ISBN for SETE2018: 978-1-925627-15-2

The role of scenarios in model-based management of Capability Programs

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ABSTRACT

In 2016, following the First Principles Review, Defence introduced an updated Capability Life Cycle and the Program Management construct to develop and manage Defence Capabilities for the Joint Force. Conventional wisdom holds that to realise the potential of the Joint Force and the capabilities that support it, careful analysis of the capabilities and their integration and interoperability is required. Programs are a step towards more formally managing the complex capabilities and their integration and interoperability demands and are in addition to the Project/Product level management previously undertaken.

Programs have been formed by combining existing Projects and Products under a single banner. Program Managers are formulating an understanding of how to coordinate the various Projects and Sustainment activities. The Joint Capability Narrative, the Joint Capability Needs Statement, and the Program Integrating Operational Concept are elements that provide top-down driven understanding of what the capability must achieve, where it needs to operate, and with whom it needs to operate. The central theme of all these elements can be portrayed in a set of scenarios covering the operation and support of the capability.

Demands on the Defence budget put pressure on Programs to provide robust Capability-based business cases when seeking approval for new acquisition or upgrade Projects. The business case should include new Project justification, e.g. the capability is not effective in the new threat environment, and why the proposed acquisition or upgrade best meets the overall capability needs. This justification can be derived from analysis of the current and proposed capabilities in Program-level scenarios against an agreed set of Program-level Measures of Effectiveness.

This paper explores the concept of defining, maintaining, and utilising Program scenarios and low-fidelity effectiveness predictions to support the ongoing management of Program effectiveness over a Program lifetime covering many decades.

INTRODUCTION

In response to the First Principles Review (FPR) (Defence 2015), the Australian Department of Defence has undergone a substantial reorganization and a redistribution of roles and responsibilities. Emphasis was strengthened on the holistic design of the Australian Defence Force and on the improvement of the integration of capabilities, in particular, joint capabilities. From the Interim Capability Lifecycle Manual (ICLM) (Defence 2017b) three new roles were defined and initially allocated to the Vice-Chief of Defence Force (VCDF):

- Force Design Authority responsible for translating strategic policy into a defensible future force structure by developing and testing operating concepts, options and potential responses to emerging threats to identify gaps, risks (both threats and opportunities) and issues.
- C4ISR Design Authority responsible for defining and validating the war-fighting environment and architecture and setting Military interoperability requirements.
- Joint Capability Authority responsible for providing Integration and Interoperability (I2) guidance and joint Test and Evaluation (T&E).

Alongside the organisation changes, Defence introduced an updated Capability Life Cycle and a Program Management construct to develop and manage Defence Capabilities for the Joint Force. Conventional wisdom holds that to realise the potential of the Joint Force and the capabilities that support it, careful analysis of the capabilities and their integration and interoperability is required. Programs are a step towards more formally managing and assessing the complex capabilities and their integration and interoperability demands and are in addition to the Project/Product level management previously undertaken. Defence has created around 40 Programs each of which is "a group of related Projects, Products, and activities that are managed in a coordinated way to optimize the capability outcome within allocated resources" (Defence 2017b).

Cook and Unewisse (2017, 2018) argue that to effectively deliver Programs, Defence needs to undertake some form of systems of systems engineering (SoSE) to translate strategic needs into ongoing capability evolution plans for each of the Programs and their constituent Projects and Products. Suitable SoSE approaches, based on International best practice, have been proposed for both the evolution and co-ordination of Programs (Cook and Unewisse 2017) and for their interoperability and integration assessment (Cook and Unewisse 2018). These approaches have been tailored for the Australian environment to support the CLC approach and Smart Buyer Framework demands in a manner that does not require large resources to deliver.

This paper explores the needs of the Programs to define, design, procure, evolve, maintain, sustain and assure an effective Defence Capability contributing to single and Joint Force operations and argues that a key success factor in successfully-managing Programs in an austere environment is to prioritise scenario-based analysis as an ongoing activity.

The paper opens with a discussion of Program Capability and the aim of the SoSE approach to achieve capability integration by design, followed by a summary of international practices involving scenario analysis. The paper then completes with a definition of the proposed methodology and a worked example showing how it can be applied.

