PROBLEM, SYSTEM, AND DATA REPRESENTATIONS

EXAMPLE: REALLY DEADLY MISSILE SYSTEM (RDMS)

An Aging System

Problem: Can we effectively employ this system without further destructive testing?

SYSTEM REPRESENTATION ISSUES FOR RDMS

The purpose of the scheduled destructive testing is to:

- Confirm the original estimated reliability
- Observe any degradation that has taken place

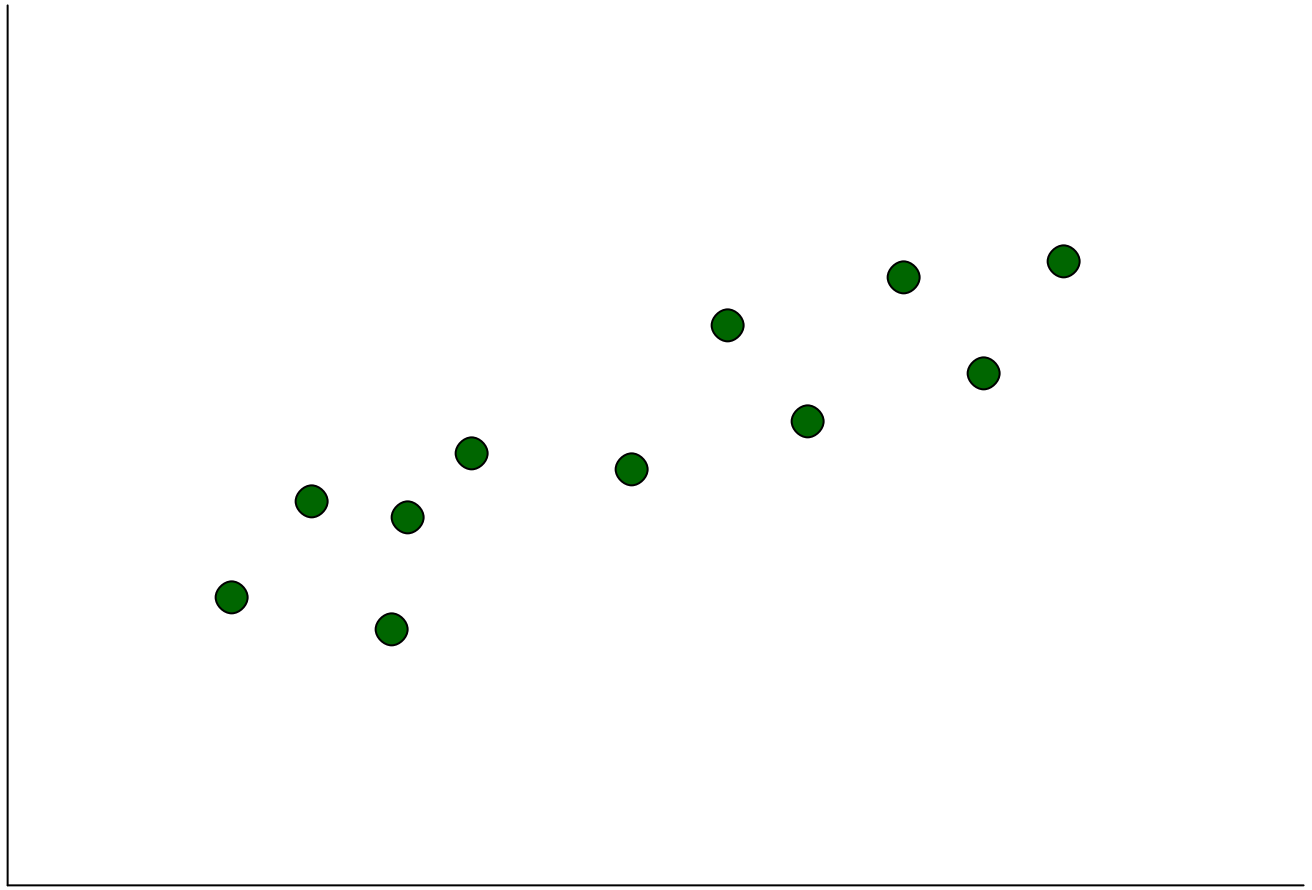
What kinds of data sources do we have?

Limited availability of **direct resources** for destructive test or evaluation if we are to keep this system fielded.

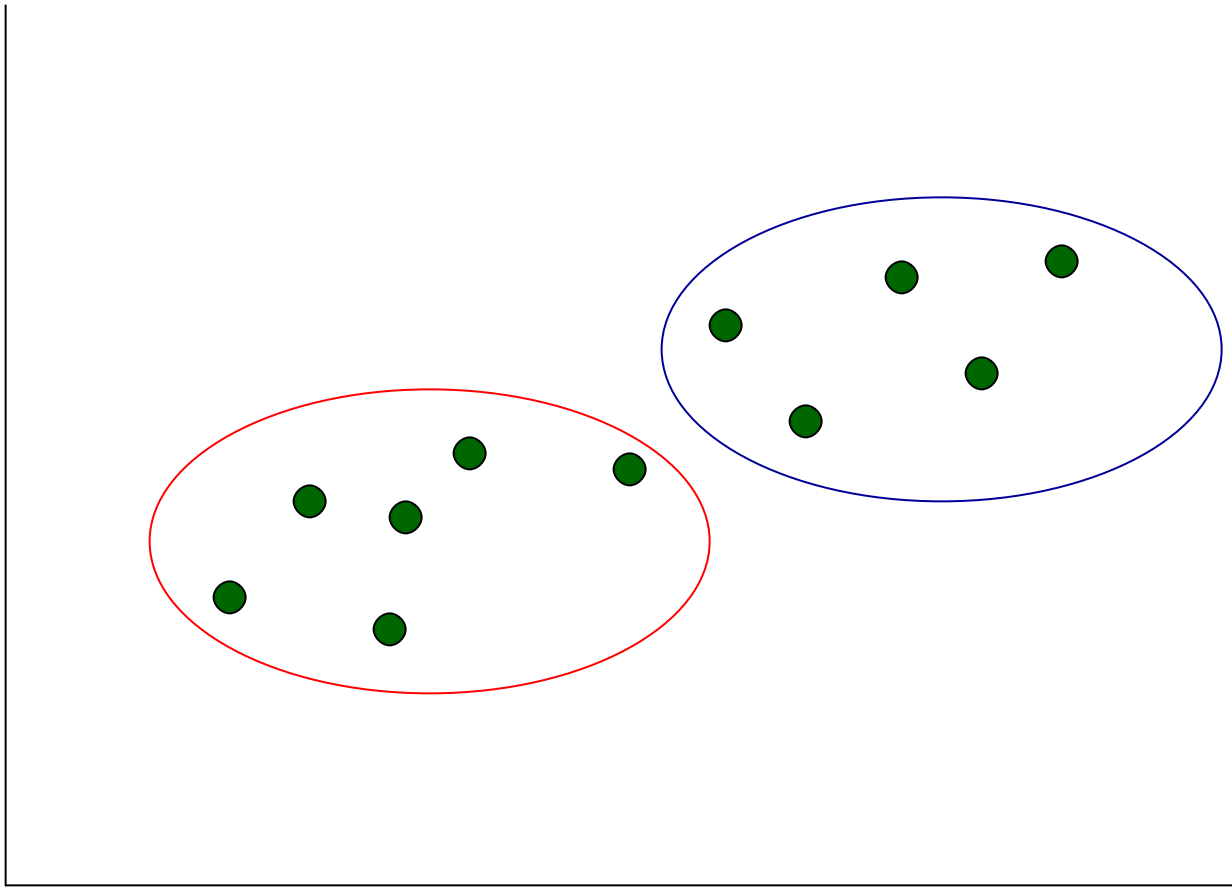
How do the data sources contribute to the assessment of reliability and degradation?

How does this information guide the decision to continue to field this weapon?

