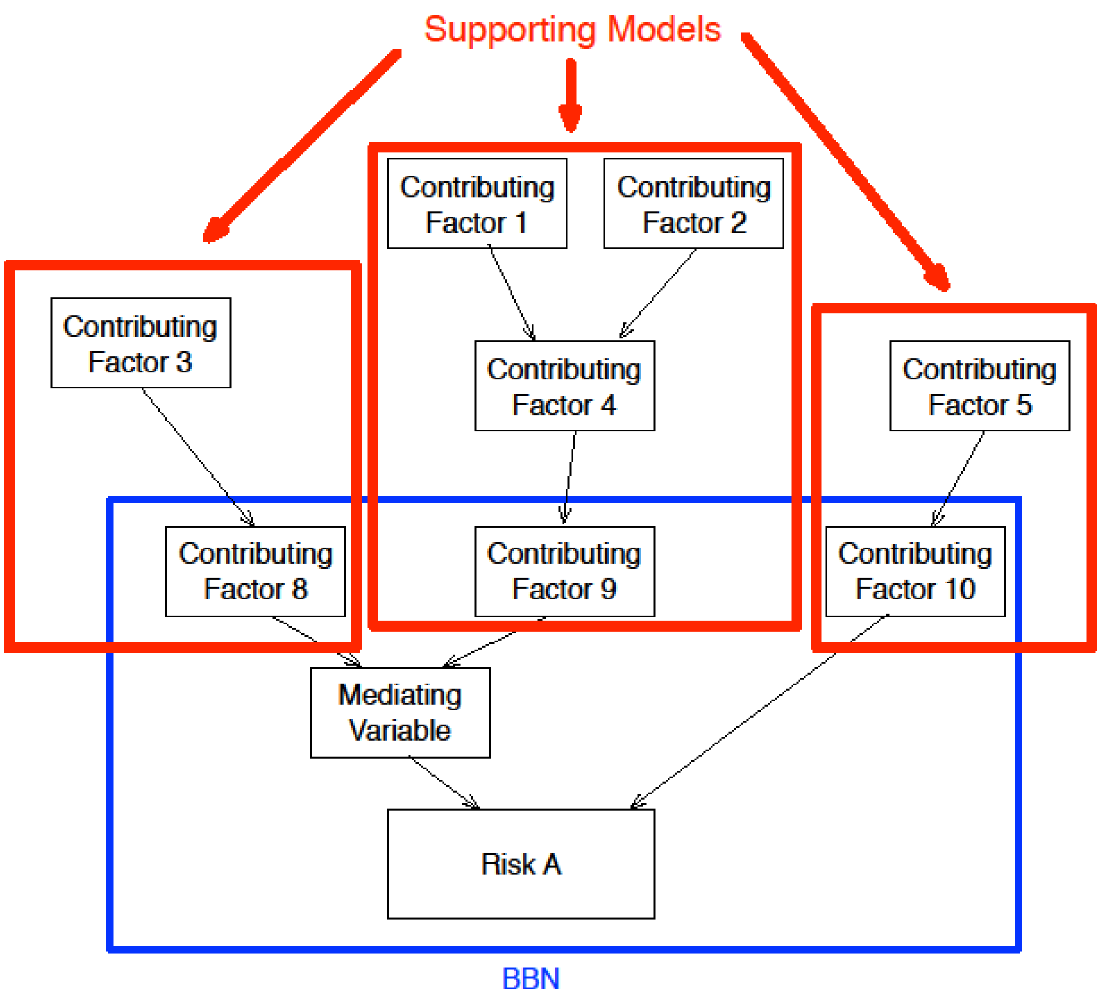
Simplified Causal Network



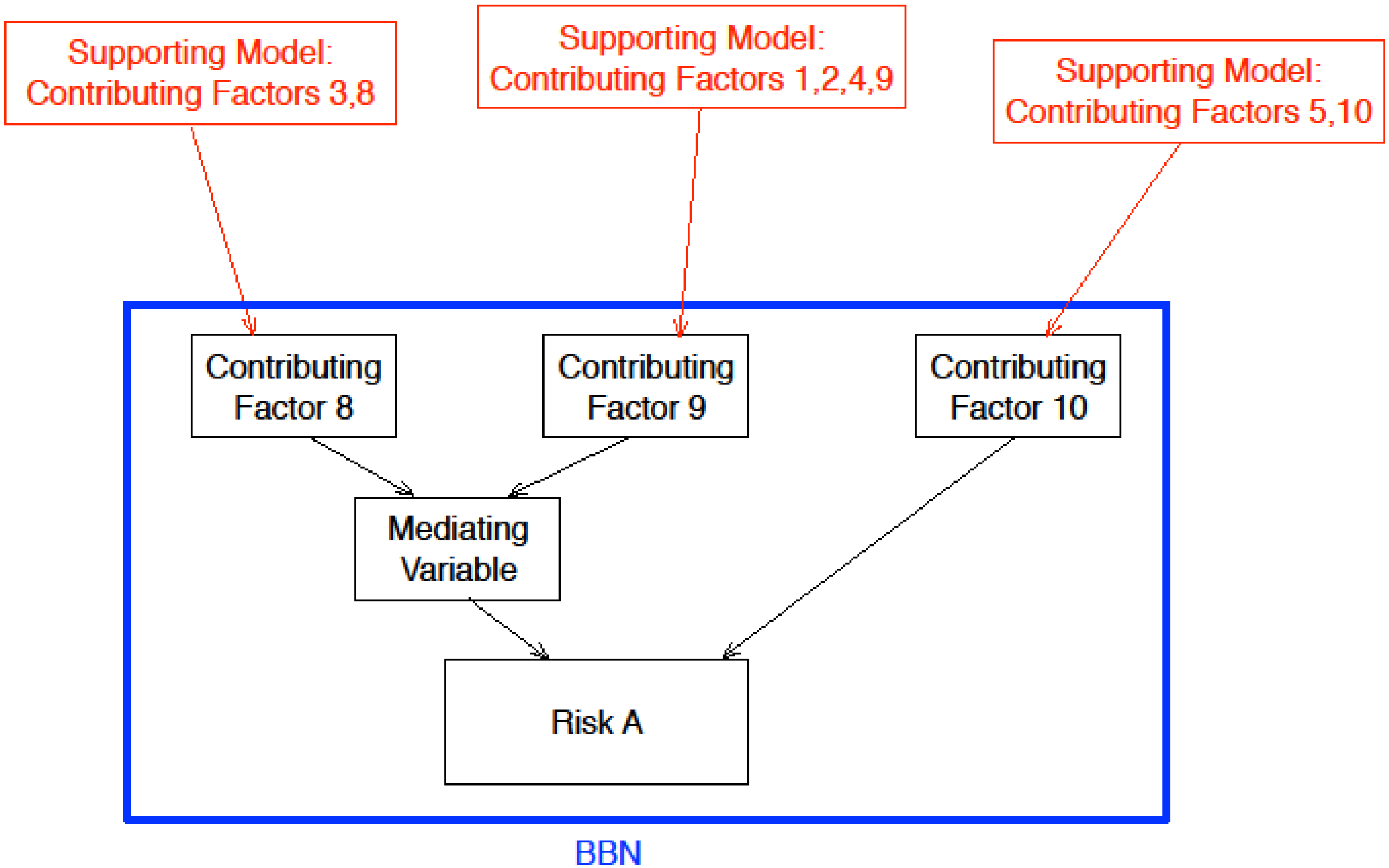
Modelling Technique Selection Tool

Model Components	Dynamic	Stochastic	Uncertainty	Component Systems	Interactions	Lifecycle	Variability	Classification	Functions	Systems Owners and Operations	Concept of Operation / Use / Employment	Relationships	Ease of creation	Verifiable	
Common Digital Comms	No	Yes	No	No	No	Operational	Yes	Acknowledged	No	No	Yes				
Common Datum	No	Yes	No	No	No	Operational	Yes	Acknowledged	No	No	Yes				
Nationalities	No	Yes	No	No	No	Operational	Yes	Acknowledged	No	Yes	Yes				
Common Language	No	Yes	No	No	No	Operational	Yes	Acknowledged	No	Yes	Yes				
Common Voice Comms	No	No	No	No	No	Operational	Yes	Acknowledged	No	No	Yes				
	0	4	0	0	0	0	5		0	2	5	0			
DES/DEVS	HIGH	HIGH	LOW	HIGH	HIGH	LOW	LOW	LOW	HIGH	LOW	LOW	HIGH	LOW	HIGH	1
Petri Nets	HIGH	HIGH	LOW	HIGH	HIGH	LOW	LOW	LOW	LOW	LOW	LOW	HIGH	LOW	HIGH	1
ABMS	HIGH	HIGH	LOW	HIGH	HIGH	LOW	LOW	LOW	HIGH	LOW	LOW	LOW	LOW	HIGH	1
System Dynamics	HIGH	HIGH	LOW	LOW	LOW	HIGH	HIGH	HIGH	LOW	HIGH	HIGH	LOW	LOW	HIGH	4
Surrogate Models	HIGH	HIGH	LOW	HIGH	LOW	HIGH	LOW	LOW	LOW	LOW	LOW	LOW	LOW	HIGH	1
ANN	HIGH	LOW	LOW	LOW	LOW	HIGH	HIGH	HIGH	HIGH	LOW	LOW	LOW	HIGH	HIGH	1
BNN	LOW	LOW	HIGH	LOW	LOW	HIGH	HIGH	HIGH	LOW	HIGH	HIGH	LOW	HIGH	HIGH	3
Markov Models	LOW	LOW	HIGH	LOW	LOW	HIGH	HIGH	HIGH	LOW	HIGH	HIGH	LOW	HIGH	HIGH	3
Game Theory	LOW	LOW	HIGH	LOW	LOW	HIGH	HIGH	HIGH	LOW	HIGH	HIGH	LOW	LOW	LOW	3
Decision Trees	LOW	HIGH	LOW	LOW	LOW	HIGH	HIGH	HIGH	LOW	LOW	LOW	LOW	HIGH	HIGH	2
Network Models	LOW	LOW	LOW	LOW	HIGH	LOW	LOW	HIGH	LOW	LOW	LOW	HIGH	HIGH	HIGH	0
EAF	LOW	LOW	LOW	HIGH	HIGH	HIGH	LOW	HIGH	LOW	HIGH	HIGH	HIGH	HIGH	LOW	2
Modelling Languages	LOW	LOW	LOW	HIGH	HIGH	LOW	LOW	LOW	HIGH	HIGH	HIGH	HIGH	HIGH	LOW	2
Monte Carlo	HIGH	HIGH	LOW	LOW	LOW	HIGH	HIGH	HIGH	LOW	LOW	LOW	LOW	HIGH	HIGH	2