PROGRAM CAPABILITY CONTEXT

The Interim Capability Life Cycle Manual (Defence 2017b) defines capability as "the power to achieve a desired operational effect in a nominated environment within a specified time and to sustain that effect for a designated period." Capabilities are formed by effectively integrating the Fundamental Inputs to

Capability (FIC) comprising personnel, organisation, collective training, major systems, supplies, facilities and training areas, support, industry, and command and management. The role of the Program is to coordinate a group of related Projects, Products and Program activities to optimise the Capability outcomes within the constraints of the resources available.

At the Program-level Cook & Unewisse (2017, 2108) recommend a tailored SoSE approach to add structure and rigour to ensure the Capability is integrated by design. The approach takes International best practice and tailors it to the austere Australian environment with the aim of providing a robust and easy to follow approach. Figure 1 illustrates the proposed approach to Program evolution in a manner that avoids over sophistication and aims to minimise process fear in the hearts of the very busy Program staff expected to implement it who often tend not to be experts in Program Management or System of Systems Engineering. The illustration shows its lineage to the SoS wave model (Dahmann et al. 2011) that was formulated from successful SoS approaches in the US Department of Defense. This stage-based approach allows Programs, and the Capabilities they manage, to evolve over time in a structured manner ensuring the functionality, performance and effectiveness of the capability, its integration with other Defence capabilities, and its interoperability with partner nation capabilities is designed in early and assessed regularly during development and operations. This fits well with the aims of the CLC, and the supporting Smart Buyer Framework (Defence 2016), to understand risk and determine the business case to proceed with development and/or acquisition activities.

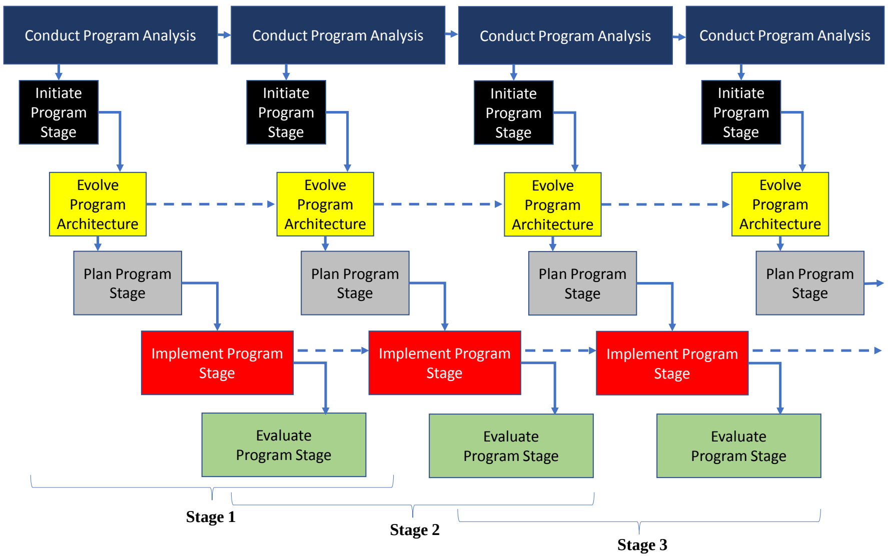

Figure 1. Proposed SoSE approach to Program execution (Cook and Unewisse, 2018).

SoSE is a methodology that is applied when many constituent systems already exist, and it becomes clear that better coordination of the operation and evolution of the constituent systems would be benefit the collective. The co-ordination is achieved through a sequence of spirals or waves, each of which, deliver defined capabilities. Cook and Unewisse (2017) describe the simplified approach that starts from gaining a clear understanding of what the SoSE is currently doing and is capable of doing and planning an increment that will move the Program towards its stated objectives. A key artefact in this process is the concept of operations that contains the key operational scenarios.

McKenna and McKay (2017) describe the long-standing capability development process used and evolved over time within defence that around the world that ensures that Defence organisations are better informed when making decisions and determining the best courses of action to achieve a desired capability while mitigating the development, acquisition, and sustainment risks. Figure 2 provides an adaption of the process from McKenna and McKay (2017) that highlights the central and key role that scenarios and their assessment plays in the development of capability understanding and the generation of the investment case (or business case) to proceed with enhancements and modification to Defence's Capabilities. The process is simple in nature and lends itself to use at the Force Design, Program Capability and Project / Product layers and can be effectively supported by Model-Based Systems Engineering (MBSE) practices and tools in common use with the Australian Defence Enterprise.

