SoS Considerations in the Engineering of Systems

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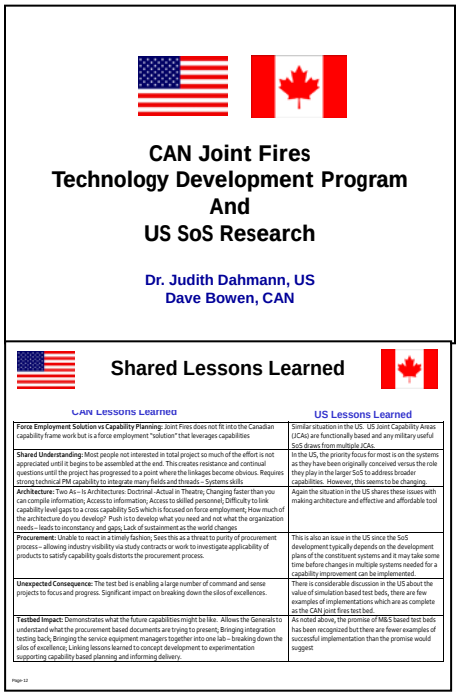
Purpose and Topics

- **Purpose**
  - Introduce new International product highlighting recommended practices for addressing SoS considerations in the engineering of systems
- **Topics**
  - Background
  - Motivation
  - Objective, Audience and Use Concept
  - Methodology
  - Structure, Tables, Elements
  - Examples
  - Exploitation and Feedback

Background: TTCP and TP-4

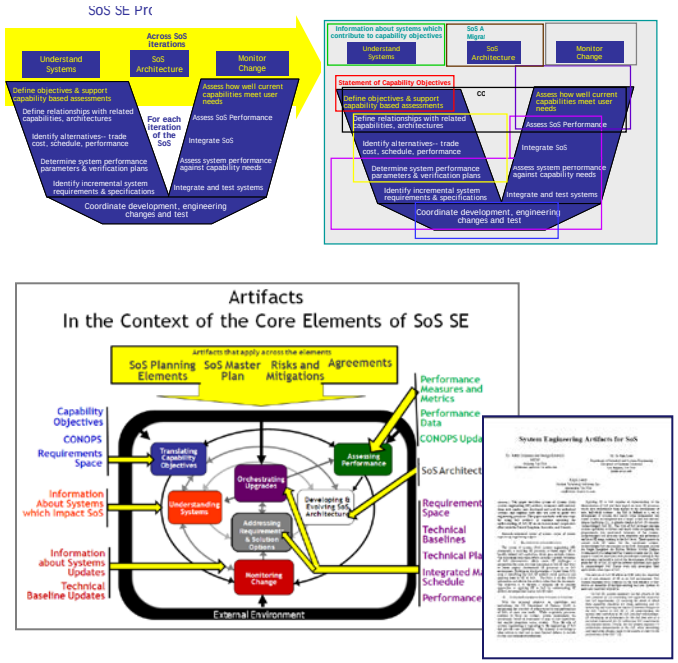
- **The Technical Cooperation Program (TTCP):**
  - An "international organization that collaborates in defence scientific and technical information exchange; program harmonization and alignment; and shared research activities for the five nations." http://www.acq.osd.mil/ttcp/
  - United States, United Kingdom, Canada, Australia, New Zealand
- **Technical Panel 4 (TP-4): "Systems Engineering for Defence Modernization"**
  - Joint Systems Analysis (JSA) Group; US, UK, Canada, Australia
- **TP-4 SoS Workstream**
  - Provides a unique venue of national technical expertise providing peer review, consultation on approaches to common problems not otherwise available
  - Enables each nation to better address challenges informed by broader experience

Background: Prior SoS Workstream Activities



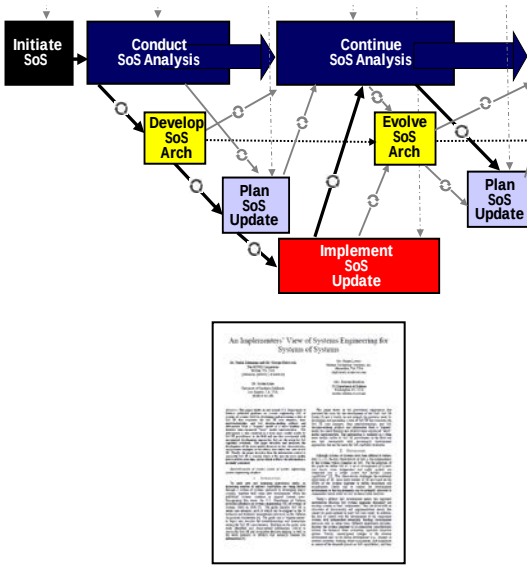
2009

- Reviewed US SoS SE concepts; CA Joint Fires experience
- Result: TTCP Internal Product



2010

- Identified SoS artifacts to support shared understanding of application of SE to SoS
- Result: IEEE paper



