Boyd, Metcalfe and Amdahl - Modelling Networked Warfighting Systems

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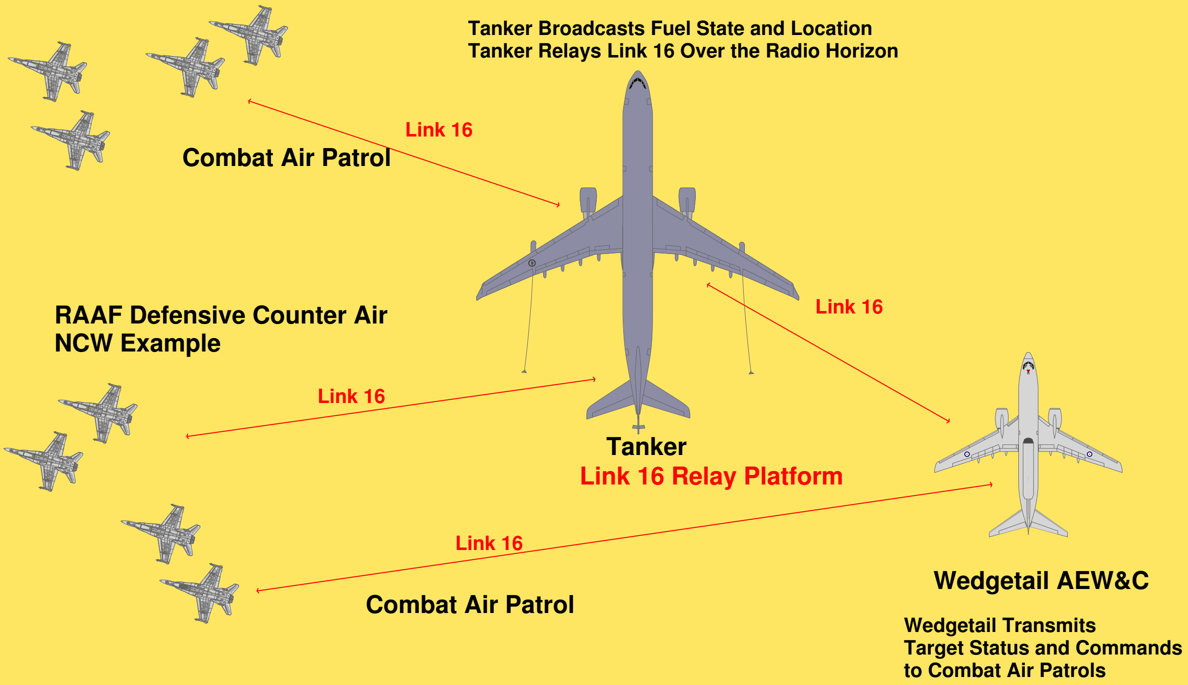
Defining the Problem

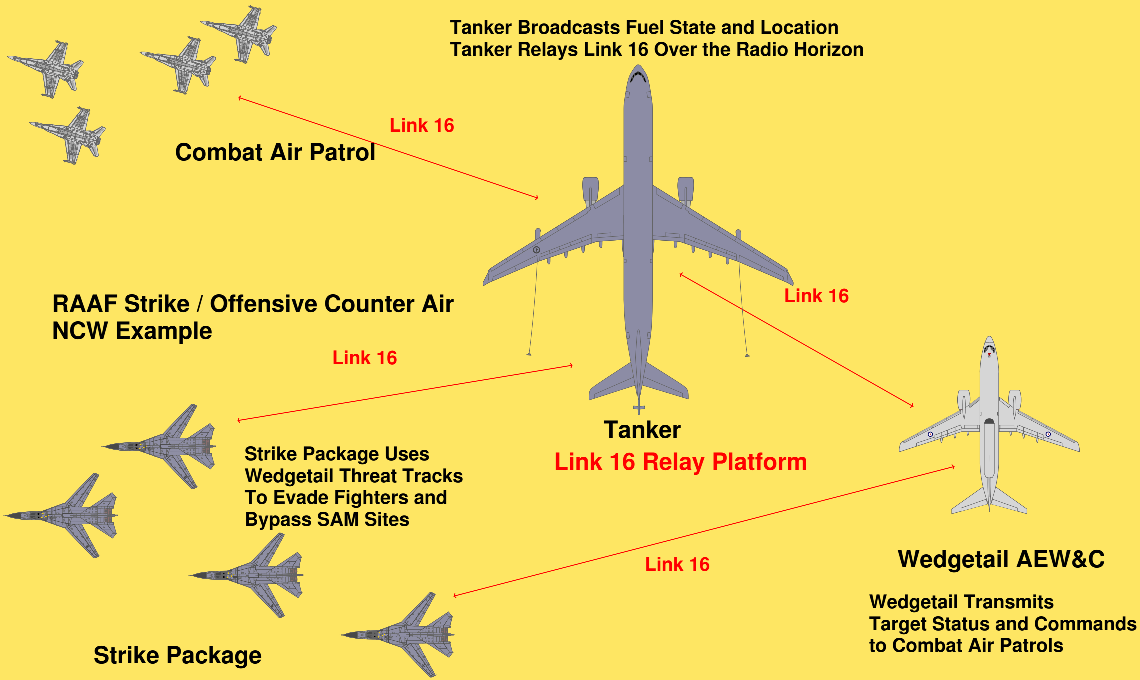
How to Quantify NCW Capability Gains?