DATA, INFORMATION, AND KNOWLEDGE



DATA, INFORMATION, AND KNOWLEDGE



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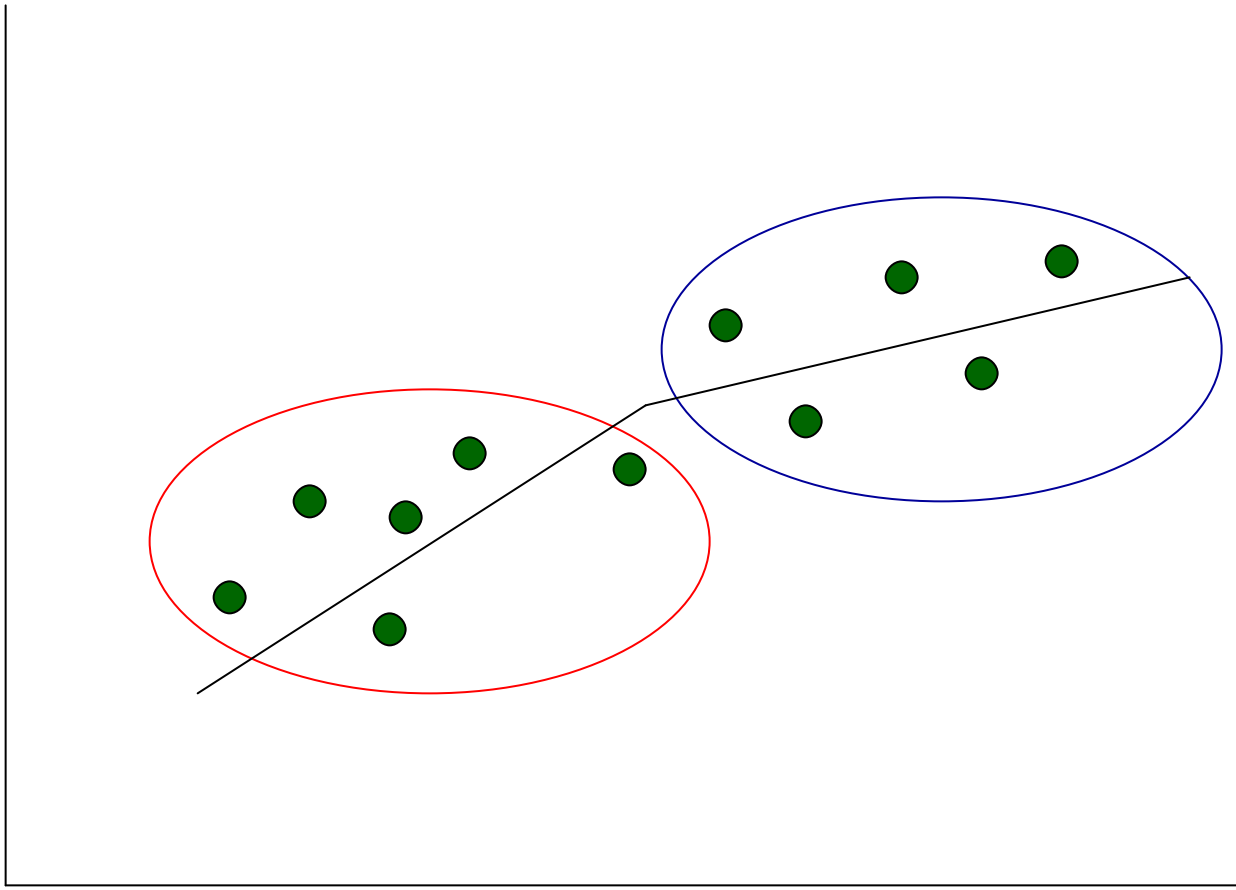


TERMINOLOGY: KNOWLEDGE

Knowledge: what qualified individuals know with respect to their technical (communities of) practices (e.g., problem solving).

How do you do "x" under circumstances "y"?
Not Knowledge in the abstract
What is it you know?
Knowledge as practice

Relates to:

Expertise (System Representation)
Expert Judgment (Data Representation)

TERMINOLOGY: COMMUNITY OF PRACTICE

Community of Practice: ***"Not only people's customs and artifacts and oral traditions, but what they must know in order to act as they do, make the things they make, and interpret their experience in the distinctive way they do."*** Quinn and Holland

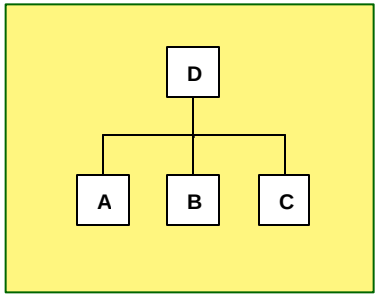
- Attention must be given to diagramming the flow of information throughout the communities and the "system" under study.
- If successful, these communities will take ownership of the entire problem/structure/analysis process, making it part of their problem-solving and decision-making culture.

ROLE OF KNOWLEDGE

Two main uses:

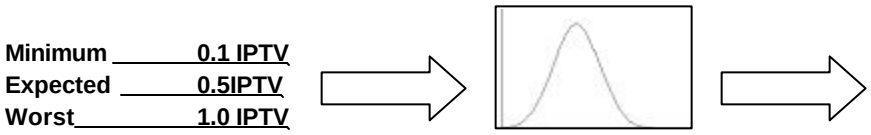
Expertise (System Representation)

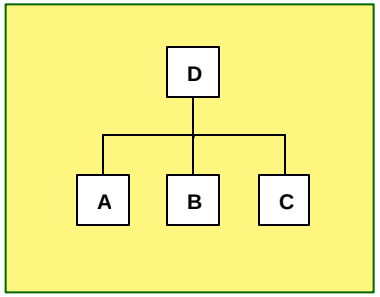
- to create a structure, model, or representation of the technical problem, and



Expert Judgment (Data Representation)

- to provide contents, such as the expert's estimates, for the structure





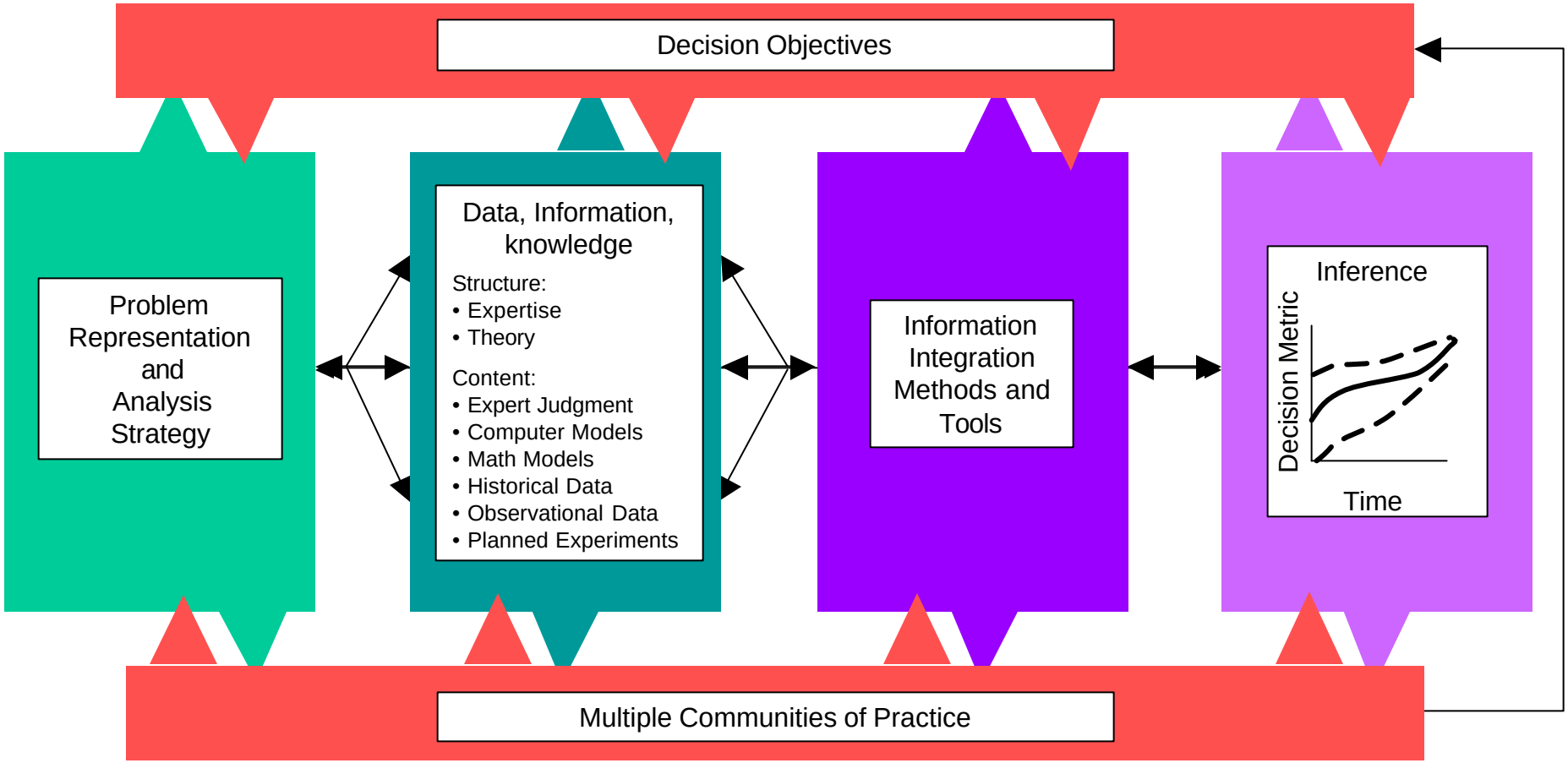
ROLE OF KNOWLEDGE IN STRUCTURING AN IIT SOLUTION