2011

- Collected feedback to implementers view of SoS SE 'wave model'
- Result: IEEE Paper

Resources: http://www.acq.osd.mil/se/initiatives/init_sos-se.html

Motivation for Recommended Practices

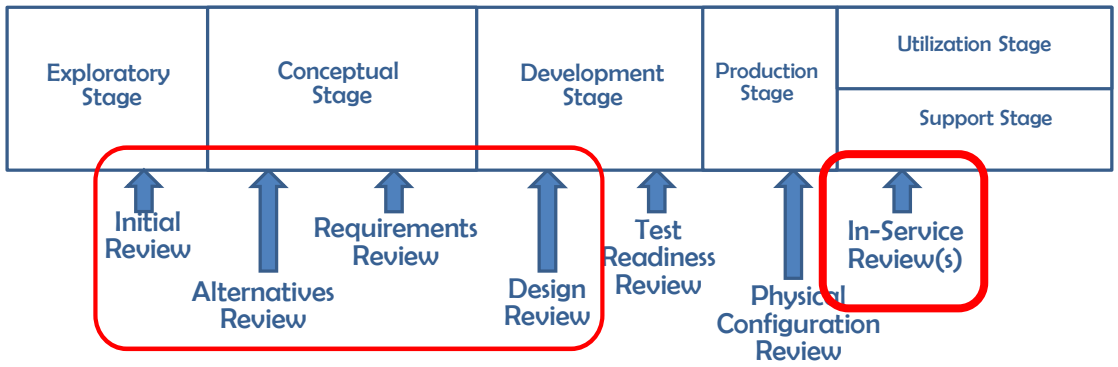
- Today almost all defense systems are part of one or more SoS
- Despite recognition of the importance of SE for SoS, all four nations' acquisition processes focus on systems
- Failure to consider SoS context early and throughout acquisition can result in significant risk to the effectiveness and successful fielding of the system

The nations identified a need for a tool to assist systems engineers and acquisition programs to address SoS considerations during the acquisition lifecycle

Objective, Audience and Use Concept

- **Objective**
  - Bring together the collective knowledge from across the nations regarding SoS considerations at key points in the system development process
- **Audience**
  - Systems engineers, program managers and acquisition oversight organizations in government and industry who are engaged in the development of defense systems in particular, but they apply more generally across large systems in other domains as well
- **Use Concept**
  - Users will adapt the information to incorporate SoS considerations at key points in the systems development process as they relate to their particular system acquisition and engineering processes

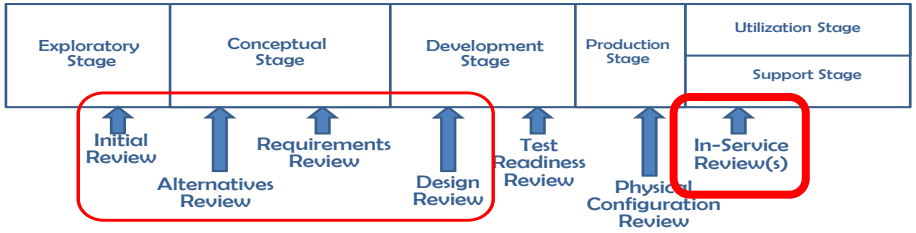
Project Methodology



- **Standards-based framework**
  - ISO 15288 used as the lifecycle framework
- **Focus on key points in development**
  - Key lifecycle review points were used to organize the information

- **Iterative collaborative development**
  - Each nation contributed their knowledge and experience into the common framework
  - Iterative releases for review and feedback over a 3-year period
  - Included engagement with external SE organizations for comment and feedback
    - NDIA SE Division
    - INCOSE SoS WG