- Networked system ‘capability gain’ remains a contentious issue.
- NCW advocates invoke Metcalfe’s Law and point to square law gains.
- NCW critics argue that the number of engagements effected is the measure of system capability.
- NCW trials and experiments do indicate measurable capability gains.
- How do these capability gains arise?
- How do we quantify these capability gains?
- How do we maximise these capability gains?
- How do we minimise an opponent’s capability gains?

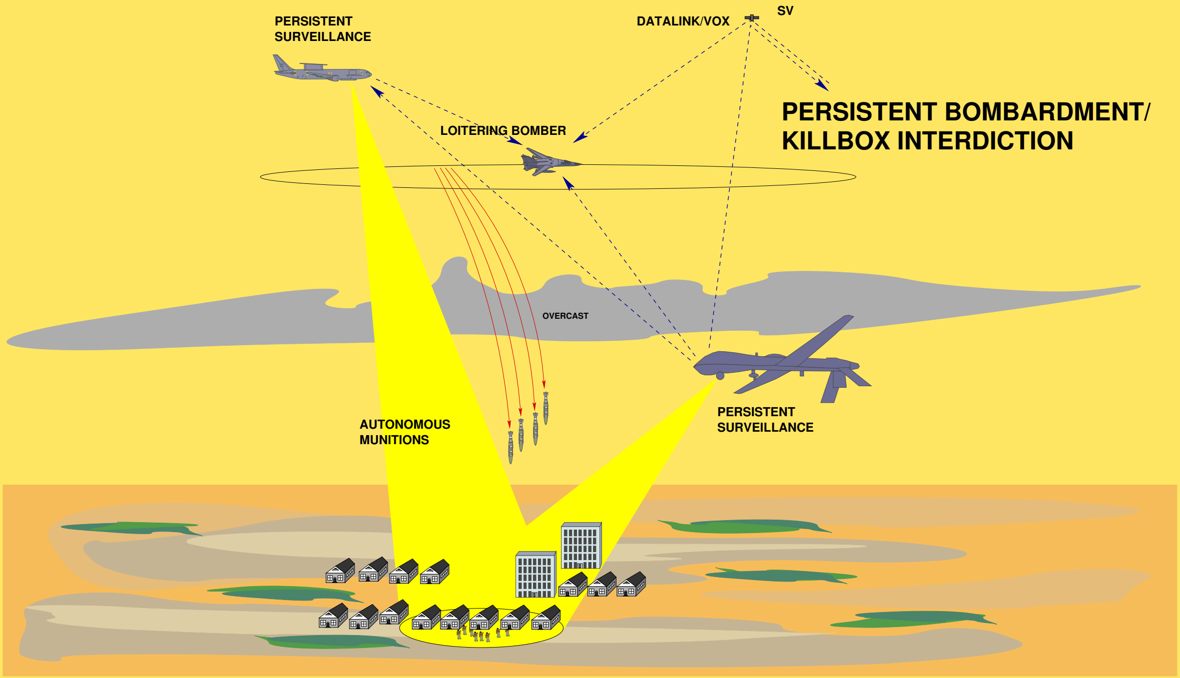
NCW - Counter-Air Environment



NCW - Strike Environment



NCW - Strike Environment

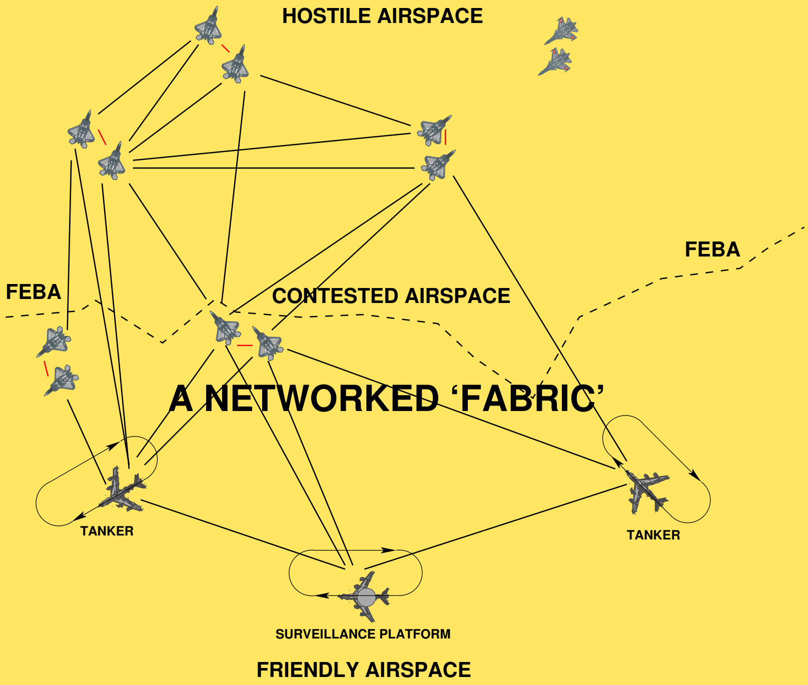


Quantifying Capability Gains

NCW vs Boyd's OODA Loop

- Boyd's Observation-Orientation-Decision-Action loop presents an abstraction to represent the event loop in an engagement.
- Vast empirical evidence to support Boyd model - also applicable to biological 'predator-prey' interactions.
- Players in the event loop *Observe* environment, *Orient* themselves to the situation by forming a model, *Decide* upon a course of action, and execute that *Action*.
- Intelligence Surveillance Reconnaissance (ISR) sensors and systems collect information and a network distributes that information.
- Networking accelerates OODA loops by accelerating the *Observation-Orientation* phases and improving situational awareness.