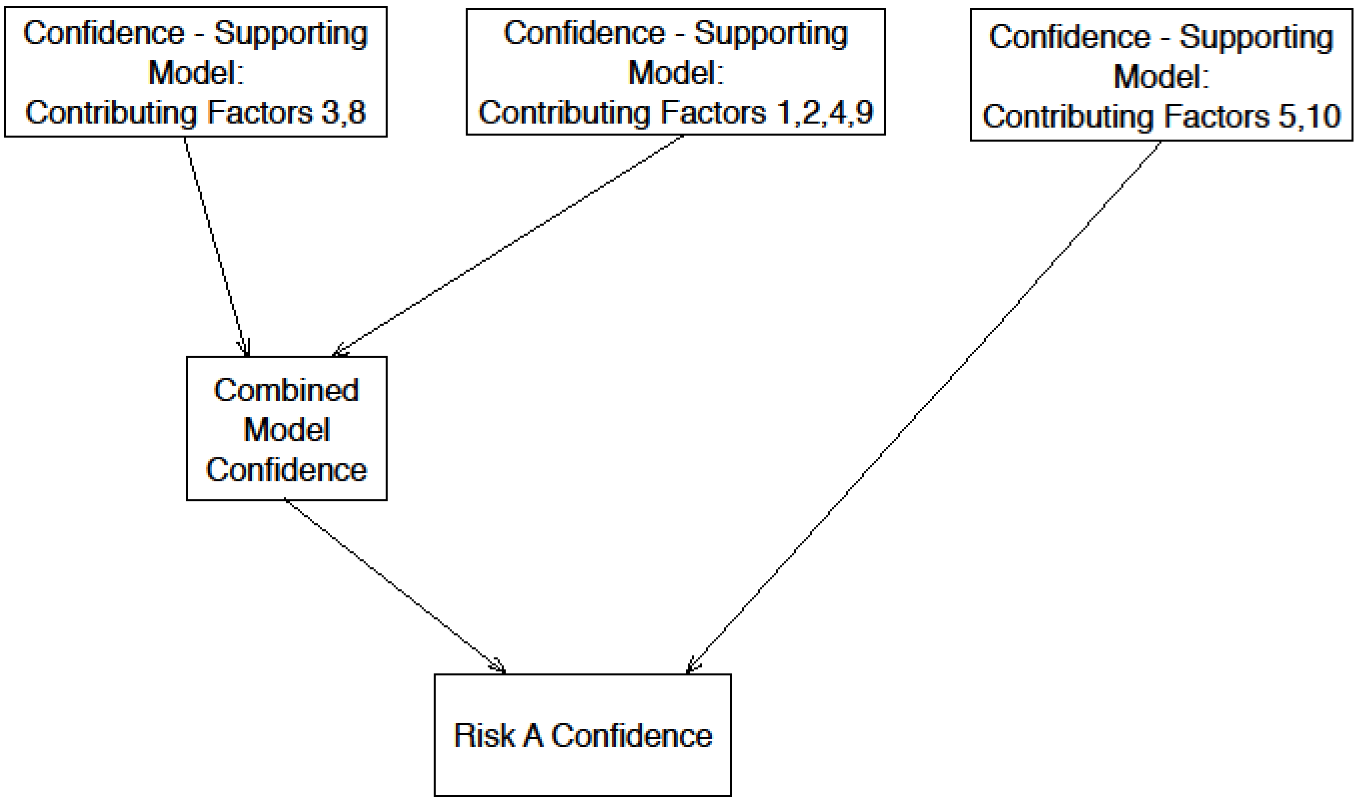
Model Architecture



BBN and Supporting Models

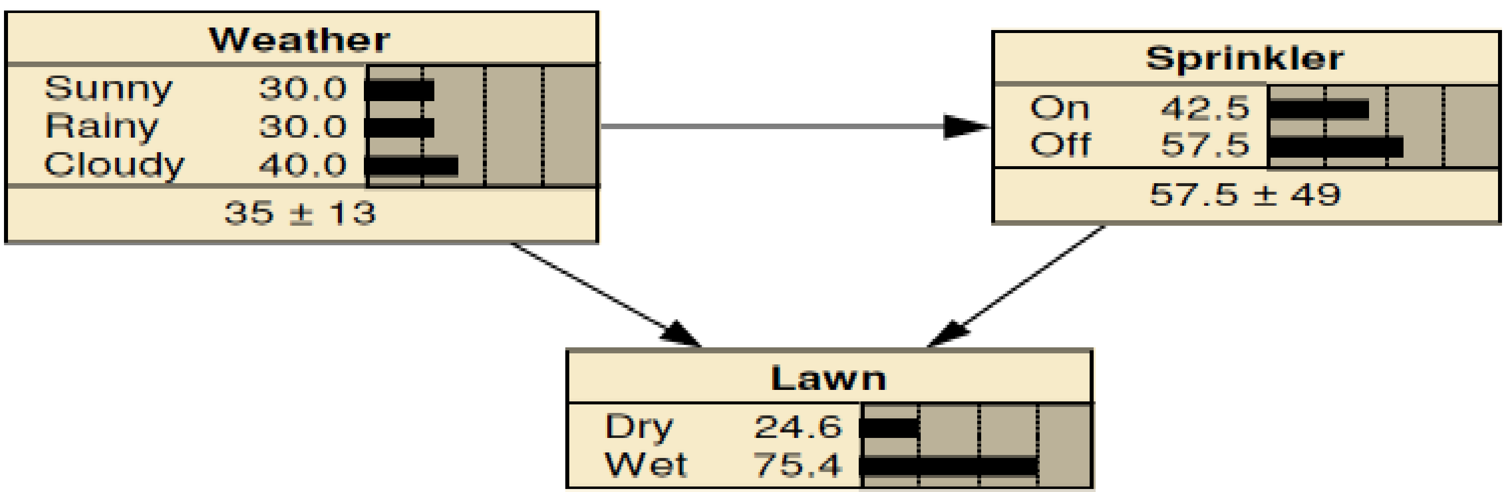


Risk Confidence

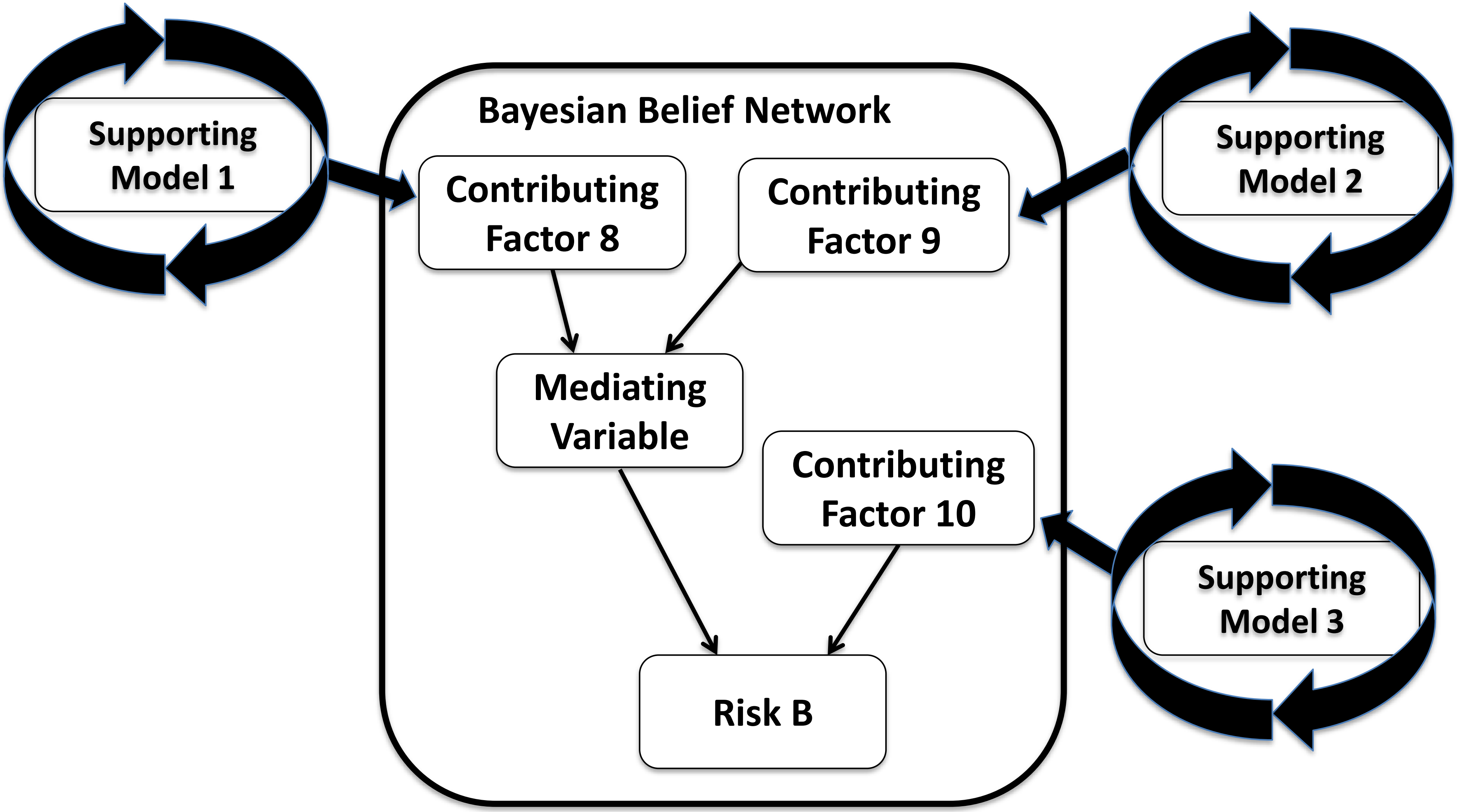


Central Bayesian Model

To enable the dependency between risks and contributing factors throughout a SoS to be modelled, it is proposed that these are represented using a Bayesian Belief Network (BBN)



