Modelling a Network of Decision Makers

Dr Tim Gardener

Professor Jim Moffat

Dr Chris Pernin (RAND)

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Acknowledgements

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  Dr Walt Perry (RAND) and Prof Jim Moffat (Dstl)

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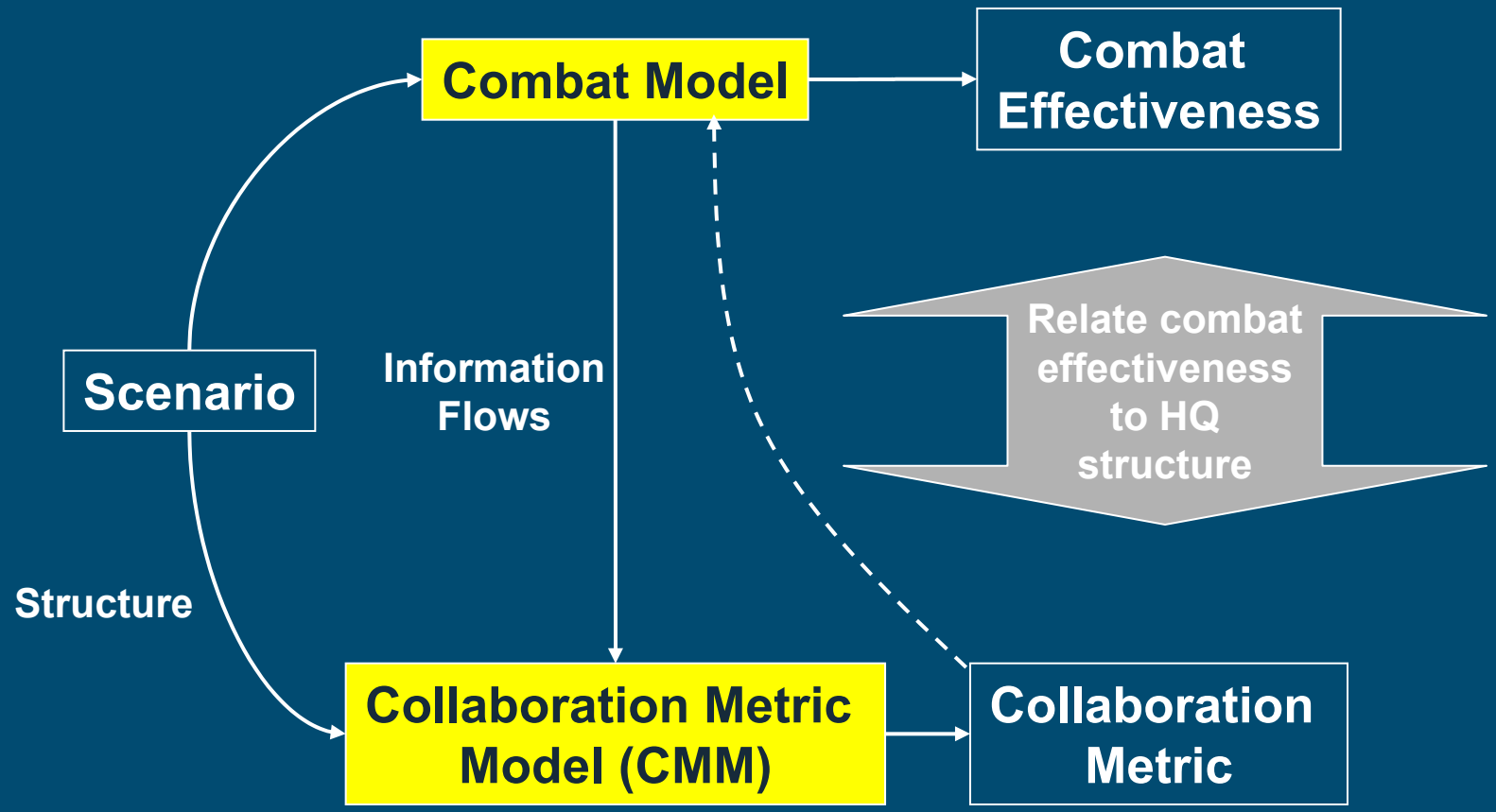
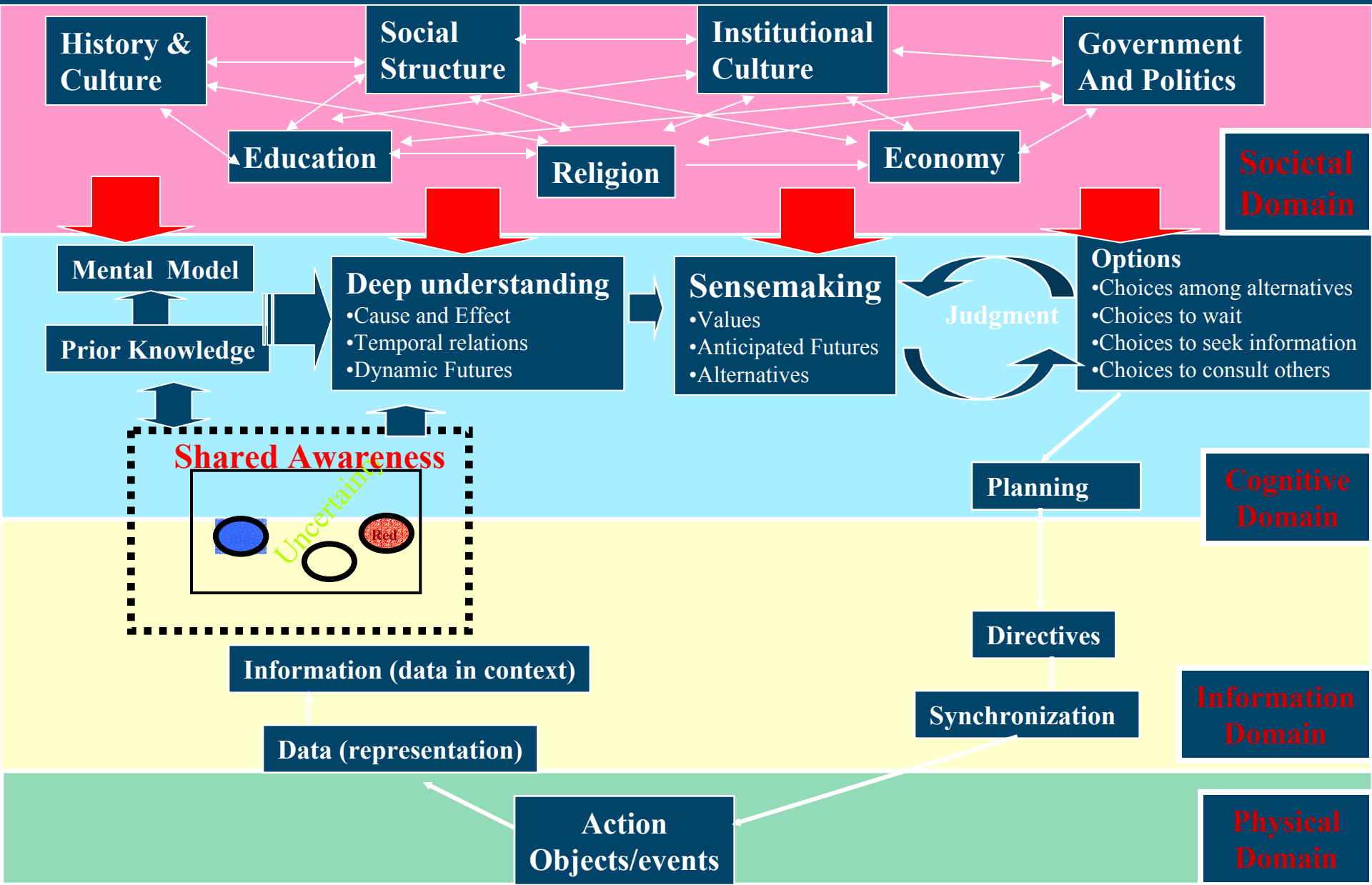
Testing the impact of shared information on Combat Outcome



