Managing the "Trick-Bag" of Intersystem Coupling

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"Law of Strong Connections"

"A system is a collection of parts, no ***one*** of which can be changed."

"In systems, all other things are rarely equal."

Weinberg, Gerald M. (2001). *General Systems Thinking (Silver Anniversary Edition)*. New York: Dorset House Publishing, p. 162.

Coupling versus Autonomy

(OSD AT&L, Air Warfare (December 2002). "Unmanned Aerial Vehicles Roadmap, 2002-2027," p. 41)

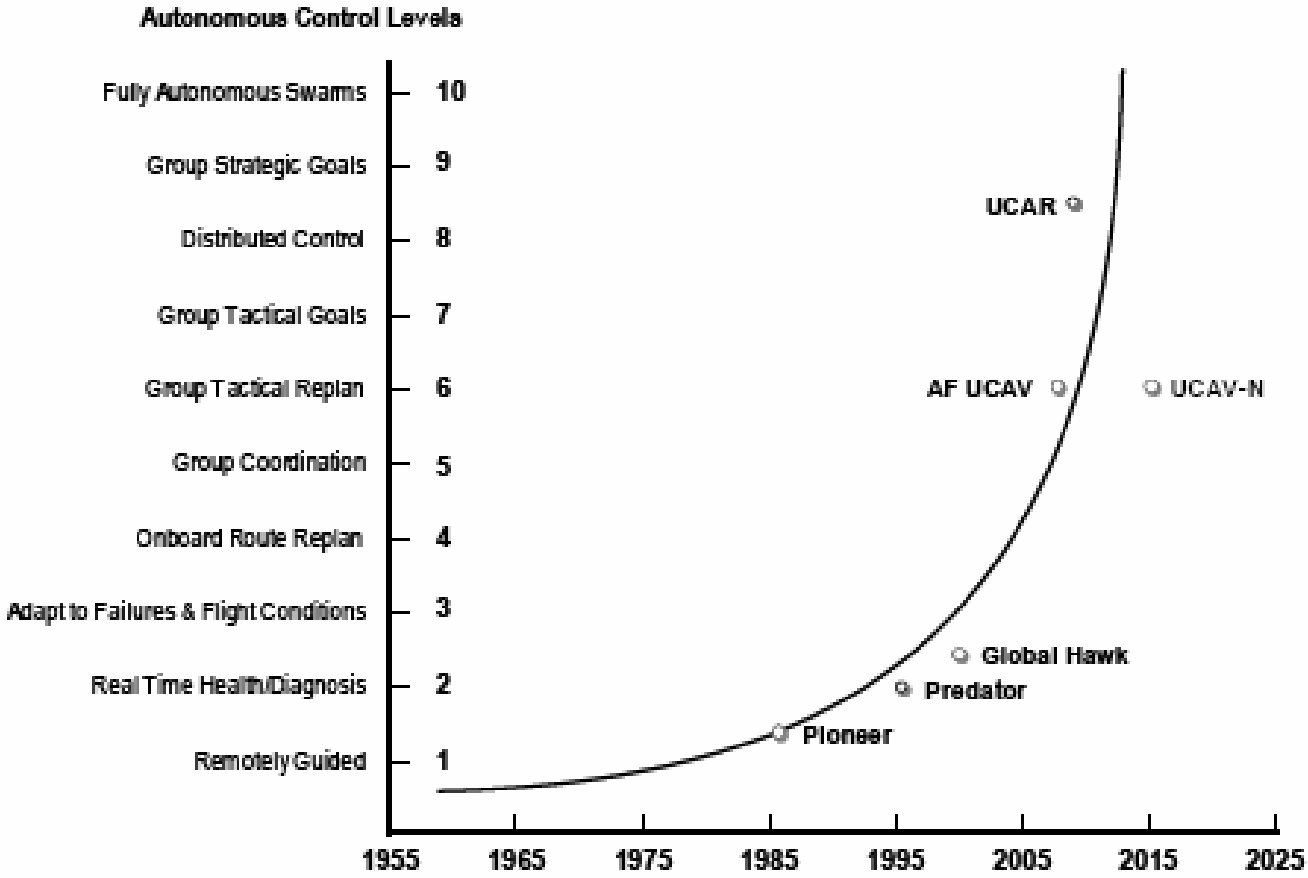


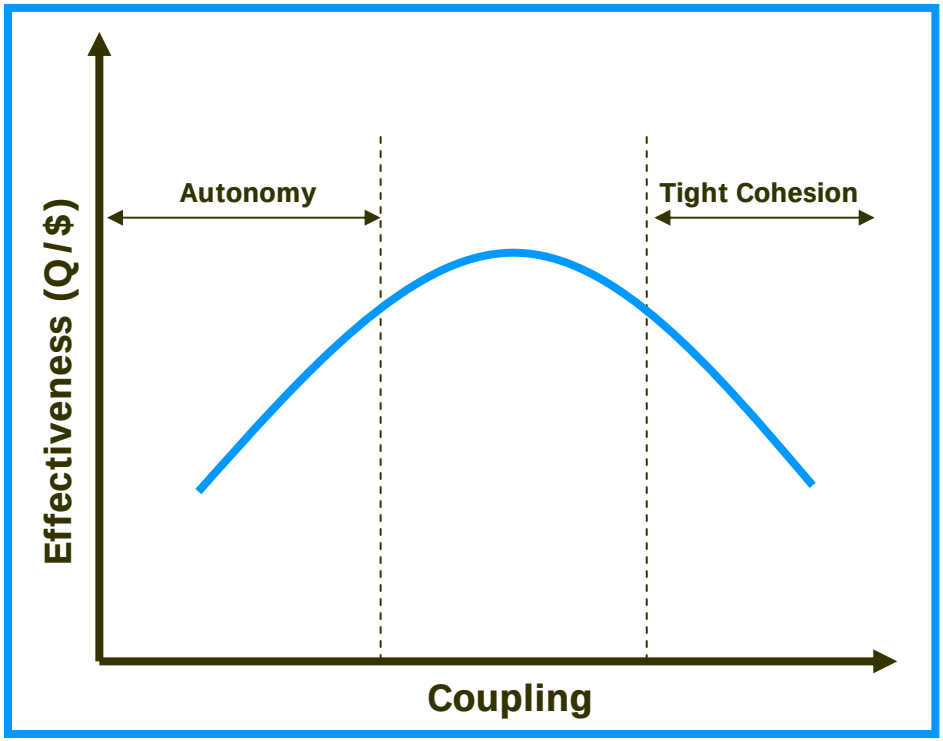
FIGURE 4.4-1: AUTONOMOUS CONTROL LEVEL TREND.

Closed systems are artificial creations of scientists and engineers

Propositions

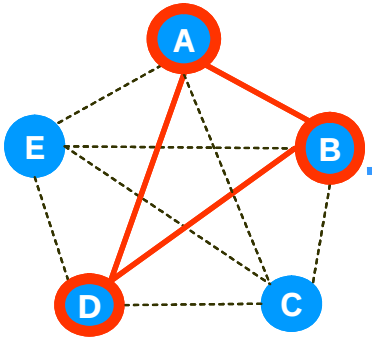
- **P1: A modicum of coupling achieves best results**
  - ***Either end of the coupling spectrum should be avoided***
- **P2: View Coupling as the effect, not just a cause**
  - ***The operational situation should dictate Coupling Required, not vice versa***

A General Model of Coupling



Coupling: Types & Measures

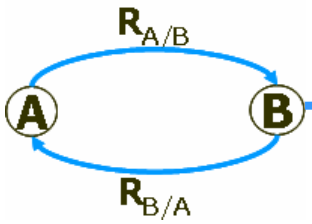
1) Inter-Capability:



$$Q = f(q_1, q_2, \ldots q_n)$$

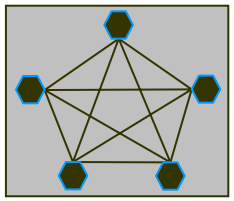
$$Y = \beta_0 + \sum_{i=1}^{p} \beta_i X_i + \sum_{i=1}^{p} \sum_{\substack{j=1 \\ i \neq j}}^{p} \beta_{ij} X_i X_j + \sum_{i=1}^{p} \sum_{\substack{j=1 \\ i \neq j}}^{p} \sum_{\substack{k=1 \\ i \neq j \neq k}}^{p} \beta_{ijk} X_i X_j X_k + \cdots$$

2) Complex-Dynamic:

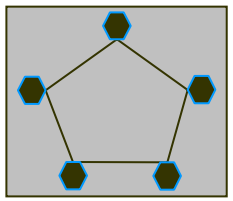


$$\frac{dQ_1}{dt} = f_1[Q_1, Q_2, \ldots, Q_n]$$
$$\frac{dQ_2}{dt} = f_2[Q_1, Q_2, \ldots, Q_n]$$
$$\vdots$$
$$\frac{dQ_n}{dt} = f_n[Q_1, Q_2, \ldots, Q_n]$$

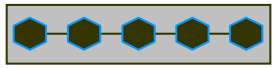
3) Inter-Nodal:



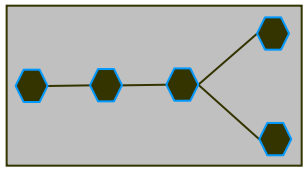
C = 5.0
C_{Index} = 0.00
N * K = 50
E/E_{max} = 1.00



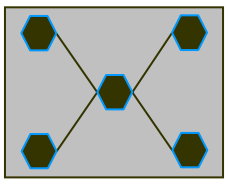
C = 5.0
C_{Index} = 0.00
N * K = 25
E/E_{max} = 0.50



