Case Studies in Defense Systems Architecture and Engineering

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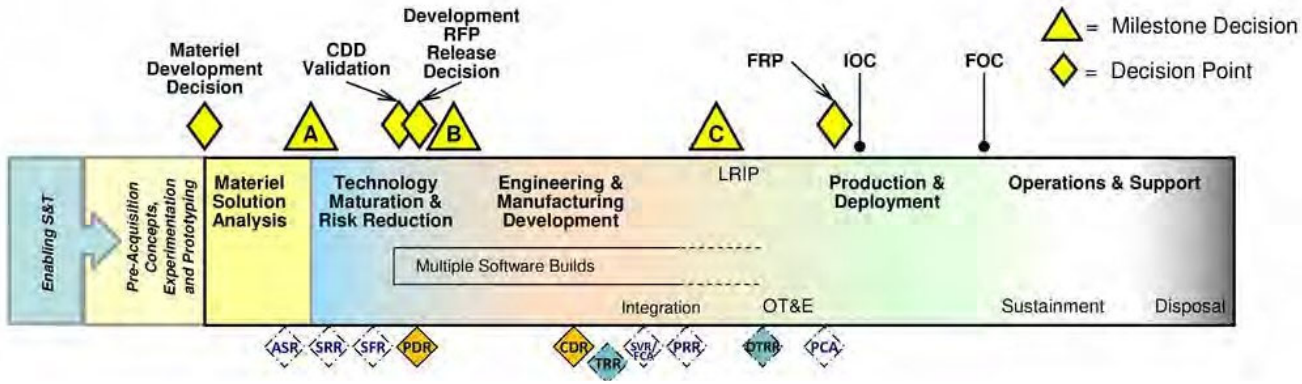
Purpose

To introduce concepts in systems architecting and systems management using real world examples from Aerospace and Defense Systems

Timelines of the Lifecycle of a System – Example F-35



1980s technology development, development planning, requirements analysis	1993 Joint Advanced Strike Technology Program	1997 Concept development contract awarded	2001 Engineering/ Manufact Development awarded	2006 First flight Test A/C	2011 Aircraft Deliveries Begin	2015 -- Today Marine IOC Air Force IOC International Deliveries	2020 Sustainment contracts awarded

System Life Cycle spans decades. Early architecting/engineering decisions have lifelong impacts

Challenge for Systems Professionals – Gaining Experience needed

- Systems professionals should gain experience
  - Across the breadth of the system life cycle with
  - With depth in areas of design, test, fielding, sustainment
- Systems architects must possess knowledge across the spectrum
  - Decisions made at the beginning have implications throughout

	Apprentice Engineer	Engineer	Senior Engineer	Principal Engineer	Distinguished Engineer
Level	0	1	2	3	4
"Keywords"	"New at SAAB"	"Implement systems from existing design"	"Implement and improve systems from new design"	"Develop systems from scratch"	"Develop systems from systems from scratch"
Role	Software Systems Design Analysis	Software Systems Design Analysis Test Engineer	Software Systems Design Analysis Airworthy Certification First Test Engineer	Technical leader ATA, MGA, CVE Design leader Chief Systems Engineer Ass. CI Senior Test Engineer INCOSE certified developer	Chief Engineer Chief Test Engineer CVM Fellow "Expert"
Min. years	0 - 2	2-	4-	6-	10-
Determination to reach the level	Through the appointment procedure	Section Head	Area Head & Technical Head	Area Head & Authorisation Council Chief Engineer, CVM	Specialist Board HoD EASA/Flygi
Now %	1 %	37 %	47 %	13 %	2 %
Goal %	10	20	50	18	2

At SAAB: Ten years of experience required to develop systems from systems from scratch

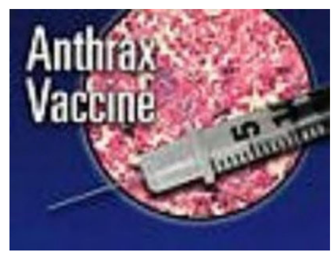
Example: Engineering Development Path at SAAB

Why case studies? Provides a means to compensate for experience gaps

- Case studies can be used to develop systems professionals
- Early to Mid year professionals with a desire to be better systems architects and engineers
- Opportunity to see the bigger picture of systems development. Many engineers and program managers don't get the opportunity to see the big picture.