Structuring uses *Expertise*

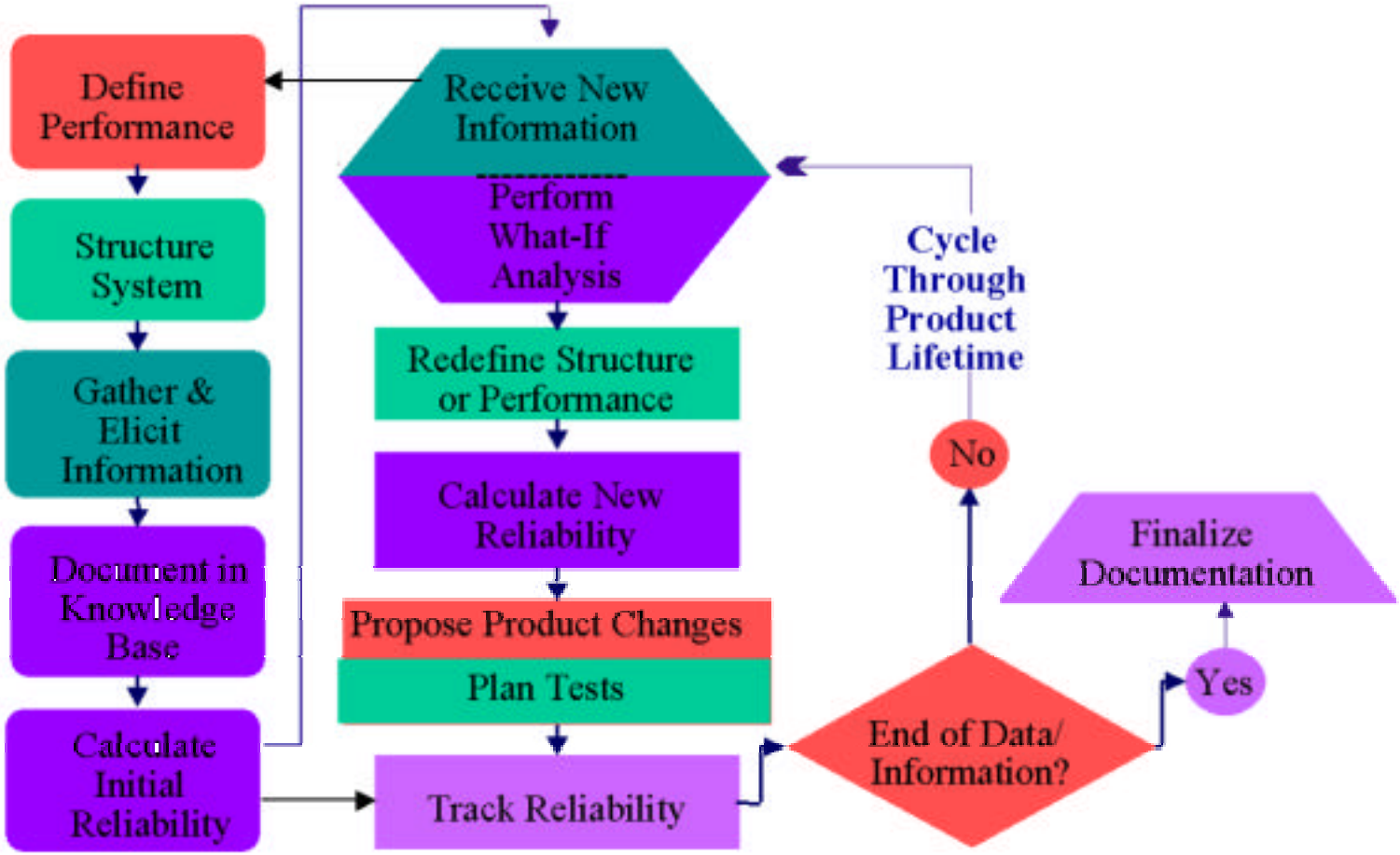
- to define the problem,
- to organize the domain, the information flow,
- to identify the relevant data and information (e.g., codes, experimental results, surveillance findings. . .),
- to determine how these are to be represented, and

As a starting point, we need a general framework.

