Generalization of the Kill Chain Model of C2

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Background

- Significant motivation to reexamine C2
  - Transformational Technologies
  - Non-traditional missions
- Definitional issues:
  - Joint
  - Service
  - Individual
- Numerous models:
  - OODA
  - MAPE
  - Find, Fix, Finish (F2T2EA)
  - etc

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Objective – Develop a Theory of C2

- There is a need for an accepted, useful Theory of C2
- Current theories are not satisfactory
- We've been trying to develop the basis for such a theory whose components are:
  - Necessary
  - Complete
- We've looked at metrics associated with the Theory
- We've looked at the simplifying cases, where the general theory simplifies into a known class of problem

Command and Control:
The ability to exercise authority and direction by a properly designated commander (decision maker) over assigned and attached forces in the accomplishment of the mission.

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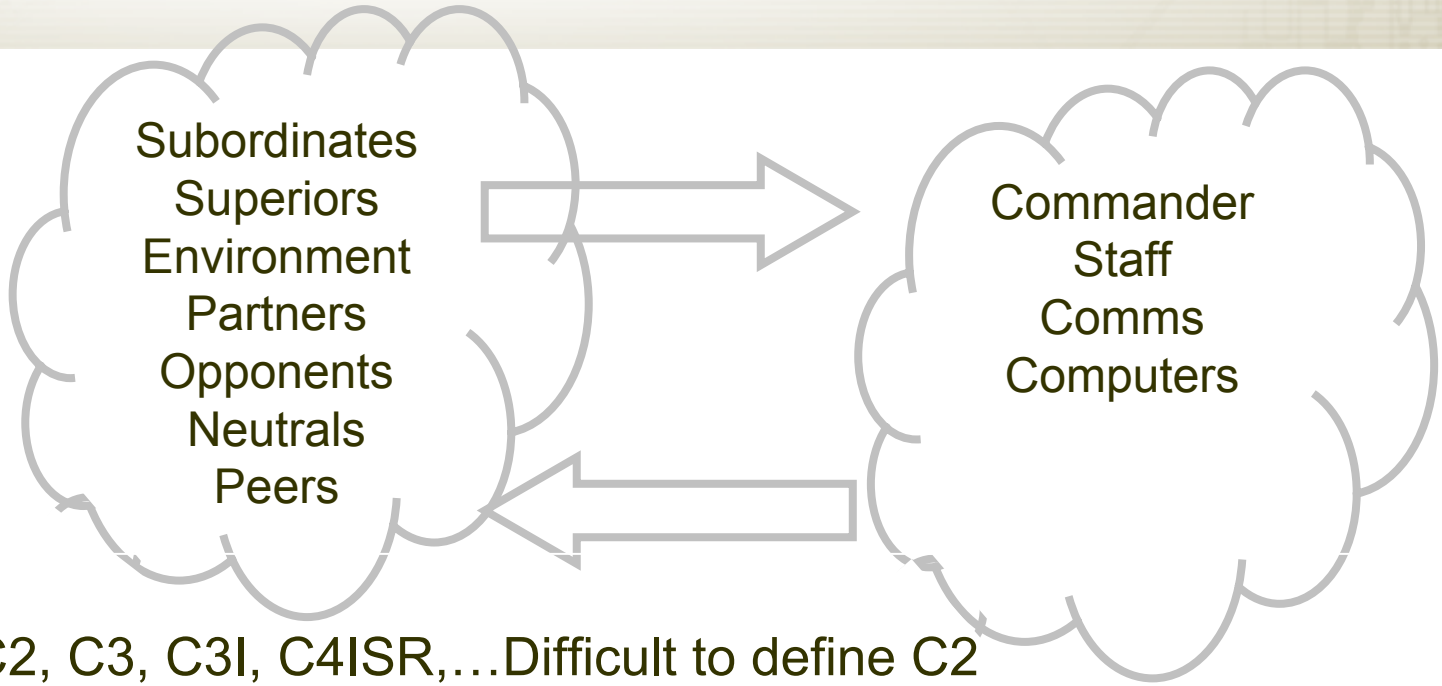
The C2 Boundary: What isn't C2?



- C2, C3, C3I, C4ISR,…Difficult to define C2
- Difficult to even set boundaries for C2.
- C2's fractal nature makes it challenging to isolate C2 functions
- The Commander (and staff) receive information, make decisions, and communicate those decisions
  - This suggests that the communication marks the beginning and end of the C2 process boundaries