Monte Carlo Simulation

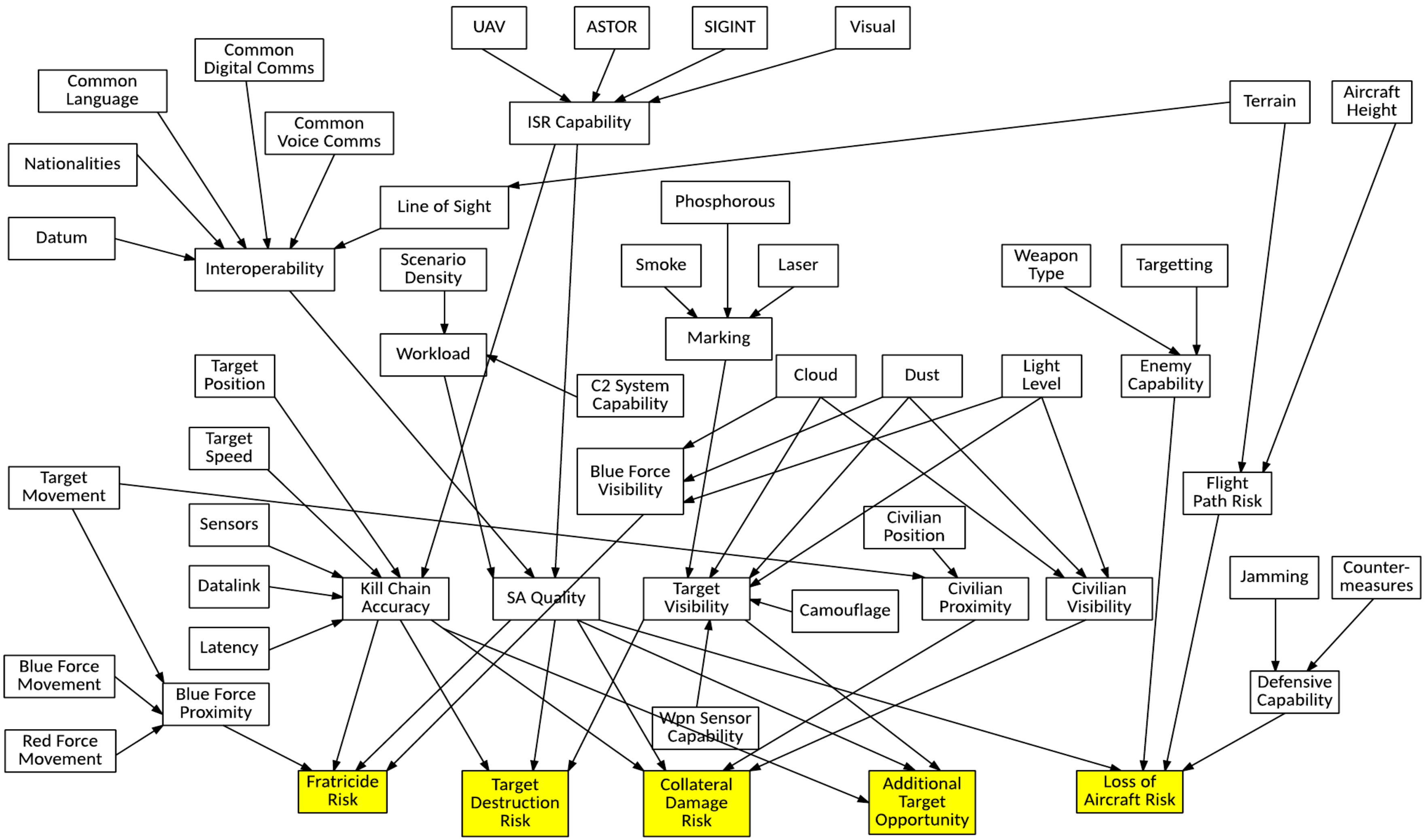


Close Air Support – Case Study

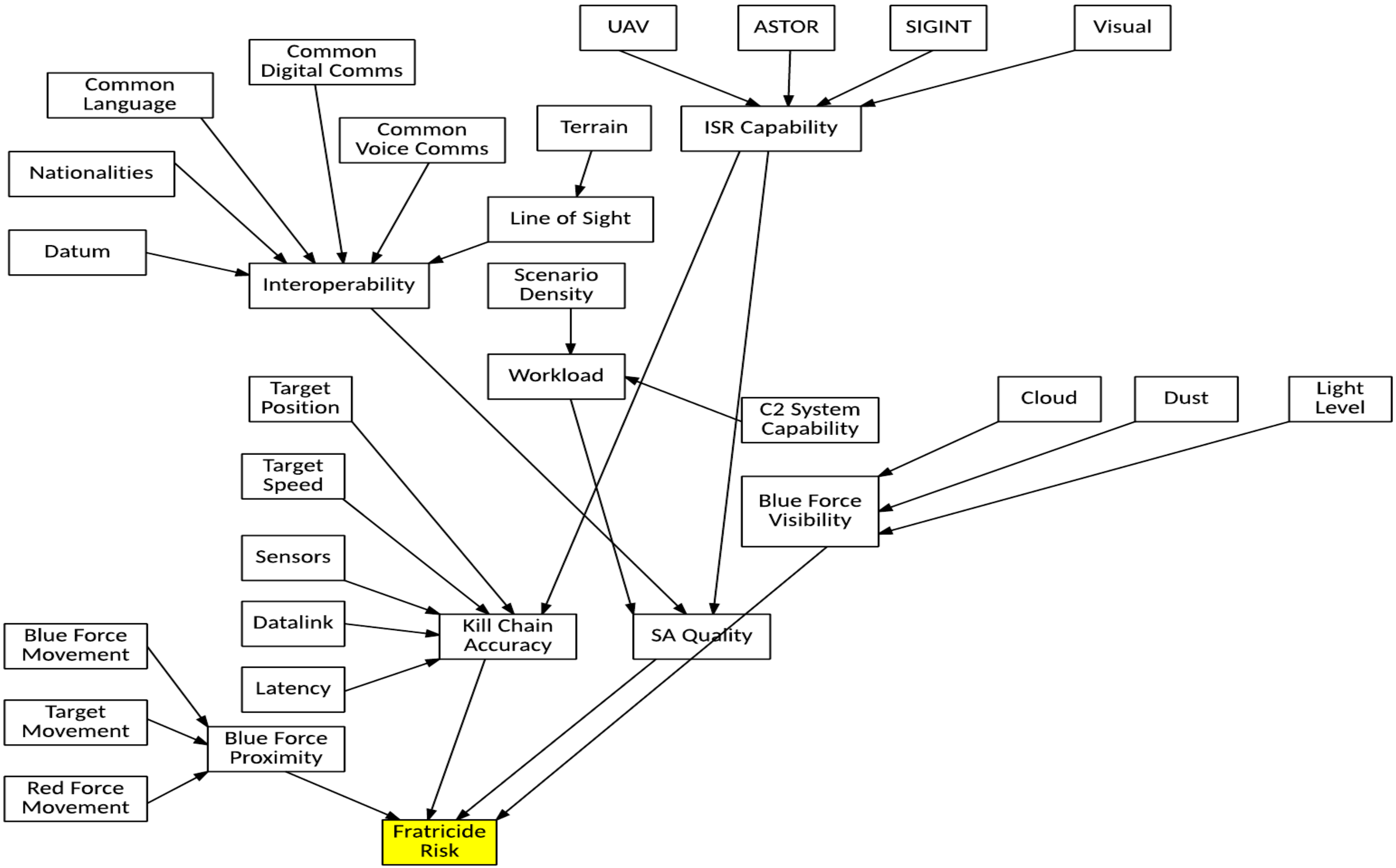
"...air action against hostile targets which are in close proximity to friendly forces and requires detailed integration of each air mission with the fire and movement of those forces."