Physical - Information - Cognitive - Societal

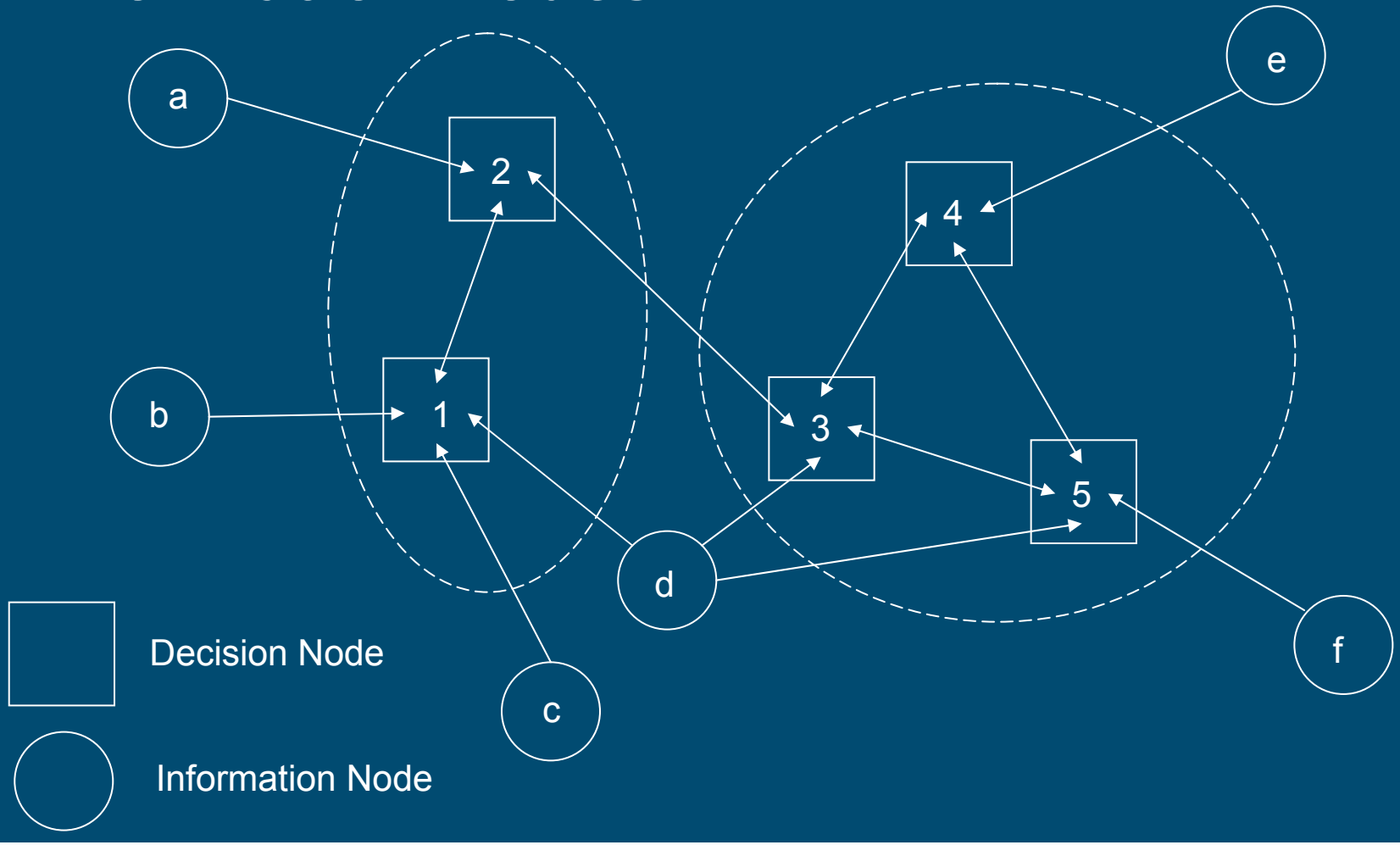
Ed Smith "Effects Based Operations"



Some simplifying assumptions

- Focus on the Information Domain and the Cognitive Domain
- Network comprises nodes and edges between nodes together with flows through the graph
- There are two types of node
  - Decision Making node
  - Information node
- There may be several different flows simultaneously

Network of decision making nodes and Information nodes



Cognitive Domain
The Recognition Primed Decision Model

A decision is simply the selection of a Course of Action in response to a situation

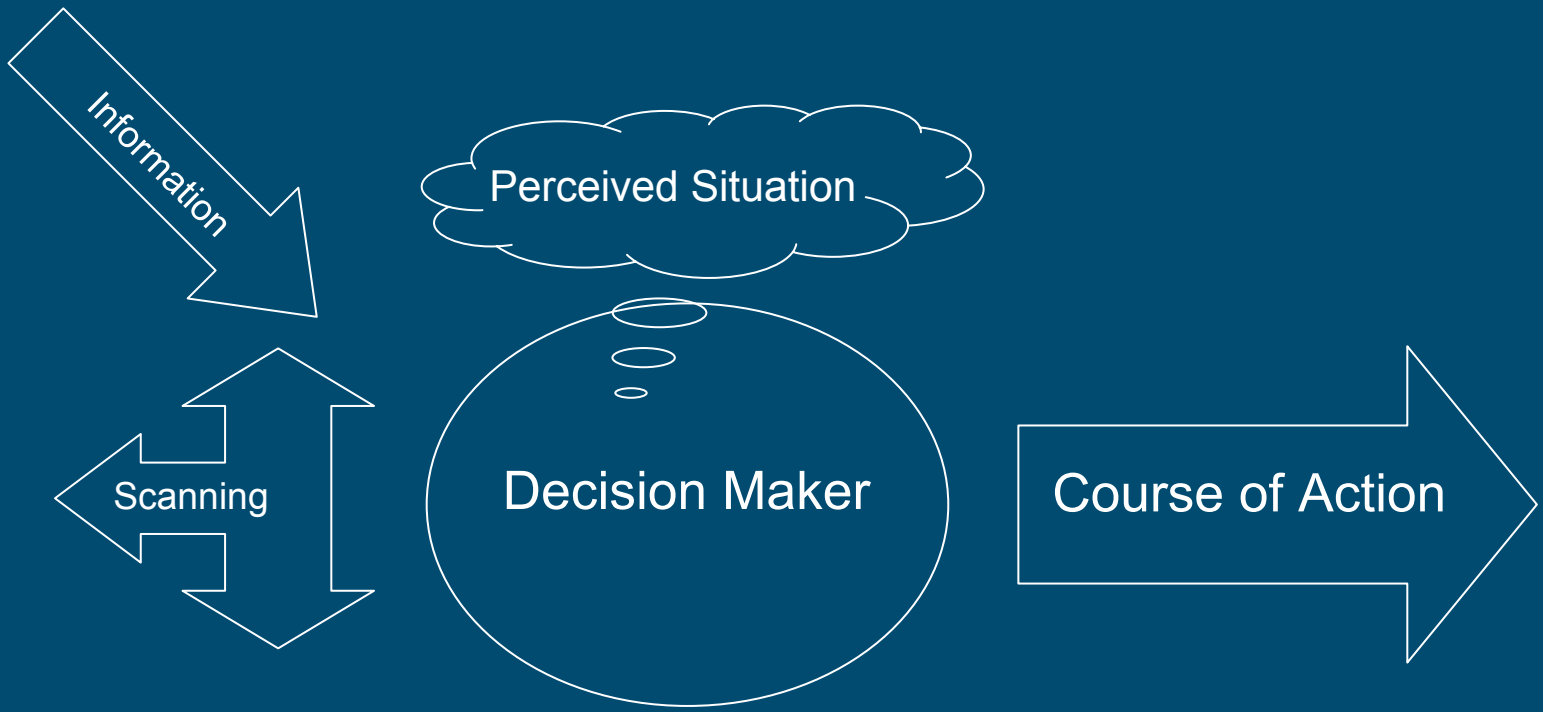
Recognition Primed Decision Model

More accurately, the decision maker bases his decision on perception of the situation