NCW - A Networked Fabric



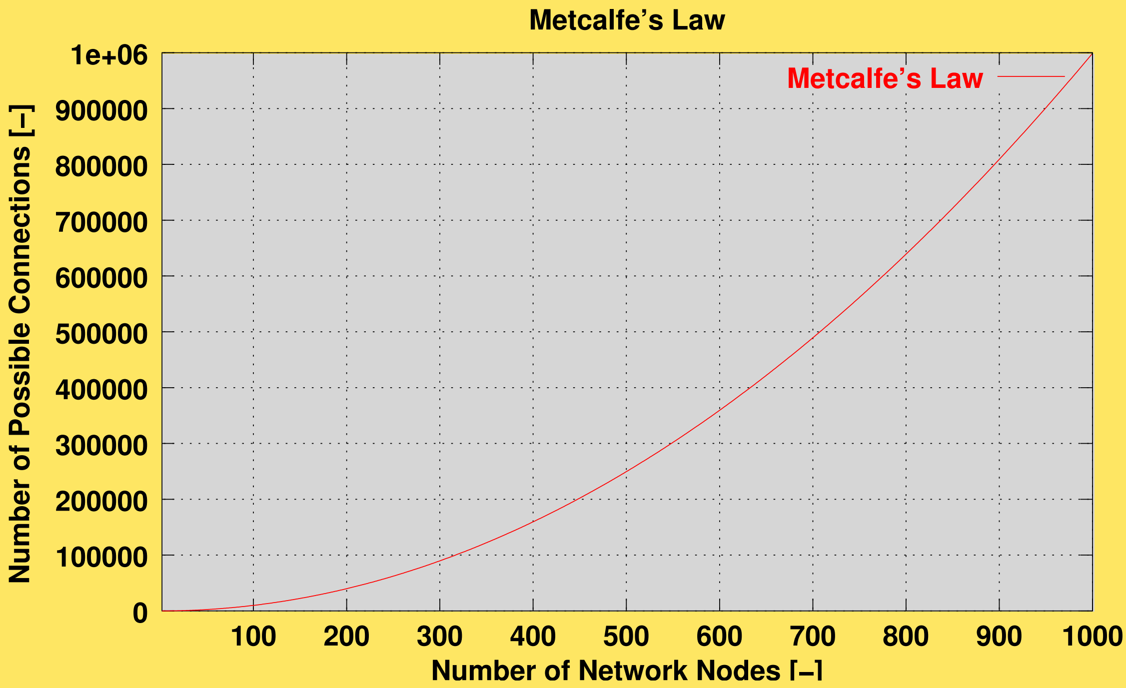
The Incompleteness Problem

- Representing capability gains using OO phases of OODA loop puts focus on *information domain* gains.
- Real world systems combine *information domain* and *kinetic domain* elements.
- Using only *information domain* elements neglects constraining system behaviours imposed by *kinetic domain* elements.
- The result can be highly optimistic and unrealistic conclusions about achievable capability gains.
- *Representative modelling of complete system capability gains requires a complete model which can encompass both the OO and DA phases of the Boyd OODA loop.*

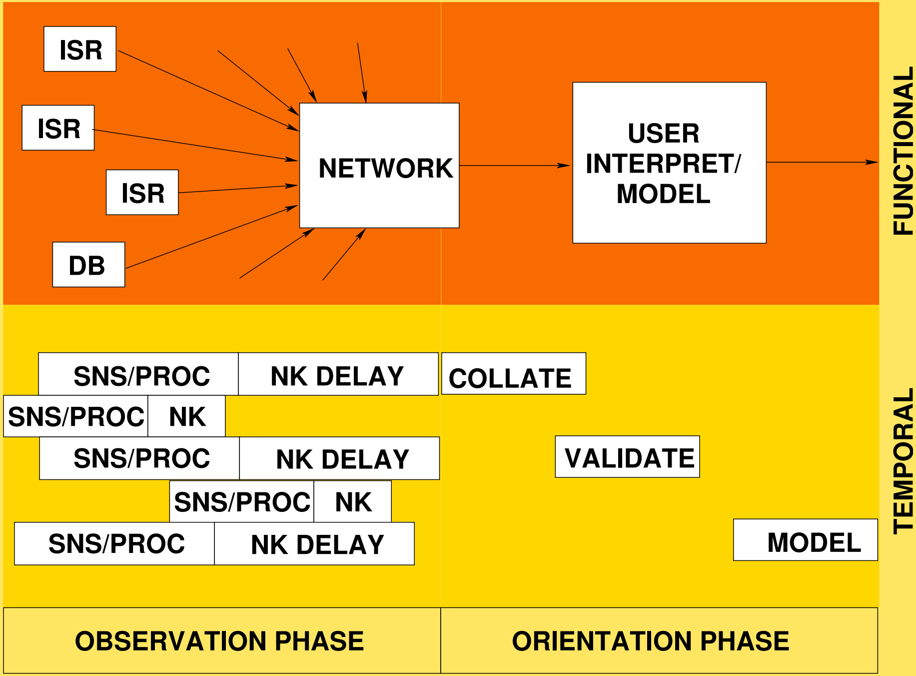
Metcalfe's Law

- Metcalfe's Law asserts that the usefulness or utility of a network increases with the square of the number of nodes in the network.
- Empirically demonstrated on the WWW by correlating gains in sales revenue against number of nodes connected to the network.
- Metcalfe's Law is not a predictor of achieved utility, but rather an indicator of *achievable utility*.
- 'Utility' is seen in terms of connectivity.
- Widely cited as a measure of capability gain in networked warfighting systems.
- Metcalfe's Law contains no implicit mechanism to quantify time domain behaviour in the system.