Product Structure



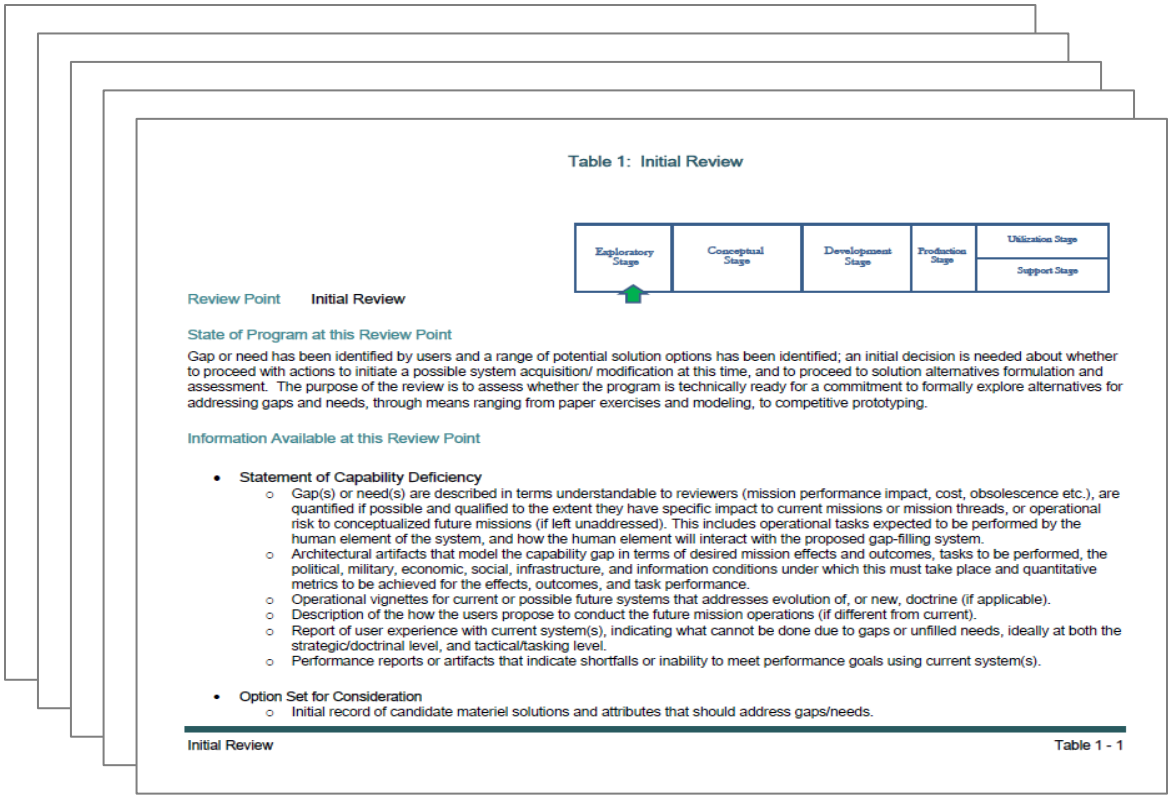


Table 1: Initial Review

Exploratory Stage | Conceptual Stage | Development Stage | Production Stage | Utilization Stage / Support Stage

Review Point **Initial Review**

State of Program at this Review Point

Gap or need has been identified by users and a range of potential solution options has been identified; an initial decision is needed about whether to proceed with actions to initiate a possible system acquisition/ modification at this time, and to proceed to solution alternatives formulation and assessment. The purpose of the review is to assess whether the program is technically ready for a commitment to formally explore alternatives for addressing gaps and needs, through means ranging from paper exercises and modeling, to competitive prototyping.

Information Available at this Review Point

- **Statement of Capability Deficiency**
  - Gap(s) or need(s) are described in terms understandable to reviewers (mission performance impact, cost, obsolescence etc.), are quantified if possible and qualified to the extent they have specific impact to current missions or mission threads, or operational risk to conceptualized future missions (if left unaddressed). This includes operational tasks expected to be performed by the human element of the system, and how the human element will interact with the proposed gap-filling system.
  - Architectural artifacts that model the capability gap in terms of desired mission effects and outcomes, tasks to be performed, the political, military, economic, social, infrastructure, and information conditions under which this must take place and quantitative metrics to be achieved for the effects, outcomes, and task performance.
  - Operational vignettes for current or possible future systems that addresses evolution of, or new, doctrine (if applicable).
  - Description of the how the users propose to conduct the future mission operations (if different from current).
  - Report of user experience with current system(s), indicating what cannot be done due to gaps or unfilled needs, ideally at both the strategic/doctrinal level, and tactical/tasking level.
  - Performance reports or artifacts that indicate shortfalls or inability to meet performance goals using current system(s).
- **Option Set for Consideration**
  - Initial record of candidate materiel solutions and attributes that should address gaps/needs.

Initial Review Table 1 - 1

- **Structured as a series of tables focused on each of the selected review points**
  - **Initial Review**
  - **Alternatives Review**
  - **Requirements Review**
  - **Design Review**
  - **In-Services Review(s)**

Contents for Each Review Point

Review Point: **Review Name**

State of Program at this Review Point:

This section describes the acquisition program as you would expect it at this review point including what has been accomplished so far and what nest steps are anticipated.

Information Available at this Review Point

- This section lists the information about the system which you would expect to be available at this review point

System Issues at this Review Point

Questions

This section lists the types of questions which are typically asked at this point to assess whether the system development is mature enough to proceed further.