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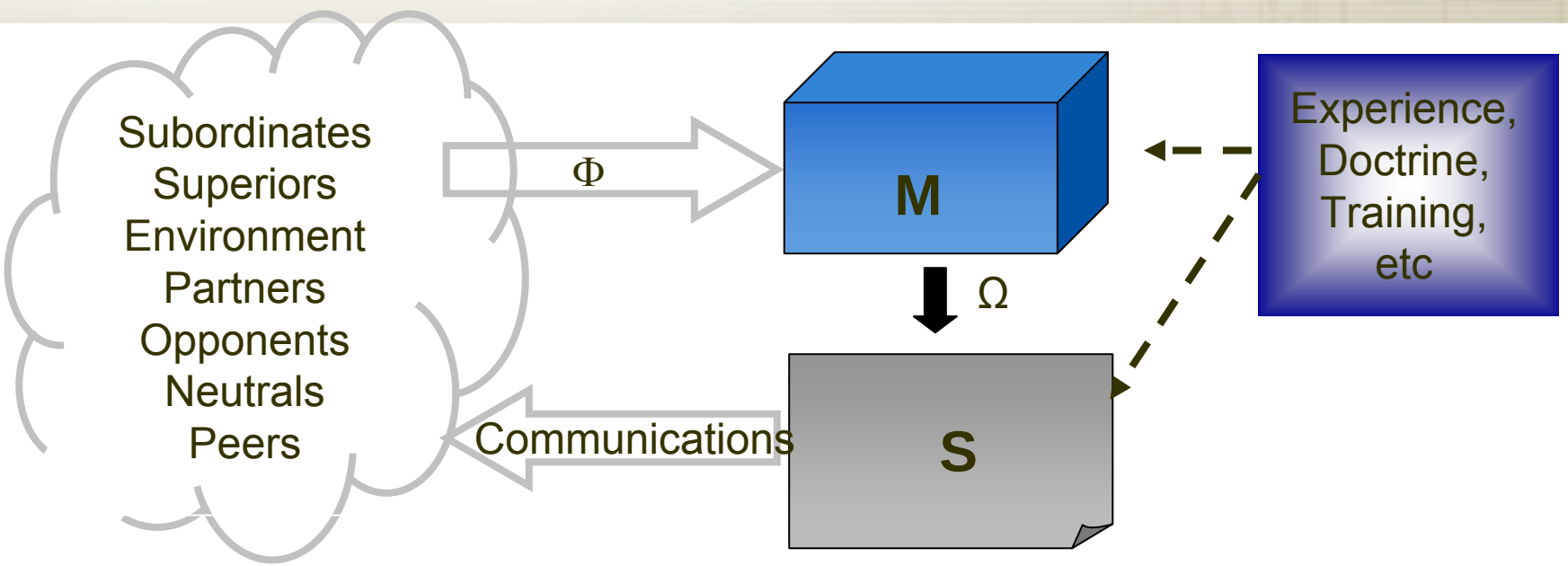
The C2 Problem: Description



- Φ, The set of information received by the commander (and staff)
- M, "Machine" that takes Φ as an input and produces Ω.
- Ω, Set of Opportunities that resources may be assigned against.
- S, "Machine" that takes Φ ,Ω as inputs and produces orders.
- Communications, Set of communication that indicates the COAs selected and actions to be taken. Note that communications may also take place within the functions M and S. They are likely to be dispersed throughout the enterprise.

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Probability Model With a Given Set of Information

- Generalization of the Find, Fix, Finish model (also F2T2EA, F2T2K, etc)
- Optimal Solution Probability model: The probability that a C2 system will produce the optimal solution (OS) (when one is known to exist) is:

  Given a set of information, Φ ;

  $Pr(OS) = Pr(\Omega \text{ contains } OS \mid \Phi) * Pr(S \text{ chooses } OS \mid \Omega) * Pr(\text{Orders are received and understood} \mid OS)$
- How can the optimal solution NOT be chosen?
  - Not considered
  - Considered but not chosen
  - Chosen but not executed

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Probability Model With a Multiple Possible Information Sets

- What if you want a robust C2 system and you want to evaluate multiple possible information sets?
- This approach is most appropriate when ISR and stochastic effects are being considered.
- The same approach would be used but the probabilities must be summed over all information sets.
- Optimal Solution Probability model: The probability that a C2 system will produce the optimal solution (OS) (when one is known to exist) is:

  Given multiple sets of information, Φ_i ;

  $Pr(OS) = \sum Pr(\Phi_i)*Pr(\Omega \text{ contains } OS \mid \Phi_i)*Pr(S \text{ chooses } OS \mid \Omega)*Pr(\text{Orders are received and understood})$

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What if There is No “Optimal Solution”?

Instead of “Optimal”, some other measure such as “sufficient” or even “winning” could be used.

- most useful when the solution can be evaluated (perhaps by simulation) and the range of outcomes could be compared with an “optimal” solution.
- This approach could also be used when the quality of solutions if difficult to identify and expert opinion forms the evaluation function.