Metcalfe's Law



Metcalfe's Law - Time Domain



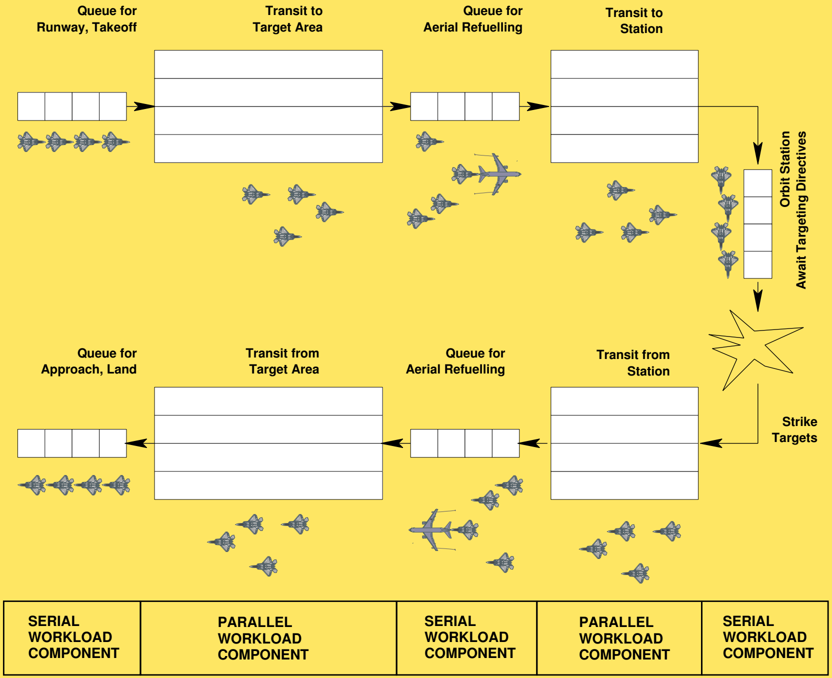
Metcalfe's Law Limitations

- Implicit assumption that gains in connectivity produce gains in time domain performance.
- Complex time domain dependencies in ISR system and network behaviour not accounted for.
- Network saturation and load effects not accounted for.
- Effects of hostile jamming not accounted for.
- *Metcalfe's Law at best a useful predictor of bounds on capability gain.*

Kinetic Domain - Decision-Action

- Completeness in modelling capability gains requires a *kinetic domain* model which can encompass the Decision-Action phases of the OODA loop.
- Establish what bounds exist on the number of engagements the system can produce within a defined time, with some bounded number of elements.
- *Decision* processes involve delays since decision-makers often dependent on inputs from superiors and subordinates, introducing queueing behaviours into the system.
