Abstract*— *The transition to new technology, innovative ideas, and resistance to change is something that every industry experiences. Recent examples of this shift are changing to using robots in the assembly line construction of automobiles or the increasing use of robotics for medical procedures. Most often this is done with cost-reduction in mind, though ease of use for the customer is also a driver. All industries experience the push to increase efficiency of their systems; National Aeronautics and Space Administration (NASA) and the commercial space industry are no different. NASA space communication services are provided by three separately designed, developed, maintained, and operated communications networks known as the Deep Space Network (DSN), Near Earth Network (NEN) and Space Network (SN). The Space Communications and Navigation (SCaN) Program is pursuing integration of these networks and has performed a variety of architecture trade studies to determine what integration options would be the most effective in achieving a unified user mission support organization, and increase the use of common operational equipment and processes. The integration of multiple, legacy organizations and existing systems has challenges ranging from technical to cultural. The existing networks are the progeny of the very first communication and tracking capabilities implemented by NASA and the Jet Propulsion Laboratory (JPL) more than 50 years ago and have been customized to the needs of their respective user mission base. The technical challenges to integrating the networks are many, though not impossible to overcome. The three distinct networks provide the same types of services, with customizable data rates, bandwidth, frequencies, and so forth. The differences across the networks have occurred in effort to satisfy their user missions' needs. Each new requirement has made the networks more unique and harder to integrate. The cultural challenges, however, have proven to be a significant obstacle for integration. Over the past few decades of use, user missions and network personnel alike have grown accustomed to the processes by which services are provided by the NASA communications and navigation networks. The culture established by each network has created several challenges that need to be overcome in order to effectively integrate the networks. As with any change, there has been resistance, an apprehension to explore automation of existing processes, and a working environment that attempts to indirectly influence change without mandating compliance. Overcoming technical and cultural challenges is essential to successfully integrating the networks and although the challenges are numerous, the integration of the networks promises a more efficient space communications network for NASA and its customers, as well as potential long-term costsavings to the agency. This paper, Challenges of Integrating NASA Legacy Communications Networks, will provide a brief overview of thecurrent NASA space communications networks as well as the an overview of the process implemented while performing the SCaN Trade Studies and an introduction to the requirements driving integration of the SCaN Networks. This paper will describe in detail the challenges experienced, both technical and cultural, while working with NASA space communications network-specific personnel. The paper will also cover lessons learned during the performance of architecture trade studies and provide recommendations for ways to improve the process.

Challenges of Integrating NASA's Space Communications Networks

Jessica Reinert, Patrick Barnes

NASA Glenn Research Center

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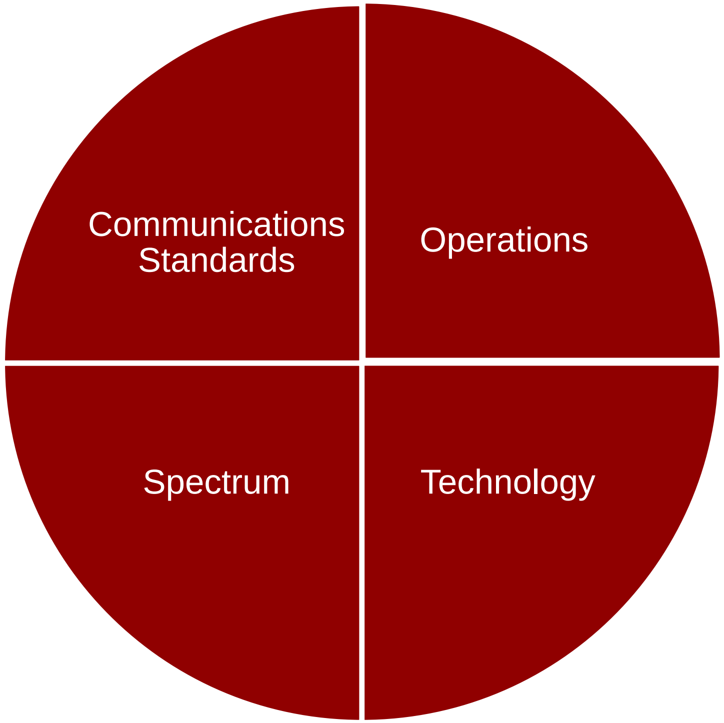
Agenda