Recognition Primed Decision Model

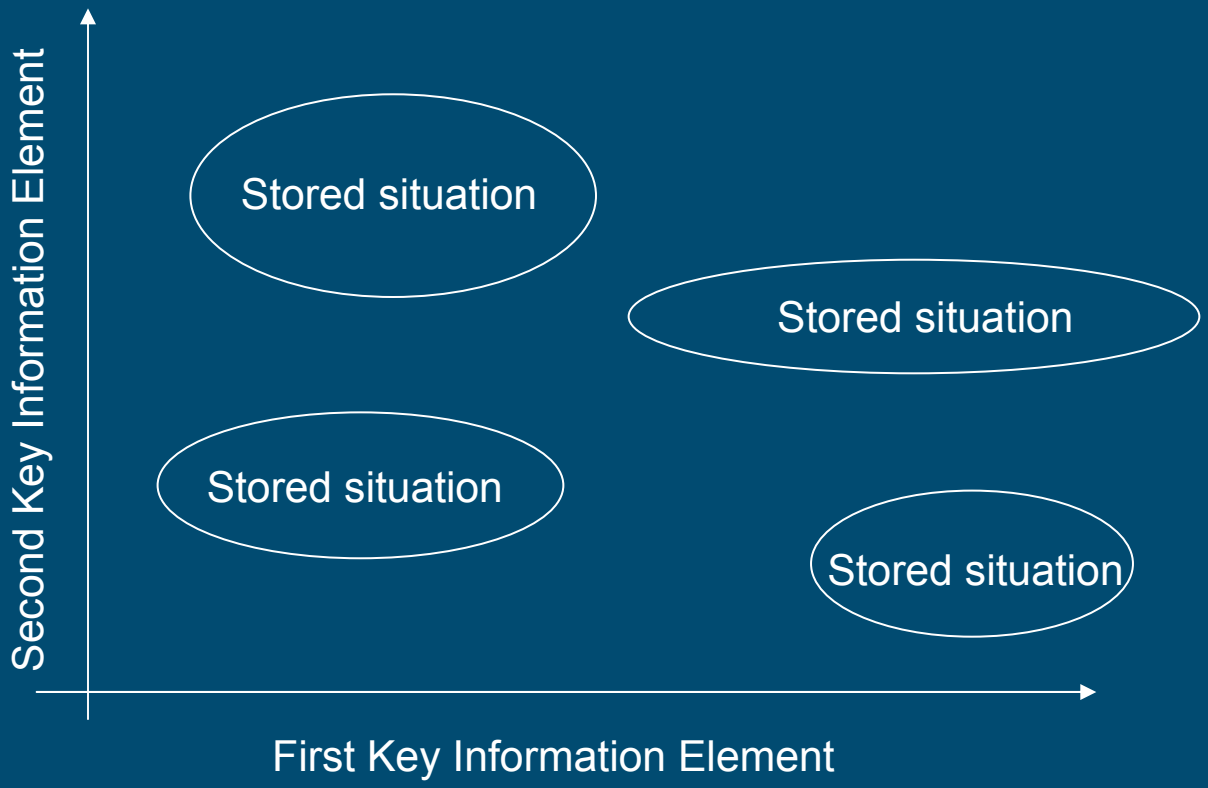
The decision maker scans the environment for clues and cues that might clarify his perception of the given situation

Key Information Requirements



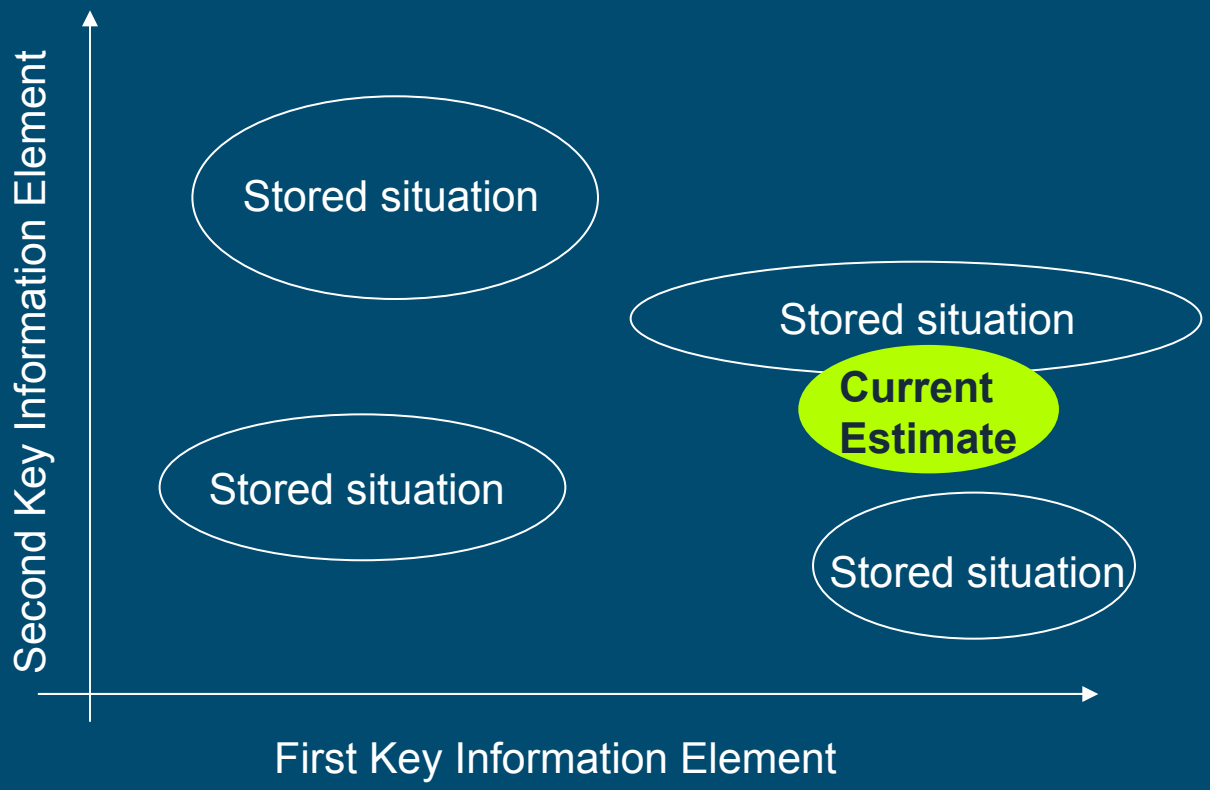
Recognition Primed Decision Model

Situations from experience are stored in the decision maker's mind
Each experience is labelled by a region in the "Information Element Space"
To each stored situation is associated a Course of Action