NATO publication; Tactics, Techniques and Procedures for Close Air Support Operations

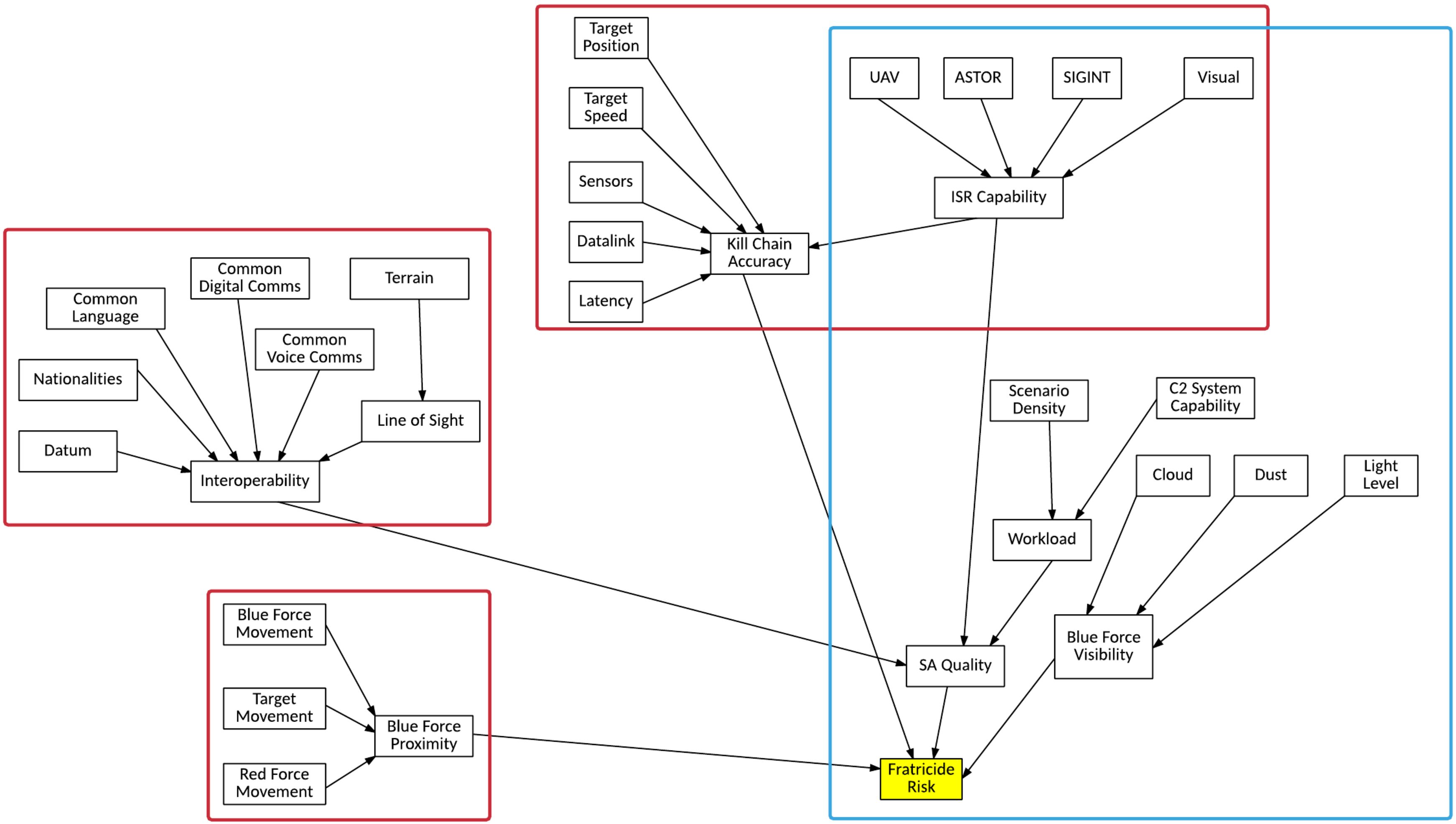
Causal Network



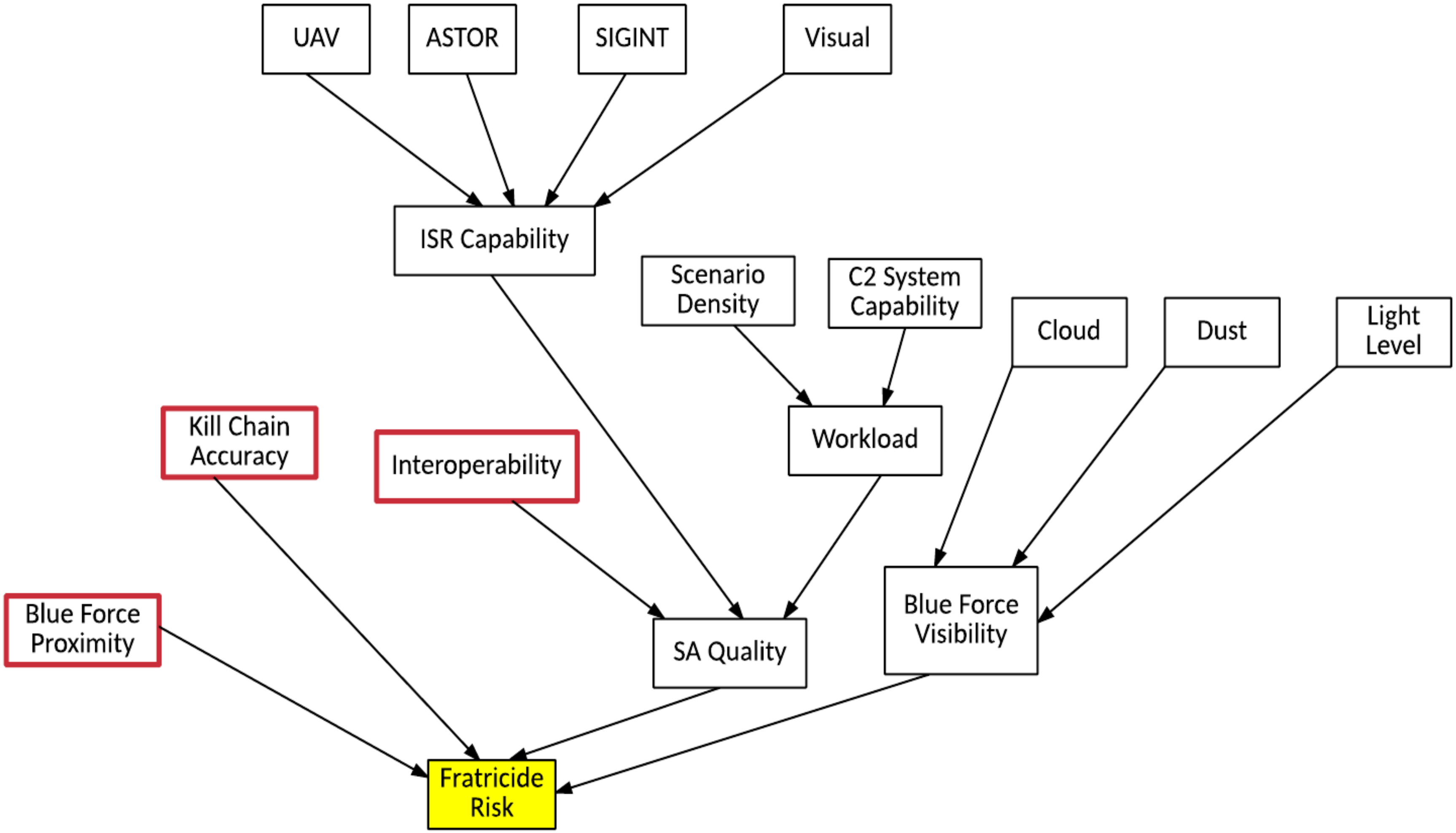