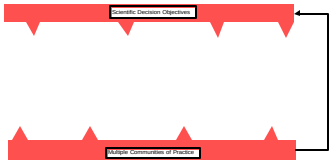
IIT FRAMEWORK



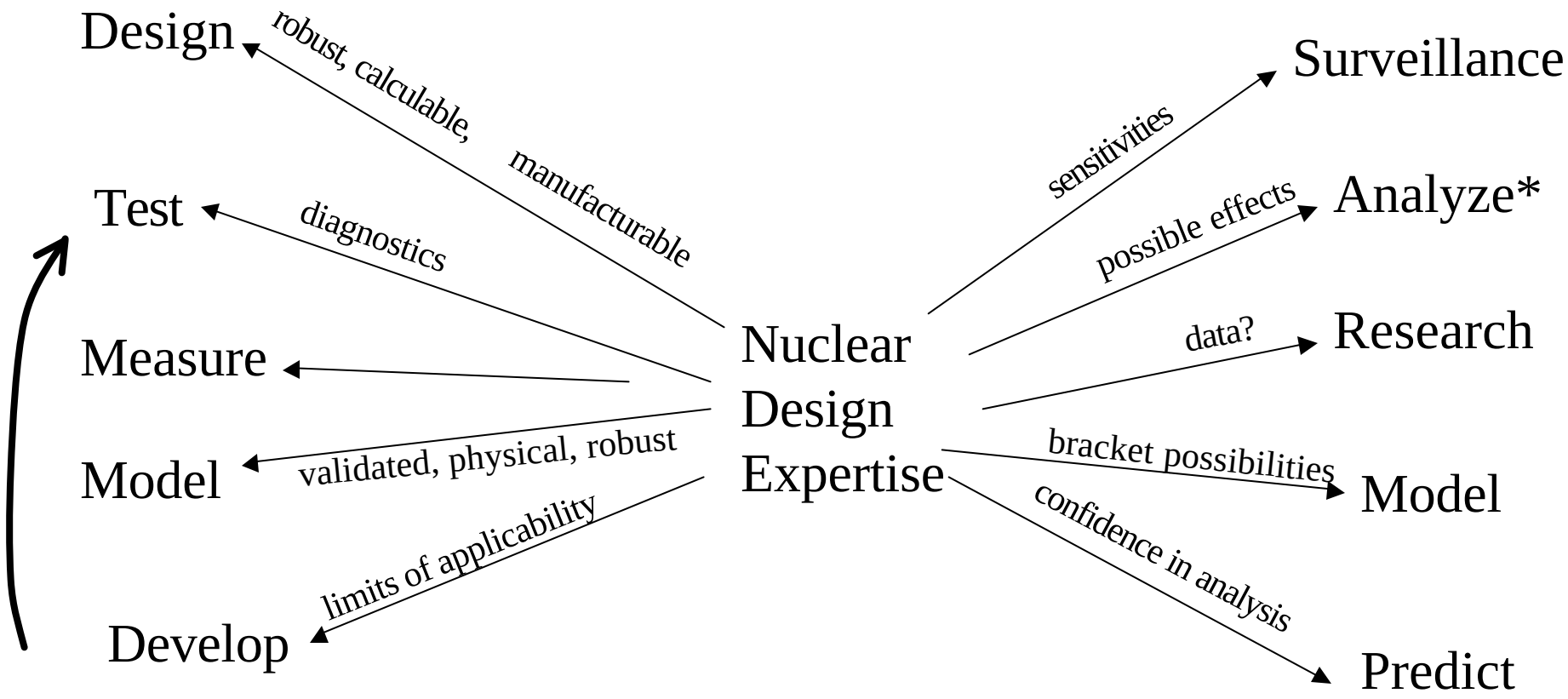
IIT FRAMEWORK APPLICATION FOR AUTOMOTIVE SYSTEM PROBLEM



DECISION CONTEXT

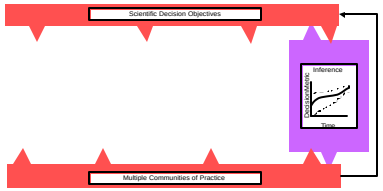


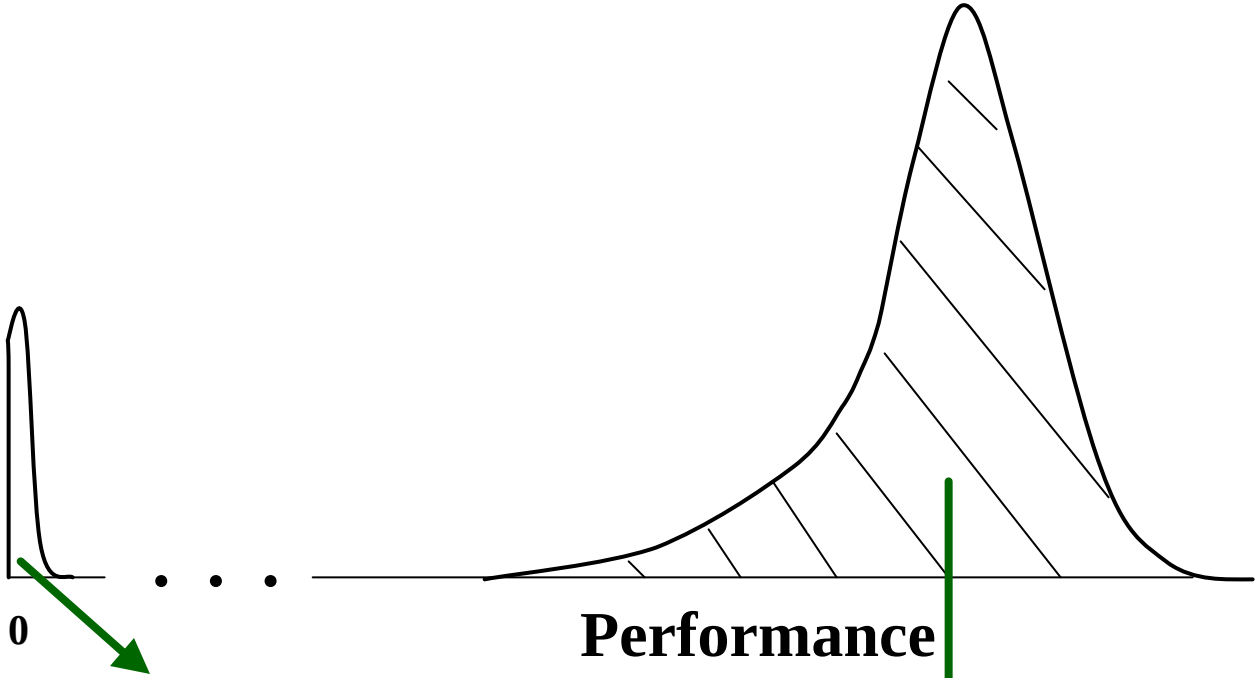
Development **vs.** **Assessment**



*Any relevant NTS or other experience? If not, can't certify.

DECISION METRICS





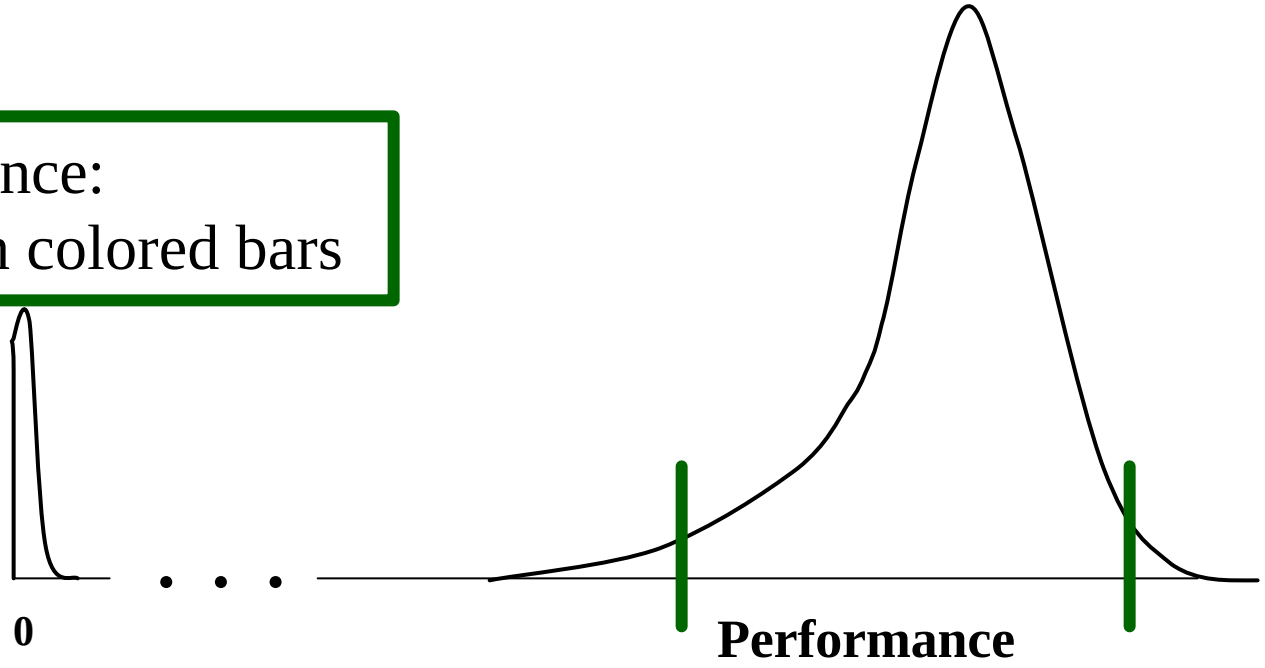
Catastrophic Failures
Infant Mortality
From manufacturing,
Poor quality control, etc.

Reductions in performance from uncertainties, new parts, etc.