C = 6.7
C_{Index} = 0.40
N * K = 20
E/E_{max} = 0.40



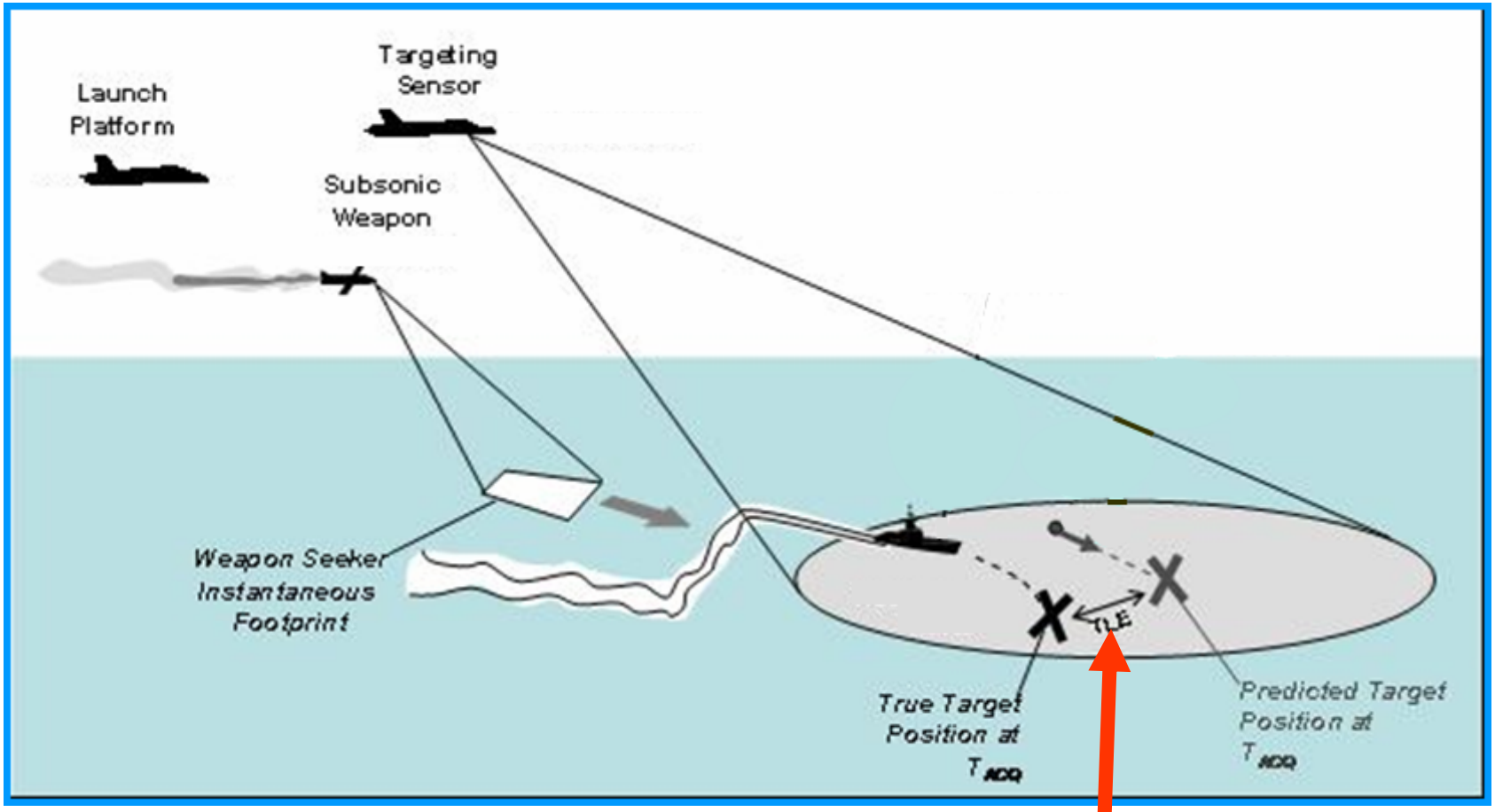
C = 7.2
C_{Index} = 0.44
N * K = 20
E/E_{max} = 0.40



C = 8.0
C_{Index} = 0.42
N * K = 20
E/E_{max} = 0.40

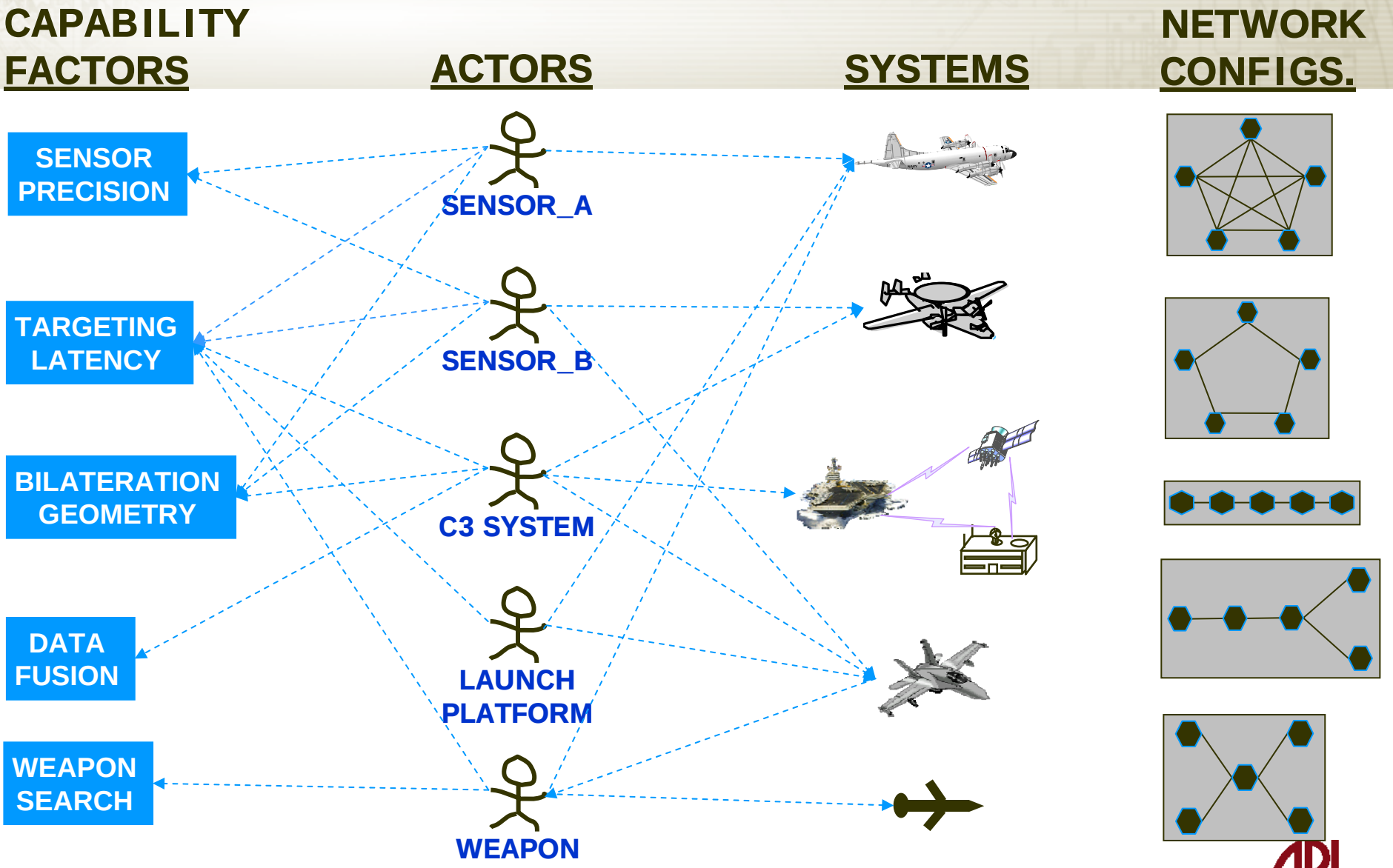
"Law of Mass Action" or "The System Concept"

Notional Problem Application: Standoff Attack of Moving Targets



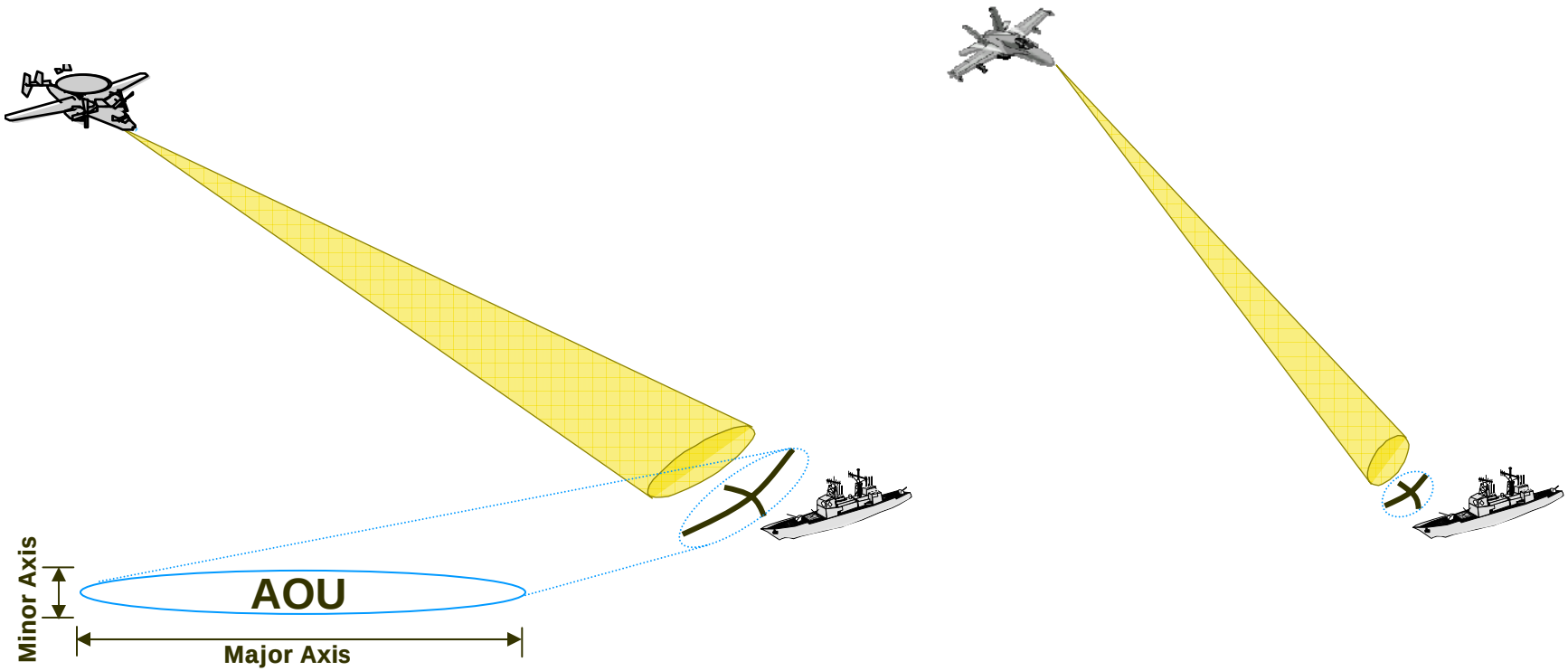
PROBLEM: "Target Location Error" (TLE) is dynamic