Rapid Prototyping gone wrong

System of Systems Integration at its Best



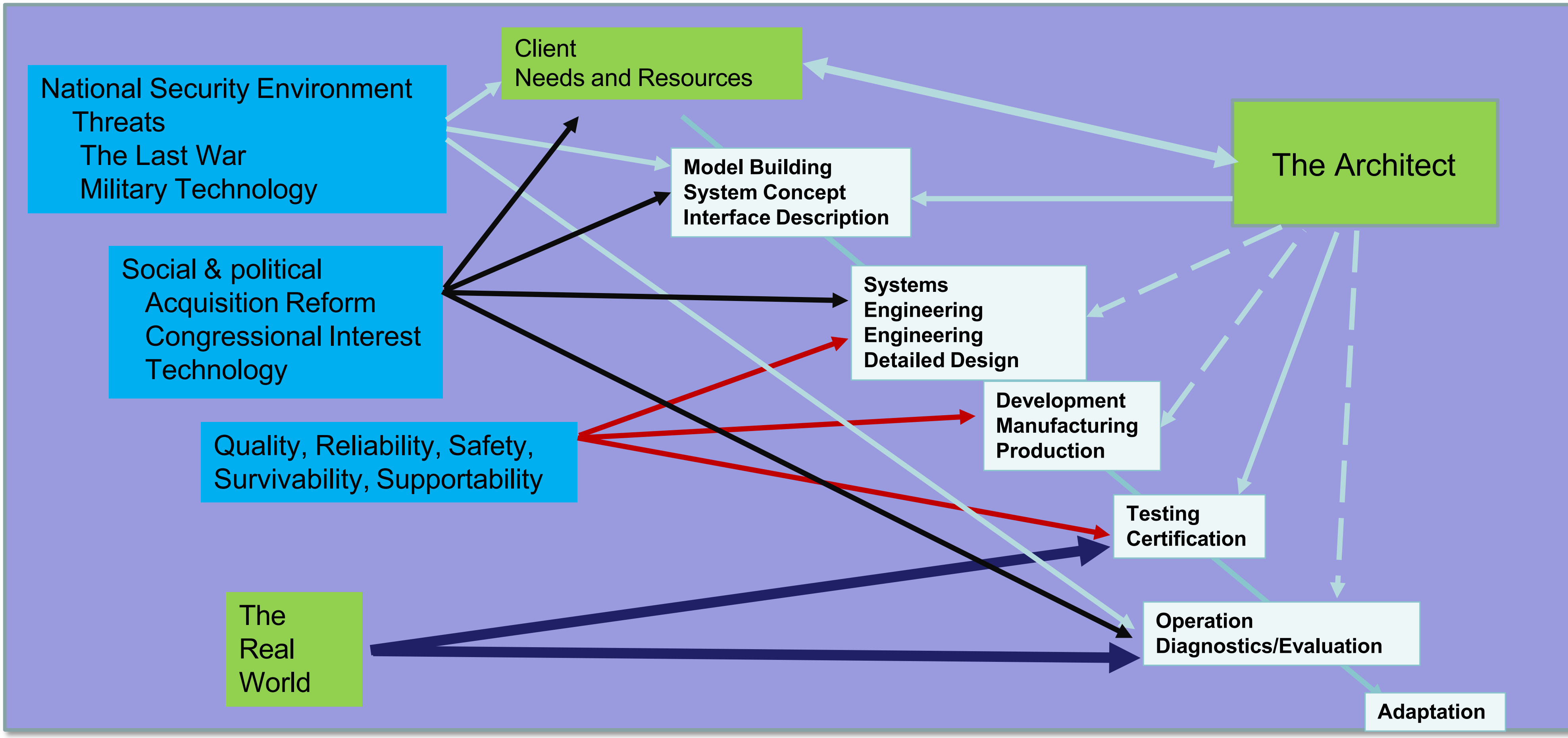
Emotional Intelligence and System Engineering

Systems Engineering and Agile Software practices mismatch

Overview

- Organizing construct for systems architecting
- Example: Transformational Satellite Communications System (TSAT)
- Lessons Captured for the Future