- Space Communication and Navigation (SCaN) Program
  - SCaN Networks Today
  - Integration Goals
  - Trade Study Processes
- Integration Challenges
  - Legacy Systems
  - Technical Challenges
  - Cultural Challenges
- Lessons Learned
- Conclusions

SCaN Program

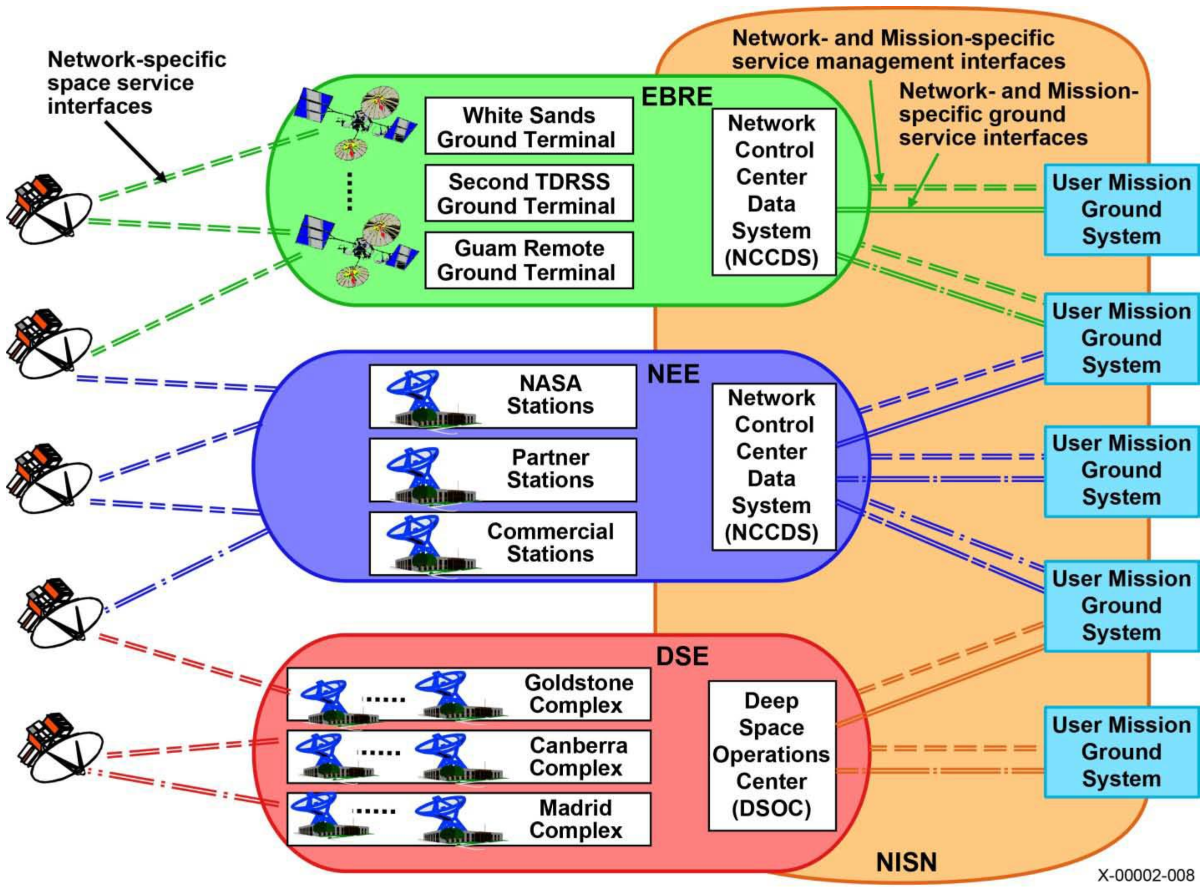
- SCaN Networks Today
- Integration Goals
- Trade Study Processes