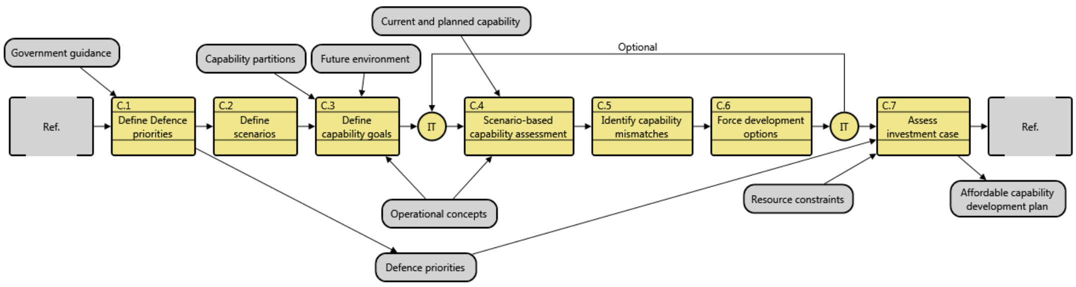

Figure 2. Generic Capability definition process (adapted from McKenna and McKay 2017).

There is an equivalent set of functions in Cook & Unewisse (2017) spread across the first four elements of their process. The essential difference is that the SoSE aims in include a greater degree of engineering knowledge to better inform investment decisions and to achieve successful integration and interoperability. Furthermore, it should be noted that SoSE goes beyond planning; it encompasses implementation and evaluation of the evolving SoS capability. Cook & Unewisse (2017) identify a number of client needs that drive a SoSE approach covering the areas of Governance (G), Personnel (P), Process (PC), Tools (T), Information (I), Culture (C) and Evidence (EV). The scenario-based approach proposed in this paper is constrained by or aims to contribute towards meeting these needs. Table 1 identifies the sub-set of the needs defined by Cook & Unewisse (2017) that are relevant to this paper.

Table 1. SoSE needs addressed by the scenario methodology.

Need #	Need
G5	Senior decision-makers should consider making decisions at the Program level rather than on disconnected individual Project proposals.
G6	Need to ensure that there is a common understanding of the nature and scope of the SoS capability.
P1	Need to keep SoSE team small.
P2	Need people with appropriate competencies, i.e. technical and social systems people.
PC1	Seek to address immediate SoSE design and integration considerations, while building a foundation to deliver a more systemic approach SoSE to achieving integration by design.
PC2	Need to take a multi-stage approach to implementing SoSE for enduring Programs.
PC3	Program SoSE methodologies must be tailored to the specific Programs, environments and missions. They must be blended approaches that adapt over time as the Program evolve.
PC4	Support lean processes and minimal artefacts to match austere SoSE resource levels.
PC5	SoSE approaches must be value-driven, demonstrating positive cost-benefits from SoSE to potentially sceptical stakeholder as the SoSE implementation evolves.
PC6	Processes need to prioritize risk management.
PC7	Technical aspects need to include first-order engineering analysis and design of the system architectures, standards selection, dependency analysis, and integration and performance measures.
PC8	Need to address human and organizational aspects of Program development to ensure that they effectively supporting SoS outcomes.
T1	Ensure that tools meet key quality attributes including: comprehensiveness, effectiveness, adaptability and scalability, supportability, information availability, efficiency, learnability, consistency, acceptability and

Need #	Need
	manageability.
T3	Minimize the overheads needed to populate, maintain and utilize the tools.
T4	Ensure tools are moderately insensitive to problems and inconsistencies in the available data.
I3	Senior decision-makers must be provided with clear and actionable information to support SoS level decisions.
EV1	Need appropriate SoSE key performance parameters that: • can assess the effectiveness of the Program capability against the goals of each iteration; • provide appropriate SoSE assessment of both the capability and associated management processes; and • provide leading indicators of SoSE success and/or failures.
EV2	Need evaluation and feedback mechanisms on the effectiveness of Program design and implementation.
EV3	Enable future evolution toward a Mission Engineering approach for operational SoS assessment.
EV5	Enable SoS test and evaluation to both validate Program-level capabilities and support decision-making.

SCENARIOS AND THEIR TRADITIONAL USE

As part of the development of a Program level scenario approach to capability design, a literature review into the past and current implementation of scenarios within capability development was conducted to assess the relevance, usefulness, uniqueness, and potential advantages of a Program scenario methodology. There is a bias towards Defence-based considerations, with a summary of the Australian perspective also provided. The usage of scenarios was explored within the context of Capability Based Planning (CBP), Project level capability development, the Feasible Scenario Space (FSS) approach, and Mission Engineering.