- Executing *Actions* involves sequences of events such as positioning a platform for an engagement, also introducing queueing behaviours into the system.

Kinetic Domain Constraint Example



Kinetic Domain - Decision-Action

- In practical terms the system at the Decision-Action level involves complex mixes of sequential / serial / queueing behaviours, and some parallel behaviours.
- *How do we best model a complex mix of serial and parallel functions?*
- **Answer: exploit Amdahl's Law used in supercomputing.**

Amdahl's Law

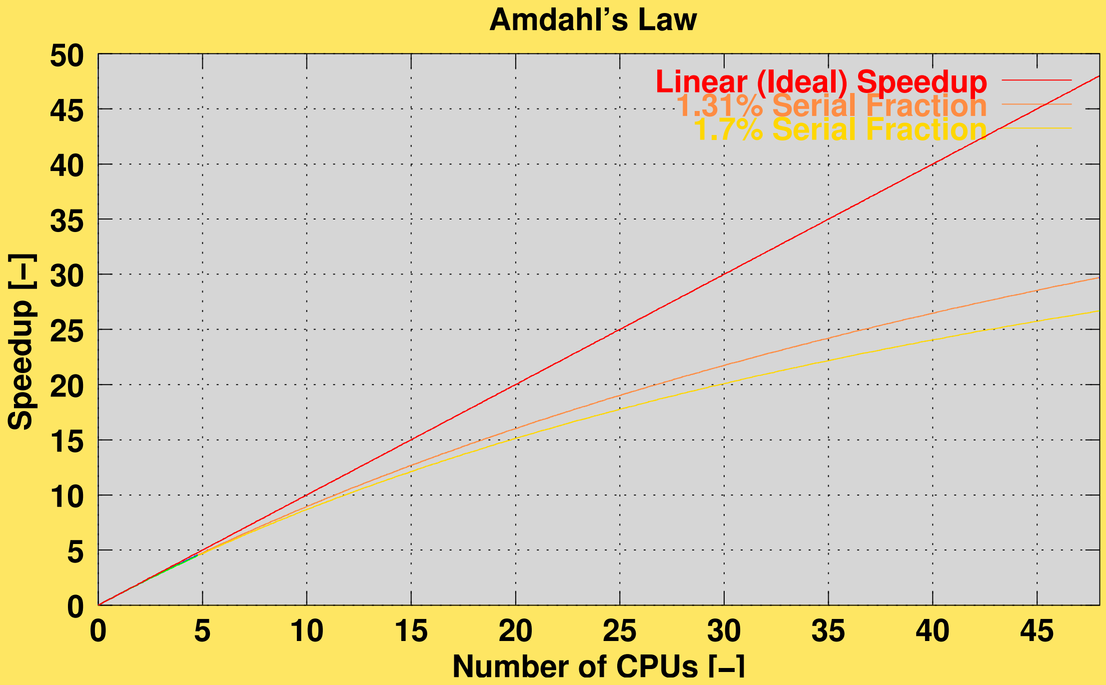
- Amdahl's Law asserts that a large system of 'processors' working in parallel to solve a single problem can never achieve aggregate performance equal to the sum of the achievable performance of each and every individual processor in that system. The idealised 'linear speedup' in problem solving cannot be achieved for any real world problem, or:

  $$\mathbf{Speedup = (s + p\ )\ /\ (s + p\ /\ N\ ) = 1\ /\ (s + p\ /\ N\ )}$$

  - where s and p are the serial and parallel time fractions.

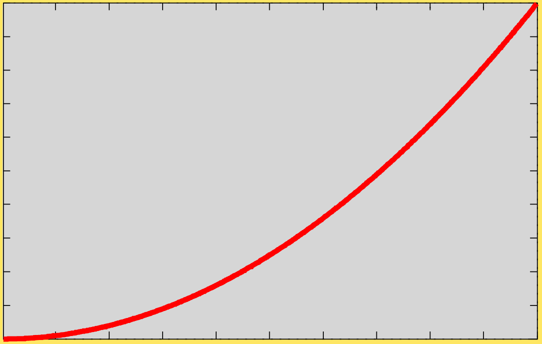
- In Amdahl's Law, the nature of the workload imposes constraints on behaviour, regardless of the number of elements in the system performing work. In networked warfighting systems, we thus treat entities performing work as processors in a complex serial / parallel system, executing tasks.

Amdahl's Law

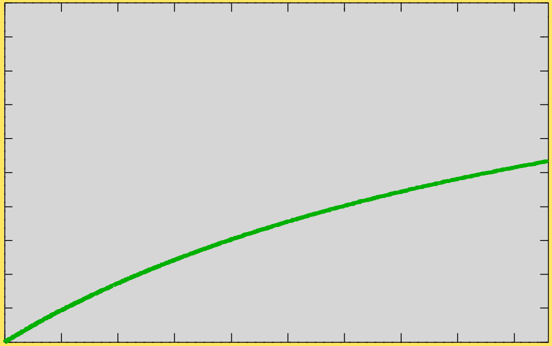

Amdahl's Law
Linear (Ideal) Speedup
1.31% Serial Fraction
1.7% Serial Fraction
Speedup [–]
Number of CPUs [–]
0
5
10
15
20
25
30
35
40
45
50

Boyd vs Metcalf vs Amdahl

Metcalfe's Law



Amdahl's Law



OBSERVATION	ORIENTATION	DECISION	ACTION

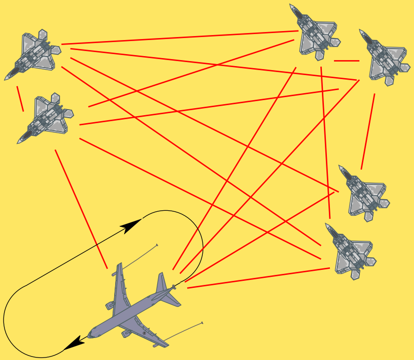
Decision Action Capability Gains

- Capability of the system in the Decision-Action phases reduces with the increasing number of 'serial chains' within the system.
- Capability of the system in the Decision-Action phases increases with the increasing level of parallelism in the system.
- Complex sequential decision processes thus impair capability regardless of networking capability.
- Maximising the number of platforms, maximising concurrent engagements per platform and maximising platform persistence in proximity to targets maximises parallelism and thus capability.
- Empirical experience supports conclusions derived from Amdahl's Law.
- Metcalfe and Amdahl models are complementary, not exclusive.