Actor → Factor Linkages



Sensor Precision

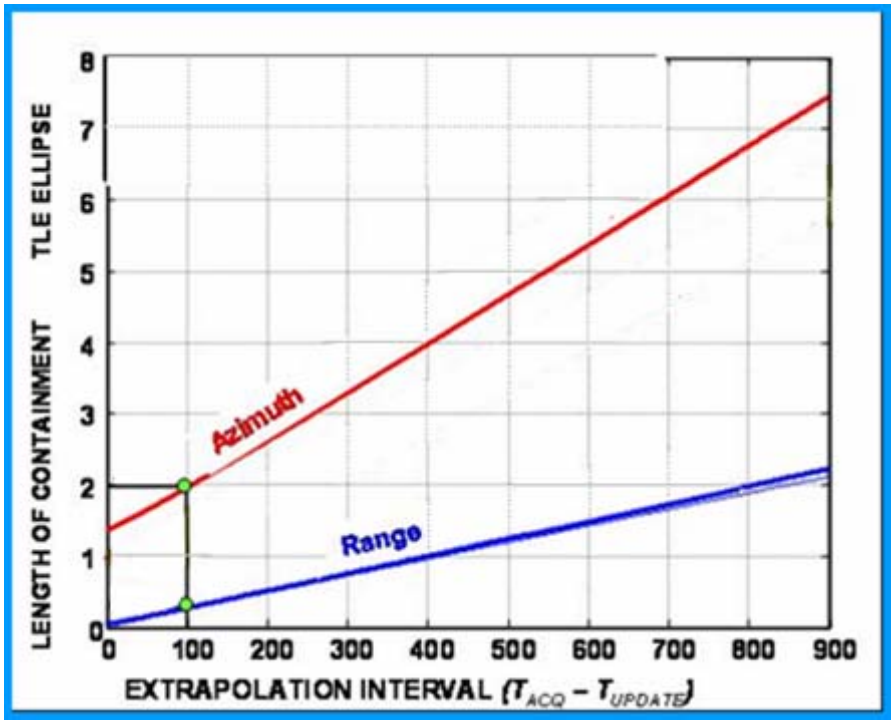
- **Values: Low Precision Vs High Precision**



All else being equal, high sensor precision decreases AOU size

Targeting Latency

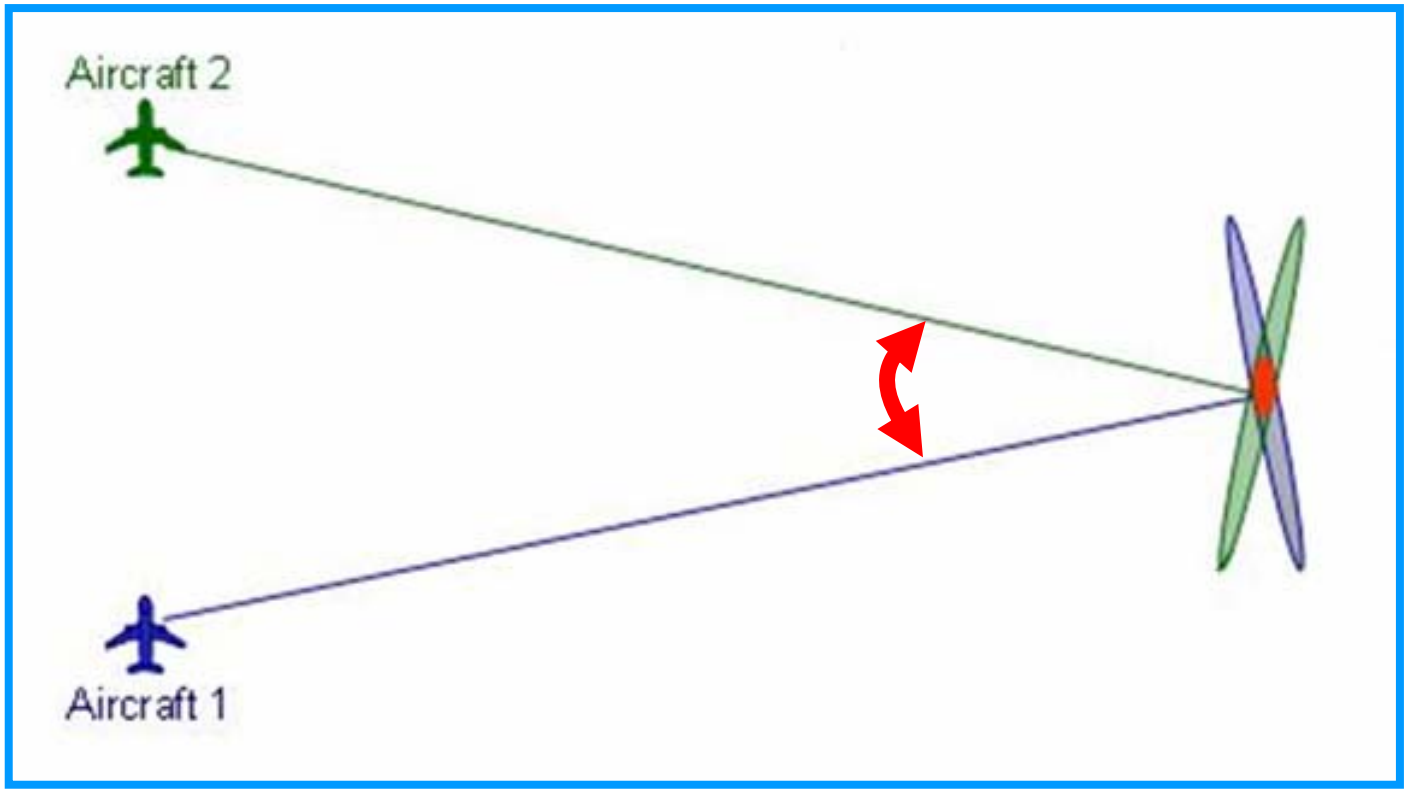
- **Values: High (min) Vs Low (sec)**



All else being equal, low latency decreases AOU size

Sensor Bilateration Geometry

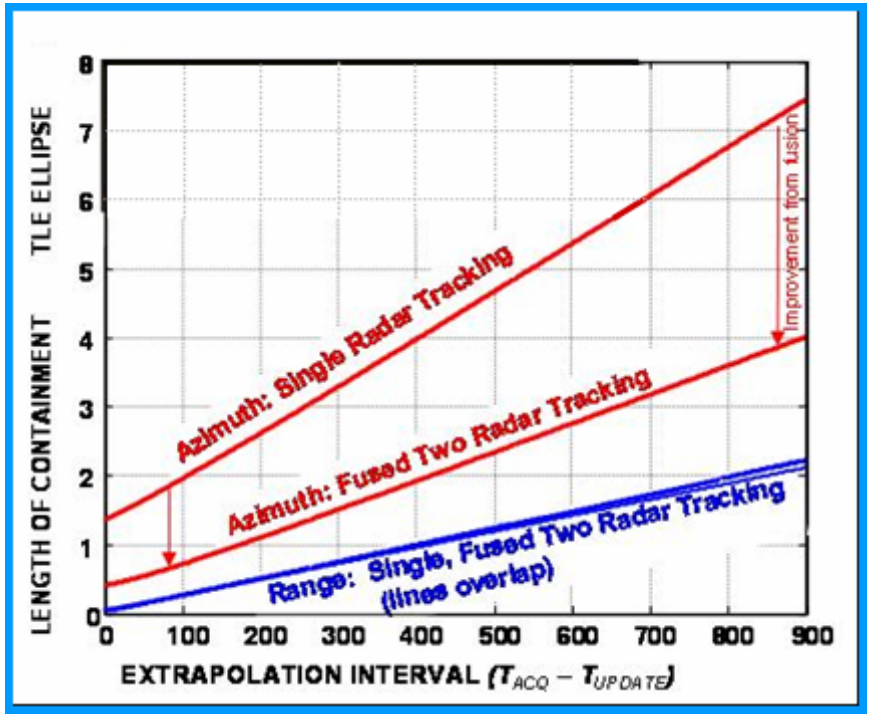
- **Values: Low Azimuth Vs High Azimuth**