Fratricide Causal Network



Model Architecture

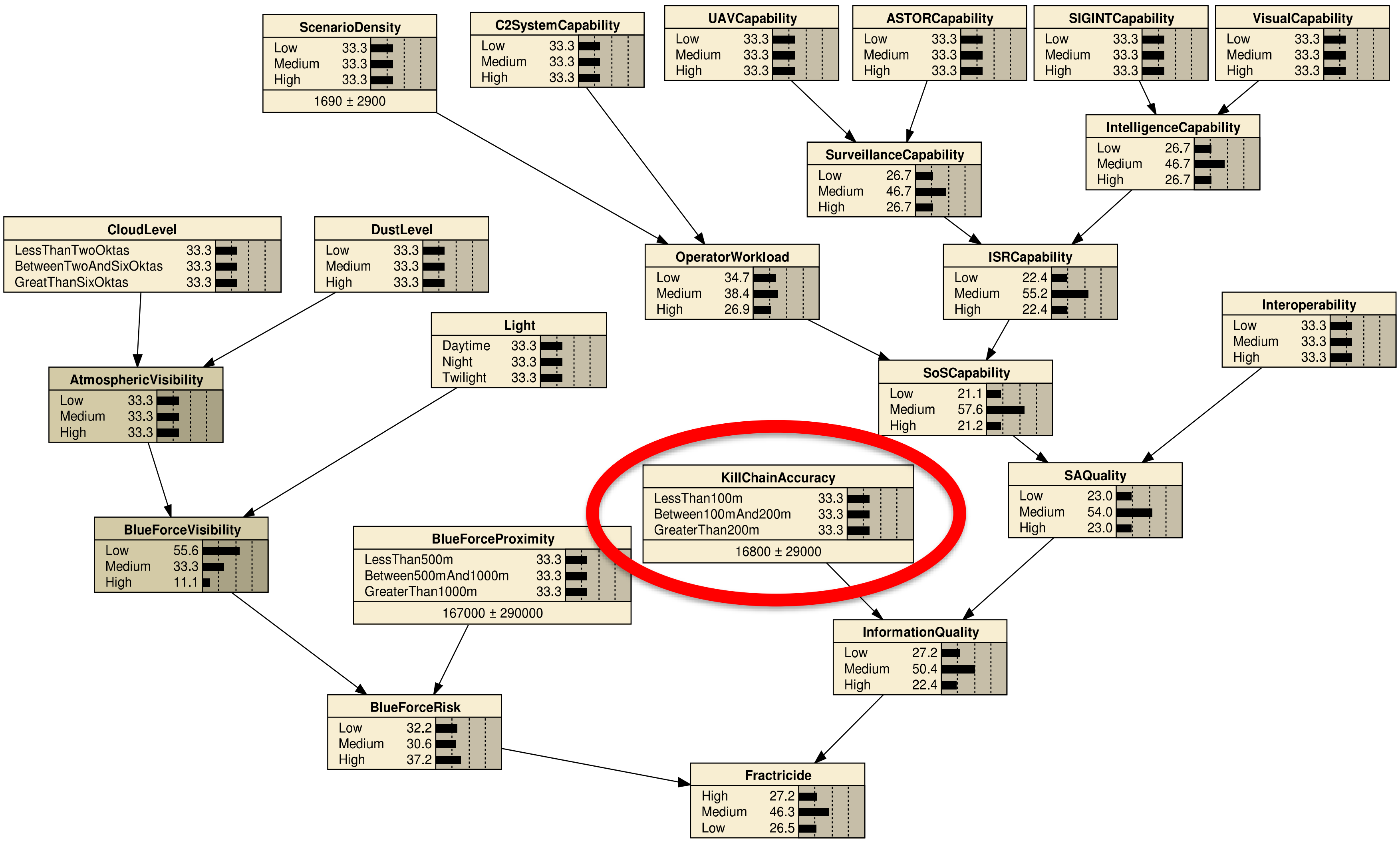


Model Architecture

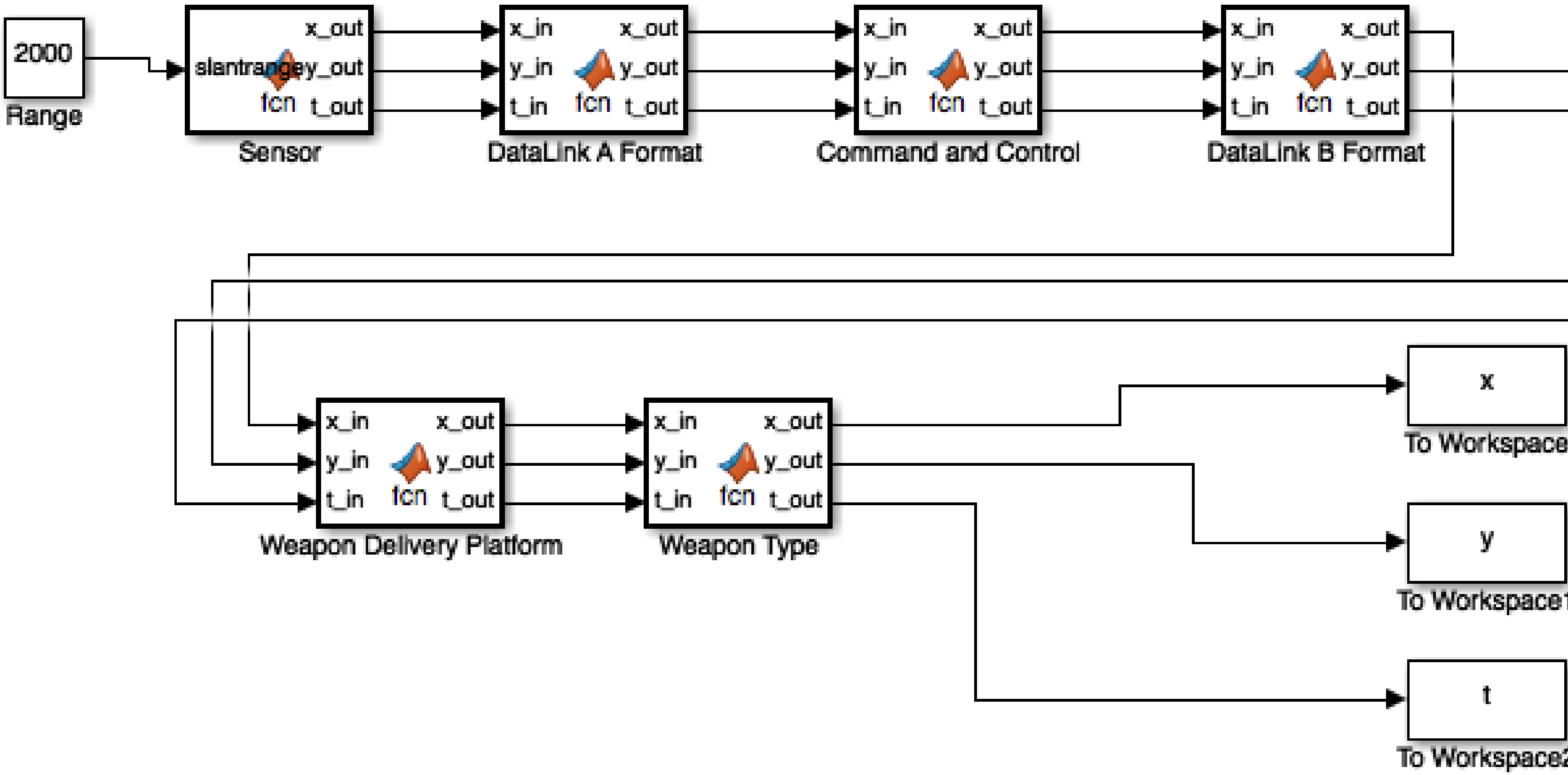


ATEQ Consulting

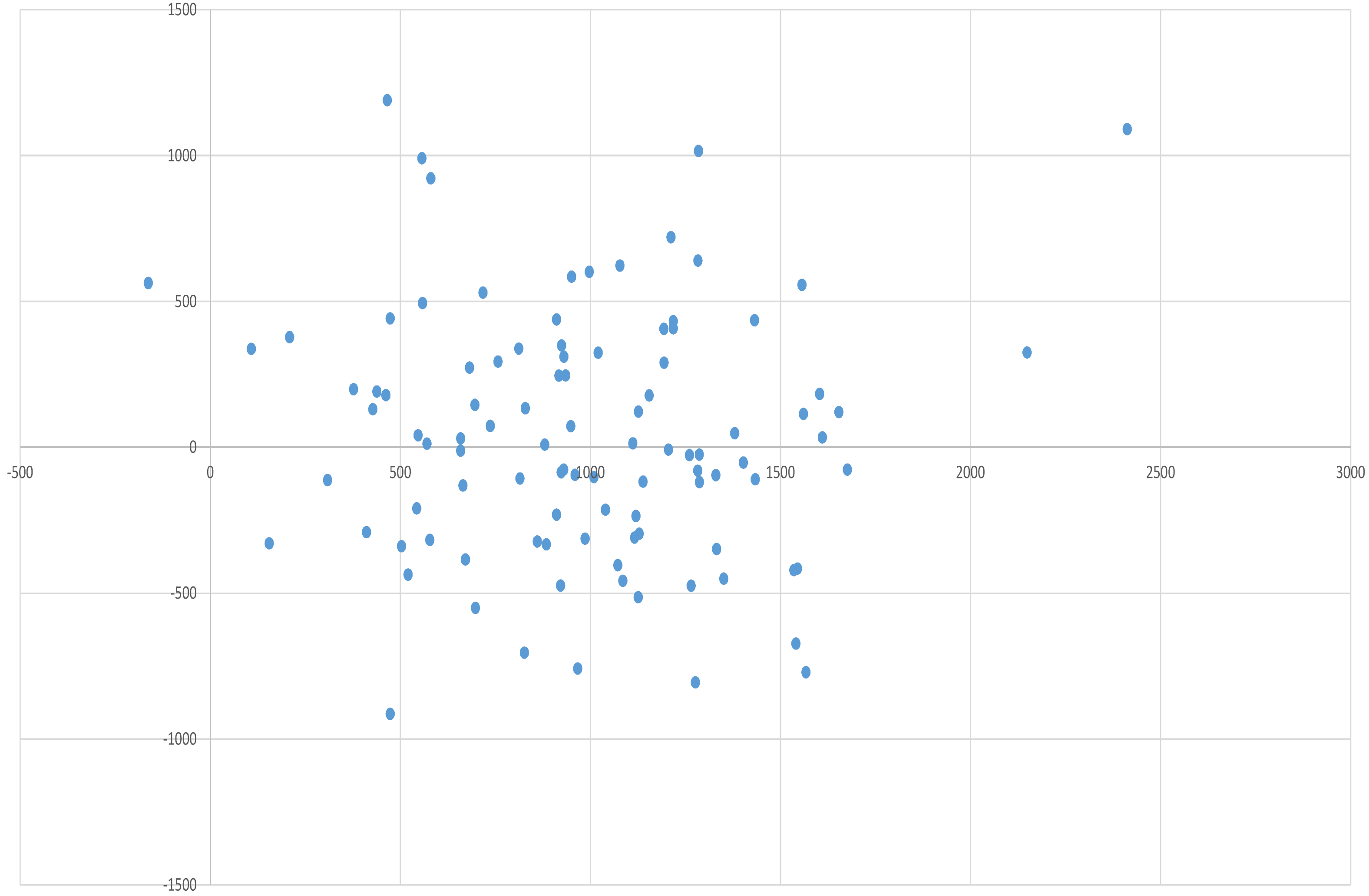