DECISION METRICS

Terminology not standardized

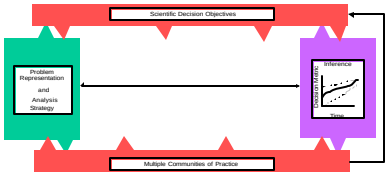
Performance:
•Between colored bars



Performance distribution:
•Entire dual curve
•Curve on right

Reliability:
•1.0-left curve
•Between colored bars
•Prob(performance > some value)

PROBLEM STRUCTURING



System

Design
(Parts)

Process
(Things Done)

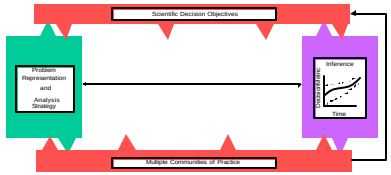
System level
Subsystems
Assemblies
Components
Failure Modes

Physics / Chemistry
Mechanics
Quality Control
Assembly
Testing

FUNCTIONS OF DIAGRAMS

- Subsystems and their connections (functional diagram)
- Information flow (data and uncertainty)
- Problem-solving process

REPRESENTATIONS



Problem Structure Representations:

- Scratch Nets
- Factor Complexes
- Concept Maps

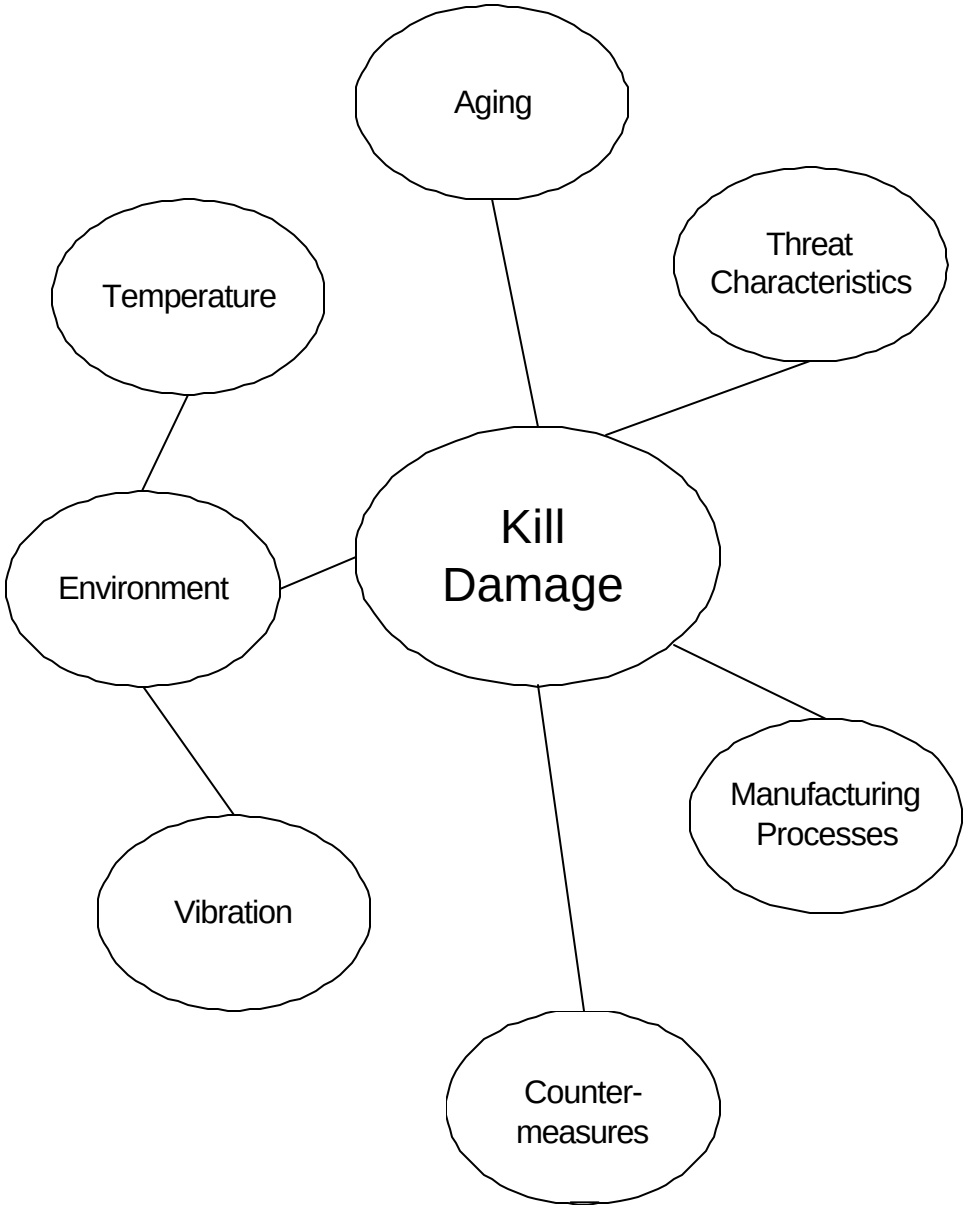
Statistical/Mathematical Representations:

- Logic models/Block Diagrams
- Event trees/Fault trees
- Bayesian networks
- Influence diagram
- Process trees

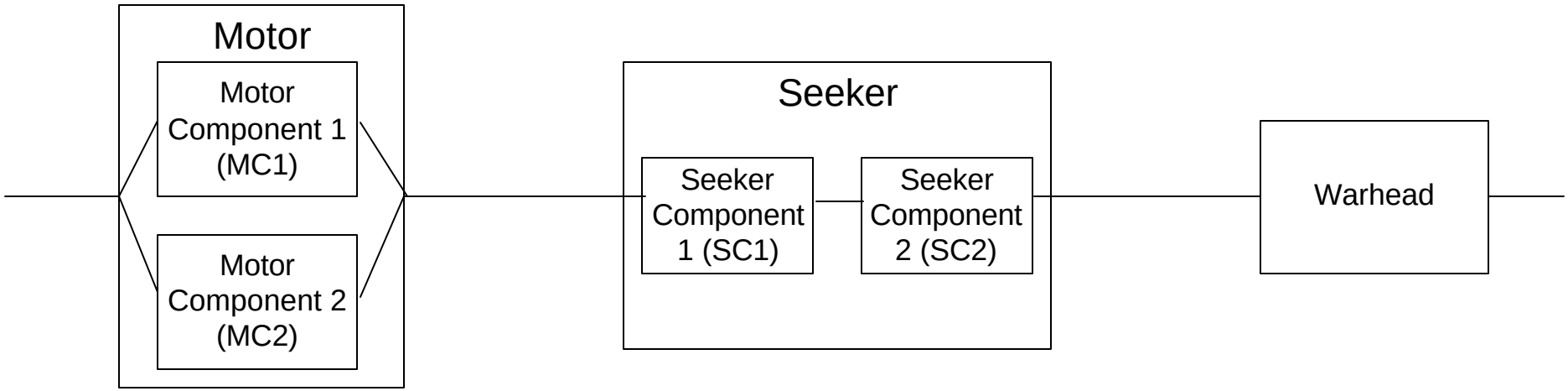
Integration/Connection of Representations

Use multiple representations to capture the knowledge of "communities."