SCaN Networks Span the Globe[1]

SCaN Networks today

- Deep Space Network (DSN)
  - Deep Space Element (DSE)
- Near Earth Network (NEN)
  - Near Earth Element (NEE)
- Space Network
  - Earth-Based Relay Element (EBRE)



SCaN Networks today[1]

Deep Space Network

- Three station global network of large-scale antennas
- Focused on detecting and differentiating faint signals from stellar noise
- Optimized for data capture from deep space distances orders of magnitude above near Earth

Example Missions: Kepler, Cassini, Mars Rovers and Orbiters , Mars Science Laboratory, (Curiosity), Voyagers 1 and 2, Spitzer Space Telescope

SCaN Networks today[1]

Near Earth Network

- World-wide network of stations
- Evolved from fully NASA-owned to portfolio of owned assets and procured commercial services (greater than 50%)
- Surge capability through partnerships (e.g., NOAA)
- Optimized for cost-effective, high data rate services

Example Missions: Aqua, Aura, Lunar Reconnaissance Orbiter, Landsat, Radiation Belt Storm Probes

SCaN Networks today[1]

Space Network

- Global orbital satellite communications fleet with ground control stations
- Optimized for continuous, high data rate communications
- Critical for human spaceflight safety and critical event coverage
- Essential for all US government launches

Example Missions: International Space Station, ISS Resupply: NASA CoTS, ESA ATV, JAXA HTV; Hubble Space Telescope, Terra, Fermi Gamma-ray Space Telescope

SCaN Integration Goals[2]

2006

- SCaN Program assigned management and Systems Engineering and Integration (SE&I) responsibilities for the Agency's space communications and navigation assets

2009

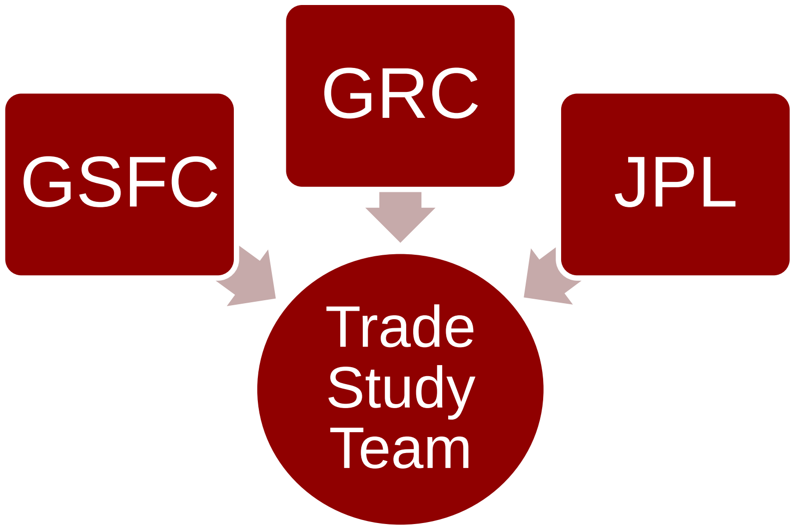
- **SCaN Program Commitment Agreement (PCA)**
  - Provide communications and navigation services (including systems engineering and planning) to user missions
  - Maintain and evolve the SCaN architecture to effectively and efficiently meet user missions' present and future needs.
- The PCA included seven objectives which have become the SCaN Program's driving requirements.
  - SCaN0.01 SCaN shall develop a unified space communications and navigation network infrastructure capable of meeting both robotic and human exploration mission needs.