Recognition Primed Decision Model

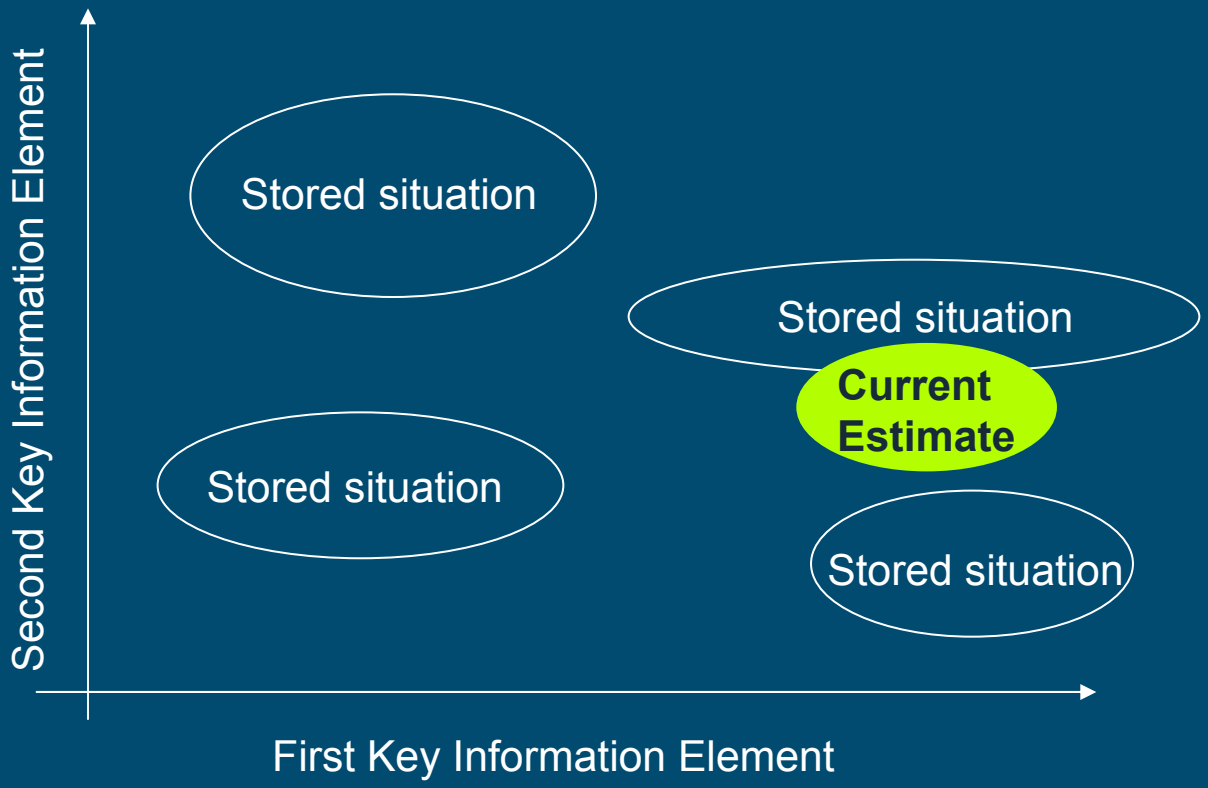
The decision maker's estimate of the current situation is plotted in the Information Element Space - ***with a volume of uncertainty***



Recognition Primed Decision Model

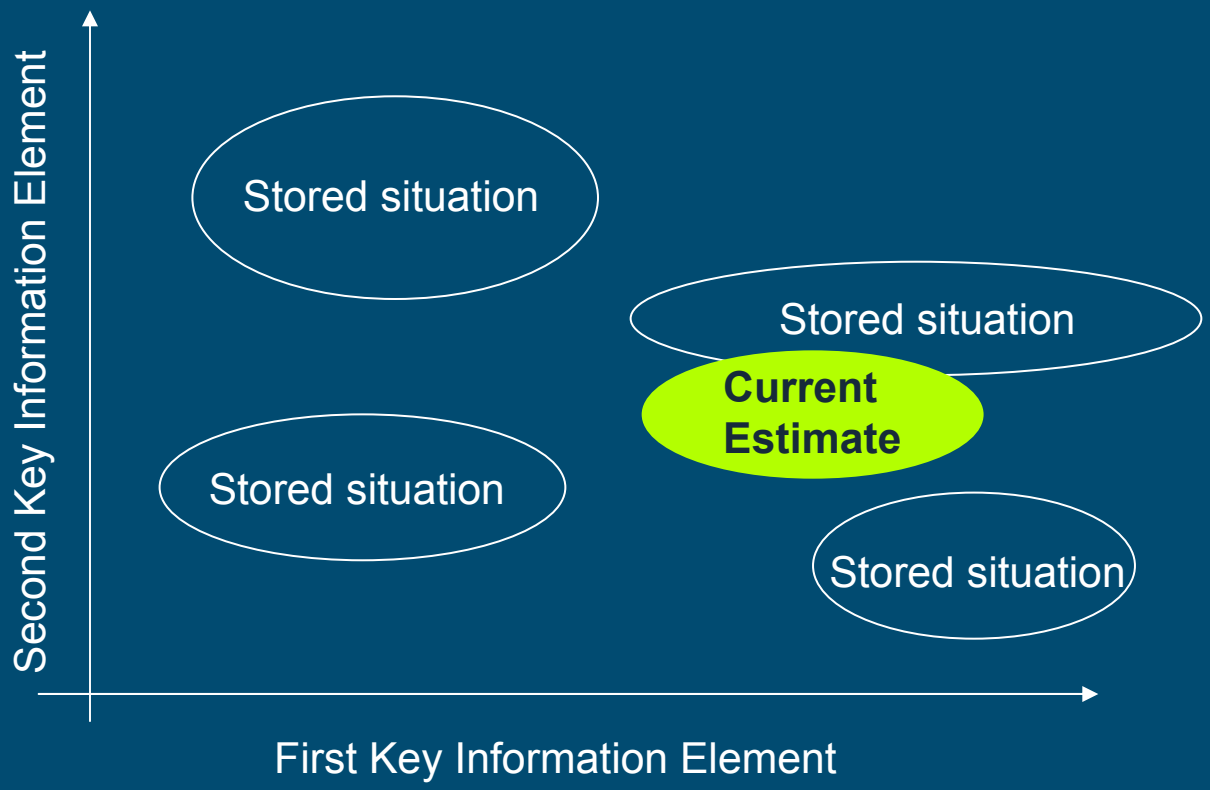
How closely must the perceived situation match a stored situation for the stored Course of Action to be chosen?

Is the decision maker feeling lucky?



Recognition Primed Decision Model

As time goes by, the estimate will change and the degree of uncertainty may increase