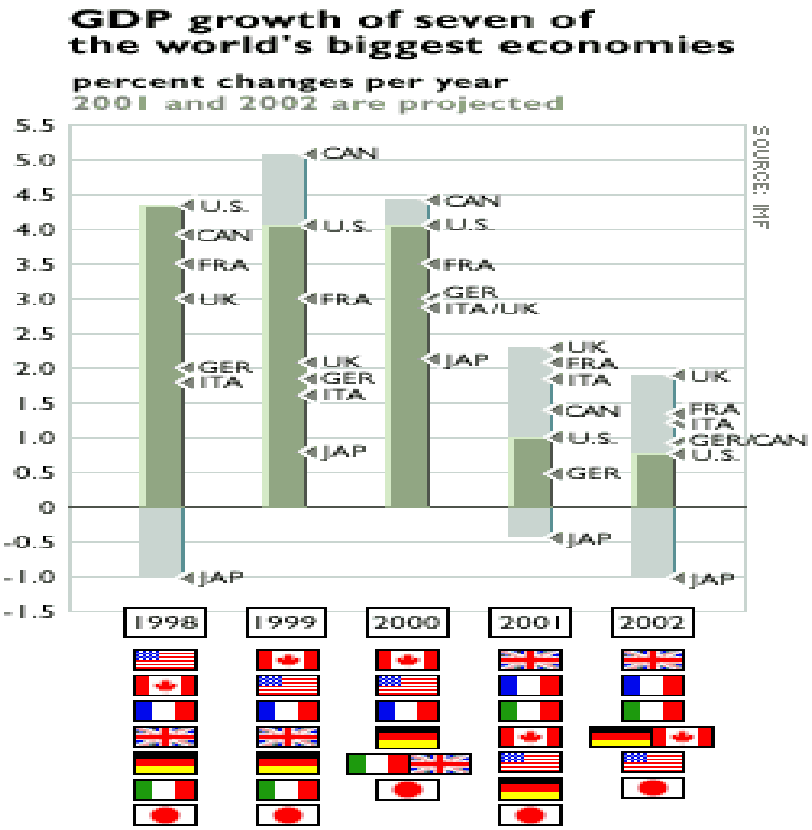
Organizing Construct



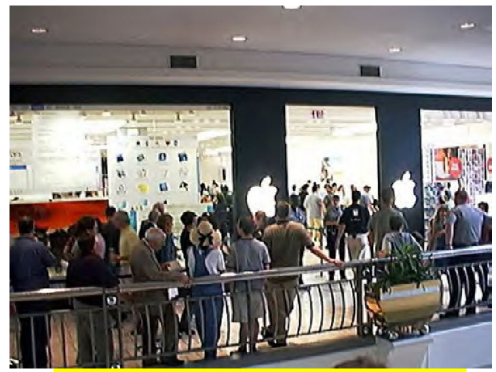
Environment that Birthed TSAT

- World Events
- Military Environment and Needs
- Social and Political Situation
- Quality, Reliability, Safety