SCaN Integration Goals[3]

- A scalable and integrated infrastructure that provides comprehensive, robust, and cost effective space communications services at order-of-magnitude higher data rates to enable NASA's science and exploration missions
- Infrastructure will be adaptable to accommodate new and changing technologies
- Will preserve current capabilities to support user mission critical events and emergencies
- Increase usage of common equipment and processes across the three networks
- Make it easier for user missions to acquire services from SCaN by providing a unified coherent interface with user missions for all network assets

Trade Study

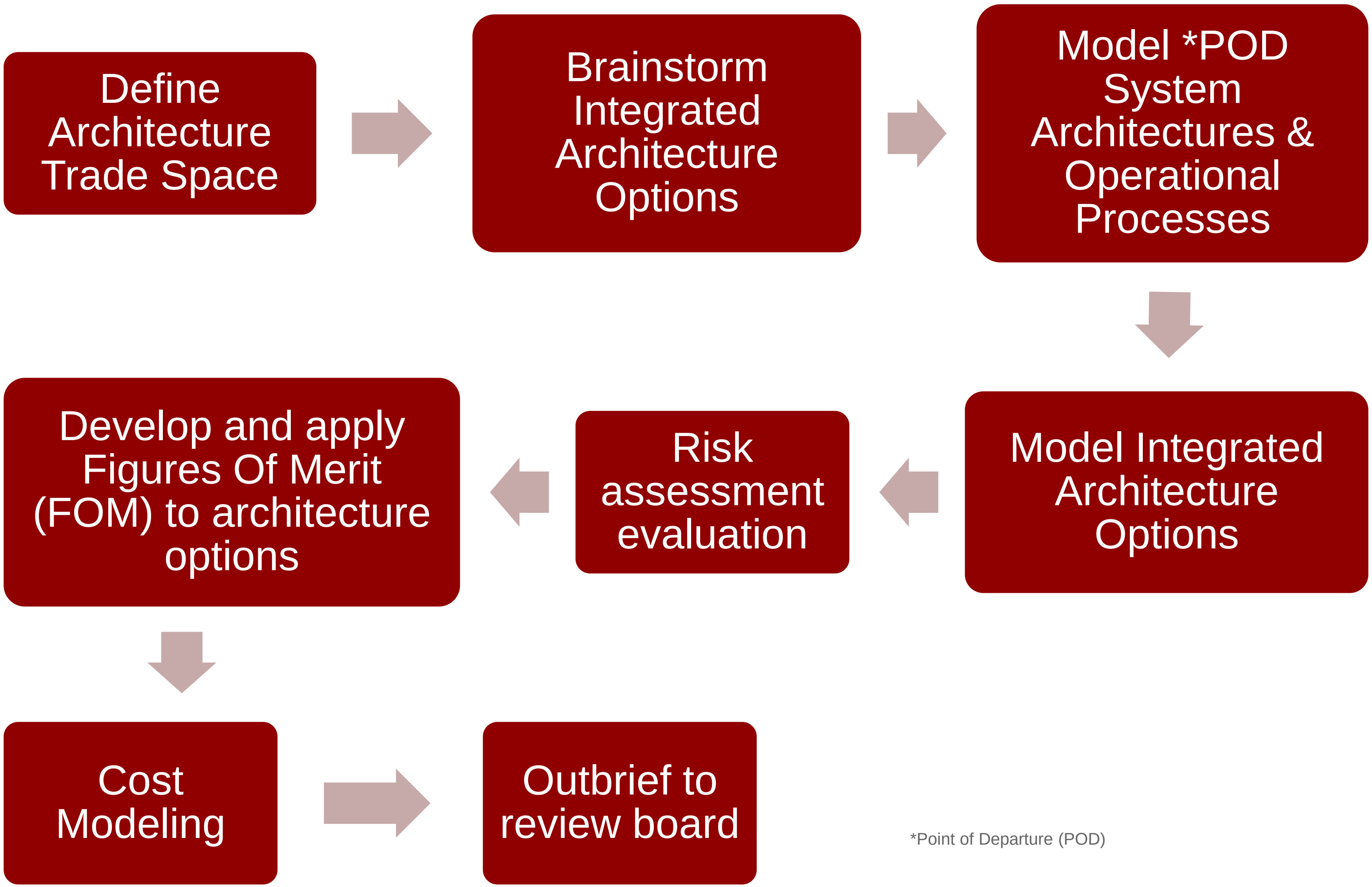
- Trade Study team was organized in response to driving requirement to develop a unified space communication and navigation architecture
- Purpose: select the best-value architecture alternative that meets the SCaN Integration Goals