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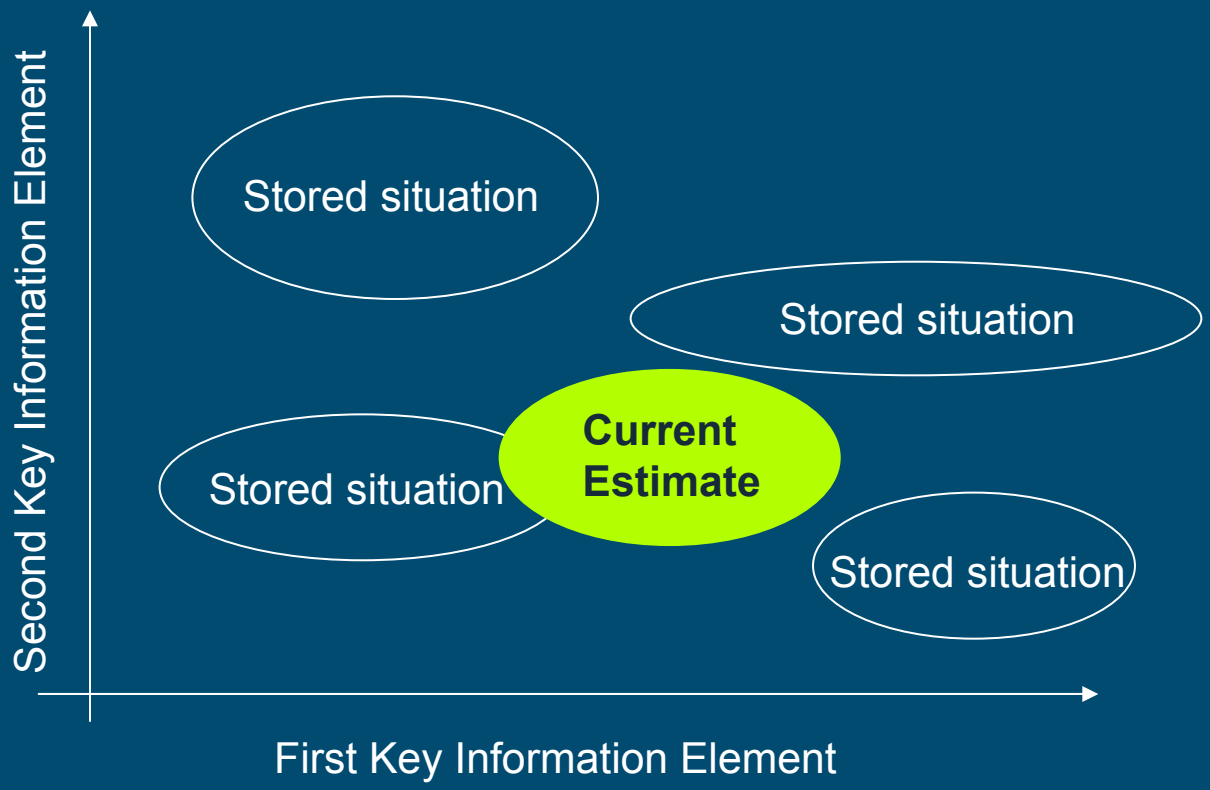
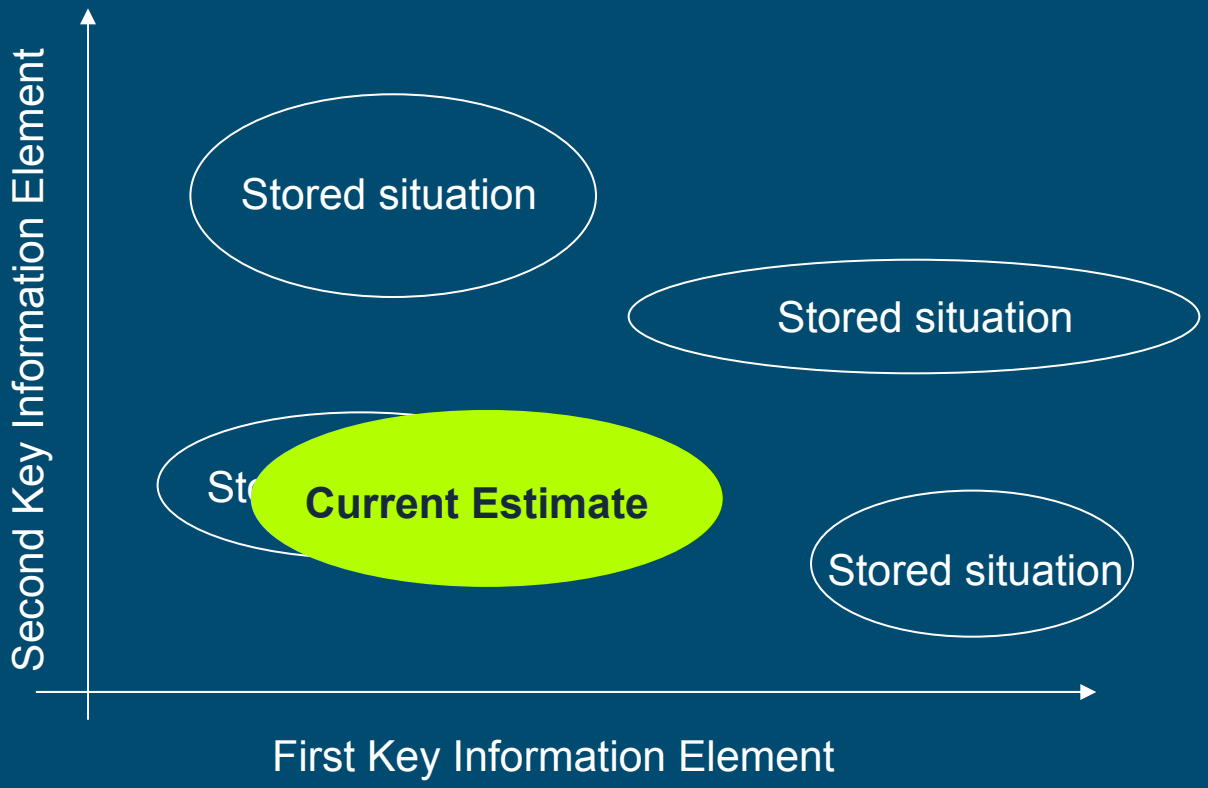


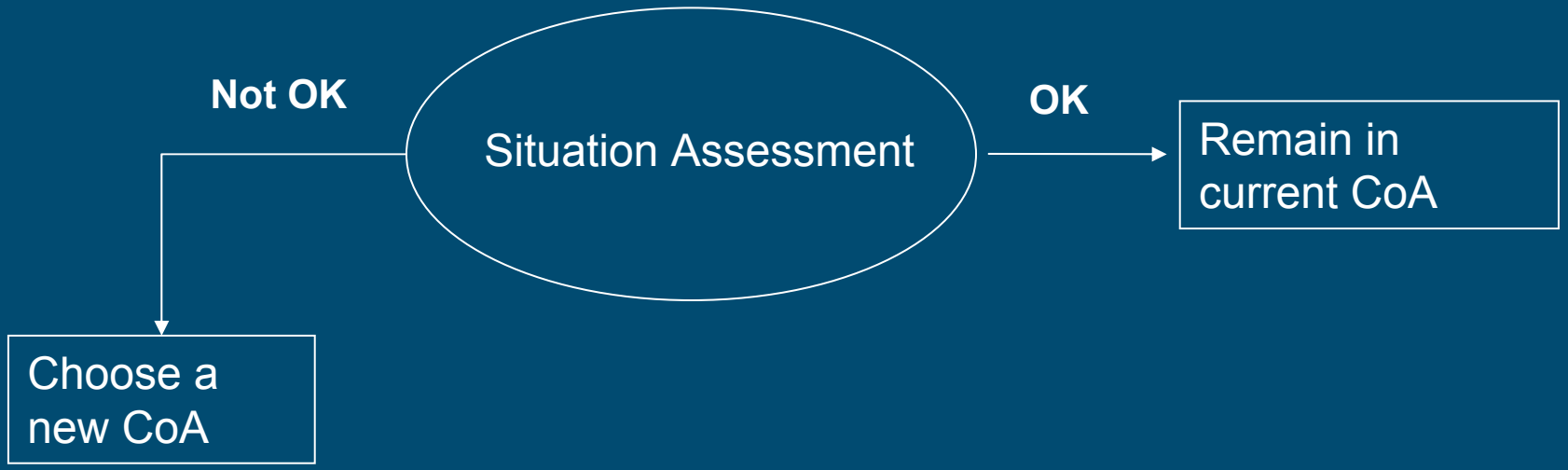
Recognition Primed Decision Model

As time goes by, the estimate will change and the degree of uncertainty may increase - until a change in the course of action is desirable or inescapable



Recognition Primed Decision Model

Situation assessment - OK / Not OK



Information domain - Representing Uncertainty

Information Element Space is spanned by a small number of critical information elements $\mathbf{A} = \{a_1, \ldots\ldots a_N\}$

Example: $\mathbf{A} = \{\text{location, altitude, speed, direction, missile type}\} = \{\mathbf{a}_1, a_2, a_3, a_4, a_5\}$

Each of these information elements is given by a probability distribution

The mean vector represents current estimate $\boldsymbol{\mu} = [\mu_1, \mu_2, \Lambda, \mu_N]$

The covariance matrix of the multivariate distribution represents uncertainty

$$\boldsymbol{\Sigma} = \begin{bmatrix} \sigma_1^2 & \Sigma_{1,2} & \Lambda & \Sigma_{1,N} \\ \Sigma_{2,1} & \sigma_2^2 & \Lambda & \Sigma_{2,N} \\ \mathrm{M} & \mathrm{M} & \mathrm{O} & \mathrm{M} \\ \Sigma_{N,1} & \Sigma_{N,2} & \Lambda & \sigma_N^2 \end{bmatrix}$$

Representing Uncertainty

Decisions depend on the confidence of the decision maker in the accuracy of the estimation

A measure of Uncertainty from Shannon's *Theory of Information* is **Information Entropy**

The Information Entropy contained in a joint probability density function f(**X**) is given by

$$H(\mathbf{X}) = E[-\log f(\mathbf{X})] = -\int_{x_1}\int_{x_2}\Lambda\int_{x_N} f(\mathbf{X})\log f(\mathbf{X})dx_N\,\Lambda\,dx_2 dx_1$$

Representing Uncertainty

Decisions depend on the confidence of the decision maker in the accuracy of the estimation

A measure of Uncertainty from Shannon's *Theory of Information* is **Information Entropy**

The Information Entropy contained in a multivariate normal distribution was calculated by Shannon in 1948.

$$H(\mathbf{X}) = \frac{1}{2}\log(2\pi)^N|\mathbf{\Sigma}| + \frac{N}{2} = \frac{1}{2}\log\left[(2\pi e)^N|\mathbf{\Sigma}|\right],$$

Metrics - How good is my information?