Fratricide BBN



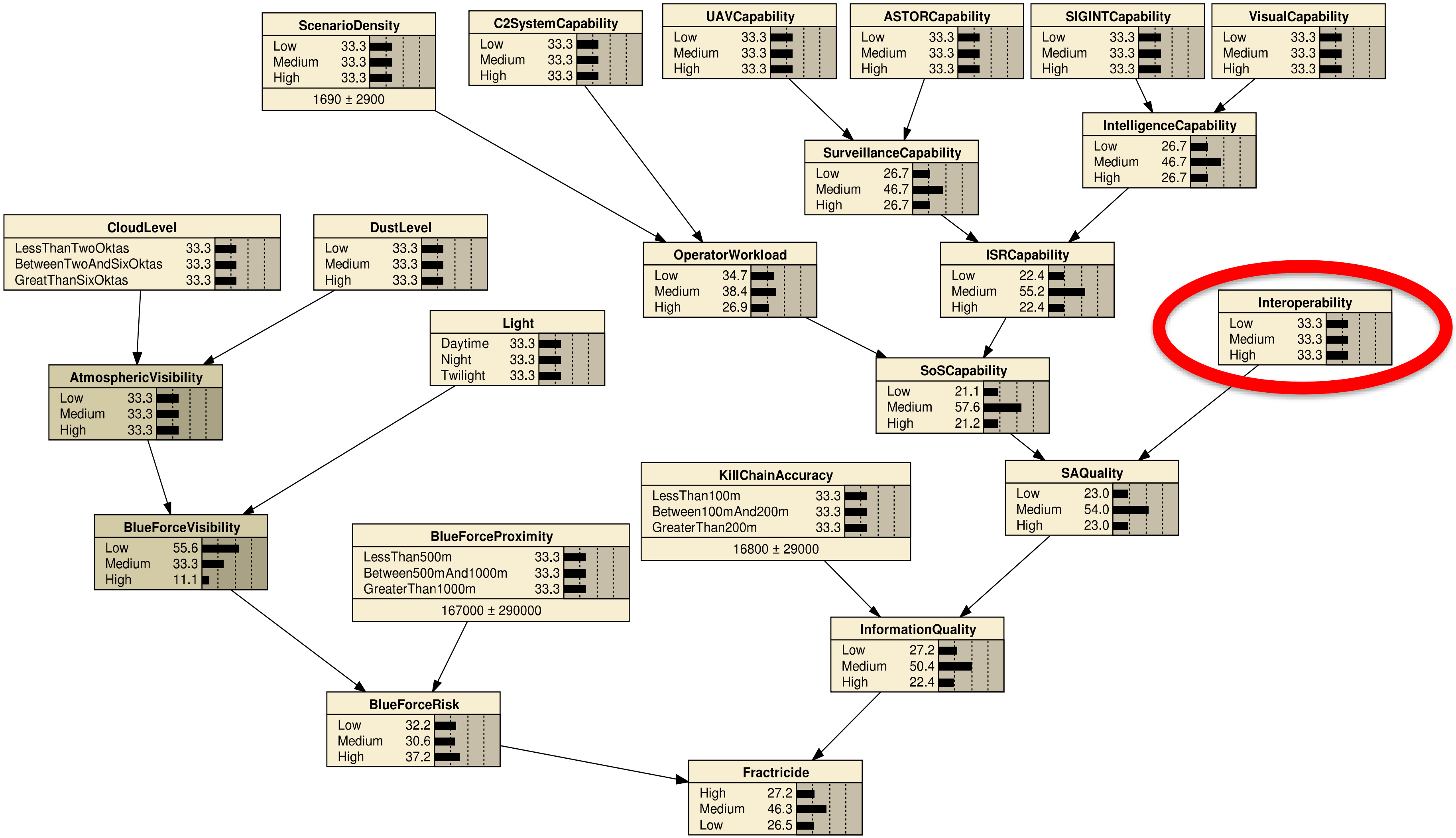
Kill Chain Model



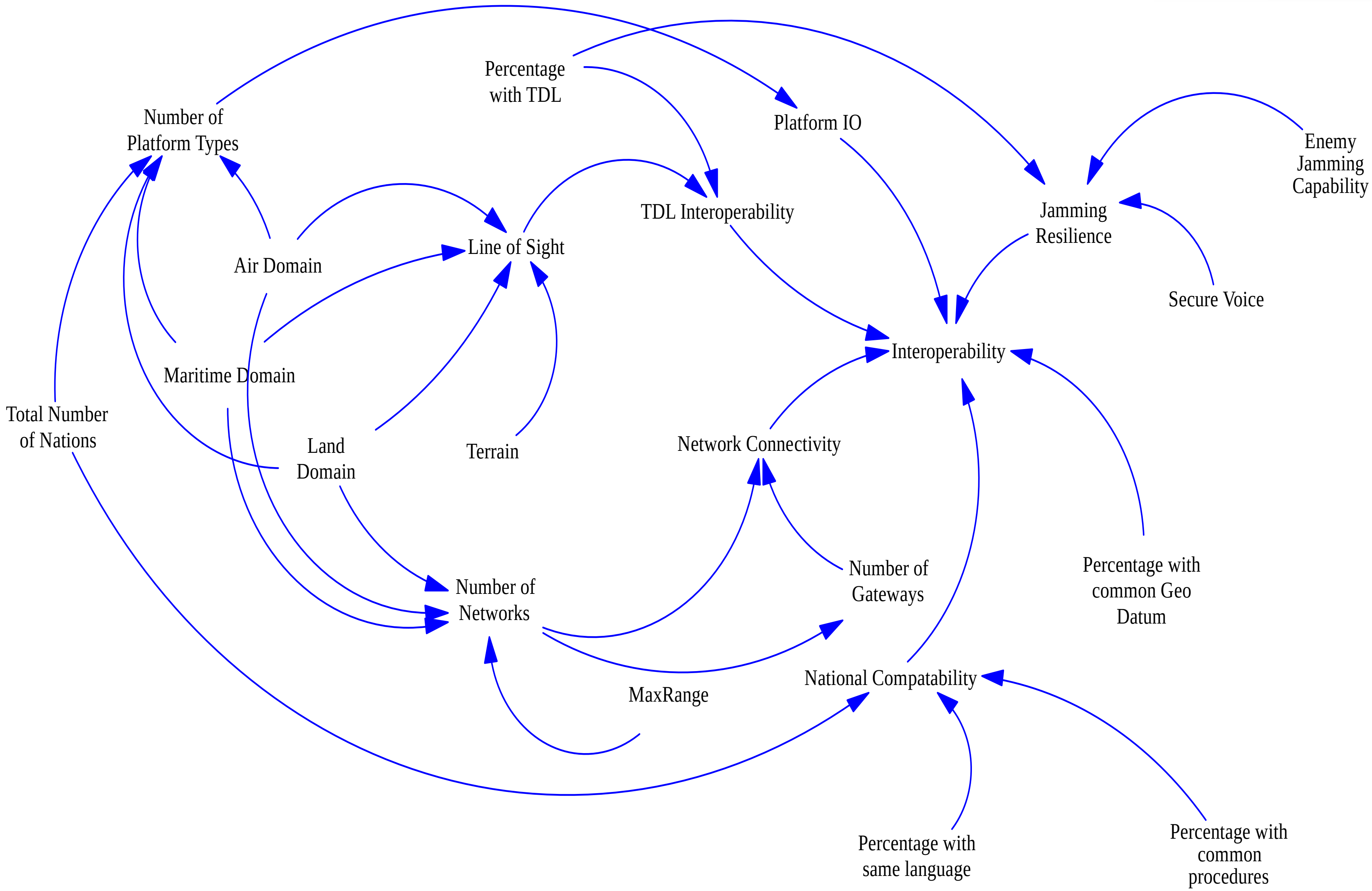
Kill Chain Model Output



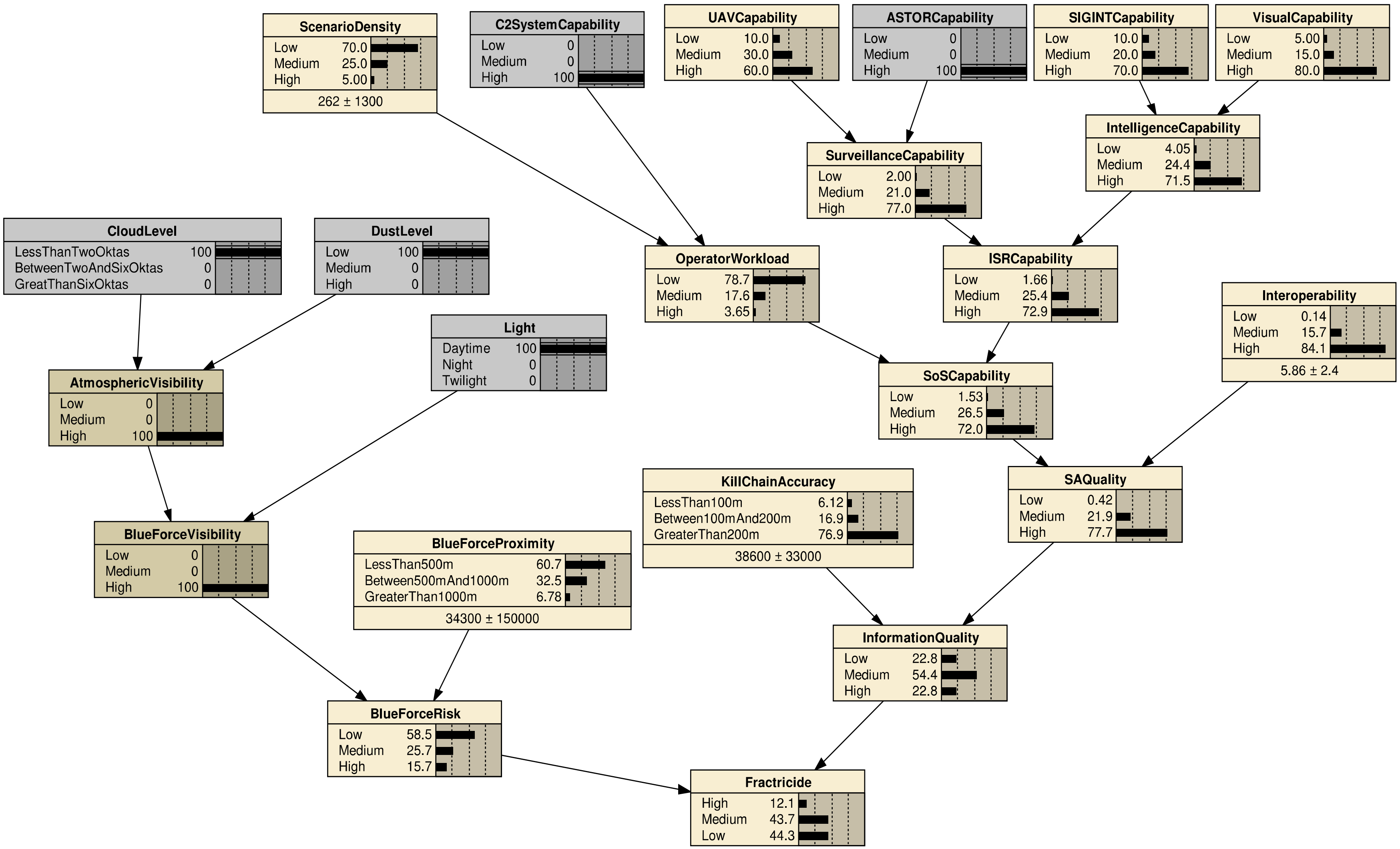