Team Members

- Subject Matter Experts
- Systems Engineers
- Software Engineers
- Various levels of experience
- Some with Network specific experience, others more general

Trade Study Process



*Point of Departure (POD)

Integration Challenges

- Legacy Systems
- Technical Challenges
- Cultural Challenges

Legacy Systems

- DSN uses the most current software languages and coding techniques
  - Leads to increased scalability and extensibility
  - Example: Service Scheduling Software (SSS), developed using modern development paradigms.
- NEN software system uses older languages and coding techniques
  - Monolithic by design
  - Small changes in the code may result in major changes elsewhere
- SN software system uses older software techniques
  - Reworked many times to solve issues, bugs, apply patches, etc.
  - Increasingly more difficult for new developers to understand

System and software upgrades can make maintenance and sustainment simpler and more efficient.

Legacy Systems

- SCaN Network Customization
  - User missions request communication services necessary to enable the mission including new services
  - SCaN Networks paid the majority upgrade costs
  - SCaN Networks strive to meet the needs of their diverse user mission customers
  - Networks continually become less similar as the following increases
    - » Specialized services, unique equipment, customized software code

The design and implementation of legacy systems have impacted the design of the Integrated Architecture Options

Technical Challenges

On-going Recapitalization and Upgrades

- DSN
  - Service Scheduling Software
  - DSN Enhanced Aperture Project
- SGSS: Modernization of the SN Ground System[4]
  - Deliver high quality services & meet stakeholder requirements
  - Significantly reduce required operations and maintenance resources
  - New software & hardware
- NEN
  - Desires to upgrade software & hardware
  - Unable to do so due to budget constraints

Modernization projects are important for sustained operations, but on-going changes make it more difficult to define the vision for future integration.

Technical Challenges

- Cost and timing of SGSS has driven SCaN to consider adaption of upgrades to NEN & DSN
  - Hardware and software cannot be used “as-is”, modifications will be necessary
  - Operational processes will have to be modified based on each change implemented
  - Each network must still provide domain specific services
- Common background or experience does equate to common terminology
  - Assuming common understanding of terms can lead to misunderstandings

Cultural Challenges

- SCaN Networks were developed independently driven by
  - Primarily different user mission communities with different needs
  - Different management philosophies
  - Ability to adopt new technology is funding dependent
- Processes and modes of operation, which serve the same purposes differently, were uncovered
  - When differences are small and integration into a common process is easy to envision and implement
  - When processes are well tailored to existing operations and have been in existence for a long time changes to these processes are usually unwelcome

Independent development and oversight may lead to operational processes and equipment that are more different than necessary.

Cultural Challenges

- SN & NEN Scheduling system

  Conflict resolution: based on mission priority and absolute priority

- DSN Scheduling system

  Conflict resolution: negotiation based collaborative process, with noted absolute priorities

- Integrated Priority-based scheduling

  Eliminate or reduce the hands-on collaboration

  Make the scheduling process more efficient

- Integration into a single scheduling system may be a part of the integration of the SCaN networks.

  The transition of user missions to new systems is a key challenge facing SCaN

All impacted parties, e.g. system implementers and customers, must be considered when determining how to implement new systems.

Cultural Challenges

- Resistance to change makes implementing automation more difficult.

  Enable operators to handle additional communications links

  Minimize operator intervention in the operations process

- Analysis of operational processes has shown that efficiency can be gained through automation

  Operator pushes a button to allow the process to proceed to the next step

  Software intelligence has the ability to check parameter and makes the decision to proceed to the next step

- SCaN operators can focus on addressing emergent issues and emergencies, as opposed to nominal operations

- Future savings of automation must be assessed against near term implementation costs

Quantifiable evidence, proving the benefits of automation, make progress towards implementation easier to achieve.