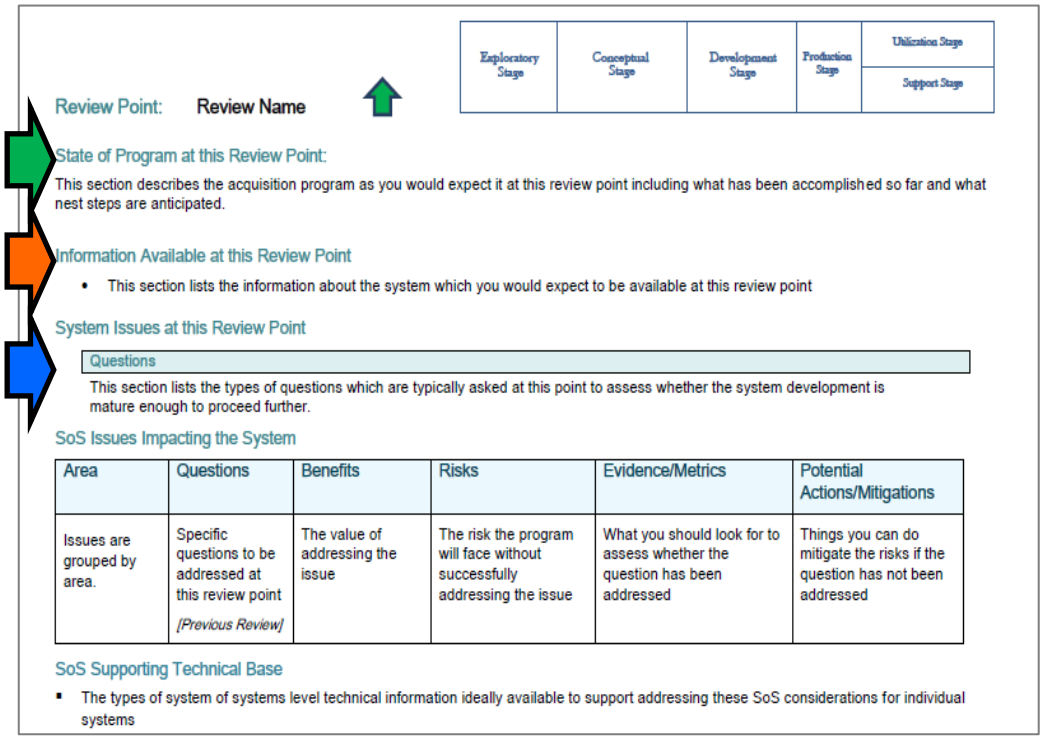
SoS Issues Impacting the System

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Issues are grouped by area.	Specific questions to be addressed at this review point *[Previous Review]*	The value of addressing the issue	The risk the program will face without successfully addressing the issue	What you should look for to assess whether the question has been addressed	Things you can do mitigate the risks if the question has not been addressed

SoS Supporting Technical Base

- The types of system of systems level technical information ideally available to support addressing these SoS considerations for individual systems

System Context



Exploratory Stage	Conceptual Stage	Development Stage	Production Stage	Utilization Stage / Support Stage

Review Point: Review Name

State of Program at this Review Point:

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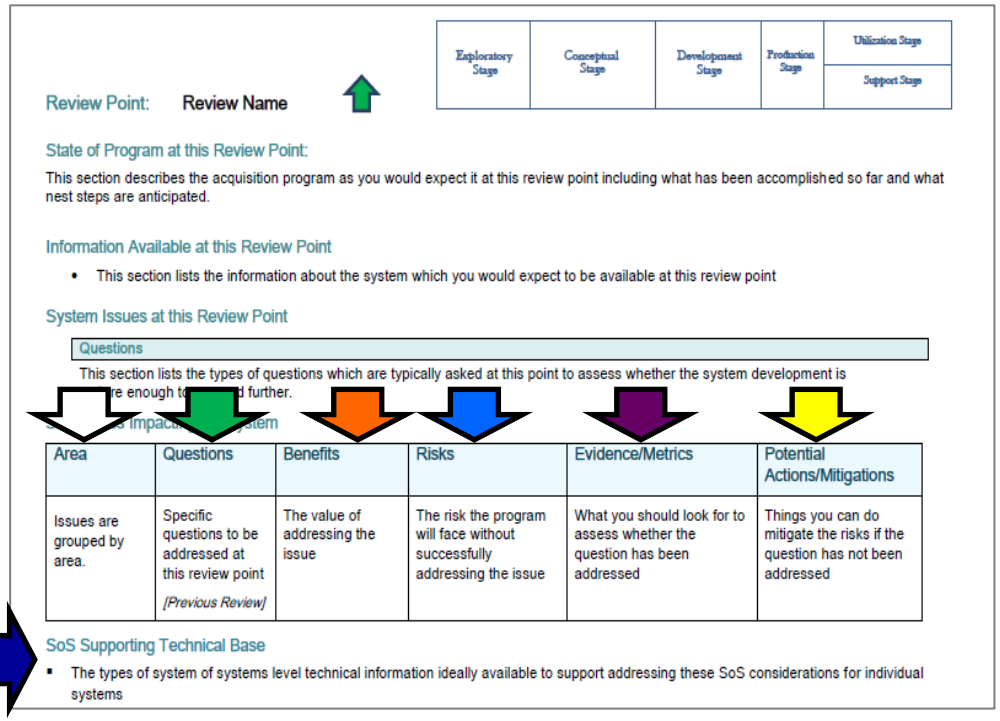
SoS Supporting Technical Base

- The types of system of systems level technical information ideally available to support addressing these SoS considerations for individual systems

Provide context for users to position review point in their local context and translate information to their own acquisition process

- **Addressed the following at each Review Point:**
  - What would be expected of an acquisition program at this review point?
  - What activities have been completed and what are the next activities anticipated?
  - Information expected to be available for the system reflecting its stage of development
  - Typical questions used to assess system maturity at each review point are provided here.