SCRATCH NET/FACTOR COMPLEX



BLOCK DIAGRAM

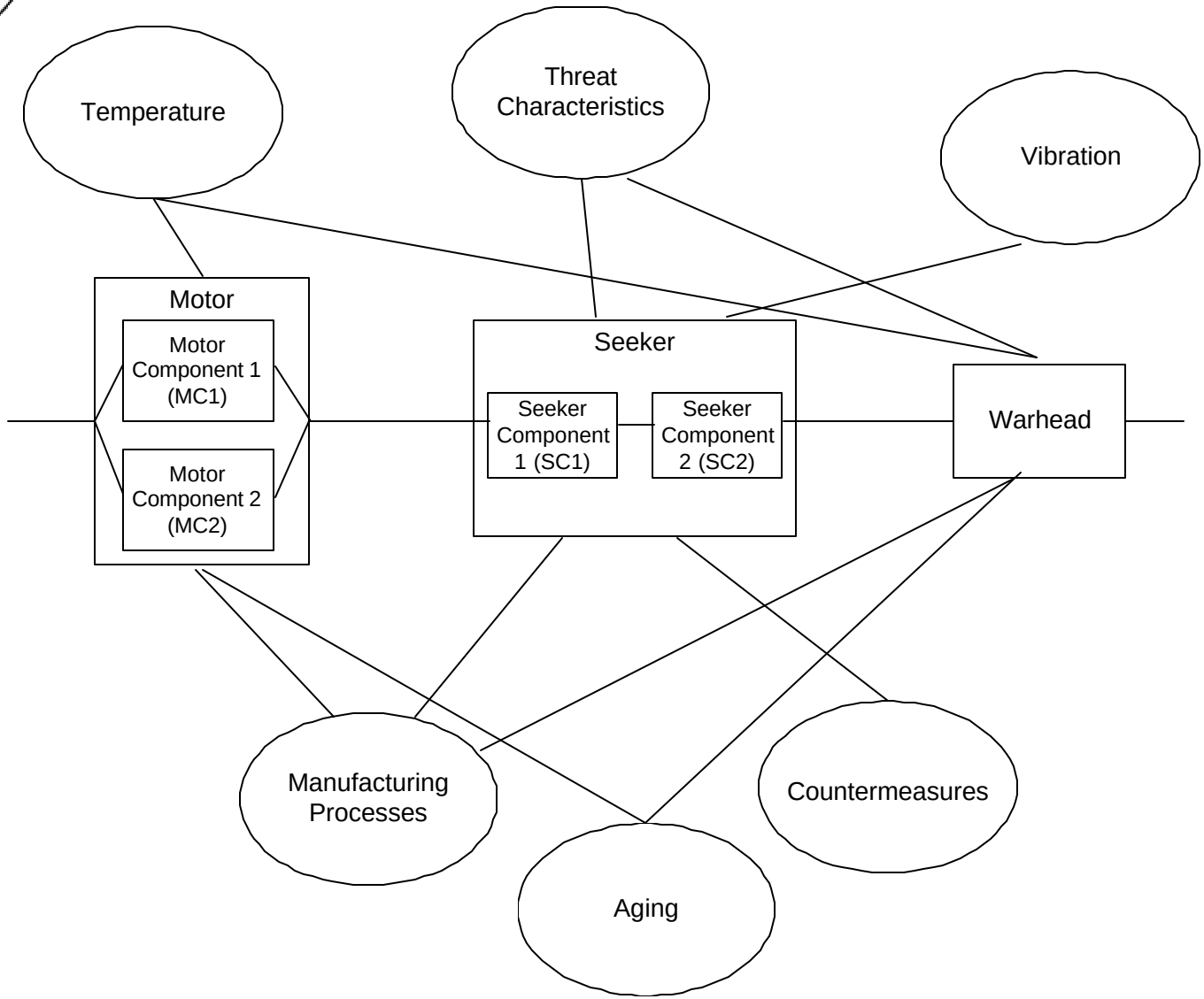


Working Motor gets Seeker close to target.

Working Seeker closes final distance to target.

Working Warhead kills target.

MAKING CONNECTIONS



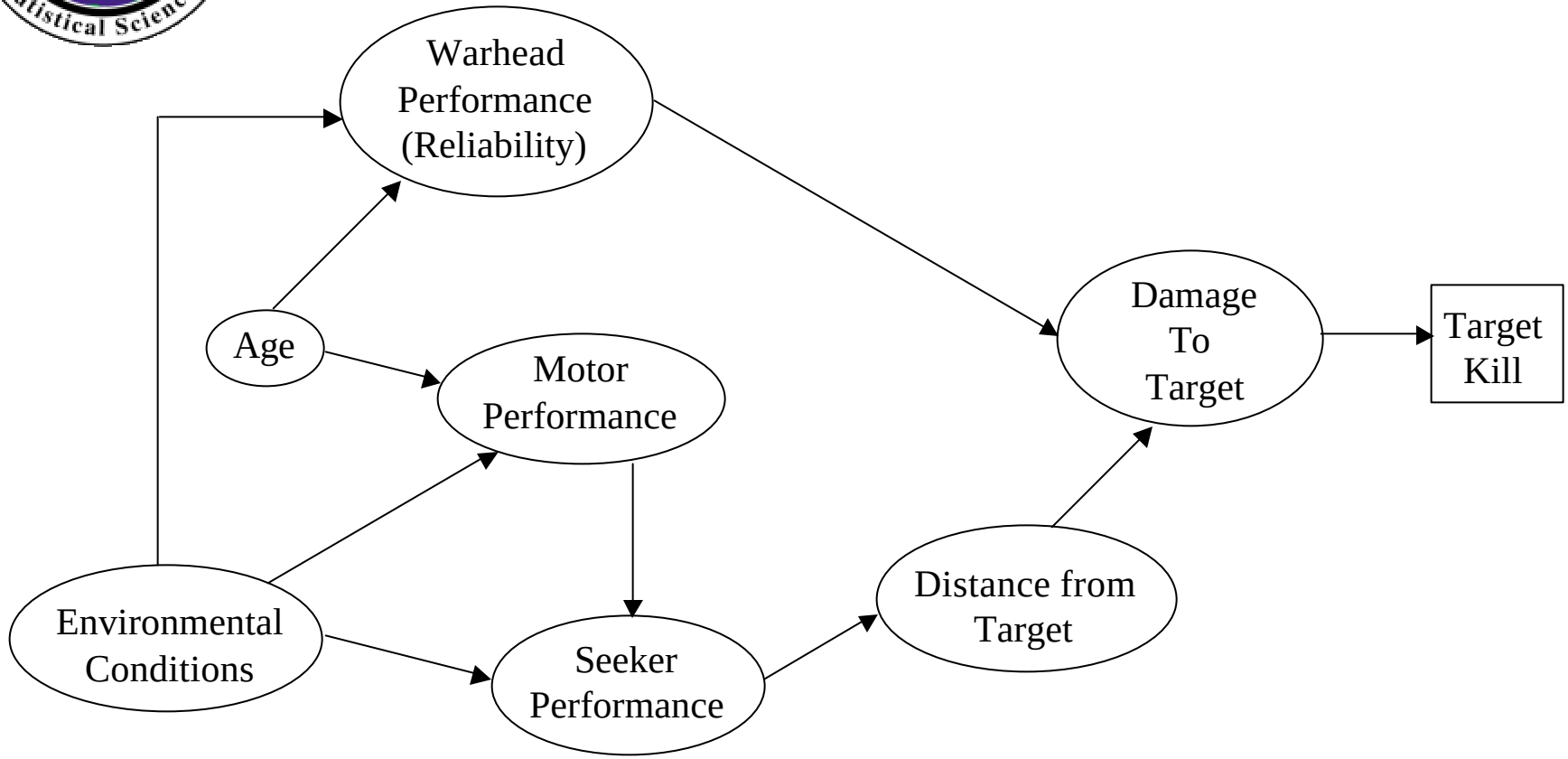
BAYES NET

The Bayes net representation has two purposes:

(1) To show how data contributes to decisions

(2) To capture the statistical model for calculating variables of interest, e.g., estimating reliability

RDMS BAYES NET



If any path to ***"Damage to Target"*** gets broken, there will be no ***"Target Kill."***

FAULT TREES AND RELIABILITY BLOCK DIAGRAMS

Useful:

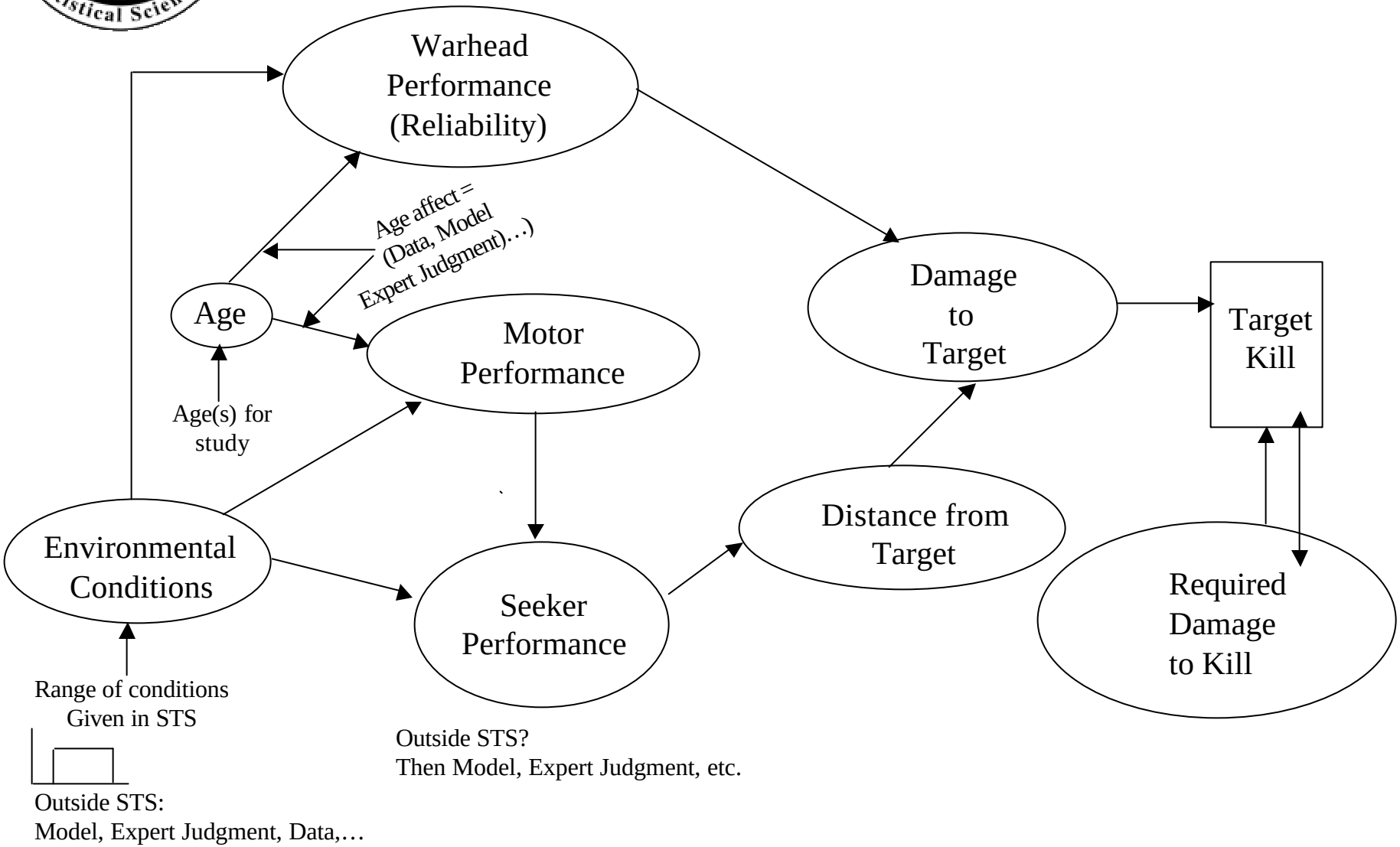
For many engineering considerations that can be expressed in terms of discrete events. (Many continuous processes can reasonably be discretized.)