2002 – Global Connections and Interdependence



World Economies Sink Together



First Apple Store Opens

X-Box with on line gaming Released

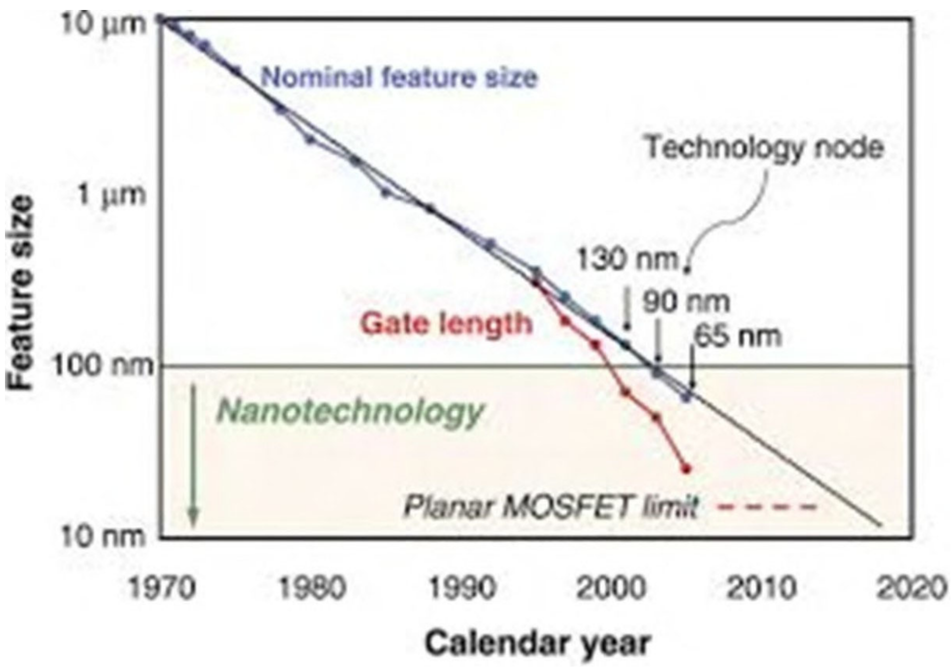
World unites against 9/11 attacks

2002 – State of Technology --Electronics

Cell Phones
still just phones

Larger SATCOM
Terminals still the
standard

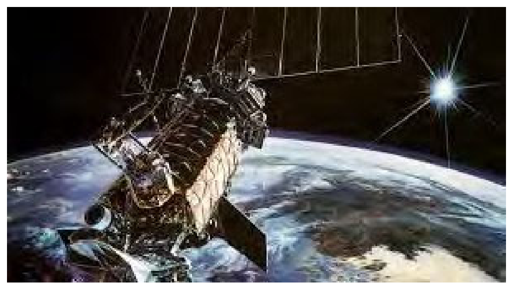
Small Satcom
Terminals emerging



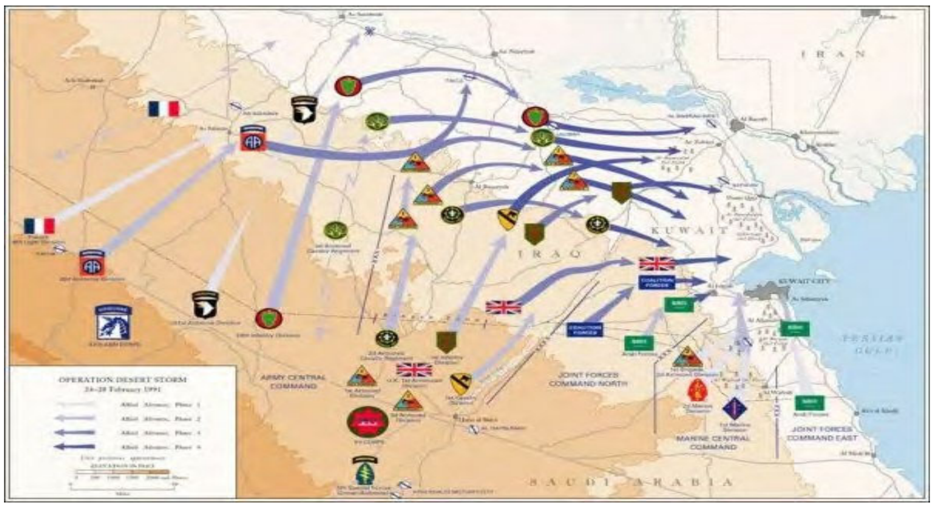
Moore's Law continues. Feature
sizes of 60 nm achievable.

Military Environment – Winning the Last War

"Satellites were the single most important factor that enabled us to build the command, control, and communication network for Desert Shield" -- Gen Colin Powell



Desert Storm Shortfalls



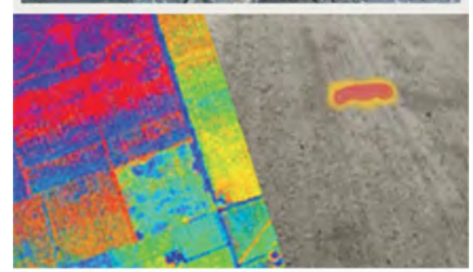
"Left Hook" operation demonstrated need for tactical protected communications

Milstar – secure, protected, comm – low data rates, limited capacity, not mobile

SCUD Hunting Highlighted the need for access to national space assets

Post 9/11 Military Environment

- More comm for tactical forces
- Protected comm for ground forces
- More access to Space reconnaissance capability
- Importance of coalition interoperability
- Remotely Piloted Vehicles – secure comm for C2 and data dissemination



Hyperspectral sensors have commonly been used to look for disturbed earth where IEDs have been buried

Military Environment and Needs

- The Last War – Lessons Learned
- Current Environment – Post 9/11 Counter terrorism operations
- Space systems recapitalization
- **Bottomline:** The Client (US Military) was hungry for capability and saw the recapitalization efforts as the opportunity to get it.