SoS Considerations



SoS Supporting Technical Base

- The types of system of systems level technical information ideally available to support addressing these SoS considerations for individual systems

4 Areas of Consideration

- Capability, Technical, Management & Cost

Questions

- Formulated in terms of questions which should be addressed when reviewing systems at each review point; note some question appear in multiple reviews

Benefits

- Benefit to the system of addressing these SoS questions

Risk

- Risks associated with failing to successfully address the SoS questions

Evidence/Metrics

- Information or artifacts that provide the information needed to address the questions

Potential Actions/Mitigations

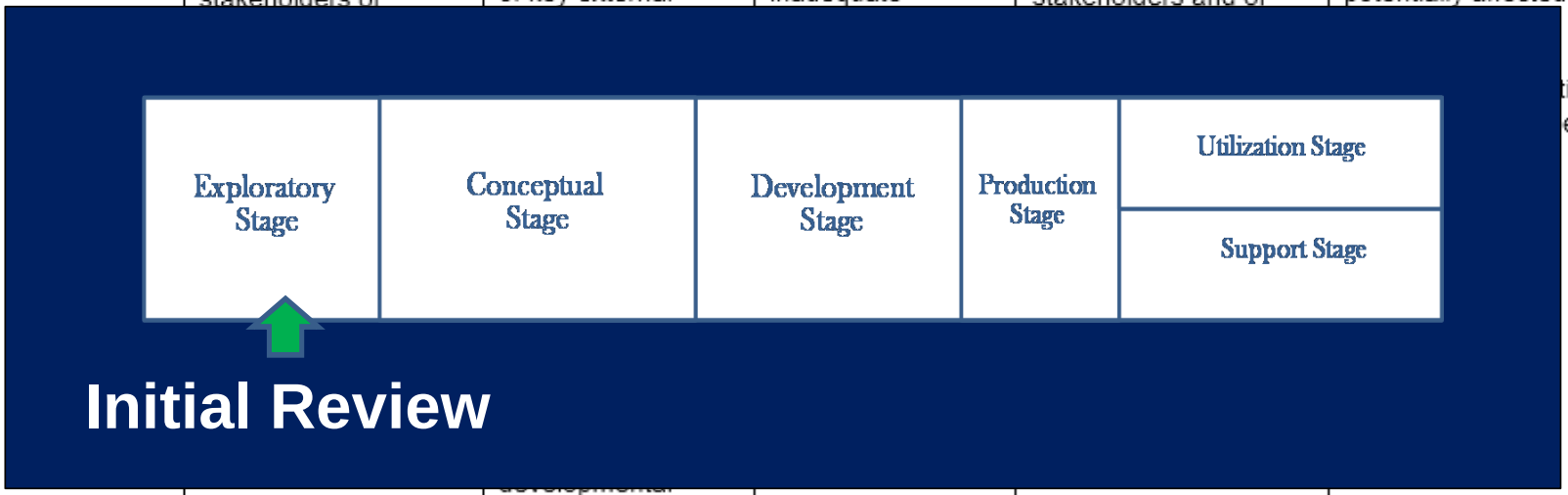
- Possible mitigating actions when the questions are not satisfactorily addressed

Example: Technical Consideration at Initial Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Technical	Have the external stakeholders or external systems/infrastructure affected been identified? This includes both i. Systems/services on which the new or upgraded system depends; and ii. Systems/services that depend on the new or upgraded system. Is there an understanding of the ability to influence resource changes in associated systems, infrastructure, or non-material factors?	Early identification of key external parties impacted by the new system and their ability to affect and provide the resources for the needed changes will provide a realistic planning basis for the system development. Including identification of any potential or current shared developmental costs and dependencies tools.	If there is inadequate understanding of the systems context for the acquisition, the risk is that the selected solution may not be feasible due to needs of stakeholders of affected systems or an inability to adjust associated systems to address capability gaps.	Lists of external stakeholders and of dependent systems and their proponents and resource sponsors, including maintainers for in-service systems. Early list of assumptions and dependencies.	Identify and contact potentially affected stakeholders. Stakeholders identify subject matter experts (SMEs).

Example: Technical Consideration at Initial Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Technical	Have the external stakeholders or	Early identification of key external	If there is inadequate	Lists of external stakeholders and of	Identify and contact potentially affected
	Is there an understanding of the ability to influence resource changes in associated systems, infrastructure, or non-material factors?	costs and dependencies tools.			