All else being equal, high-azimuth geometry decreases AOU size

Sensor Data Fusion

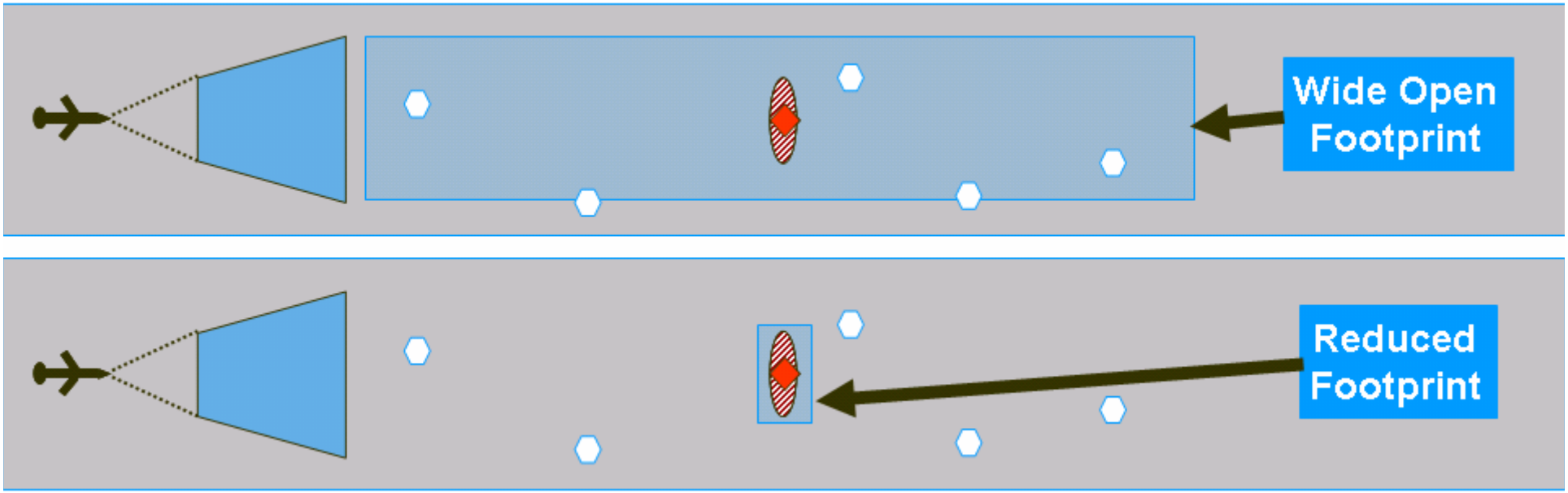
- **Values: Not Available Vs Available**



All else being equal, sensor data fusion decreases AOU size

Weapon Search

- **Values: Wide_Open Vs Reduced**



MOE = Target Selectivity

All else being equal, reduced search decreases the probability of detecting a neutral vessel

Data from Design of Experiment

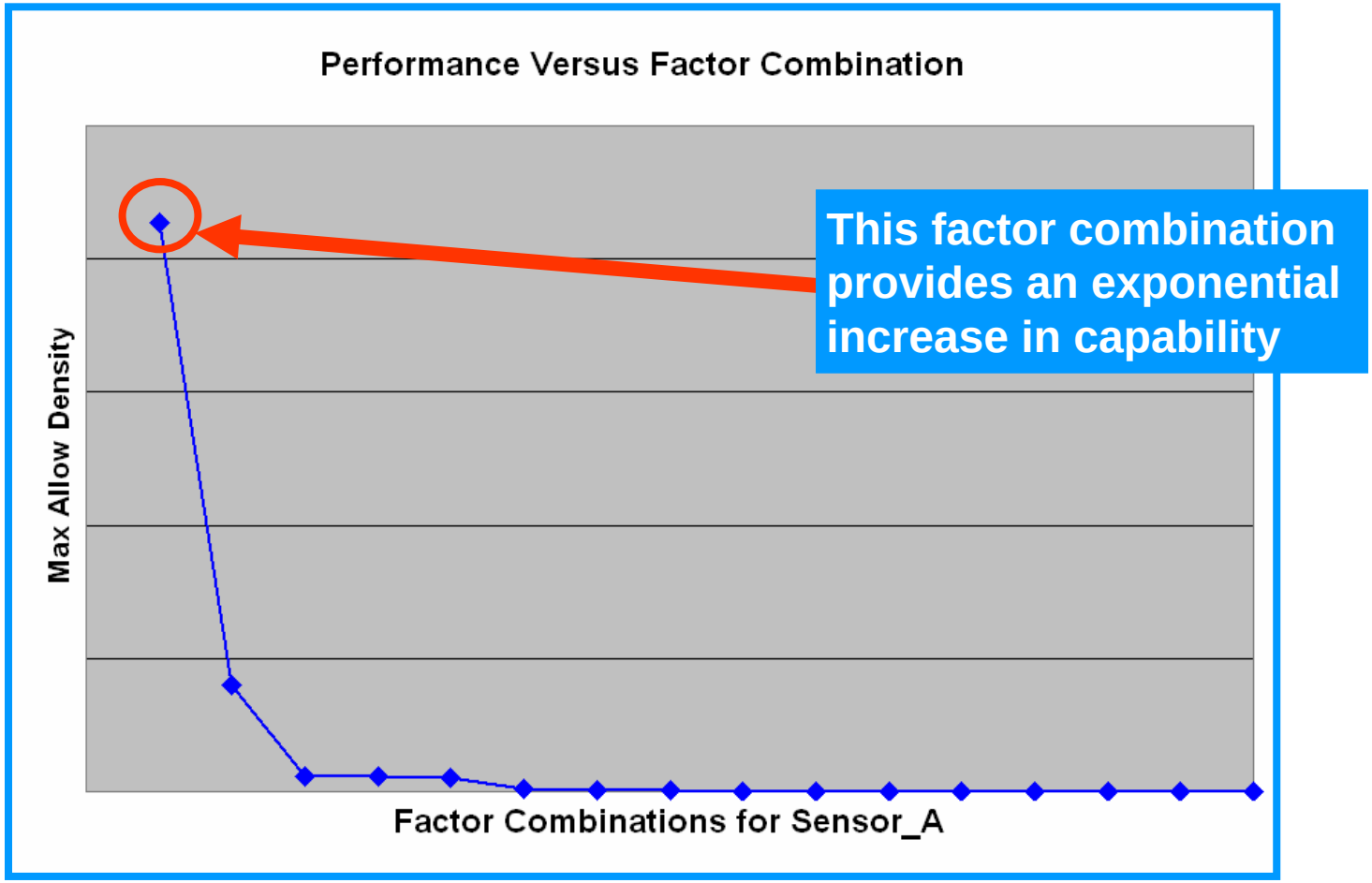
	Seeker_Search (Reduced Vs Open)	Sensor_Precision (High Vs Low)	Fusion (Yes Vs No)	Latency (Low Vs High)	Bilat_Geometry (Hi-Az Vs Low-Ax)		Y1a: Max_Allow_Density (Partial_Wide-Open_Skr)
1	Reduced	High	Yes	Low	Hi-Az		213,800
2	Reduced	High	Yes	Low	Lo-Az		40,100
3	Reduced	High	Yes	High	Hi-Az		247
4	Reduced	High	Yes	High	Lo-Az		247
5	Reduced	High	No	Low			5,940
6	Reduced	High	No	Low			5,940
7	Reduced	High	No	High			230
8	Reduced	High	No	High			230
9	Reduced	Low	Yes	Low	Hi-Az		7,517
10	Reduced	Low	Yes	Low	Lo-Az		548
11	Reduced	Low	Yes	High	Hi-Az		197
12	Reduced	Low	Yes	High	Lo-Az		107
13	Reduced	Low	No	Low			700
14	Reduced	Low	No	Low			700
15	Reduced	Low	No	High			91
16	Reduced	Low	No	High			91
17	Open	High	Yes	Low	Hi-Az		5,365
18	Open	High	Yes	Low	Lo-Az		1,006
19	Open	High	Yes	High	Hi-Az		179
20	Open	High	Yes	High	Lo-Az		164
21	Open	High	No	Low			298
22	Open	High	No	Low			298
23	Open	High	No	High			164
24	Open	High	No	High			164
25	Open	Low	Yes	Low	Hi-Az		94
26	Open	Low	Yes	Low	Lo-Az		94
27	Open	Low	Yes	High	Hi-Az		164
28	Open	Low	Yes	High	Lo-Az		89
29	Open	Low	No	Low			94
30	Open	Low	No	Low			94
31	Open	Low	No	High			76
32	Open	Low	No	High			76

Tightly Coupled Condition

- **Q1: Which factor is most important?**
- **Q2: Which factor combination is most important?**