Capability Based Planning (CBP) developed as an alternative to threat-based planning and has been utilised for force-level Defence and whole-of-government security planning for more than a decade (Kwon & Cook 2010, Ween et al. 2013), albeit with differing levels of success (Taylor 2014). CBP, as defined by Davis (2003), involves "planning, under uncertainty, to provide capabilities suitable for a wide range of modern-day challenges and circumstances, while working within an economic framework." Within the CBP methodology, scenarios are used to establish the context within which to transition from government prescribed strategic-level objectives / defence priorities to the development of capability goals (TTCP 2004, Ween et al. 2013, Gori et al. 2006, Taylor 2014). Assessment of existing and planned defence capabilities against the capability goals allows for the identification of capability gaps or excesses (TTCP guide, Taylor 2014). These capability gaps or excesses are a catalyst for the generation of capability options, which once assessed against cost, risk, schedule and other considerations, ultimately lead to decisions on capability investment (Chim et al. 2010).

TTCP (2004) and Taylor (2014) state that the scenario set developed as part of the CBP methodology should be derived from plausible situations (ranging from real world to generic or fictional; a compromise between security classification issues and the credibility of the scenario) that capture the range of operations that a government would reasonably expect its forces to engage in. There is a need to develop sufficiently challenging and stressful scenarios to ensure that capability weaknesses may be identified. The scenarios should also account for the time dependent nature of capability, facilitating assessment of capabilities through time. TTCP (2004) and Taylor (2014) go on to say that commonality of scenarios across the defence force also provides advantages around the decision-making process, allowing capabilities to be assessed under the same assumptions and within the same contexts. Taylor (2014) states that whilst the scale of the defence force should dictate the scale of the scenario set required to adequately capture the range of defence force operations, resource limitations are the ultimate constraint on the number of scenarios that can be considered.

From an Australian perspective, the Australian Capability Context Scenarios (ACCS), a product of the Strategy Framework, represent the standardised strategic-level scenario set used as part of a CBP

approach. The ACCS are a collection of scenarios that reflect the plausible future circumstances under which the future joint force might be employed. Their intent is to provide a consistent baseline for capability development and analysis, enabling Defence to make broad capability decisions (Defence 2010).

At a Project level, the ACCS serve as a strategic-level nucleus from which more detailed operational scenarios may be developed, thus assuring their strategic validity (Gori et al. 2006). Often termed vignettes, these operational scenarios are intended to inform concept development in a solution independent manner, leading to the development of operational needs for a proposed capability, and ultimately culminating in the prescription of system level requirements through functional analysis.

Scenario-based planning has been successful employed in defence planning for a long time. Nonetheless, it is not able to meet the needs listed earlier (in particular PC7) because its focus is operational and technical analysis is rarely included.

Noting that scenarios represent a reduced set of all possible futures within a large multi-dimensional space of uncertainty (Abass et al. 2008), Bowden et al. (2015) proposed an alternative approach to the assessment of capability options. Defined as the Feasible Scenario Space (FSS) approach, rather than discretising the scenario space and assessing options against a prescribed scenario set, this approach asks, "what parts of the scenario space does a given capability set allow you to achieve with acceptable risk?". The intent is to provide decision-makers with an understanding of the possible futures within which a given capability option can effectively operate, rather than providing the performance of capability options against a prescribed scenario set (Bowden et al. 2015), i.e. the use of the ACCS in the Australian CBP context. Given the increase in size of the scenario space through time, this approach to capability assessment is both more complex and more resource intensive than traditional scenario methods.

An important approach gaining momentum is Mission Engineering. Mission Engineering places emphasis on capability-based assessments with the aim of supporting informed and effective decision making for the integration of naval warfare capabilities within joint warfighting campaigns. The US Navy have developed this approach in response to failures in their traditional approaches to acquiring sensors, effectors, C4I and platforms separately and then attempting to integrate the mission systems and naval SoS as items are delivered. Mission Engineering aims to focus development and acquisition efforts on providing an integrated capability at sea by placing the mission at the forefront of all activities to define, develop, integrate, test and deliver the required warfighting effects. It is a systematic and iterative SoSE approach to executing the assessment of capabilities and/or systems. These assessments are carried out against mission threats, similar in nature to strategic level scenarios that provide the context for understanding the current and future readiness of a joint force, with the findings captured in effects/kill chains (Moreland 2015).