- Precision - function of the covariance
- Accuracy - function of the mean
- Completeness - measure of how critical are the critical information requirements?

These are combined into one single metric - the **Collaboration Measure**

Some Effects of Collaboration

Sharing information reduces uncertainty and leads to greater precision, greater accuracy

Sharing information $\Longrightarrow$ more complete information

Some Effects of Collaboration

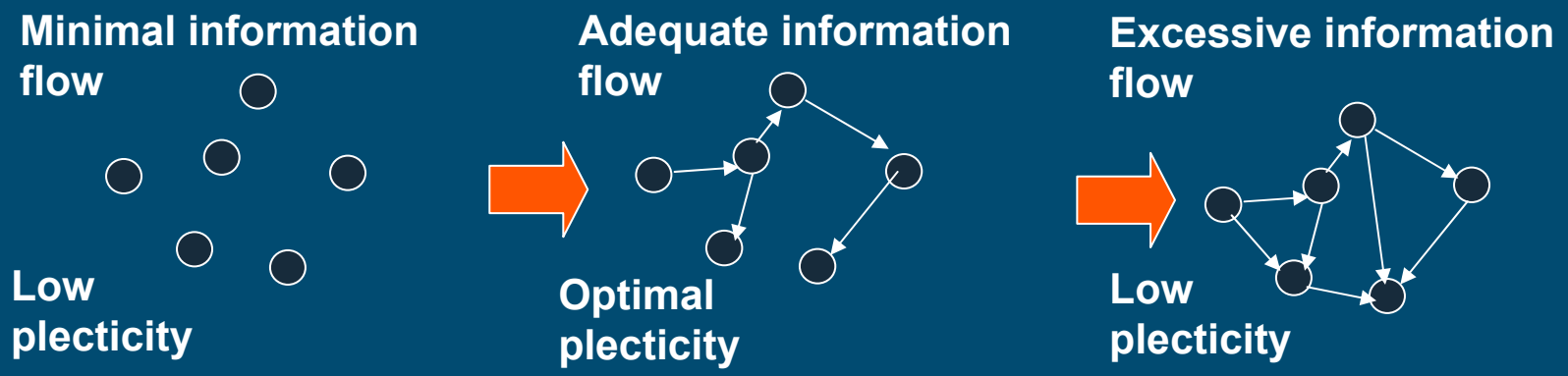
Sharing information reduces uncertainty and leads to greater precision, greater accuracy

Sharing information ⟹ more complete information

Sharing information cost - time, volume, disconfirming evidence

Metrics - How good is my network?

- Network Redundancy - measure of the reliability of the network
  - this is simultaneously a cost and a benefit
- Access Cost - connectivity score based on the distance piece of information must travel from source to decision maker
- Information Overload Cost - measure of the process time required to distinguish between needed and unneeded information