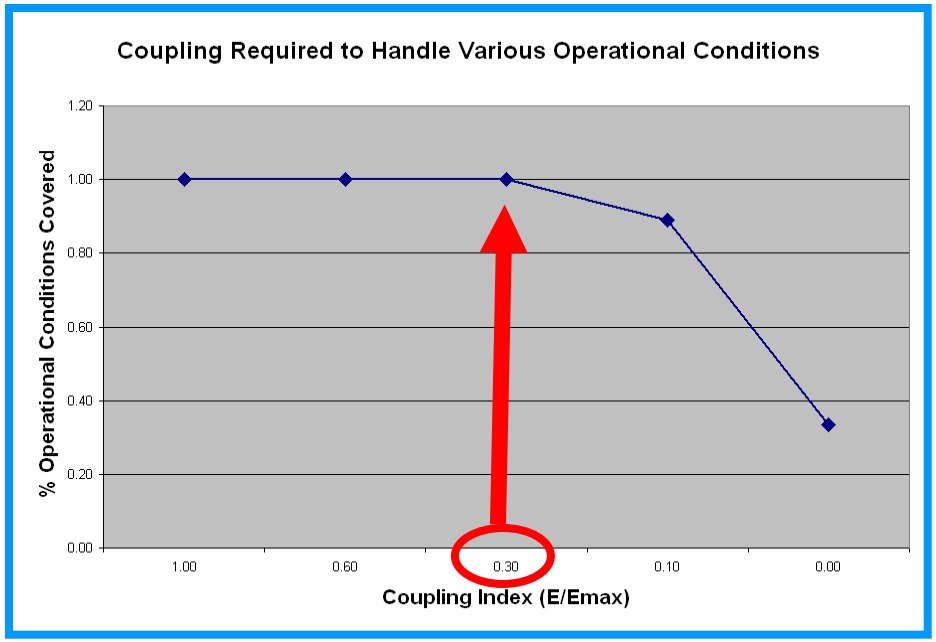
Loosely Coupled Condition

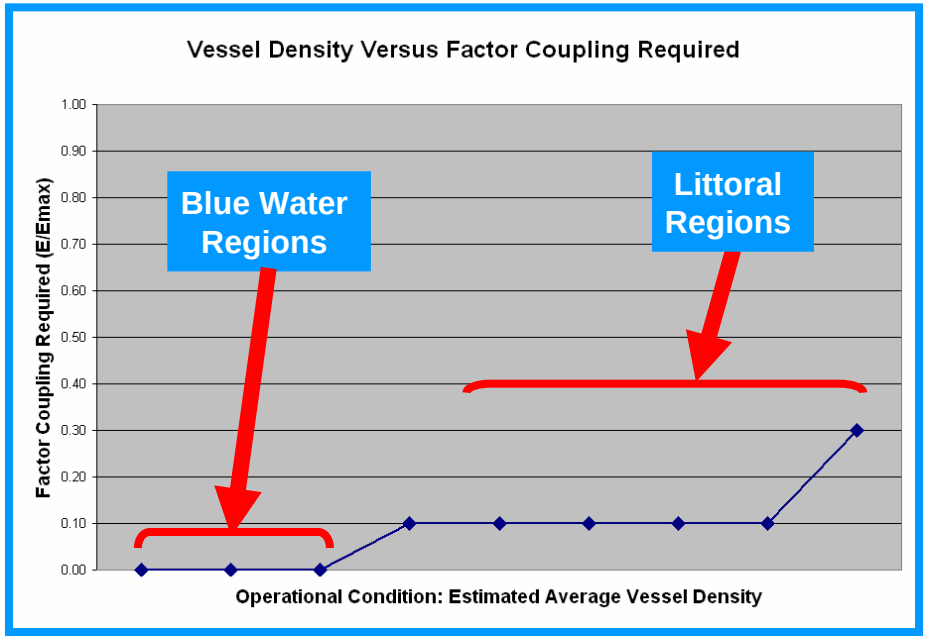
Data Analysis → Benefit of Tight Coupling



CAUTION: Tight coupling will be hard to achieve operationally & programmatically

Data Analysis → Requirement for Coupling

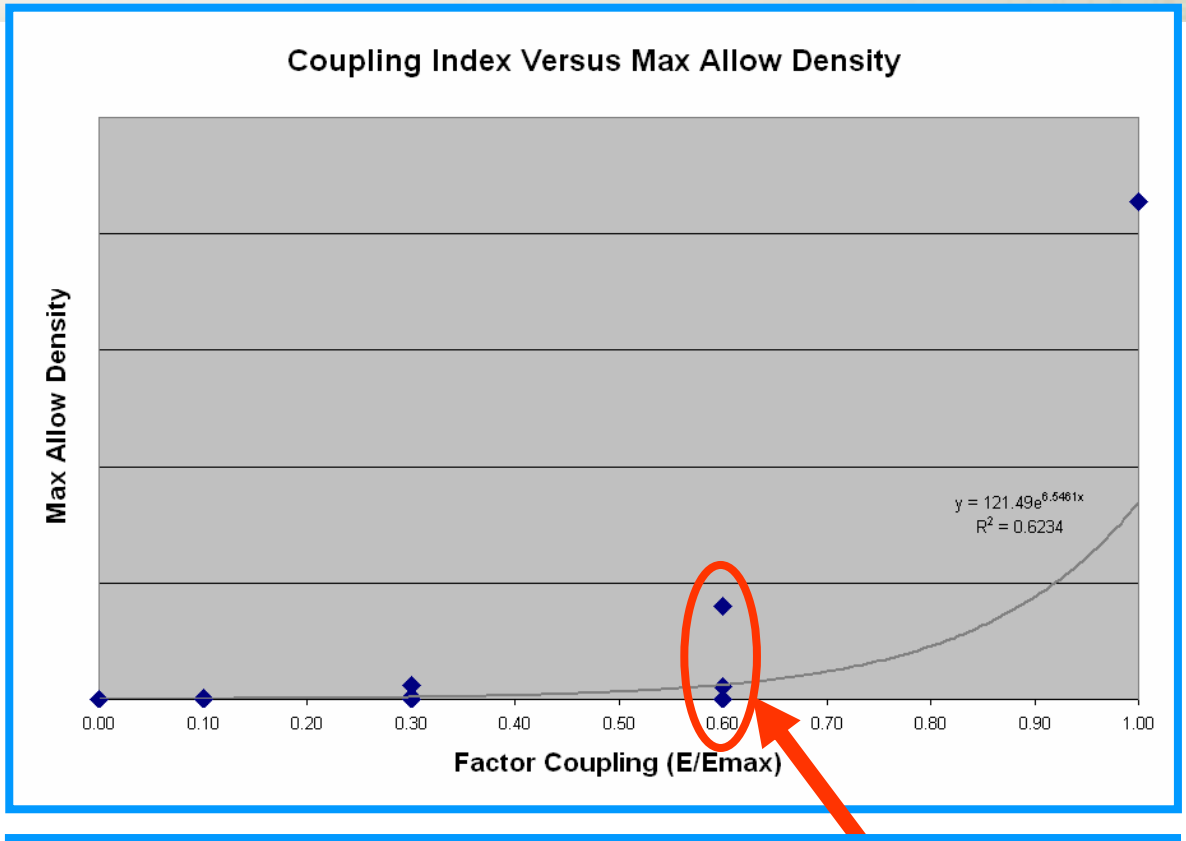




30% coupling covers 100% of all operational conditions studied

Only an extreme condition requires tight coupling

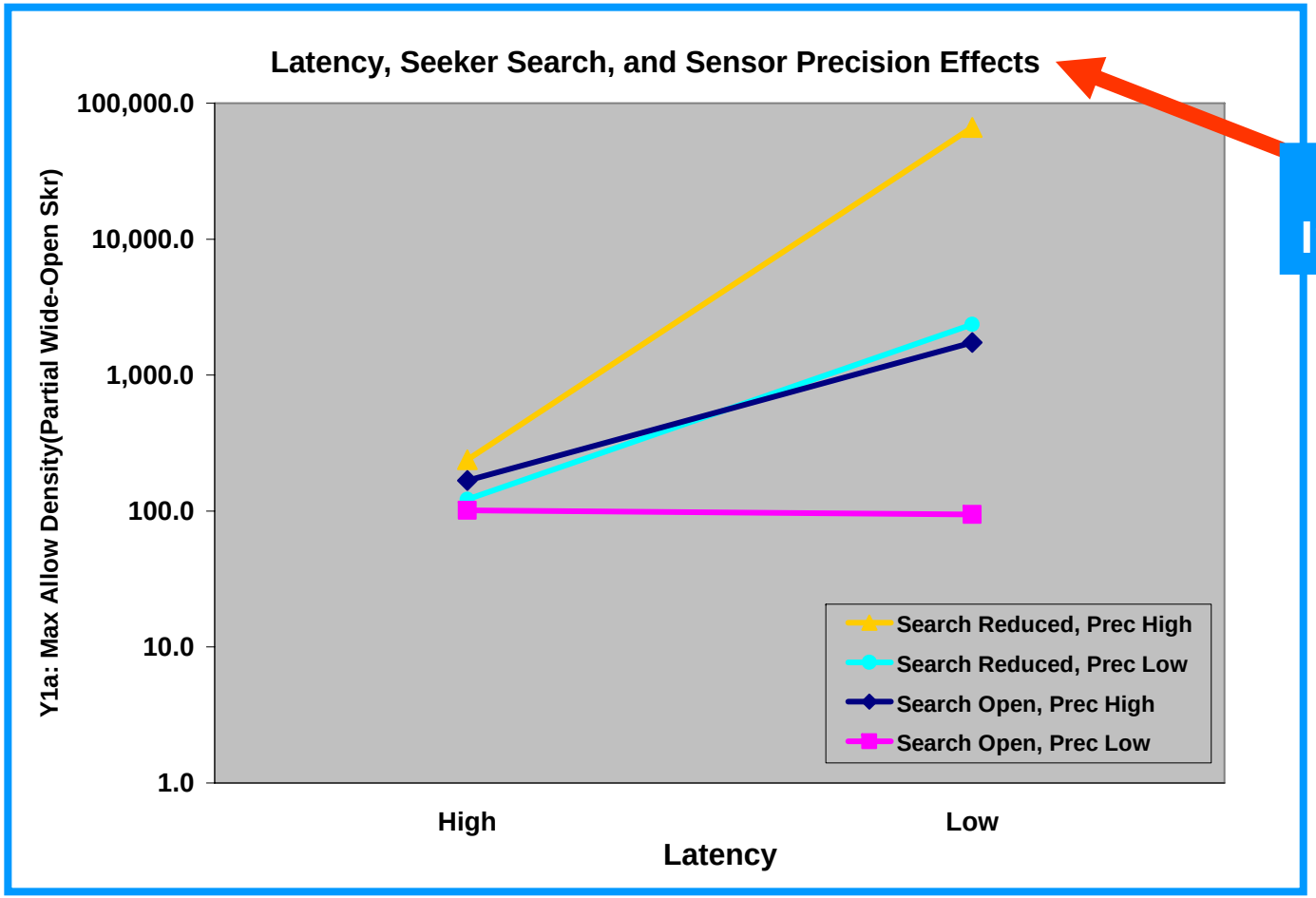
Data Analysis → Performance Sensitivity to Coupling



NOTE: In some cases, the same value of coupling results in high variation in performance → WHY?