Political/Social: Understanding the Environment
Program Management and Systems Engineering Practices

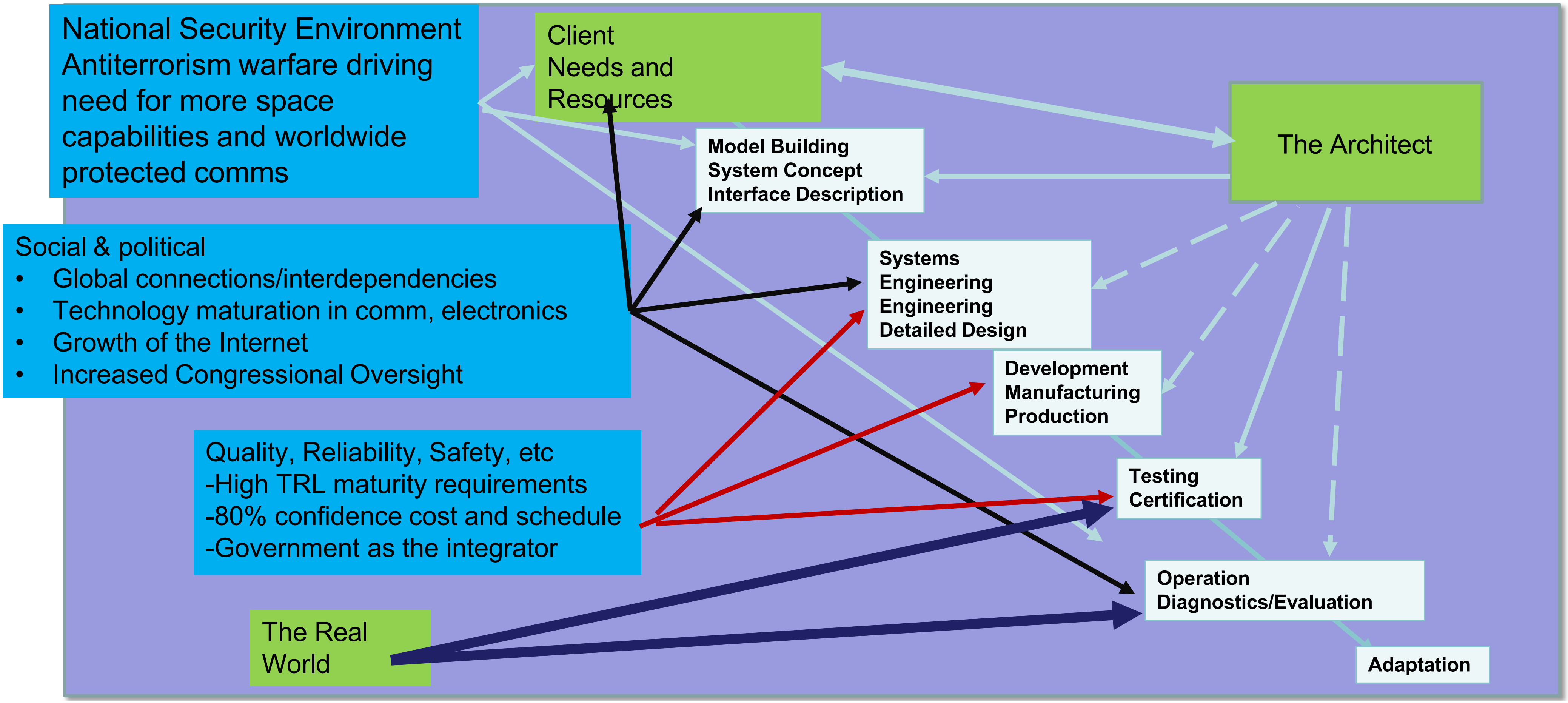
- 1990s – Reinventing Government
  - William Perry banned military specifications
  - Total System Performance Responsibility
  - Lightening Bolts – streamlined program offices
  - Duncan Hunter – "Too many buyers"
- 2000s – Back to Basics
  - Defense Acquisition Performance Review
  - Better Buying Power
  - Risk aversion – Nunn McCurdy proofing
- 2014 – Improve speed
  - Streamline, prototype, fail fast

- 1990s –
  - Organic systems engineering competency eliminated
  - Contractor systems engineering discipline succumbed to budget pressure
  - Loss of expertise, atrophy of practices
- 2000s – Back to Basics
  - Systems Engineering revitalization
  - Growth of Systems Engineering Research
  - Dogmatic following of "best practices" without regard to the environment
- 2014
  - TBD -- Can we go fast without sacrificing systems engineering quality? Do we need new or updated practices? What heuristics still apply?