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Technical	Have the external stakeholders or external systems/infrastructure affected been identified? Is there an understanding of the ability to influence resource changes in associated systems, infrastructure, or non-material factors?	Early identification of key external parties impacted by the new system and their ability to affect and provide the resources for the needed changes will provide a realistic planning basis for the system development. Including identification of any potential or current shared developmental costs and dependencies tools.	If there is inadequate understanding of the systems context for the acquisition, the risk is that the selected solution may not be feasible due to needs of stakeholders of affected systems or an inability to adjust associated systems to address capability gaps.	Lists of external stakeholders and of dependent systems and their proponents and resource sponsors, including maintainers for in-service systems. Early list of assumptions and dependencies.	Identify and contact potentially affected stakeholders. Stakeholders identify subject matter experts (SMEs).

Technical Consideration

Example: Technical Consideration at Initial Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Technical	Have th… stakehol…	Early identification of key external	If there is inadequate	Lists of external stakeholders and of …dent systems …eir proponents …source sponsors, …g maintainers …ervice systems. …st of …ptions and …dencies.	Identify and contact potentially affected stakeholders. Stakeholders identify subject matter experts (SMEs).

Questions

Have the external stakeholders or external systems/infrastructure affected been identified?

This includes both

i. Systems/services on which the new or upgraded system depends; and

ii. Systems/services that depend on the new or upgraded system.

- Is there an understanding of the ability to influence resource changes in associated systems, infrastructure, or non-material actors?

Example: Technical Consideration at Initial Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Technical	Have the external stakeholders or external material factors?	Early of key parties	If there is inadequate understanding of	Lists of external stakeholders and of dependent systems roponents rce sponsors, maintainers ice systems. f ns and cies.	Identify and contact potentially affected stakeholders. Stakeholders identify subject matter experts (SMEs).

Benefits

Early identification of key external parties impacted by the new system and their ability to affect and provide the resources for the needed changes will provide a realistic planning basis for the system development. Including identification of any potential or current shared developmental costs and tools.

Example: Technical Consideration at Initial Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Technical	Have the external stakeholders or external systems/infrastr affected been identified? This includes bo i. Systems/servi which the new c upgraded syste depends; and ii. Systems/serv that depend on new or upgrade system. Is there an understanding c ability to influen resource chang associated systems, infrastructure, or non-material factors?	Early identification of key external parties impacted by	If ther inadeq unders g of	Lists of external stakeholders and of dependent systems	Identify and contact potentially affected stakeholders. keholders identify ject matter experts Es).

Risks

If there is inadequate understanding of the systems context for the acquisition, the risk is that the selected solution may not be feasible due to needs of stakeholders of affected systems or an inability to adjust associated systems to address capability gaps.

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Evidence

Lists of external stakeholders and of dependent systems and their proponents and resource sponsors, including maintainers for in-service systems.

Early list of assumptions and dependencies.

Example: Technical Consideration at Initial Review

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Mitigations

Identify and contact potentially affected stakeholders.

Stakeholders identify subject matter experts (SMEs).

Example: Capability Consideration at Requirements Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Capabilities	Is the SoS context clearly defined in the updated description of how the users will conduct the operation and how the system will be used in this context and in the user statement of need? Has this changed since the last review? *[Initial and Alternative Reviews]*	A clear, early understanding of the system's context and its potential impact on system requirements and dependencies will provide a solid basis for development of a system which will meet user needs.	If there is no description of how the users will conduct the operation as context for system use, the risk is that the requirements and dependencies may be missed, potentially leading to: • an ineffective system; • unexpected higher costs; • schedule slips; • too narrow a description of how the users will conduct the operation and how the system will be used in this context to cover the full requirement or to enable emergent behavior.	Written system description of how the users will conduct the operation with a clear delineation of how the new system will work in context of other systems and SoS operational context.	Develop and validate how users expect to use the new system, clearly identifying the key elements external to the proposed system and their impact on system attributes and functionality, as well as impacts of the system on these external factors. Ensure compatibility with description of how the users will conduct the operation overall, including the other systems supporting the operation.

Example: Capability Consideration at Requirements Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Capabilities	Is the SoS context clearly defined in the updated description of how the users will	A clear, early understanding of the system's context and its potential impact on system requirements and	If there is no description of how the users will conduct the	Written system description of how the users will conduct the operation with a	Develop and validate how users expect to use the new system, clearly identifying the
			will conduct the operation and how the system will be used in this context to cover the full requirement or to enable emergent behavior.		supporting the operation.

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Capability Consideration

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			cover the full requirement or to enable emergent behavior.		

Questions

Is the SoS context clearly defined in the updated description of how the users will conduct the operation and how the system will be used in this context and in the user statement of need?