- There is likely to be a trade-off between risk and mission success. Unless the commander’s utility of risk vs reward is specified, the best planners can do is present a range of options that identify the tradeoff between risk and success

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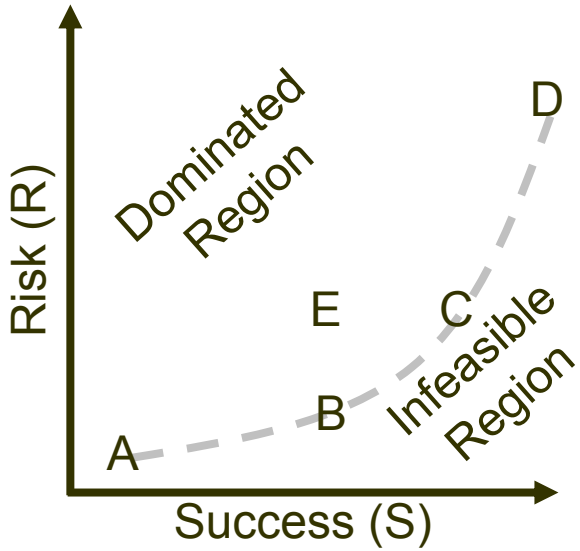
Efficient Frontier of Risk vs. Reward



Genetic Algorithms can be used to construct the efficient frontier of solutions.

Other methods can be used iteratively with slowly changing parameters.

- Similar to investment portfolio selection. There is no one right answer. It is all about balancing risk vs. reward
- The efficient frontier is the boundary between the dominated region and the infeasible region.
- COAs A, B, C, and D lie on the efficient frontier and a commander might choose any of them depending on the risk/reward tradeoff
- E should never be chosen, because B and C are both strictly better than E.

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Example

- Country X has a dual-use facility associated with weapons of mass destruction
- The objective is for them not to use it for the purpose of creating weapons of mass destruction
- Set of opportunities:
  - A – Show of force to convince them to allow inspections
  - B – A and then C if needed
  - C – Destroy the facility via strike
  - D – Occupy the facility – inspection by force

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Metrics

- Speed of the C2 process has always been the easiest metric
- Decision Quality is much more difficult
  - Depends on the specific nature of the problem
  - Model-based evaluation vs. human evaluation
- The theory suggests some key metrics in addition to speed. Metrics should identify measure the performance of the various parts of the C2 process:
  - Opportunities identified vs. optimal opportunities
  - Opportunities identified vs. optimal opportunities given the information available
  - The quality of the opportunities chosen vs. optimal
  - The quality of the opportunities chosen vs those identified
  - The efficiency of the resource utilization given the opportunities chosen

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Summary

- C2 needs a mathematical basis to enhance future research
- A new C2 theory and model proposed
- Communications marks the boundary of the C2 problem
- A generalized probability model may be helpful in situations where the kill chain model was of limited utility.
- Several metrics are suggested that measure the performance of the various C2 functions.

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Questions

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The C2 Problem: Description

- Maximize the utility of the expected outcomes that result from communications (of plans assigning resources to opportunities synchronized over time)

- Subject to:
  - Resource constraints (combat units, time, ROE, etc)
  - Opportunities identified (targets, show of force, humanitarian, diversion, gather more intel, etc)

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The C2 Problem: Description

$$\text{Max } Z = \alpha S - (1-\alpha)R \text{ where}$$

$$S = \sum_{i=1}^{NumO} Vo_i \Pr(O_i)$$

$$R = \sum_{j=1}^{NumR} Vr_j \Pr(R_j)$$

$$\text{Subject to:}$$

$$\sum_{i=1}^{NumO} X_{i,j} \le \text{Resource}_j \quad \text{one constraint per resource type}$$

$$\text{Additional Rules of Engagement Constraints}$$

$$0 \le \alpha \le 1$$

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Implications of C2 Problem Formulation

$$\text{Max } Z = \alpha S - (1-\alpha)R \text{ where}$$

$$S = \sum_{i=1}^{NumO} Vo_i \Pr(O_i)$$

$$R = \sum_{j=1}^{NumR} Vr_j \Pr(R_j)$$

Subject to:

$$\sum_{i=1}^{NumO} X_{i,j} \le \text{Resource}_j$$

ROE Constraints

$$0 \le \alpha \le 1$$

- The solution quality is limited to the set of options identified.
- The value of being successful for each opportunity and the value (or cost) of each risk event must be known
- $\Pr(O_i) = F(X_{i,j})$ Evaluating options requires an understanding of the relationship between assets assigned to the task and the probability of success.
- $\Pr(R_i) = F(X_{i,j})$ Evaluating the risks associated with options requires an understanding of the relationship between assets assigned to a set of opportunities and the probability of a risk event.

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α - The Risk/Reward Tradeoff

- α defines the tradeoff between risk and reward
- In cases where α is not defined, then the C2 system must present the commander with a number of Courses of Action (COAs)
- Ideally, each COA would be an optimal solution to the C2 problem, given some unique α.
- The concept of the "efficient frontier" can be helpful in identifying COAs to present.

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Applications the General C2 Model to Specific Sub-classes of Problems

In addition to the general form of the model, when the complexity of the C2 problem is reduced, the model maps to specific classes of optimization problems. (e.g., If the opportunities are independent, then each can be evaluated independently.)

- Job Shop scheduling problem: opportunities, costs and benefits are known and deterministic
- Game Theory: If we and our opponent must each choose a single opportunity and deterministic outcomes result from the pair of choices.
- Probability model: The probability that a C2 system will produce the optimal solution (OS) (when one is known to exist) is:

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