Political/Social – Acquisition Oversight Environment

- Backlash from Acquisition Reform failures of the 1990s
  - Elimination of military standards resulted in loss of quality and poor discipline
  - Total System Performance Responsibility Contracts left the DoD an un-informed buyer
  - Large bow wave of procurements that were unaffordable
- Congressional and DoD Initiatives
  - Reinstated Military Standards, particularly for Space systems
  - Mandated 80% confidence independent cost estimates
  - Reduced appetite to take risk – mandated high technology readiness levels at critical design review
  - Implemented new Nunn-McCurdy Breach rules

TSAT Architecting: Waterfall Model



Key players: Champion and Key Decision Makers

The Champion: John Stenbit

Assistant Secretary of Defense for Command, Control, Communications, and Intelligence (2001-2004)

"Moving Power to the Edge"
Vision – Bring the Internet to Space

Undersecretary of the AF

Undersecretary of the Air Force and Director of the National Reconnaissance Office

Experienced Industry Exec
Acquisition Authority for all Space Systems

Undersecretary of the Air Force

Astronaut, AF Officer, Engineer
Acquisition Authority for AF Space
Strong technologist

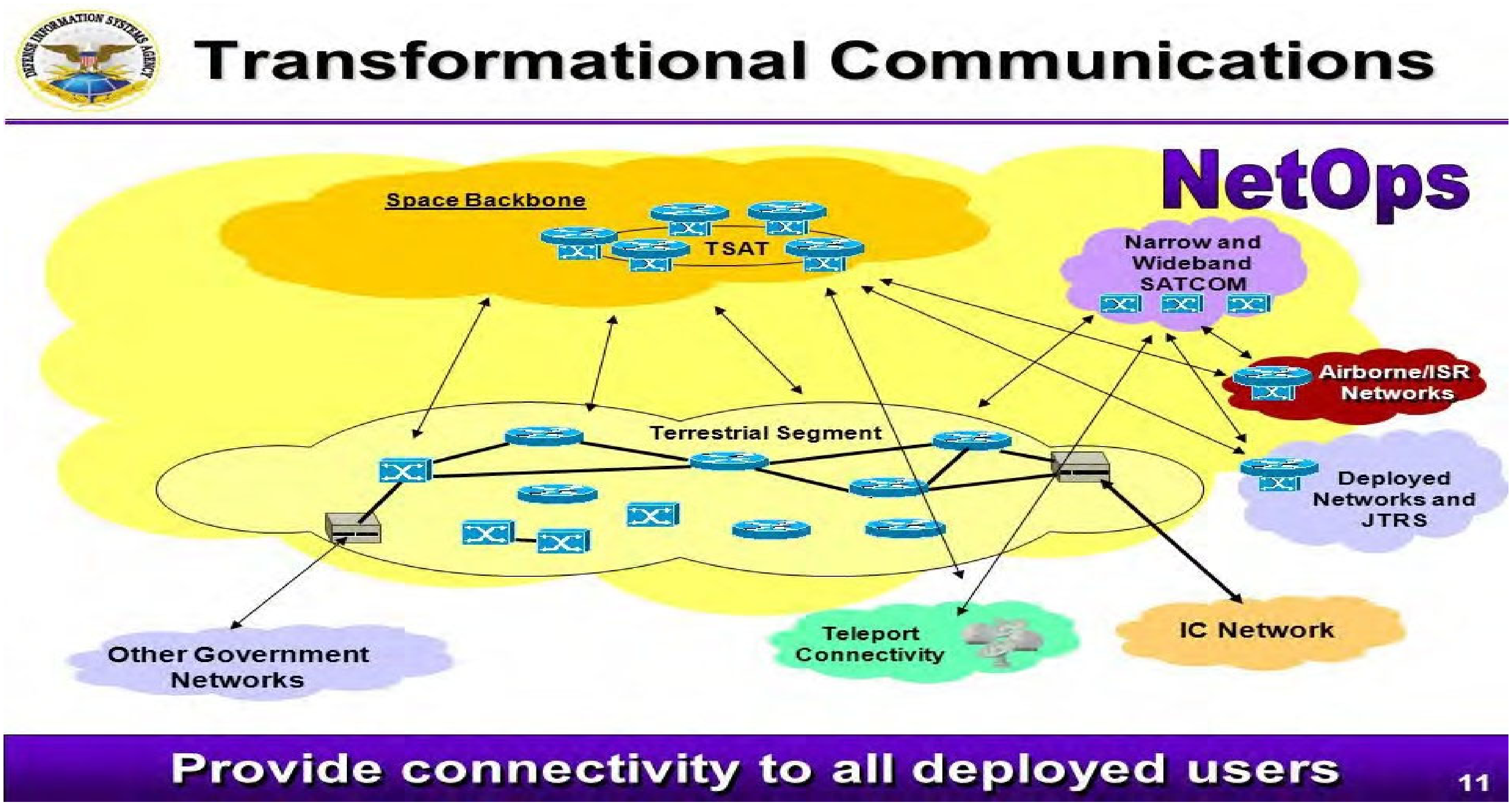
Key Decisions strongly influenced by the experience and expertise of the leaders. Every big program has a champion