Clearly it matters which capability factors are coupled together

Data Analysis → Capability Interaction

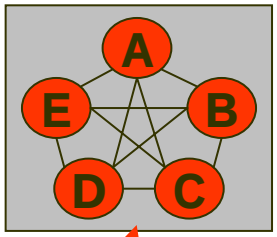


NOTE: Latency is the most important driver

Basic Network Configurations

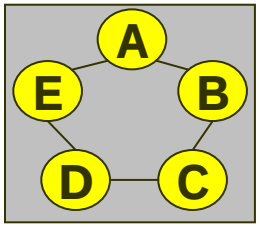
- 3rd Question: In general which network configuration works best?

I. Fully Connected

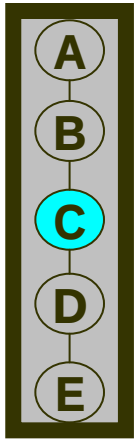


Tightly Coupled
Decentralized

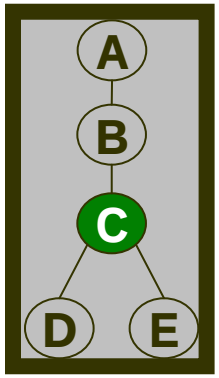
II. Circle



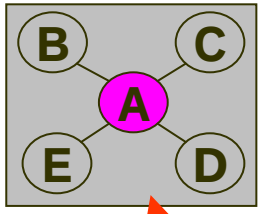
III. Chain



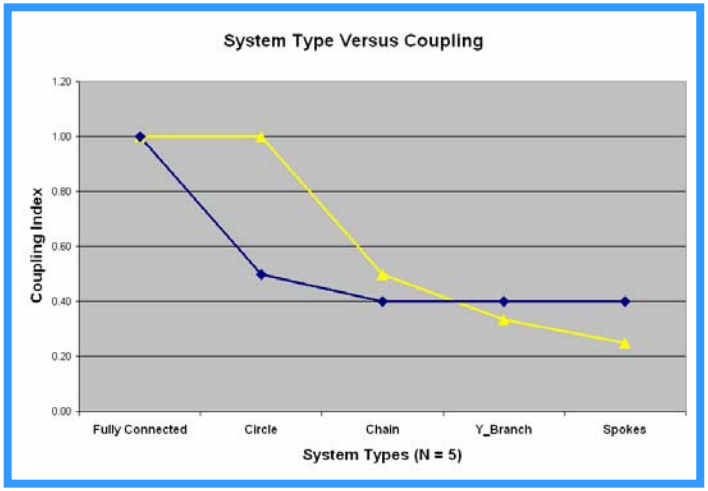
IV. Y-Branch

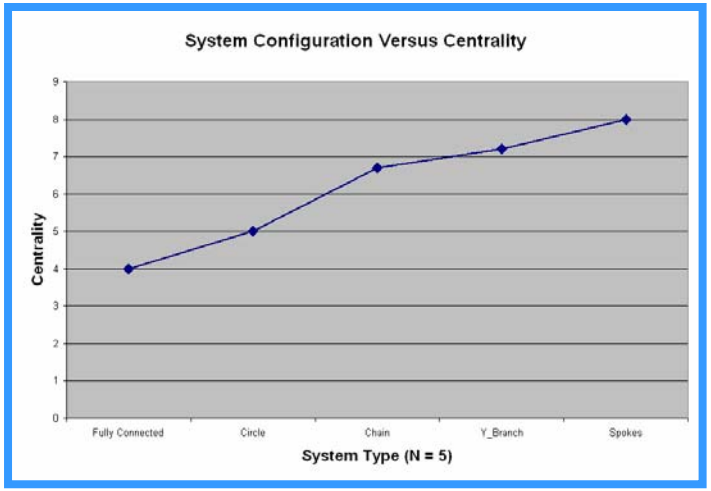