Not Appropriate:

For continuous processes like physics processes.

- Not appropriate to discretize.
- Even if appropriate, physicists often do not initially approach problems that way.

RDMS PROBLEM REPRESENTATION



RDMS DECISION CONTEXT

Suppose:

1. Due to resource limitations, it is proposed to control D-Testing/D-Evaluation of subsystems and components.

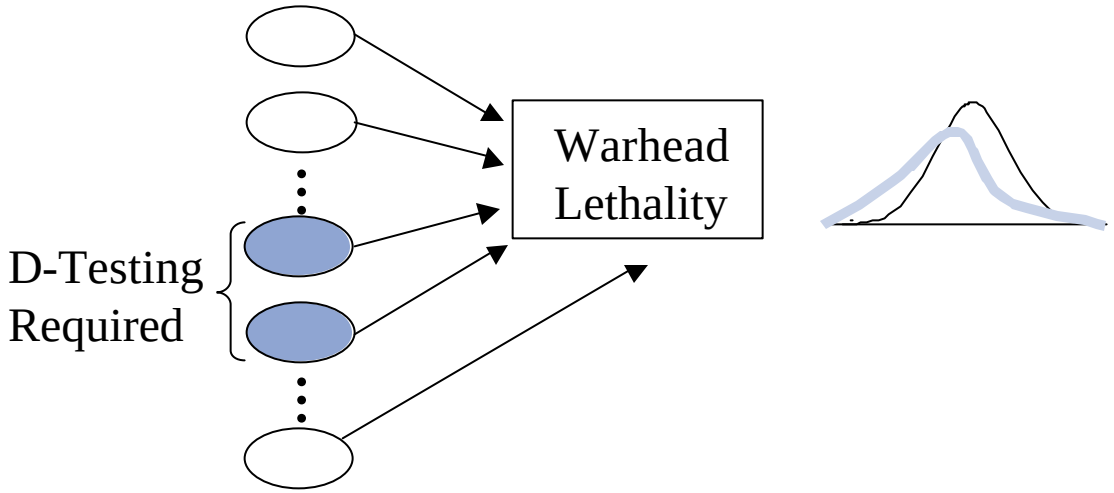
2. All functions ***except*** warhead performance can be assessed with NDE (at least in short term).

3. What happens to “kill“ distribution if DT/DE is curtailed, and aging is a consideration?

RDMS DECISION METRICS

Approaches:

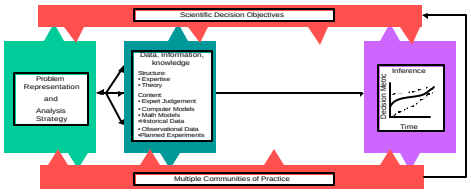
1. State that warhead reliability cannot be determined.
2. Modify warhead performance (lethality) distributions to reflect uncertainties associated with not D-Testing based on warhead performance model:



NEXT STEPS

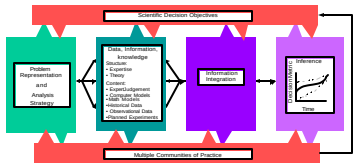
- Gather and document data for nodes
- Populate model with data
- Estimate current reliability and uncertainty (requires combining data)
- Project “what-ifs” for different scenarios of reducing or ending destructive testing
- Inform decision about destructive testing

DATA, INFORMATION, AND KNOWLEDGE



- **Expertise** (range of age and environmental conditions)
- **Expert judgment** (what happens outside STS; age effects; warhead, seeker, motor performance)
- **Historical test data** (age effects; damage to target; distance from target)
- **Data / information on similar, relevant systems, parts, processes,** etc. (age effects; warhead, seeker, motor performance; damage to target; distance from target)
- **Design specifications** (range of age and environmental conditions; required damage)
- **Computer simulation model outputs** (seeker performance; distance from target)
- **Physical model / code outputs** (age effects; damage to target; required damage)
- **Test Data** (warhead, seeker, motor performance; damage to target)

INFORMATION INTEGRATION

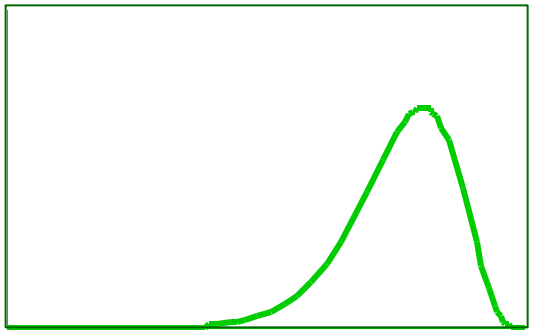


$$f_{y|x}(y|x) \;\mu\; f_{x|y}(x|y) f_y(y)$$

- Code Calculation 1
- Code Calculation 2
- Expert 2 Opinion
- Expert 1 Opinion
- Interpolated/Extrapolated Test Data from Model 1
- Interpolated/Extrapolated Test Data from Model 2
- Interpolated/Extrapolated Test Data from Model 3