Fratricide BBN



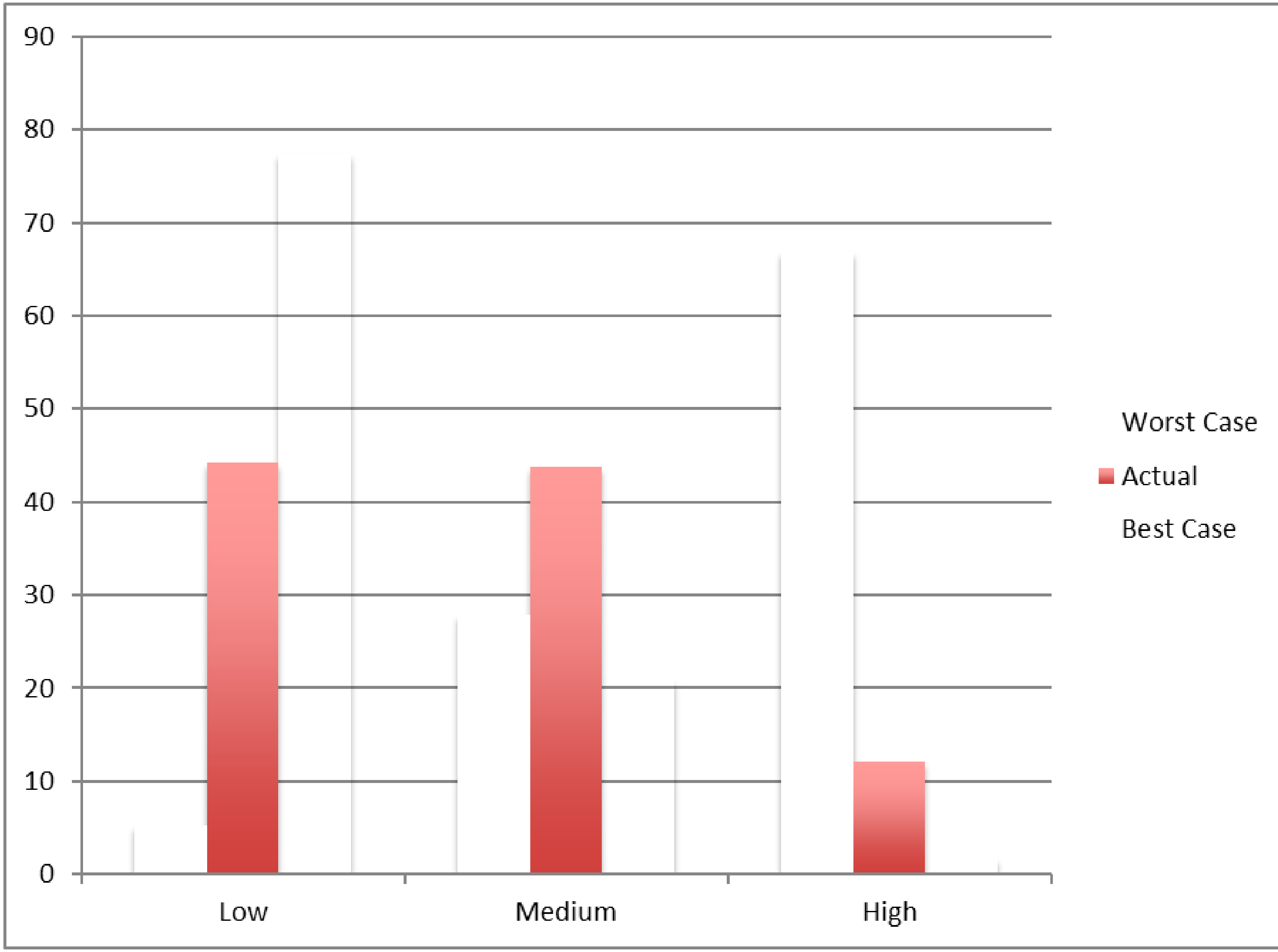
Interoperability Model



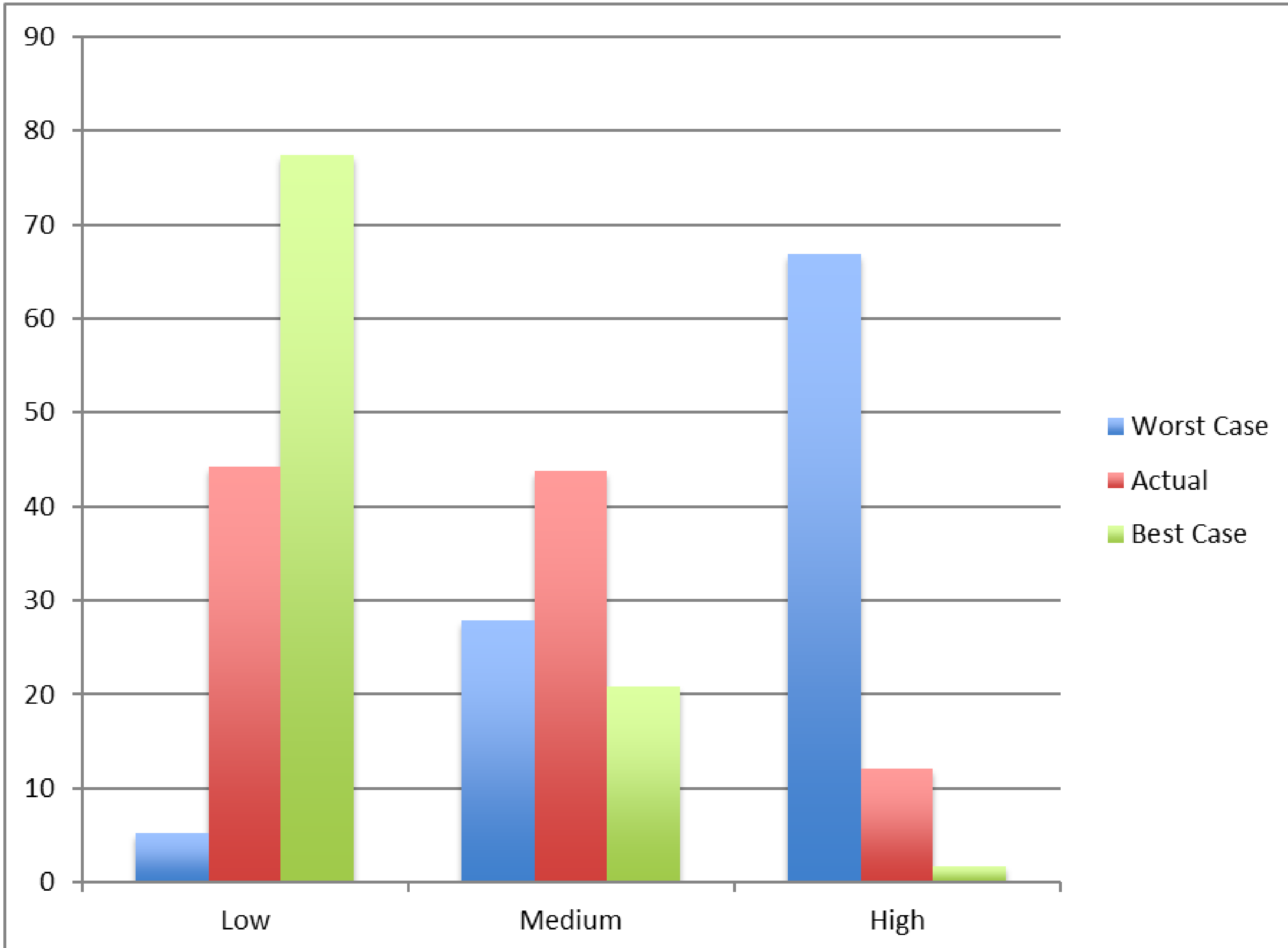
Fratricide BBN - Post Learning



Fratricide BBN – Result?