V. Spokes



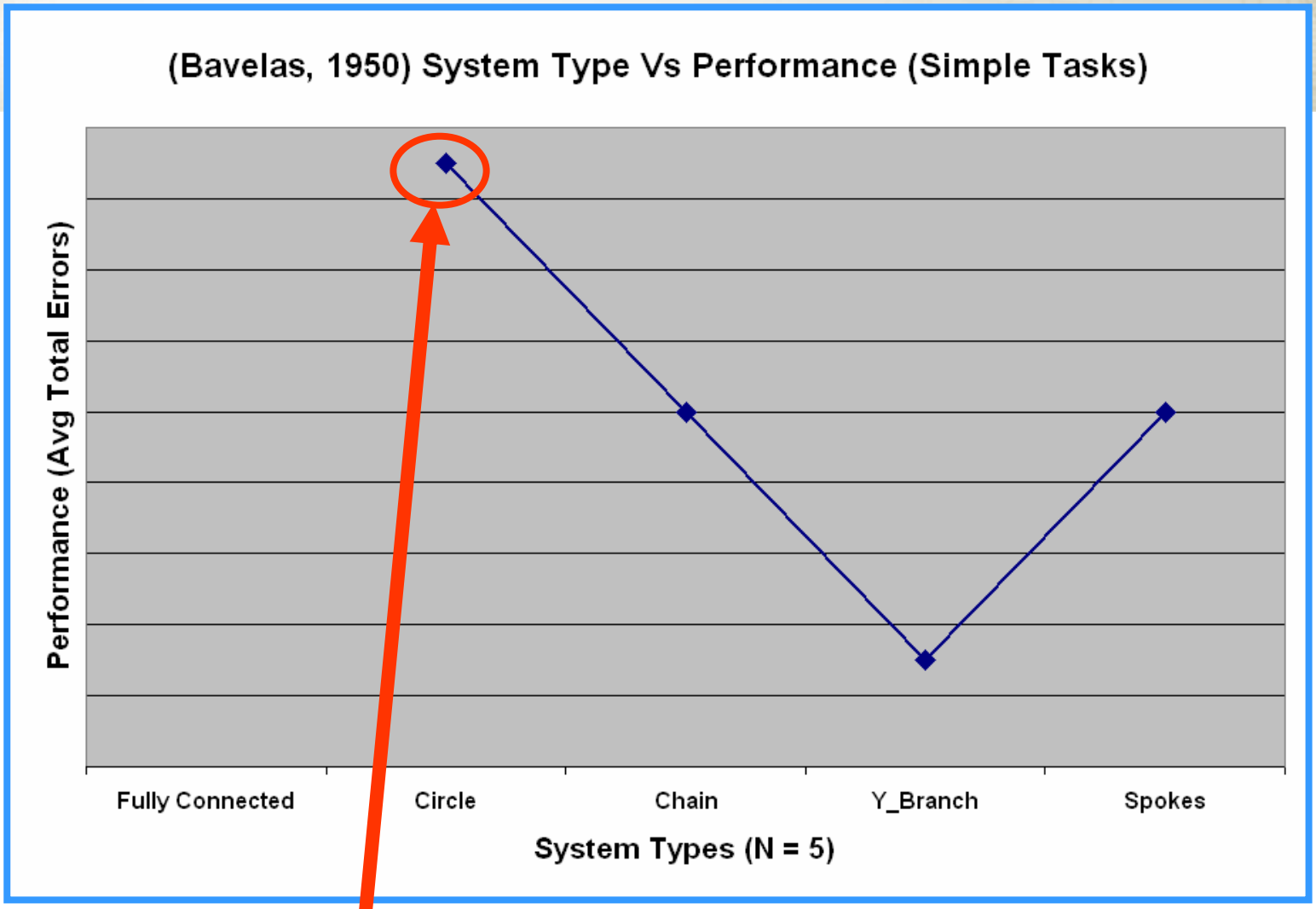
Moderately Coupled
Highly Centralized





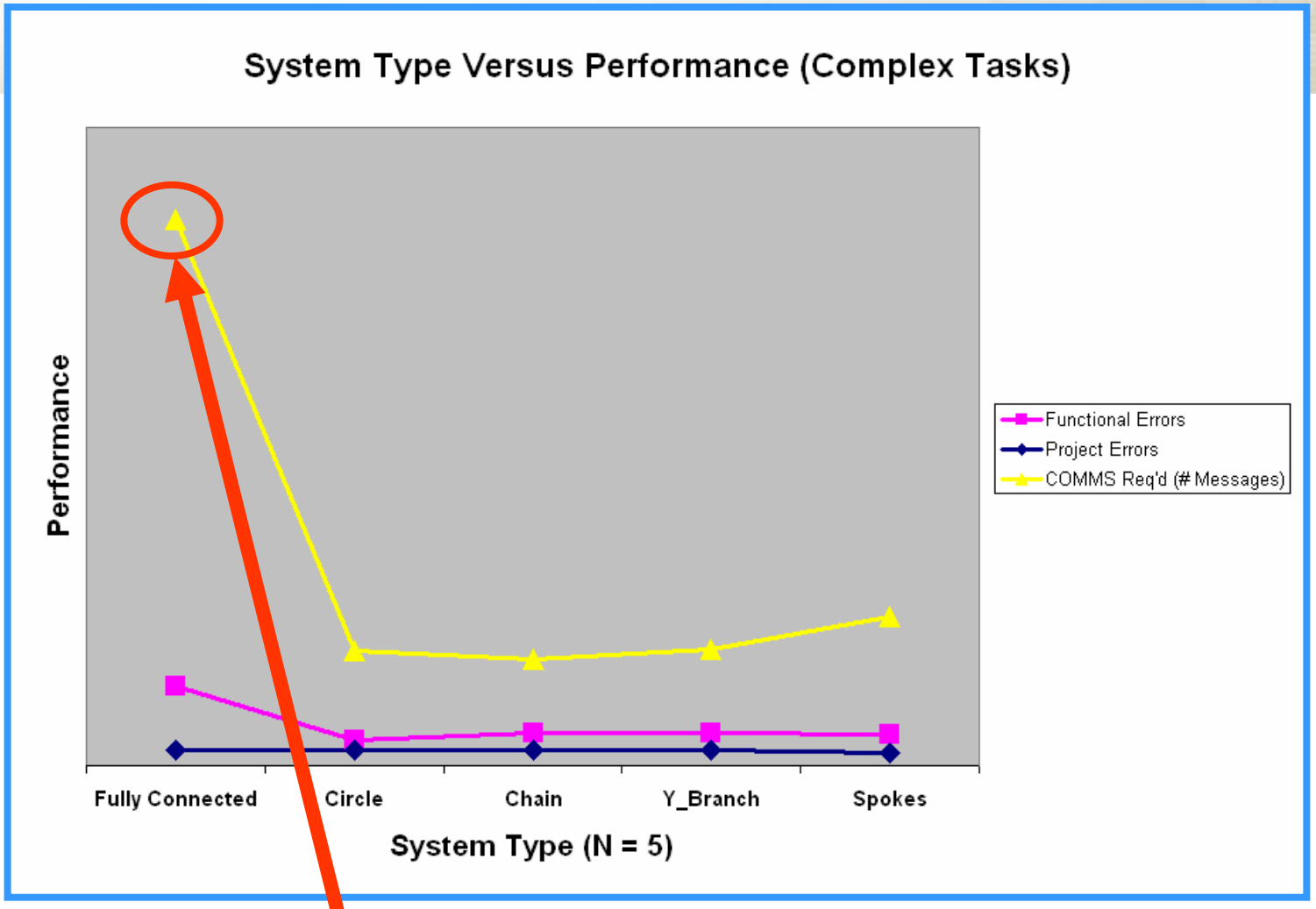
A system's organizational structure influences its performance

System Structure Vs Performance



NOTE: Tightly coupled structure has lowest performance

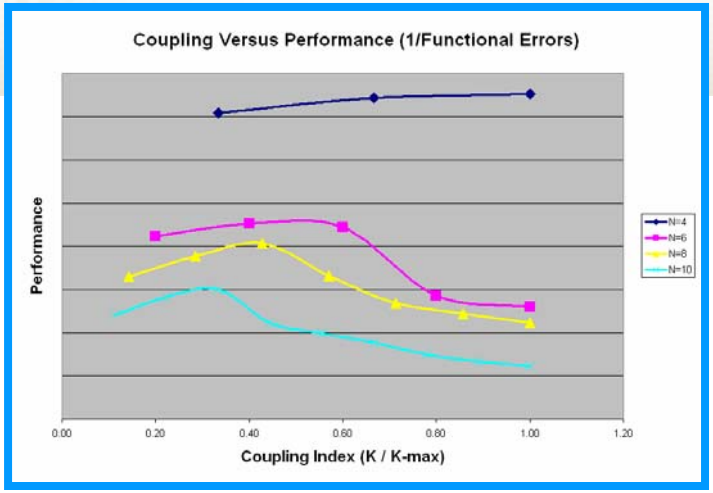
System Structure Vs Performance

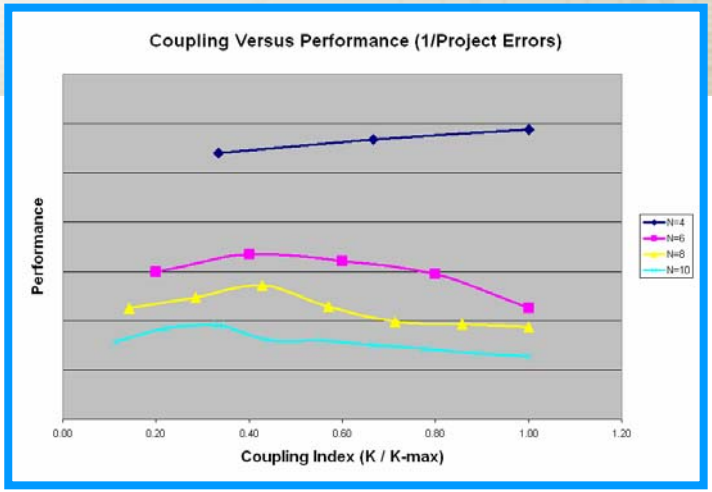


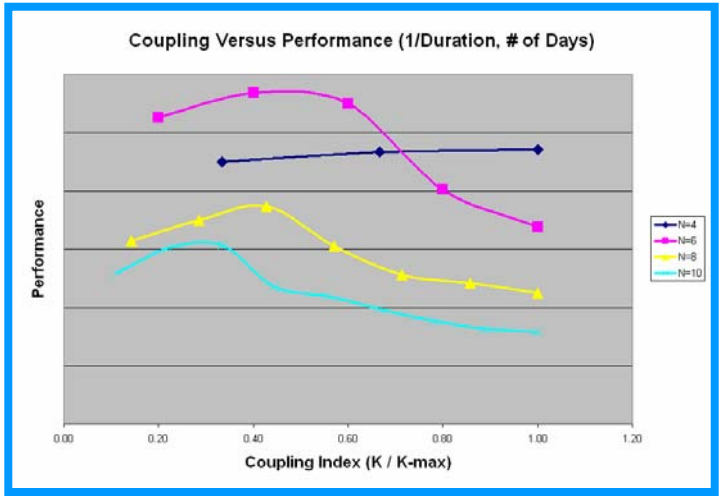
NOTE: Tightly coupled structure has lowest performance

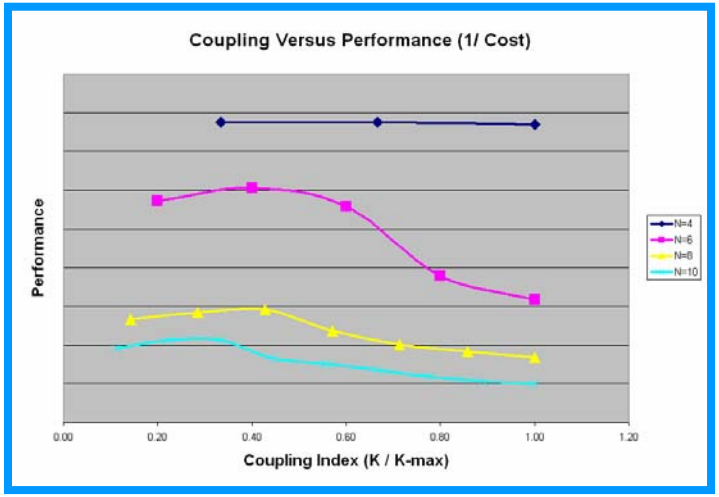
Coupling Vs Organizational Efficiency

(Caroll & Burton, 2000)