Metrics

Information Metrics

Accuracy

Precision

Completeness

Network Metrics

Information Accessibily

Network Redundancy

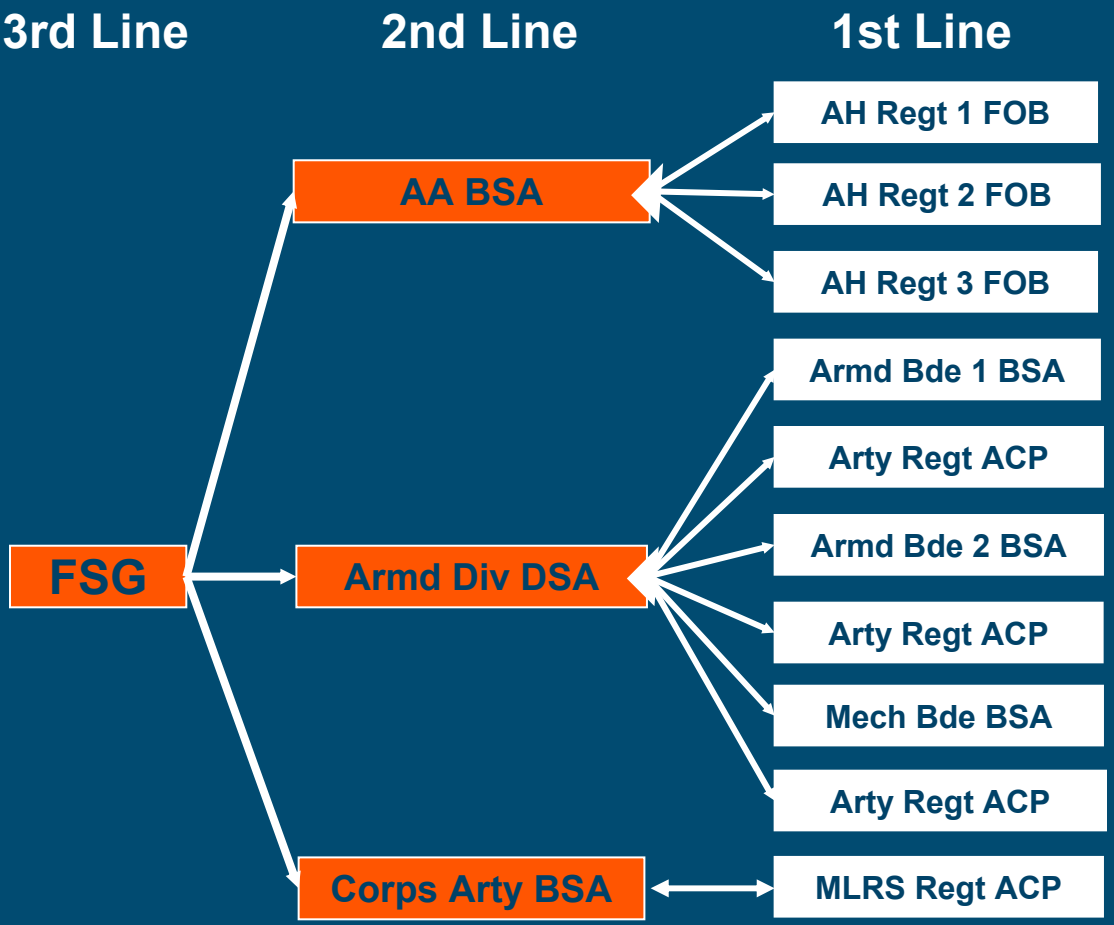
Information Overload

COLLABORATION

PLECTICITY

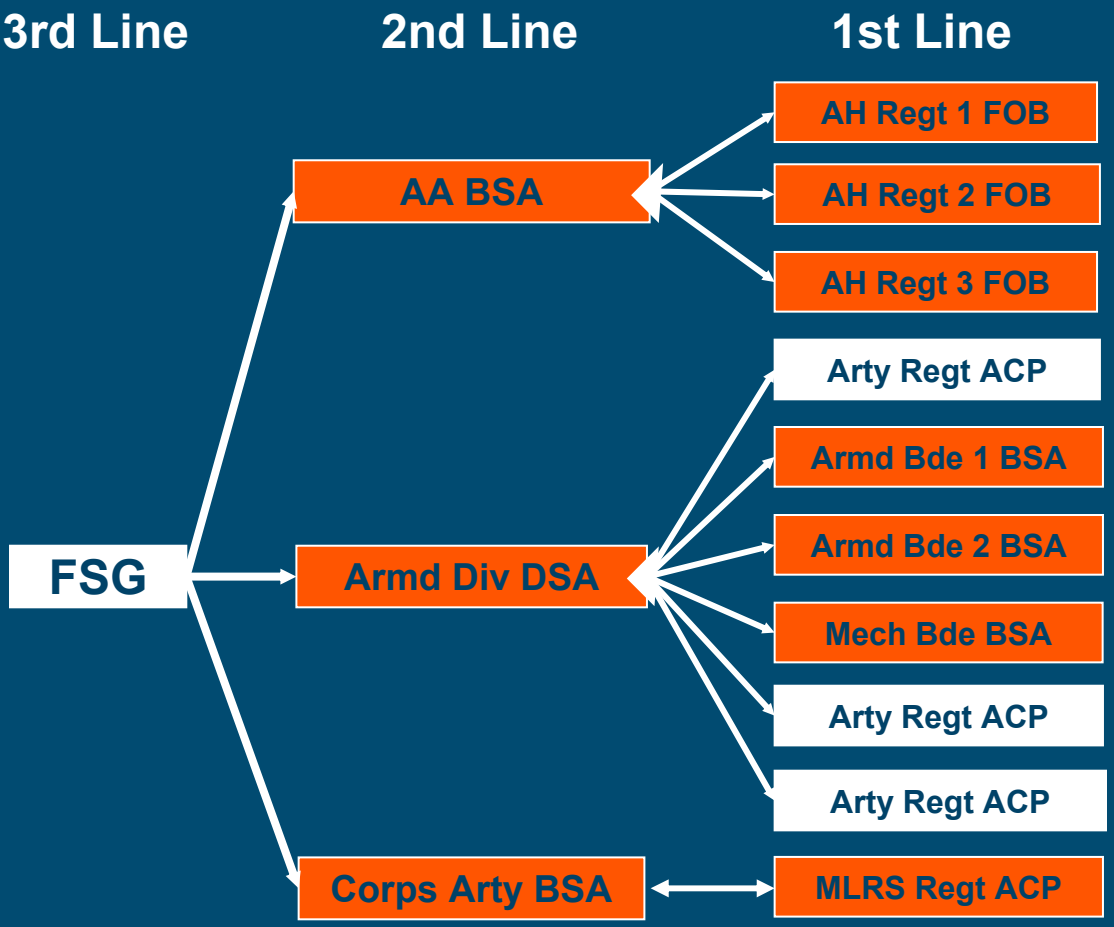
OVERALL NETWORK EFFECTIVENESS

First Network of Decision Makers
Supply Case (S)



Decision Nodes in red

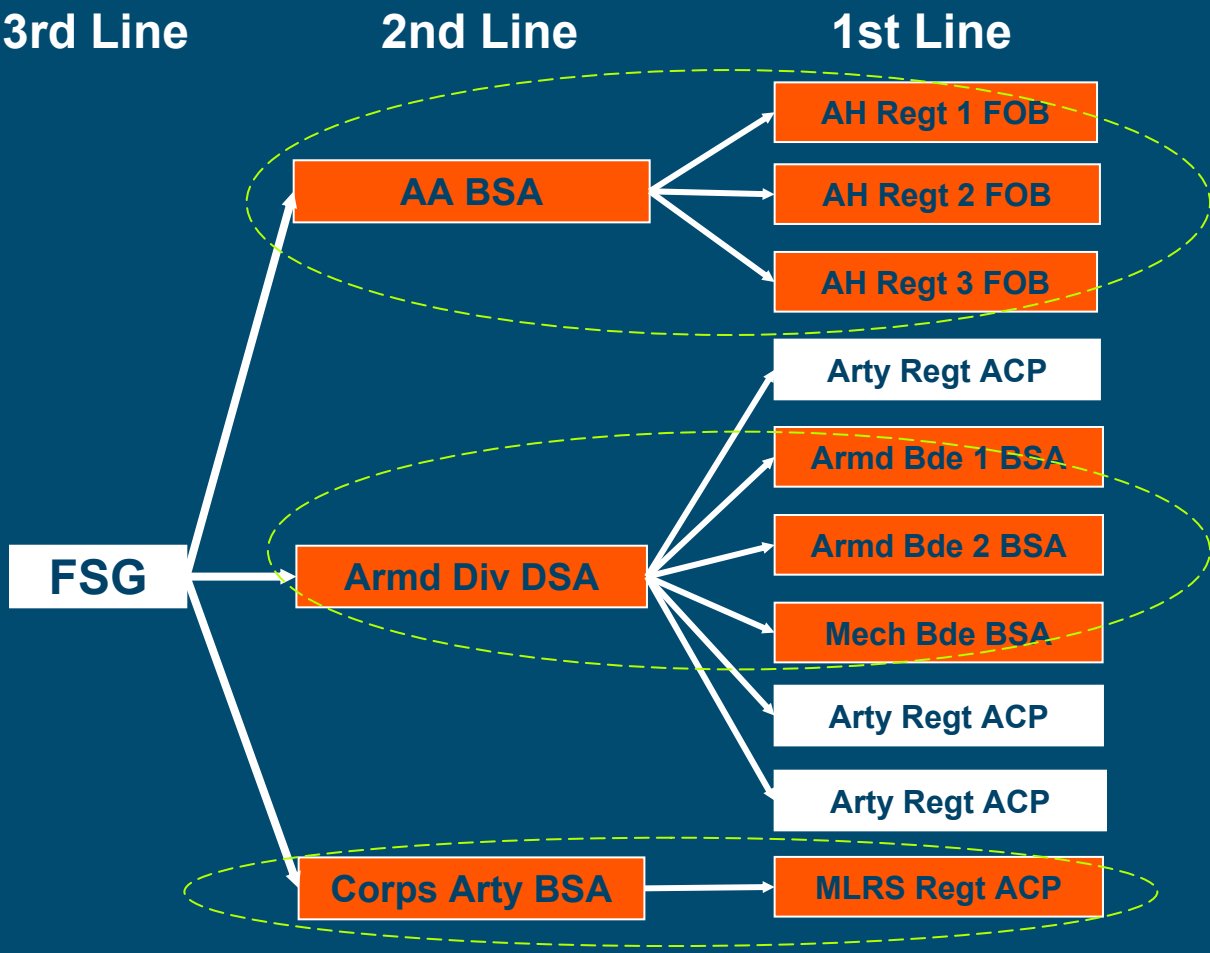
Second Network of Decision Makers
Demand Case (D10)



Decision Nodes in red

Third Network of Decision Makers

Demand Case (D3)