Cultural Challenges

- Cross support within Network Control Operations: when an operator from one network (e.g. SN) is temporarily assigned operational duties on another network (e.g. NEN)
  - Requires understanding of nominal operational processes of both networks.
- Operators are trained in the operational process of one network
  - The rigorous training process lasts six months to two years
- Differences in opinion
  - Opinion 1: Networks are simply too complicated for one operator to understand how to operate more than one
  - Opinion 2: With increased automation, an operator may be able to understand nominal operations for multiple networks well enough to support multiple networks

Cultural Challenges

- Examples of multi-tasking and cross functional tasks
  - Employees at international corporations are fluent in many languages
  - Software developers who know several development languages
- Some people are better suited to handle multiple and diverse operational procedures and languages
  - Capable of handling the training and operational processes that are required to enable network operator cross-support
  - Increased automation of the operation can reduce the burden on the operators making it easier for an operator to operate multiple networks.

SCaN needs to adapt to its changing environment and changing workforce in order to capitalize on the diverse strengths that exist within some of its employees.

Cultural Challenges

- Service Planning: NIMO and DSN Mission Services Planning & Management (DMSP&M) work with the user missions to

  Define what types of communication and navigation services are required to meet the needs of the user missions

  Establish agreements that define how the SCaN Network will provide services and how the user mission will receive services

- The process results in several coordinated documents: Service Level Agreement, Network Operations Plan, Interface Control Documents, etc.
- Each office requires a similar but different set of documentation
- If services are required from more than one network, the user mission must provide information as required by each network

Different organizations using different processes to perform similar functions increases cost.

Cultural Challenges

- Integration of these processes via a Service Portal
  - User missions access one website to learn about and complete the service planning process
  - Enter mission requirements and parameters into the portal
  - The portal generates required documentation
- The portal can be implemented without the integration of the two service planning offices
- One integrated service planning office could result in a more efficient process

Single access point for all of the SCaN Networks

Cultural Challenges

- Mission Commitment Office
  - Virtual integration of two existing service planning locations: NIMO -> MCO-G and DMSP&M -> MCO-J
- Automation of the service planning process is hoped to result in savings to the SCaN network
- Reduction in burden placed on user missions who utilize services from multiple networks
  - User missions access one website to learn about and complete the service planning process
  - Enter mission requirements and parameters into the portal
  - The portal generates required documentation

Cultural Challenges

Trade Study Reviews

- Audience: Representatives from SCaN Program and SCaN Networks
- Purpose:

  Initial Review: Publicize options being considered

  Final Review: Explain what changes were being proposed to be a part of the future SCaN Network

- These reviews presented challenges because the new or innovative ideas presented, occasionally requiring significant changes to current systems or operations, were often met by resistance

Cultural Challenges

- A common thread amongst many of the cultural challenges is a resistance to new ideas and opposition to change.
  - Familiar processes are comfortable
  - The future and change are unsettling to some people
  - New approaches were often unwelcome
  - High-degree of user mission focus
  - Pride in a history of meeting and exceeding user mission expectations
- After analysis and review of results
  - Opposition often decreased
  - New ideas were acknowledged as feasible

Opposition to new ideas is often driven by familiarity . . .however rationale discussion of quantitative data helps clarify the benefit of the change and ease concerns.

Lessons Learned

- Plan to achieve efficient maintainability & sustainability
- Lack of source code and documentation can present long term sustainability issues
- Choose integration steps wisely
- Implement enabling processes
- Balance innovation and cost
- Be aware of preconceived notions and resistance to change
- Common processes and ease of access to information can have a positive impact

Lessons Learned

- When in doubt, prove whether or not something is possible or impossible to do
- Quantifiable proof in studies is invaluable
- Terminology and common understanding cannot be assumed or over emphasized
- Understand your team and management so you can work with them to minimize the resistance to change
- Collaboration and consensus doesn’t always mean that everyone agrees that there is only one right answer

Conclusions

- Cultural and technical challenges are equally daunting
  - Technical challenges have more clear cut solutions
  - Cultural challenges require a lighter more people oriented approach
- Applying quantitative systems engineering processes was advantageous in
  - Overcoming the resistance to change
  - Overcoming differing perceptions on what level of change could be implemented

Acknowledgements

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