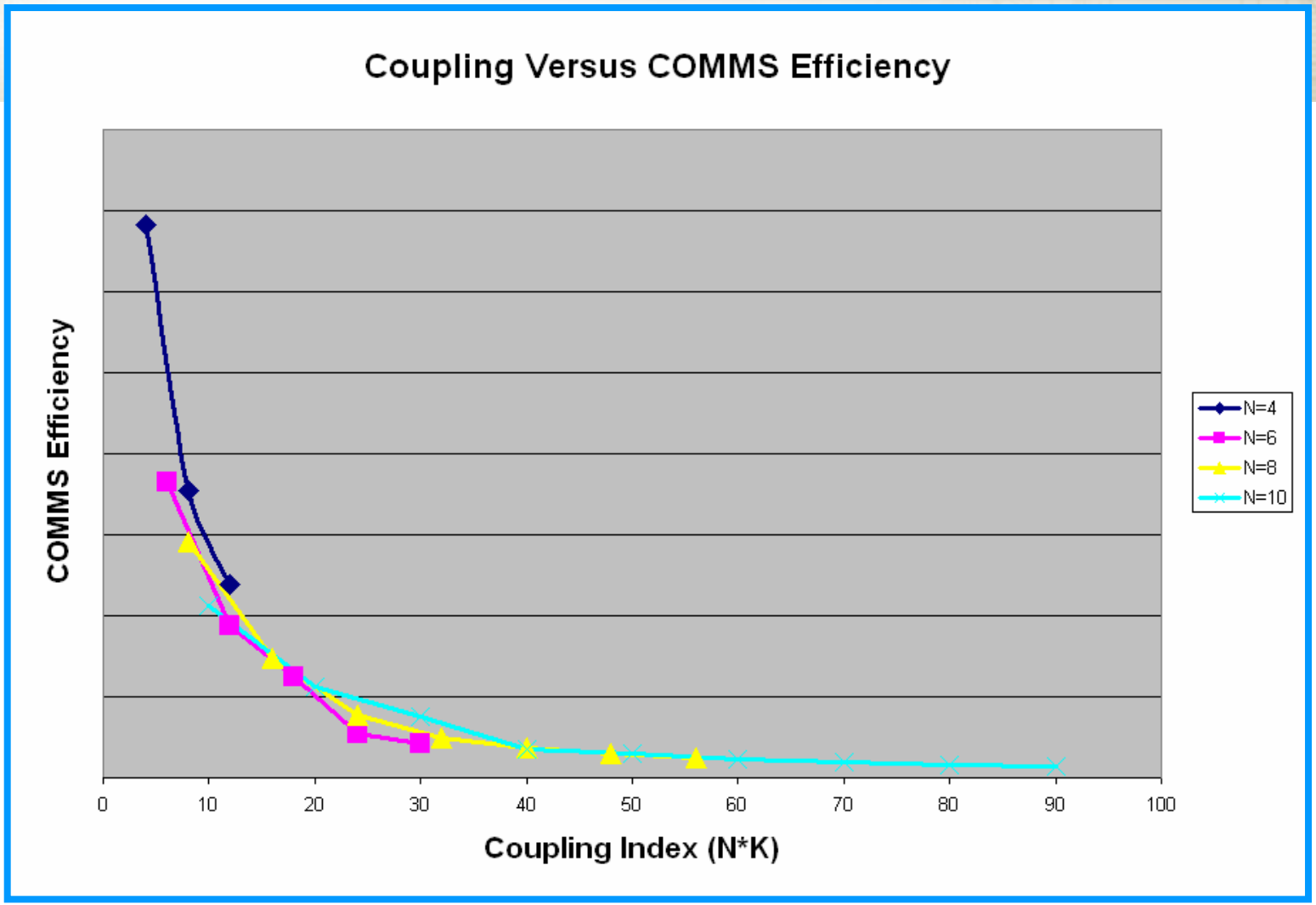






NOTE: Best performance occurs when coupling = 0.30–0.50 (~Chain & Y_Branch)

Coupling Vs Communication Efficiency



NOTE: As coupling increases, COMMS efficiency decreases exponentially

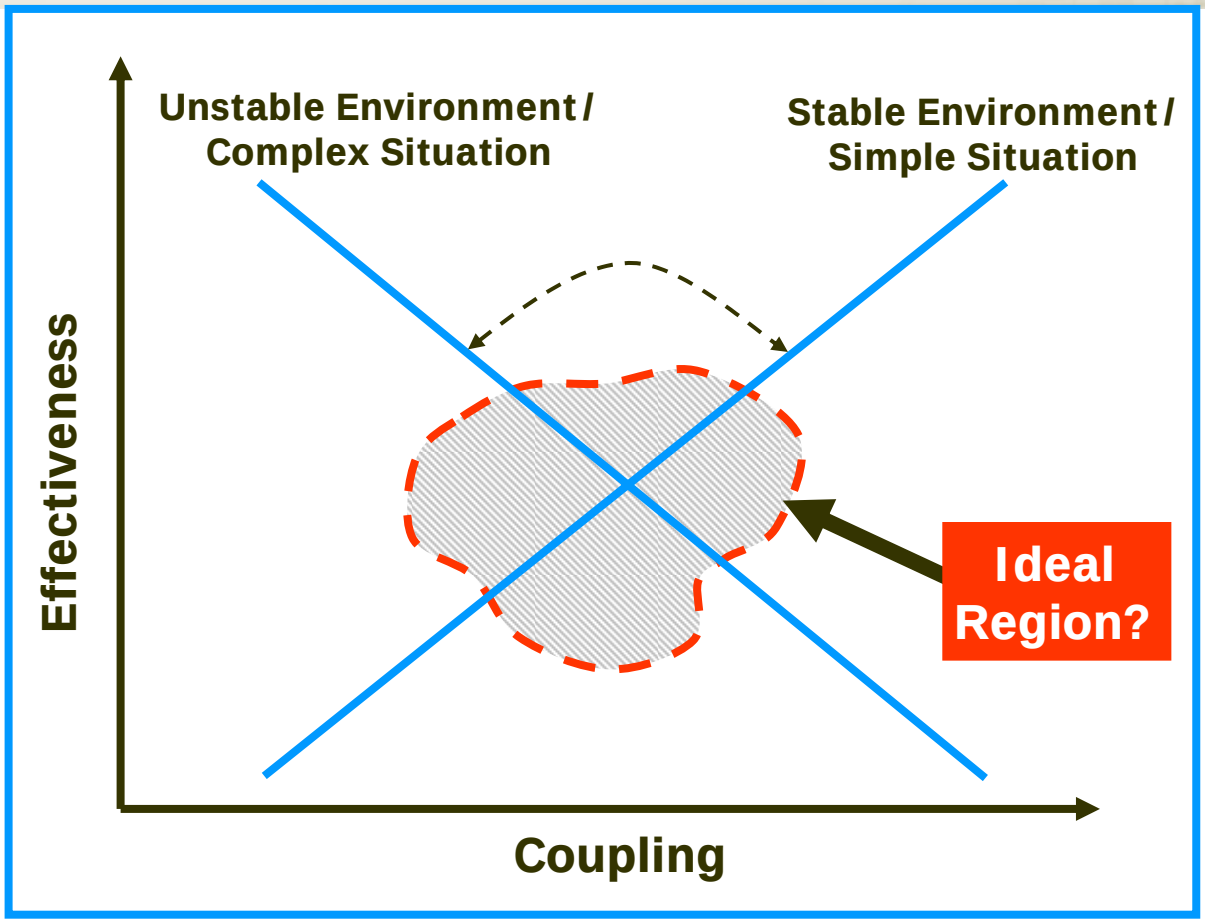
Conclusions on Tight Coupling → One size does not fit all

- Can exponentially increase your capability +
- Hard to achieve operationally & programmatically -
- Requires holistic acquisition strategy + / -
- Results in decreased COMMS efficiency & organizational performance -
- Risky → "Normal Accidents" & single points of failure -
- Need to view entire system holistically +
- It's hard to achieve holistic view of entire system -
- Tight coupling may not be an operational requirement +

Moderate coupling may be best way to manage environmental uncertainty?

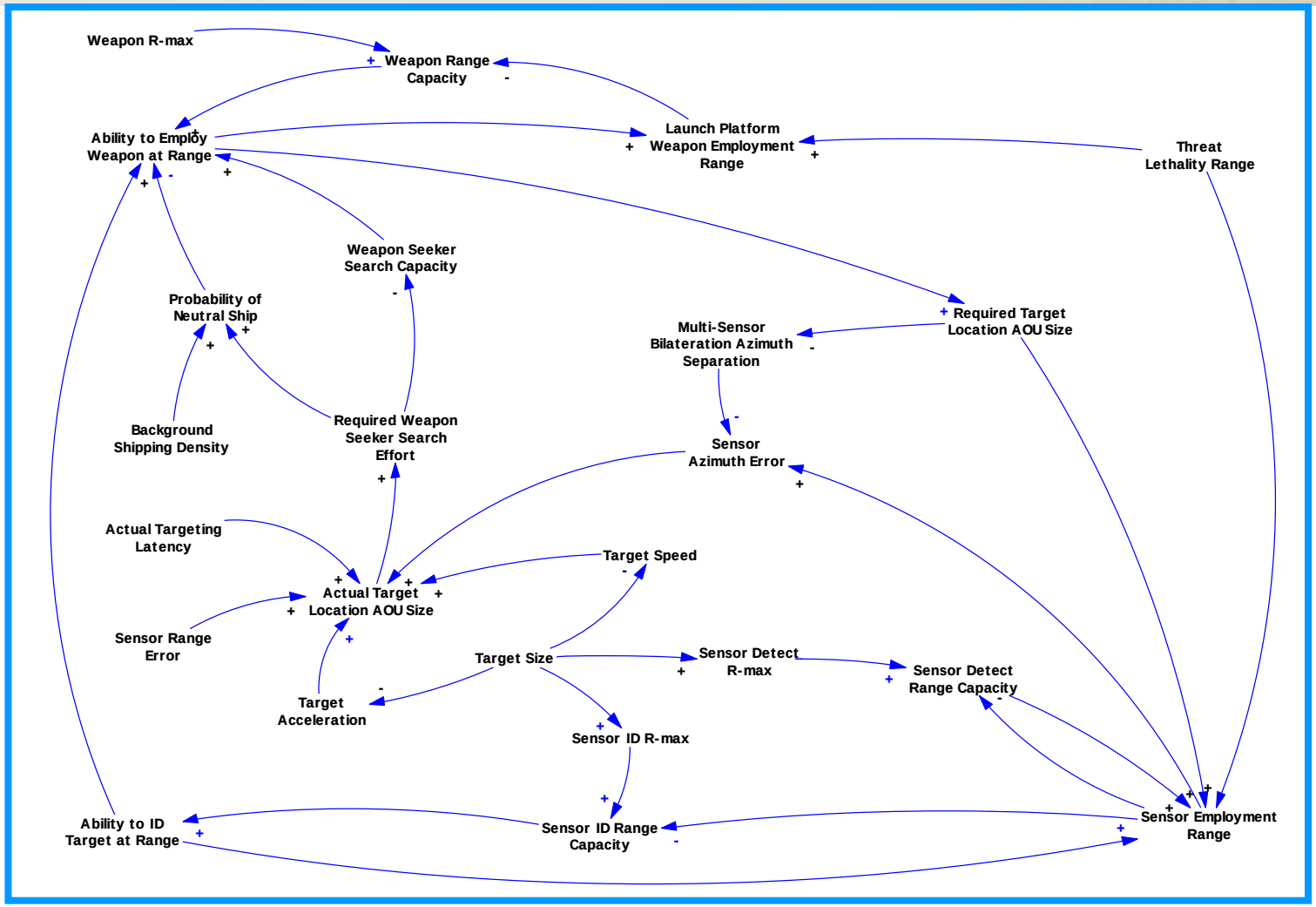
Further Research

Basis: Daft (1998), Perrow (1984) , Weick (1976)



PROBLEM: Socio-technical Systems = Leadership + Organizational + Technology

Coupling ~ Circular Causality?



QUESTIONS?

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