Has this changed since the last review? [Initial and Alternative Reviews]

Example: Capability Consideration at Requirements Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Capabilities	Is the SoS context clearly defined in the updated description of how th… conduc… and ho… will be… contex… statem… Has th… the las… *and A… Revie…	A clear, ear… standing of the sys… ext and its potential … on system	If there is no description of how the users will … how the system will be used in this context to cover the full requirement or to enable emergent behavior.	Written system description of how the users will conduct …ation with a …lineation of … new system …t in context of …stems and …erational	Develop and validate how users expect to use the new system, clearly identifying the key elements external to the proposed system and their impact on system attributes and functionality, as well as impacts of the system on these external factors. Ensure compatibility with description of how the users will conduct the operation overall, including the other systems supporting the operation.

Benefits

A clear, early understanding of the system's context and its potential impact on system requirements and dependencies will provide a solid basis for development of a system which will meet user needs.

Example: Capability Consideration at Requirements Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
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Risks

If there is no description of how the users will conduct the operation as context for system use, the risk is that the requirements and dependencies may be missed, potentially leading to:

- **an ineffective system;**
- **unexpected higher costs;**
- **schedule slips;**
- **too narrow a description of how the users will conduct the operation and**
- **how the system will be used in this context to cover the full requirement or to enable emergent behavior.**

Example: Capability Consideration at Requirements Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
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Evidence

Written system description of how the users will conduct the operation with a clear delineation of how the new system will work in context of other systems and SoS operational context.

Example: Capability Consideration at Requirements Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Capabilities	Is the SoS context clearly defined in the updated description of how the u… conduct t… and how … will be us… context a… statemen… Has this … the last r… *and Alter… Reviews*	A clear, early understanding of the system's context and its potential impact on system …	If there is no description of how the users will … behavior.	Written system description of how the users will conduct …	Develo… validate how u… …ect to use the … system, …

Mitigations

Develop and validate how users expect to use the new system, clearly identifying the key elements external to the proposed system and their impact on system attributes and functionality, as well as impacts of the system on these external factors.

Ensure compatibility with description of how the users will conduct the operation overall, including the other systems supporting the operation.

Example: Management Consideration at Design Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Management	If there is no acknowledged SoS management, then what management arrangements have been made with other systems which impact this system? Have these arrangements been implemented? *[Alternatives Review and Requirements Review]*	Establishing arrangements with other systems early in development can provide a key foundation of collaborative efforts throughout the system development.	If you do not arrange to work with other relevant systems managers as members of a system of systems community, the risk is that the system solution will not be compatible with the current and future direction of the SoS, and will not be operationally suitable or will incur added costs and time for necessary rework.	Management arrangements with the relevant systems in the form of formal agreement, and a cooperative action plan to support the development of system requirements, implementation, test, etc.	Engage with the managers or systems engineers of the relevant systems, to ensure that plans for the system in question align with those of the other constituent systems.

Example: Management Consideration at Design Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Management	If there is no acknowledged SoS management, then what management	Establishing arrangements with other systems early in development can	If you do not arrange to work with other relevant systems managers as members of a system of	Management arrangements with the relevant systems in the form of formal	Engage with the managers or systems engineers of the relevant systems, to ensure that plans for the

Example: Management Consideration at Design Review

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Management Consideration

Example: Management Consideration at Design Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Management	If there acknowl SoS manage then	Establishing arrangements with other systems early	If you do not arrange to work with other relevant systems managers as tem of ty, the tem e S, ble or osts ssary	Management arrangements with the relevant systems in the form of formal agreement, and a cooperative action plan to support the development of system requirements, implementation, test, etc.	Engage with the managers or systems engineers of the relevant systems, to ensure that plans for the system in question align with those of the other constituent systems.

Questions

If there is no acknowledged SoS management, then what management arrangements have been made with other systems which impact this system? Have these arrangements been implemented?

Example: Management Consideration at Design Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Management	If there is no acknowledged SoS management, then wi ar be sy th th be [A ar R	Establi arrange with other s early	If you do not arrange to work with other relevant systems managers as	Management arrangements with the relevant systems in the f formal ment, and a rative action plan to rt the development tem requirements, mentation, test, etc.	Engage with the managers or systems engineers of the relevant systems, to ensure that plans for the system in question align with those of the other constituent systems.

Benefits

Establishing arrangements with other systems early in development can provide a key foundation of collaborative efforts throughout the system development.

Example: Management Consideration at Design Review

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Risks

If you do not arrange to work with other relevant systems managers as members of a system of systems community, the risk is that the system solution will not be compatible with the current and future direction of the SoS, and will not be operationally suitable or will incur added costs and time for necessary rework.

Example: Management Consideration at Design Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Management	If there is no acknowledged SoS management, then what management arrangements have been made with other systems which impact this system? Have these arrangements been implemented? *[Alternatives Review and Requirements Review]*	Establishing arrangements with other systems early in development ca provide a key foundation of collaborative effor throughout the system development.	If you do not arrange to work with other relevant systems managers as	Manage arrangem with the relevant s s in the	Engage with the managers or systems engineers of the relevant systems to

Evidence

Management arrangements with the relevant systems in the form of formal agreement, and a cooperative action plan to support the development of system requirements, implementation, test, etc.