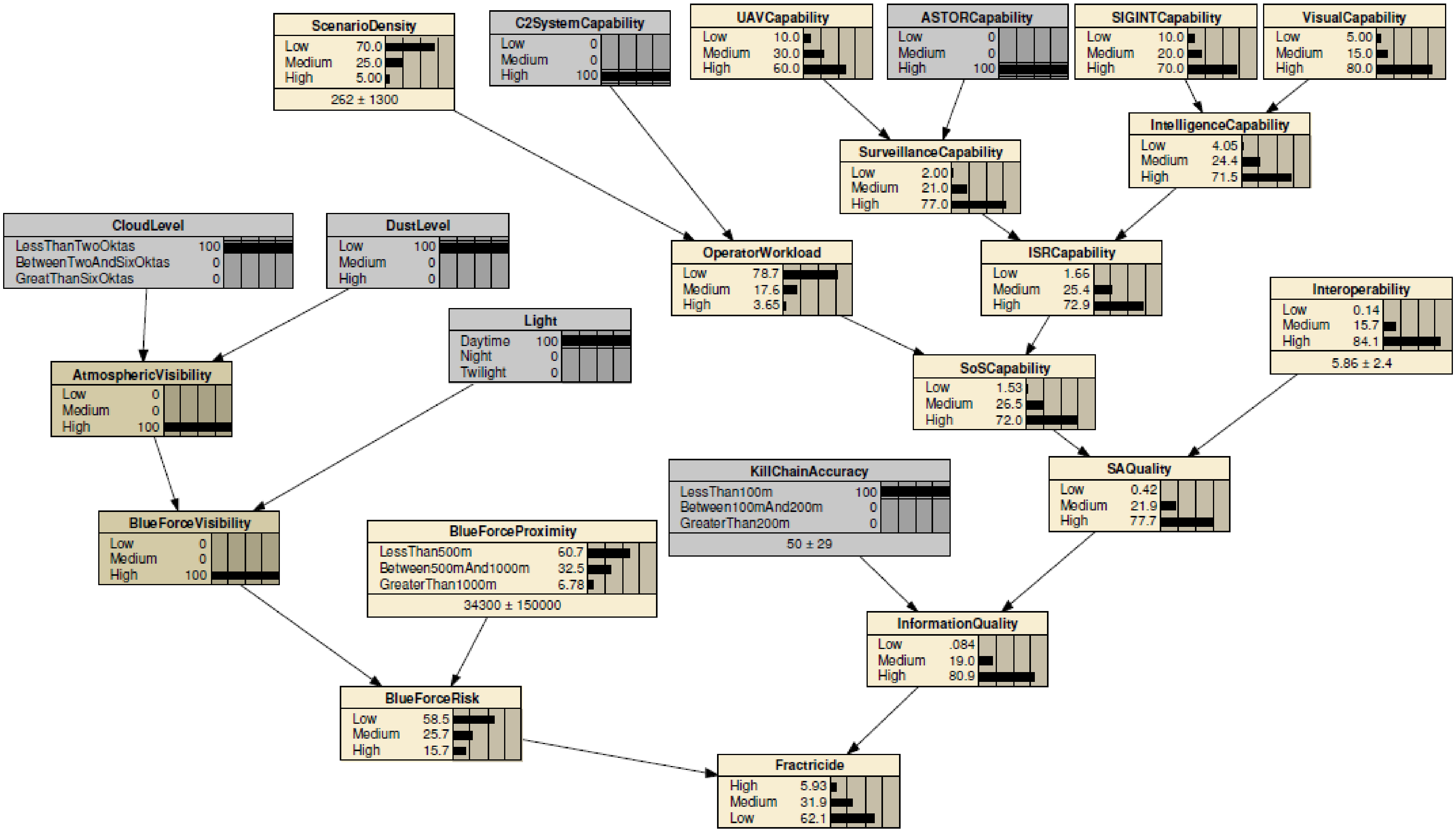


Fratricide BBN – Result Context

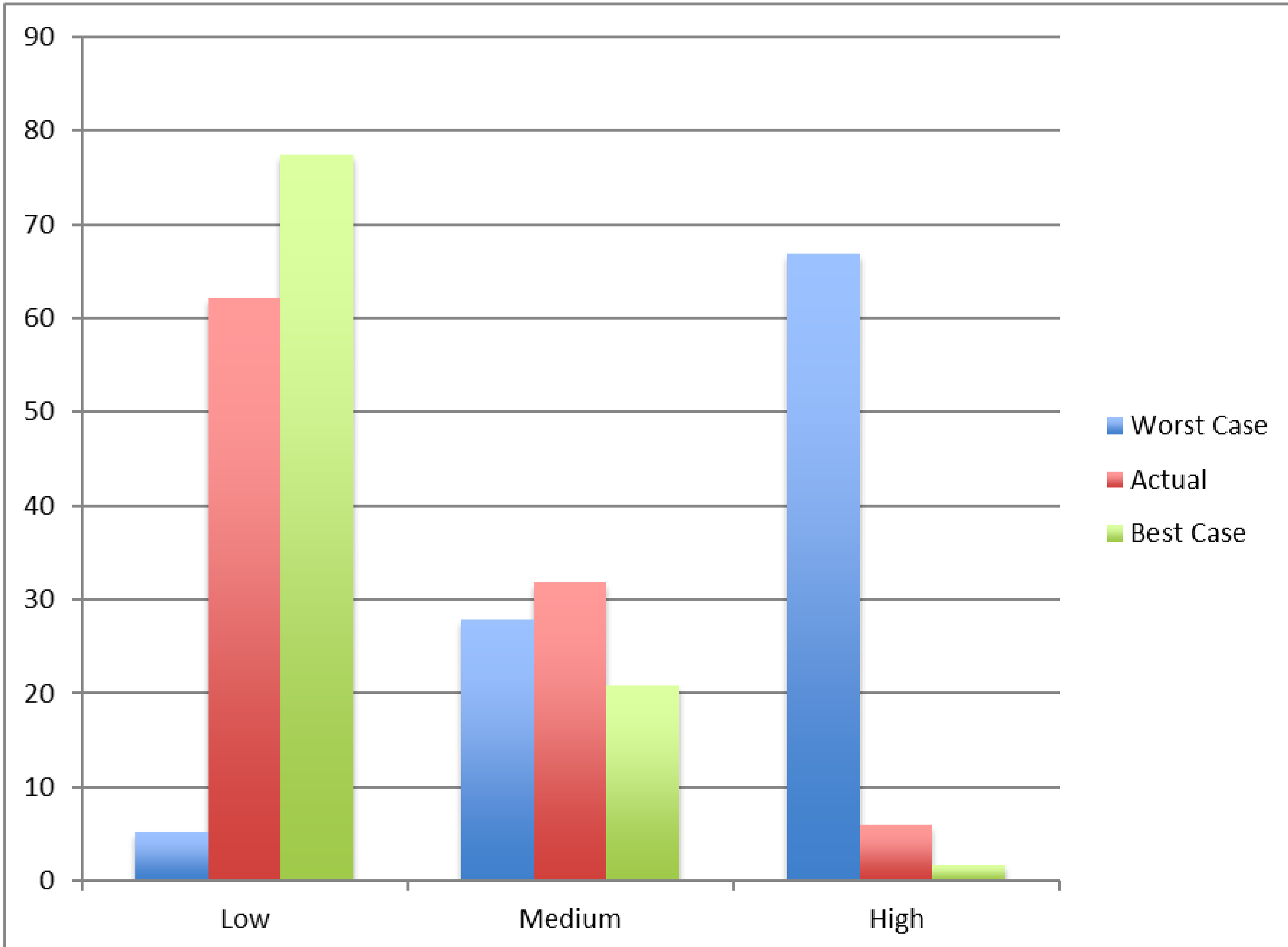


ATEQ Consulting

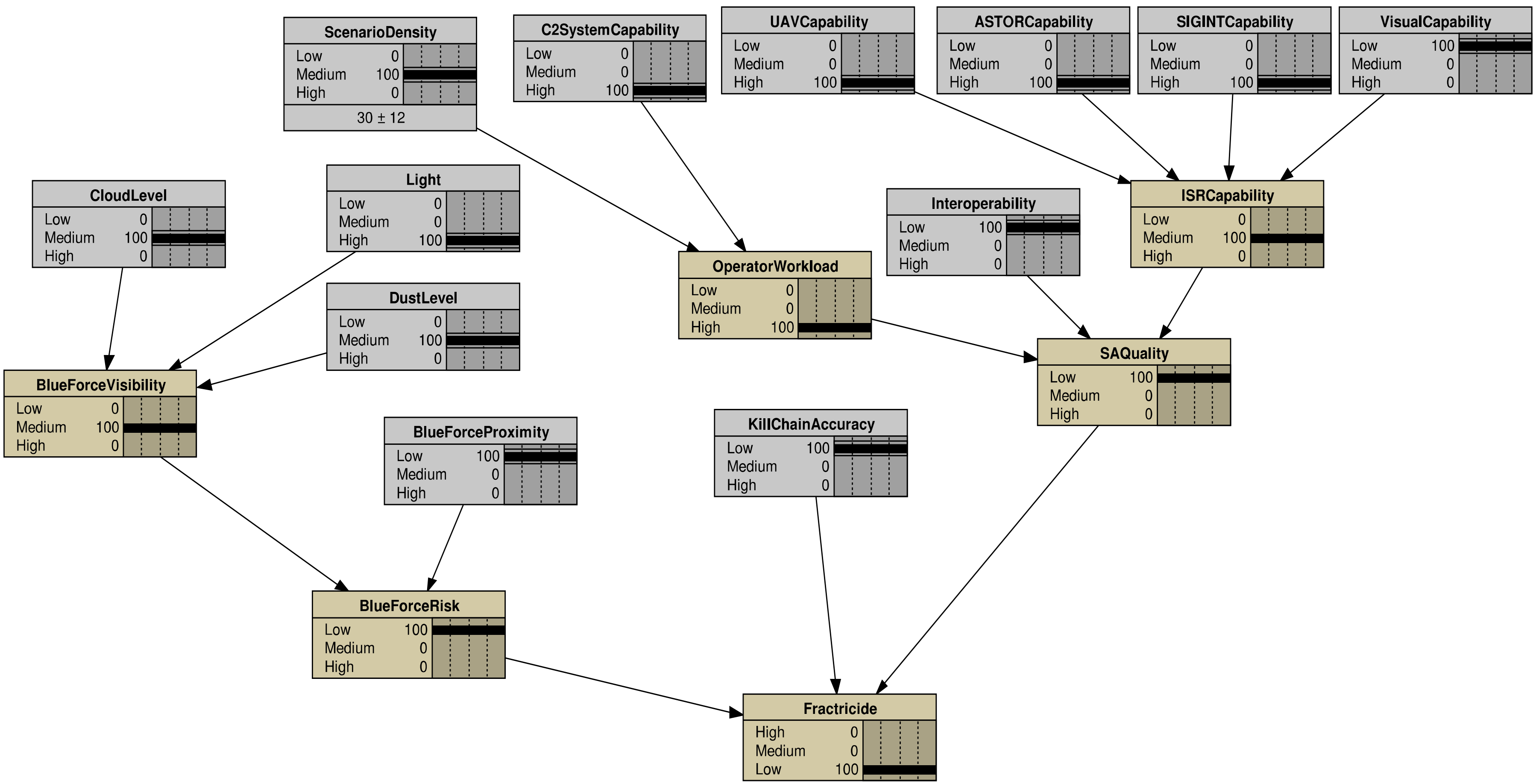
Fratricide BBN – Updated



Fratricide BBN –Result Updated



Fratricide Risk Confidence



Conclusions

- **If risk is managed for each component system then it cannot be assumed that the aggregated affect will be to mitigate risk at the SoS level**
- **Establishing the SoS System of Interest is essential for effective SoS risk identification**
- **The SoS SoI enables risk transfer to be distinguished from mitigation, which is transfer to outside the SoS boundary**
- **Due to the complex and heterogeneous nature of SoS, effective modelling requires a range of techniques where suitability is determined by the problem context**
- **A Bayesian modelling approach was found to be suitable for representing and analysing SoS risk**

ATEQ Consulting

Questions?

andy.kinder@ateq-consulting.com