Mission Engineering is having some success for the US Navy, but it should be noted that it is dependent on the availability of significant numbers of Navy staff, scientists, engineers and operations analysts coupled with modelling, simulation and assessment software that has been developed over many years in support of Navy's traditional acquisition processes. The modelling and simulation is specialist in nature, detailed, complex and requires experienced staff to set up, run and analyse the results. In the short- to medium-term, this type of approach is not within the reach of Australian Defence for all but a handful of Programs without significant investment in either DST Group or contracting of US modelling and simulation capabilities. It is significant to note that the use of mission threads (scenarios) is a key element in mission engineering.

There are a few key findings from the literature review that must be addressed within the proposed methodology if it is to offer Australian Defence effective support to Capability assessment and investment decisions. These findings are:

- the use of scenarios is key to understanding the warfighting requirements and the effectiveness of existing and proposed capabilities;
- the modelling, simulation, and analysis techniques identified can be specialist-resource intensive and time consuming;
- any results from the modelling, simulation, and analysis tools needs to be available at the right time and to sufficient fidelity to make the decisions when they need to be made i.e. fit for purpose; and
- expert judgement as opposed to detailed mathematical modelling is an acceptable approach to providing inputs to scenario simulations.

This therefore suggests that any proposed methodology to support Program and Capability development in Australia should be simple enough to inform decisions being made (rather than supporting decisions after they have been made) and utilise the limited resources sparingly.

Cook and Unewisse (2014) understood that an ADF Program-level SoSE methodology would need to sit between the extensive, detailed rigour of mission engineering and the affordable but limited purview of capability-based planning. What follows below is the description of how scenario analysis and other activities could be performed within their methodological framework.

A MODEL-BASED APPROACH TO PROGRAM LEVEL SCENARIO ANALYSIS

Defence has for many years been undertaking Capability Design activities on Projects utilising the Systems Engineering approach defined in the Capability Definition Documents Guide (Defence 2017a). This approach is implemented by Shoal Engineering in a Model-Based environment, utilising the Whole of System Analytical Framework (WSAF) developed by the Defence Science and Technology Group (DST Group) (Robinson et al. 2010). The Capability Design and associated model achieved through this methodology are descriptive in nature and form the basis upon which the Operational Concept Document (OCD), Function and Performance Specification (FPS), and Test and Evaluation Master Plan (TEMP) documents for Projects are generated and maintained.

Programs are starting to adopt a Model-Based approach to managing Program-level Capability and its integration and interoperability aspects. The framework required at the Program-level to support effective Model-Based management is an extension of the WSAF framework (Jusaitis 2018) that introduces Program-level terminology and artefacts, such as the Program Integrating Operational Concept (PIOC) (French & Heard 2018). The emphasis may be different between Program and Project layers, but much can be learnt from Project MBSE experiences and successful techniques can be evolved to suit Program needs.

Scenarios feature prominently within the OCD and are used to develop operational needs and identify issues with the existing system but are rarely maintained and re-visited as the Project progresses through Gate 2 to Acquisition and into the in-service phase. There are many reasons for this but in the main the Acquisition and Sustainment teams traditionally work to the specifications and not the operational needs when dealing with the purchase, upkeep and update aspects of the Product. It is common for scenarios to portray operations of the System in a number of environments, in a number of integration and interoperability configurations against various threats. Some scenarios may aim to stress the system of interest to determine performance targets as well as functionality. These performance targets are not

always the result of operational analysis or contained in an analytical model and are therefore difficult to fully relate to Measures of Effectiveness (MOEs) at the Capability or Joint Force level. This discontinuity is in the main caused by the lack of operational analysis models and the lack of a simulation capability in the SE tools being used. Pockets of high fidelity performance and capability modelling do exist within DST Group, but these are complex models that require detailed environmental, system of interest, and threat details for specialist staff to run. Analysis can take weeks or months to undertake and present in a form that Capability Managers and Sponsors can readily digest.