Multiple players Involved

- Requirements Definition
  - Joint Chiefs
  - Military Services
  - COCOMs
  - POTUS
  - Intelligence Community
  - National Security Agency (cyber/crypto)
- Resource Allocation
  - Department of the Air Force
  - USD Comptroller
  - OSD/PA&E (CAPE today)
  - OMB
  - Congress
- Acquisition Authority
  - Service Acquisition Executive
  - Space Acquisition Executive
  - USD (AT&L)
  - Congress

Multiple Players with Different Priorities and all with a Voice to say yes or no!

TSAT Goal – Take communication away as a constraint in military operation



Key Decisions - Requirements

Accept all requirements – attempt to meet within budget using CAIV process

Intelligence Community

Nuclear command and control

Communications on the move

RPA operations and data dissemination

Space Radar

Naval Polar Region Communications

Army

Air Force

Navy

NSA Information Assurance

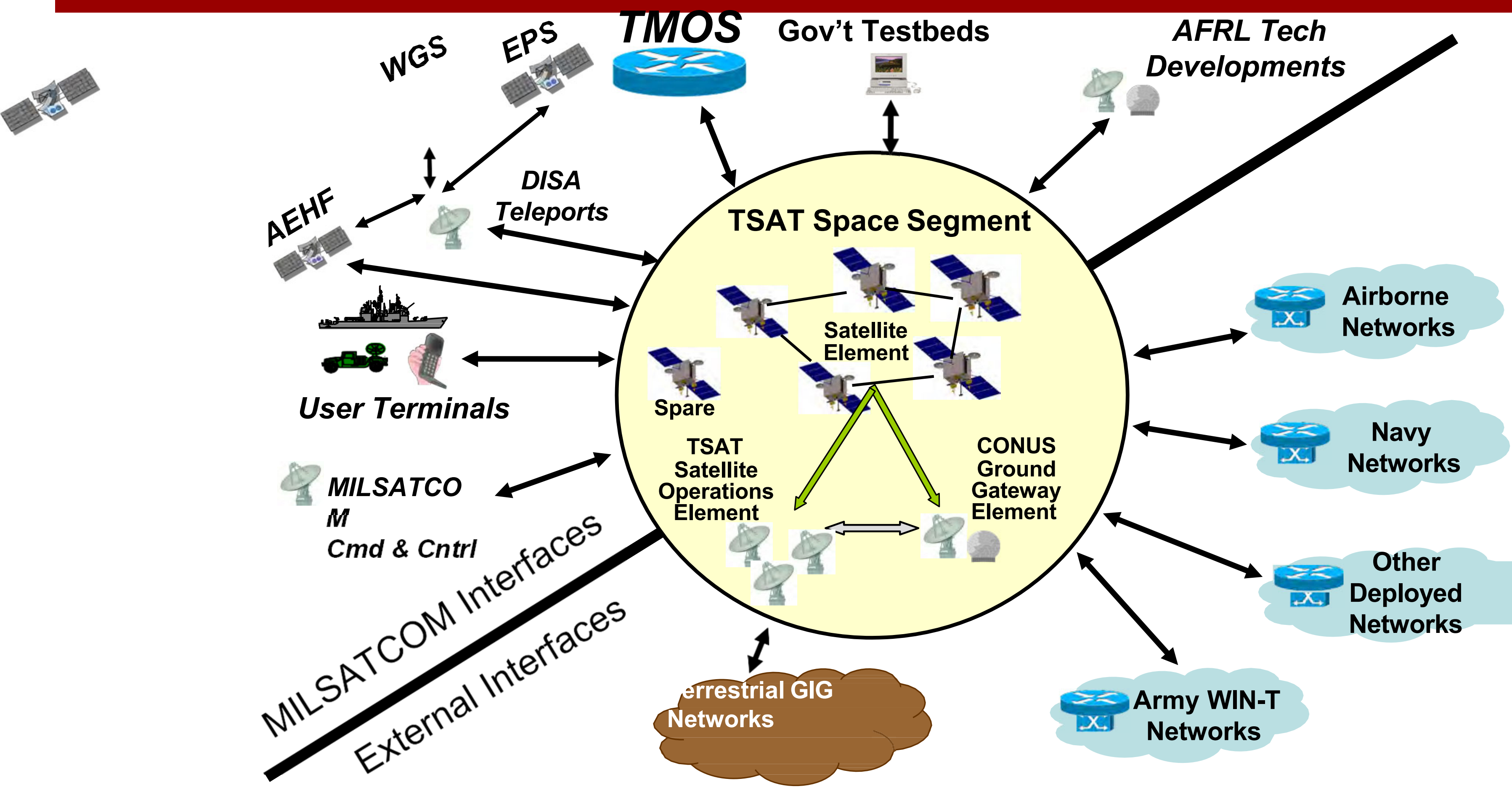
Bottomline: Too Many Requirements in both variety and quantity. No flexibility to reduce/trade requirements. Some specific tech requirements mandated.