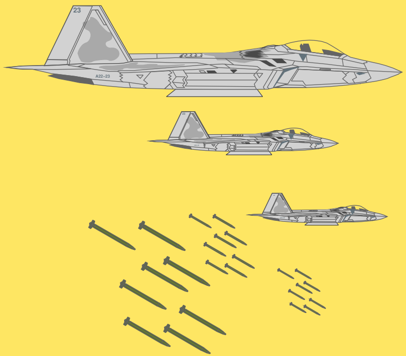
Maximising Capability Gains

OBSERVATION	ORIENTATION	DECISION	ACTION

'MAXIMISE CONNECTIVITY'
'MAXIMISE SENSOR CAPABILITY'



'MAXIMISE PARALLELISM'
'MINIMISE SERIAL CHAINS'

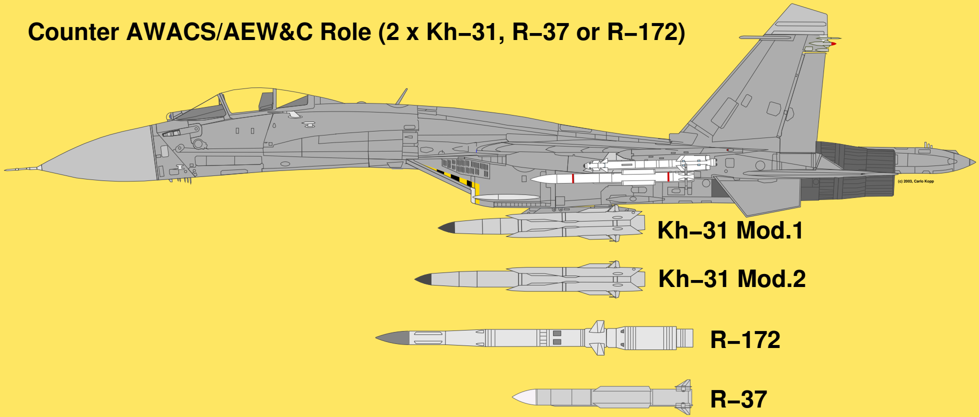


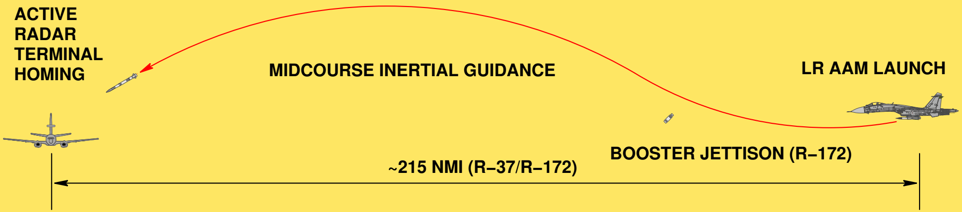
Minimising an Opponent's Gains

- Given two mutually opposed networked systems, maximising own capability requires:
  1. Maximising number of ISR elements
  2. Maximising connectivity (and link capacity)
  3. Maximising parallelism
  4. Minimising serialism
- Minimising the opponent's capability requires:
  1. Reducing the opponent's number of ISR elements
  2. Minimising the opponent's connectivity (and link capacity)

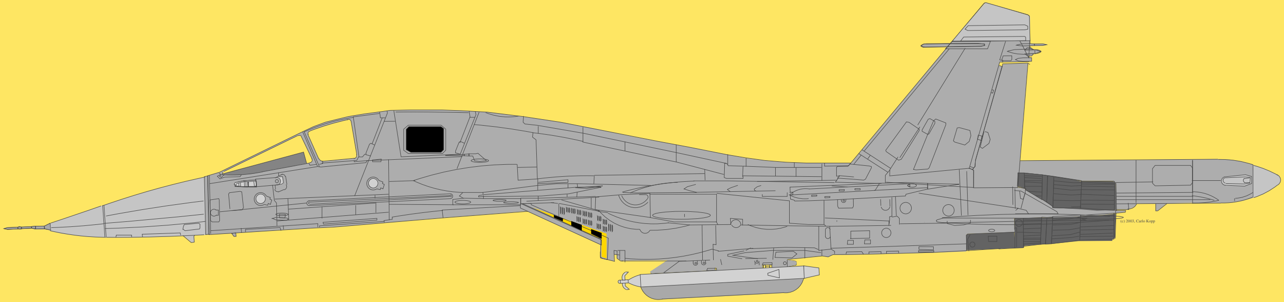
Minimising Opposing ISR Capability

Counter AWACS/AEW&C Role (2 x Kh–31, R–37 or R–172)