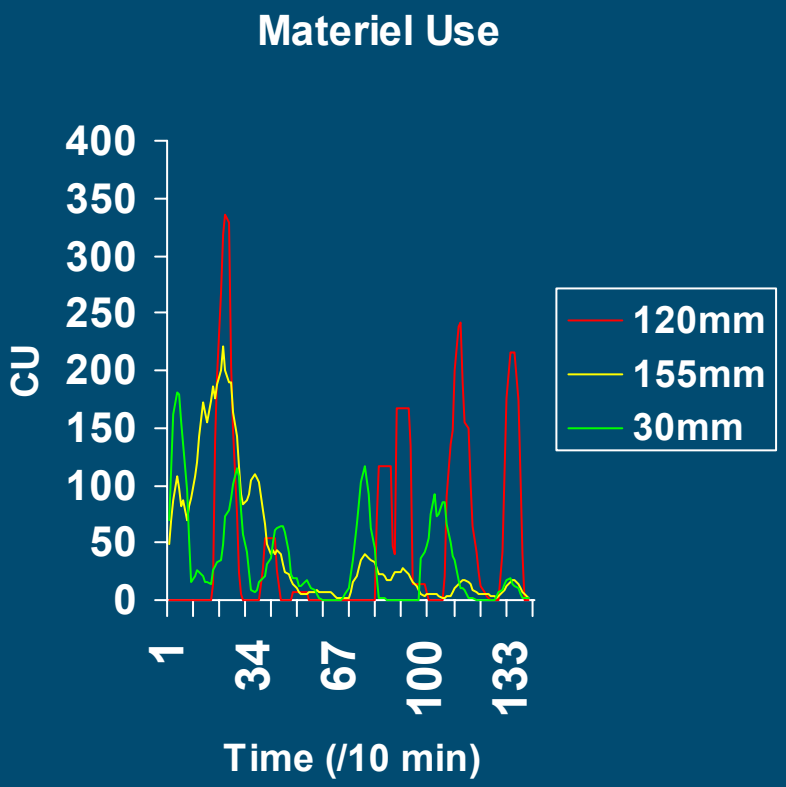


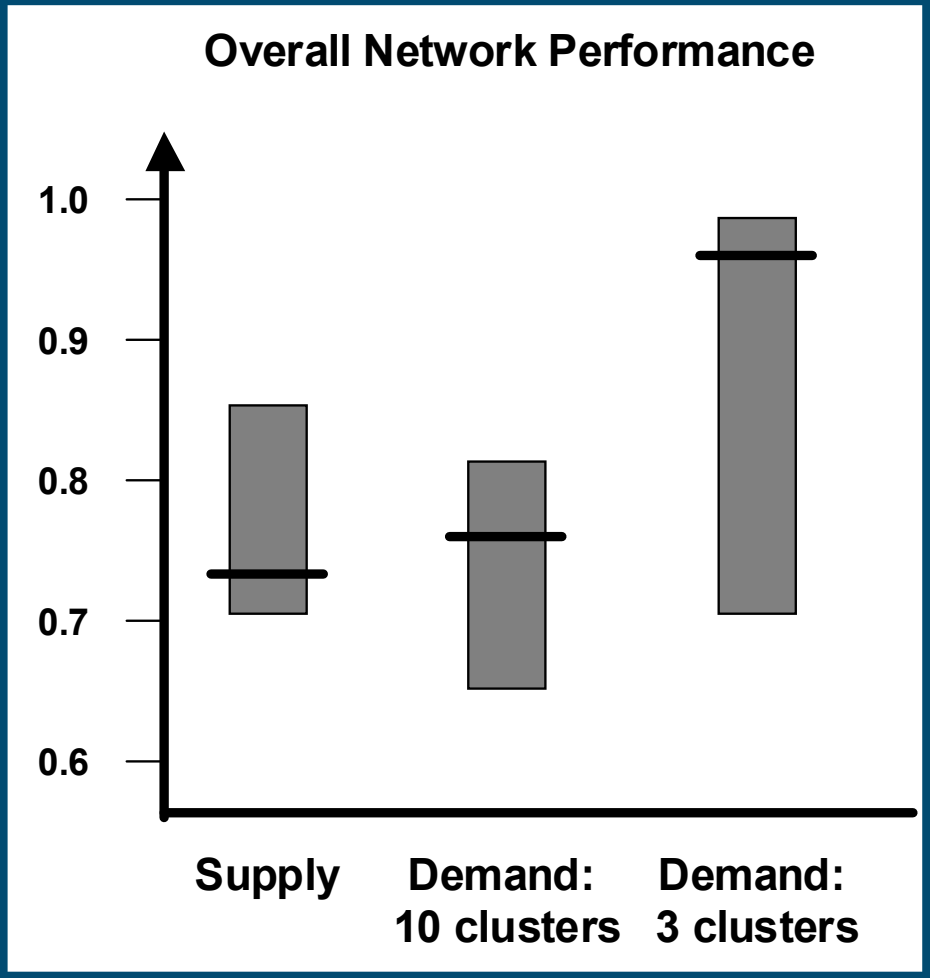
Decision Nodes in red

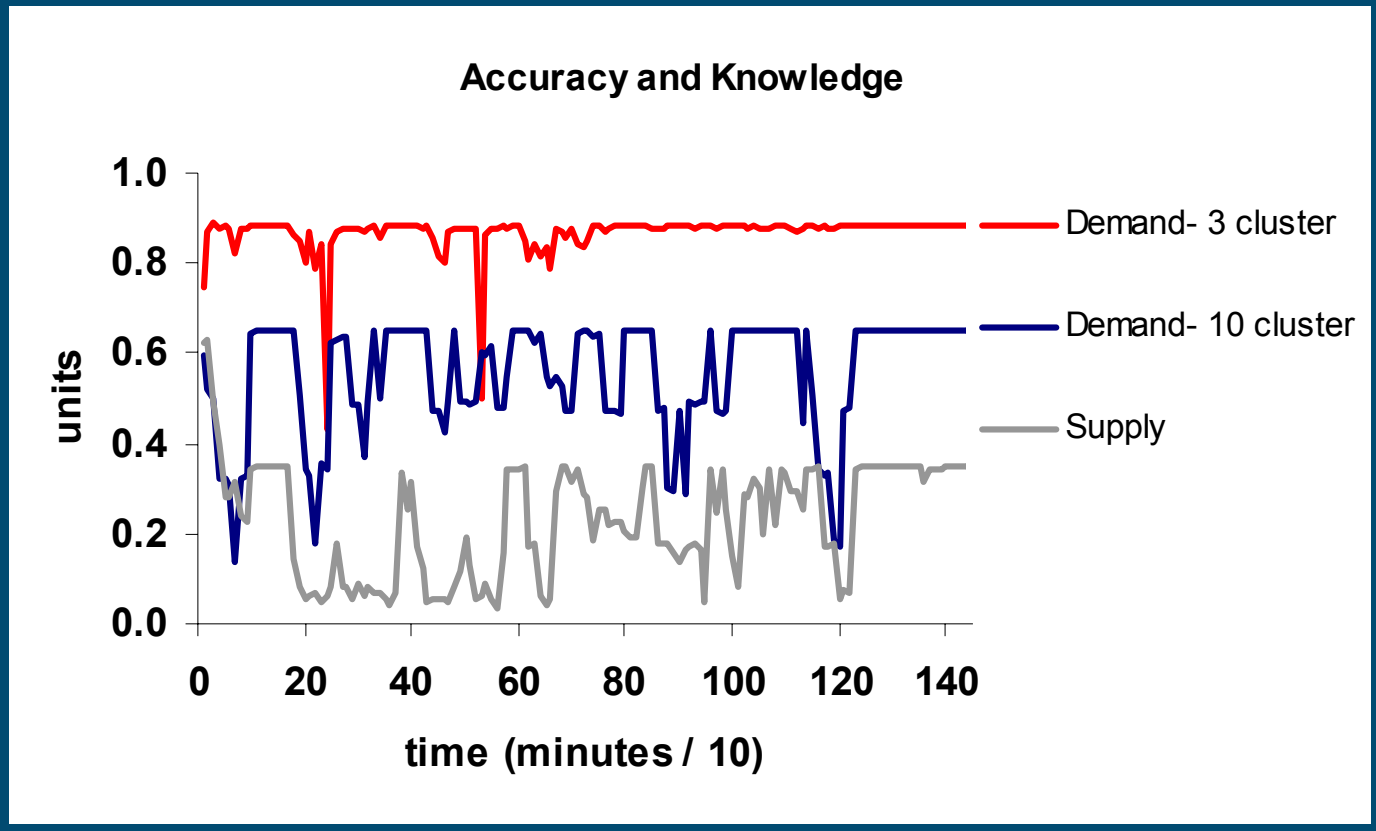
Clusters in green

Input data from the combat model

- Actual use and Consumption Unit data for Ammo and Supplies:
  - 120mm, 155mm, 30 mm, 81mm
  - MLRS, HellFire
  - Fuel, Oil+Lub, PW, Rations, Bulk Water
- Variety of first, second and third line log units
- Time steps from 1 minute increment






Accuracy and Knowledge
1.0
0.8
0.6
0.4
0.2
0.0
units
0
20
40
60
80
100
120
140
time (minutes / 10)
Demand- 3 cluster
Demand- 10 cluster
Supply

Study Diagram
CMM / Combat Model Relationship