Key Decisions – Technology – Delay Entry into Engineering Development until TRL 6 Achieved

- 90 nm feature-size electronics not at TRL 6 during Technology Readiness Assessment for CDR
  - On disciplined, low-risk plan to achieve space qualification in time for manufacturing
  - Satellite launch NET 7 years after decision – plenty of time
  - Automobile electronics using 60 nm but not space qualified
- Decision space for USECAF
  - Delay milestone approval until TRL 6 achieved
  - Accept additional technology risk by pressing ahead to engineering design
  - Drop back to more mature technology
    - 240 nm electronics – extreme impact on the design due to size, weight, and power
- Bottomline: USAF decided to delay program until TRL 6 achieved. Rescinded previous milestone approval

Lack of willingness to accept technical risk set the program back years

TSAT Interfaces



Key Decisions – Organizational Structure

1. Government would serve as the integrator –
   1. Separate Contractors for each segment of the architecture
   2. Maintaining multiple contractors per segment strained government resources
2. No single government entity would own the entire architecture
   1. Multiple interfaces between organizations and funding sources
   2. No one entity empowered to make trades across the interfaces
   3. Reactionary mode to funding decisions
   4. Management by committee of coalition of the willing

Organizational Structure created complex/unmanageable interfaces, strained government resources

Key Decision: TSAT Management Structure

- Program management
  - Multiple program offices
  - Space and Missile Systems Center Milsatcom Systems Wing
    - Satellites
    - Ground network
  - Terminals managed by each individual service
- Financing
  - Individual Military Services fund out of their own budgets
    - USAF had responsibility for the satellites and ground systems
    - Individual services for their user equipment (terminals) and integration into the platforms
- Oversight
  - USAF Undersecretary – program management
  - Joint Staff – requirements

No single entity in charge, resourcing responsibility dispersed

Key Decisions – Resourcing

Mandated 80% confidence funding
Competing resource allocation with large aircraft programs

80% confidence funding with the satellites funded in one year drove the AF to slip the program for three years in a row to keep the bow wave out of the FYDP

AF faced significant challenges with fielding of tactical aircraft, new weapons, other space programs. Trade offs were not available. Program became unaffordable

Inability to trade off requirements across the entire user base

What Happened

- Outcomes
  - TSAT technologies failed to meet maturity at prior to scheduled critical design review
    - 90 nm microelectronics
    - Space qualified internet routers
    - Complex network management
  - Uncontrolled requirements drove size and complexity of the requirement
  - AF was unable to afford the high confidence budget
    - Program continued to be slipped to the right to accommodate budget shortfalls
  - Supporting/interdependent programs were delayed or canceled
      - Terminal programs
      - Space Radar
      - Multispectral imaging sensors for drones
- Consequences
  - Program canceled in 2008 due to costs and requirement changes

- Residual effects today
  - Military operations today continue to be restricted by comm shortfalls
  - Communication critical shortfall for JADC2 success

Lessons Learned

Affordability

1) Not enough to treat cost as an independent variable - must set realistic affordability targets and min. annual funding.

Requirements Management

1) Too many initial requirements and stakeholders - need to start with scrubbed requirements and affordability targets.
2) Resolve requirements trade limitations across stakeholders outside the architecture
3) Requirements should not be defined down to the technical solution

Technology Maturation

1) Focused early risk reduction phase yielded significant benefits
2) Avoid space-based Layer 3 IP routing
3) Interconnecting IP-Based Networks Can Lead to Serious Interoperability Problems

Program Management

1) Robust multi-layer management approach proved effective in reducing priority program risks.
2)Careful planning of program synchronization factors could simplify program integration complexity and reduce costs
3) Stakeholder management investments significantly improved program integration.
4)On very large and complex development efforts, adequate integration resources, especially early in the program, are crucial to success and should not be seen merely as “overhead”

Thank you!