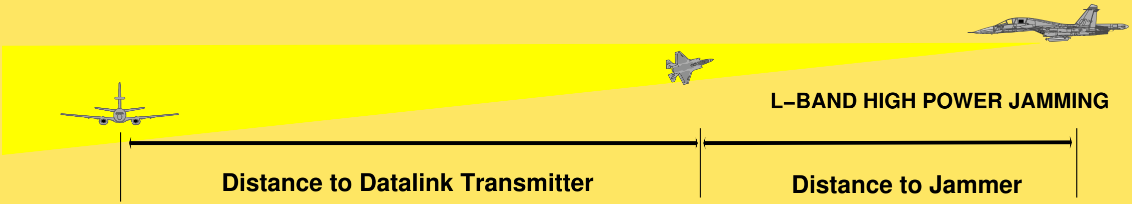




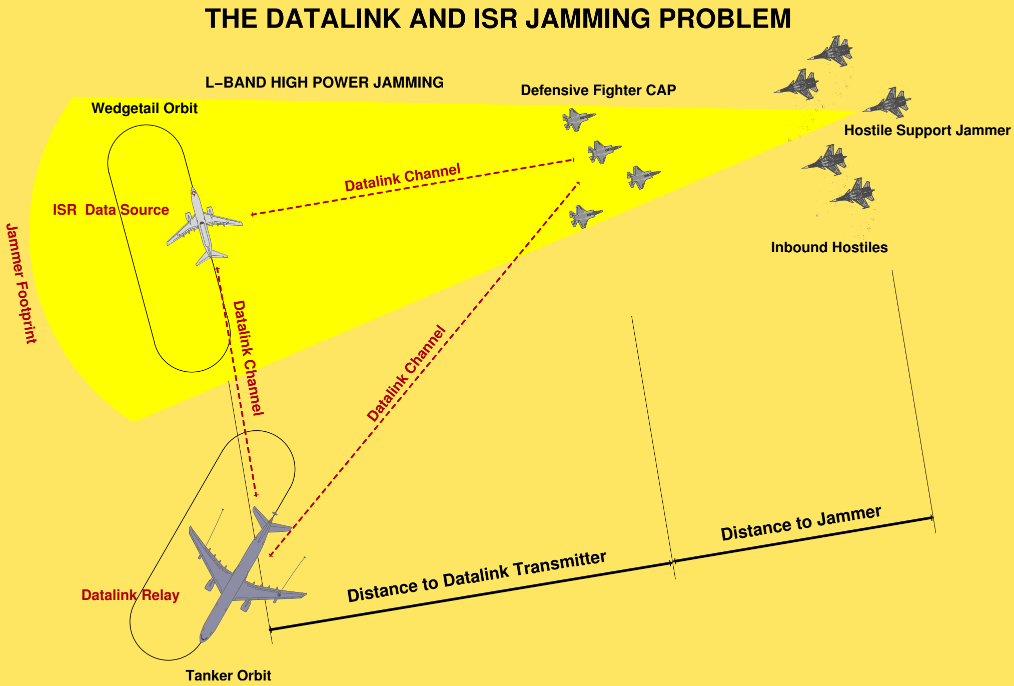
Minimising Opposing Connectivity



Su–30/32 Electronic Attack Role (2–5 x High Power Jammer Pods)



Minimising Opposing Connectivity



Conclusions

- Amdahl's Law provides a valuable abstraction for modelling the impact of the Decision-Action phases of the OODA loop on system capability gains.
- Amdahl's Law complements Metcalfe's Law by providing for a complete abstraction to model OODA loop behaviour.
- Amdahl's Law presents a model which relates achievable numbers of engagements to time.
- Metcalfe's Law, conversely, presents capability gains indirectly, as it measures utility in terms of connectivity.
- Fusion of Boyd, Metcalfe and Amdahl provides an intellectual framework for understanding capability gains in networked warfighting systems.

End Presentation

Revision Information

This document is currently at revision level:

`$Id: CSE-3141-2004.tex,v 1.1 2004/02/06 12:34:52 carlo Exp carlo $`