Example: Management Consideration at Design Review

Area	Questions	Benefits	Risks	Evidence/Metrics	Potential Actions/Mitigations
Management	If there is no acknowledged SoS management, then what management arrangements have been made with other systems which impact this system? Have these arrangements been implemented? *[Alternatives Review and Requirements Review]*	Establishing arrangements with other systems early in development can provide a key foundation of collaborative efforts throughout the system development.	If you do not arrange to work with other relevant systems managers as members of a system of systems community, the risk is that the system solution will not be compatible with the current and future direction of the SoS, and will not be operationally suitable or will incur added costs and time for necessary rework.	Management arrangements with the relevant systems in the	Engage w… managers or system… neers of the releva… ems, to

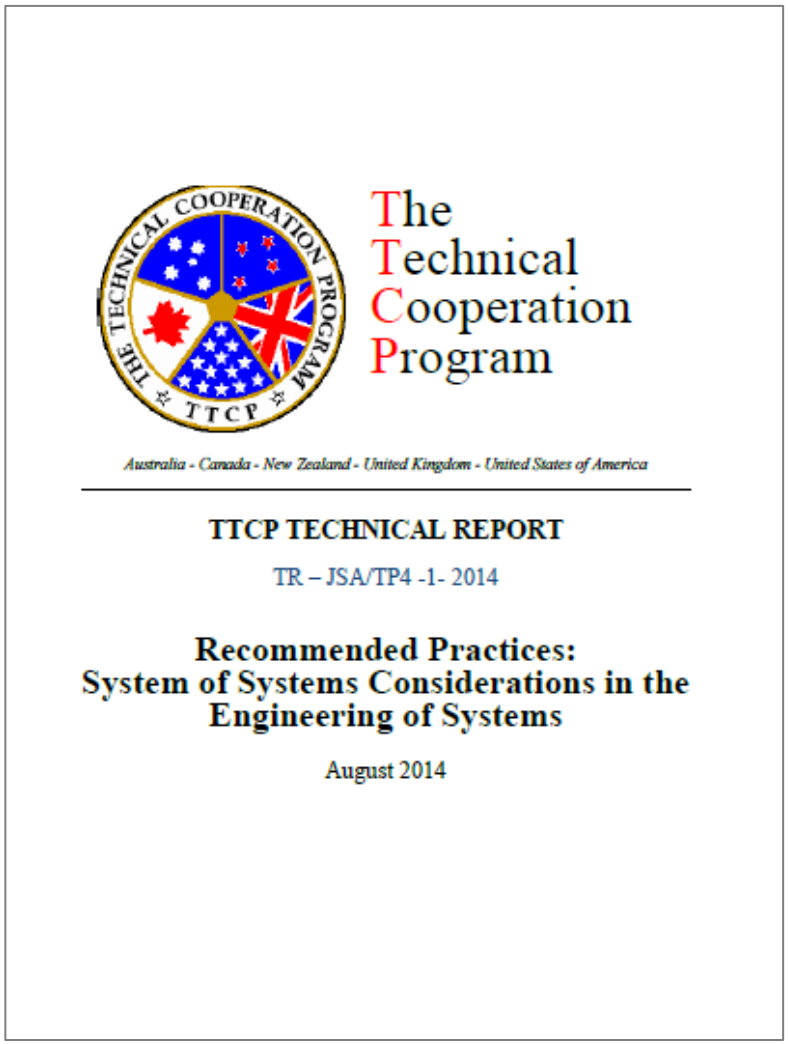
Mitigations

Engage with the managers or systems engineers of the relevant systems, to ensure that plans for the system in question align with those of the other constituent systems.

Summary and Conclusions

- **Recognition by 4 nations of the need to address SoS considerations throughout the system lifecycle**
  - ‘Recommended Practices’ provides a common tool to be used across nations building on collective knowledge
  - US integrating ‘Recommended Practices’ as reference for Defense Acquisition Guidebook
- **Cross cutting issue: Need for a consistent SoS supporting technical base for addressing system SoS considerations**
  - In many cases there is no acquisition or engineering activity at the SoS capability level to provide the SoS technical context for systems

Exploitation and Feedback



- **The TTCP product is currently in 'Exploitation' phase**
  - Each nation is reviewing Recommended Practices to assess how to best take advantage of the information
  - TP-4 SoS Team is sharing information about the Recommended Practices and making the product available
- **Feedback**
  - Feedback will guide next steps

http://www.acq.osd.mil/se/docs/TTCP-Final-Report-SoS-Recommended-Practices.pdf

For Additional Information

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Systems Engineering: Critical to Defense Acquisition










Defense Innovation Marketplace
http://www.defenseinnovationmarketplace.mil

DASD, Systems Engineering
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