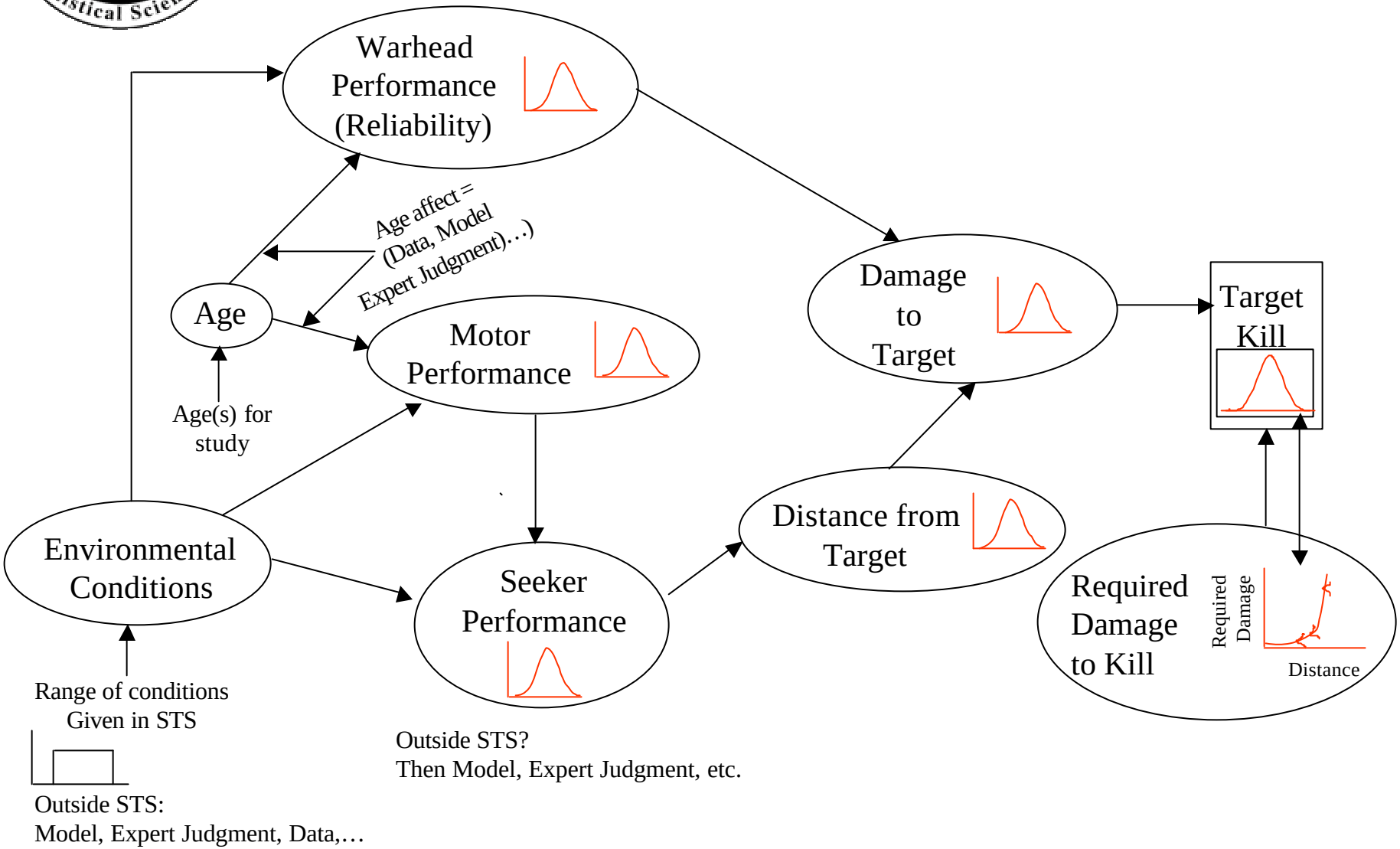
Bayes' Theorem, Weights, or Network

Combined Probability Distribution for Performance

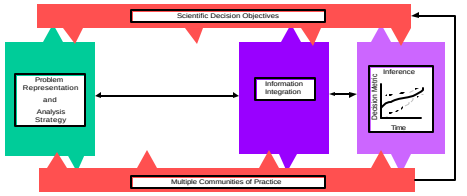


Document entire state of knowledge at a given time, e.g., in a knowledge system.

POPULATE REPRESENTATION AND INTEGRATE INFORMATION



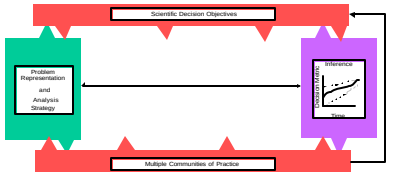
WHAT-IF ANALYSIS



- What if we run another vibration test?
- What if we change our manufacturing processes?
- What if we redesign the seeker?

- What is the probability that, for a specific set of operating conditions, the threat will be neutralized?
- How confident are we in this prediction?
- If we wanted to improve the probability of neutralizing the threat, what would be the most cost-effective way to do that?
- If we wanted to reduce our prediction uncertainty, what would be the most cost-effective way to do that?

HYBRID DESIGN

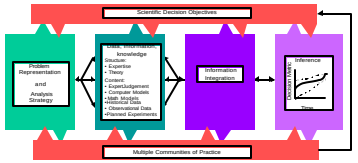


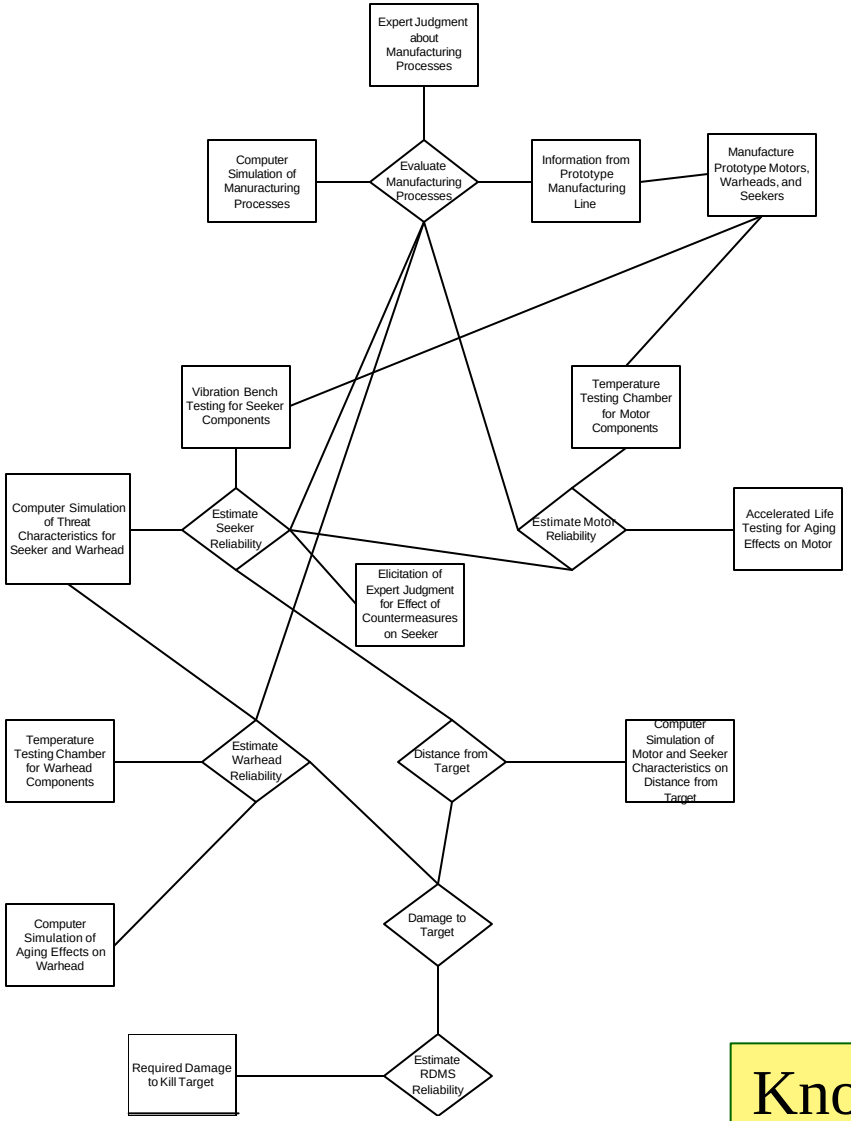
- IIT uses statistical processes, methods, and tools applied to complex systems and processes
  - Merges data, information, and expert knowledge
  - Uses tools, models, experts, and methods in place

- Two major applications within test programs
  - Hybrid Test Design: determine how limited resources should be spent to best characterize the entire space of operational conditions
  - Optimal Utilization of Collected Data: given existing data, models, and knowledge, where should future data points be collected and how much additional information will be gained for additional resource expenditure?

- Goal: Optimize data gathering across the test program to maximize confidence and minimize cost and schedule

PROBLEM SOLVING STRUCTURE





Knowledge Base Structure

CONCLUSIONS FOR RDMS

- What is our current assessment of target kill? What is our uncertainty about this assessment?
- How will that change if we cannot destructively test? What is the tradeoff with availability?
- What other data sources should we use to improve our assessment?
- How does all of this relate to the “real” decision of how to keep this weapon effectively employed?

SUMMARY

- The IIT framework specifies a formal process that is useful for addressing complex problems.

- Formal system, problem, and data structuring is a crucial first step in understanding the data and analysis methods and knowledge base tools required to address the problem.