Program use of scenarios, and how and when analysis is undertaken, differs from Projects in that Programs are more enduring and need to ensure effective joint warfighting capabilities are integrated by design and provide the required effectiveness. Programs therefore need the ability to determine where the capability gaps and issues exist and how to best spend the money they have available in improving the warfighting capability, this may be via a new major systems project, improved training, or increased support capabilities. Low fidelity (low level of detail), sometimes termed course or crude, modelling and simulation utilising Program-level scenarios offers the Program team the ability to undertake "what if" style trade studies using a combination of collected data and expert opinion. This results in timely qualitative and quantitative evaluations of the Capability as it currently is, the gaps or shortfalls in the effectiveness of the Capability and the FIC areas in which to invest. This quick look understanding of the likely effectiveness of a Capability in operational situations leads to more rapid decisions being made and areas of greatest risk more speedily identified. The analysis conducted can inform the performance thresholds from which solution value and suitability can be made. The simulation can also be used to determine bottlenecks in resources and information flows as well as support the determination and analysis of T&E activities to support the wider Verification and Validation (V&V) of the Operational Capability in place, in procurement and over the longer term.

Programs also need the ability to react to changing operational environments, tactics and threats and determine how to adapt or improve the Capability to meet the challenges. Assessing the changes in a scenario will help determine where the best value updates can be made. By conducting scenario analysis at regular intervals, the Program team can determine the progress of Projects, required changes in Project scope, any Projects that should be terminated and new Projects required.

Scenarios therefore become the central foundation upon which Capability Programs can be managed over time and ensure that "by design" Capabilities operate effectively in a Single Service, Joint, or Coalition Operation.

By undertaking the capability Design and analysis at the Program level, additional savings can be made in the effort required to get constituent Projects through Gate 2 and into acquisition. Programs can take ownership of the Capability Operational Concept and can feed down the high-level specifications of system or Product to be acquired and the manner in which it is to be tested and integrated in to the overall Capability. This removes the need for a Project to produce an OCD and provides a substantial draft of the TEMP.

The key to implementing this approach is to adopt Model-Based System Engineering utilising a tool that allows both descriptive and analytic models to be developed and links between separate Program and Project models to be made. This ensures that the work involved is focussed on the development of the required elements and utilises previous or ongoing work effectively – removing duplication whilst ensuring consistency and designed integration between Program and Project models together with traceability and justification flows. It also allows focussed scenario elements or vignettes to be fed down to Projects from the Program and analysis to be conducted in a consistent manner between Project and Program allowing the Program scenario parameters to be updated with current Project level expectations.

Scenarios developed in the MBSE environment can be defined in textural terms with their behaviour or events timelines depicted in enhanced Functional Flow Block Diagrams (eFFBD) or activity and sequence diagrams. Figure 3 shows a generic scenario building block eFFBD upon which more detailed scenario behaviour can be defined (see Figure 5 and Figure 6 later in this paper) or very crude analysis can be conducted. Once developed, the eFFBDs form the basis of the simulation to be conducted and identify the parameters required and the results to be gathered. It is possible for output from high fidelity models, in the form of performance values or effectiveness probabilities, for constituent components and threat platforms and weapons to be incorporated into the scenario simulation but the simulation is not dependent on the availability of such data.

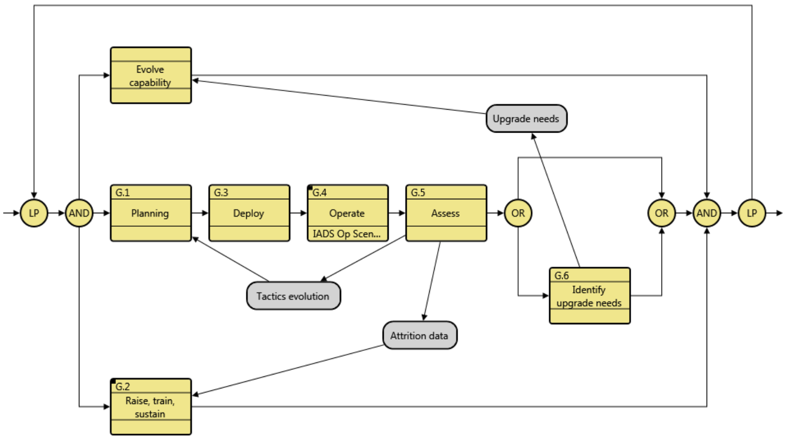

Figure 3. Generic high-level scenario flow.

With the scenario analysis being conducted within the Program-level model, the results can be quickly incorporated throughout the artefact set with very little effort whilst ensuring consistency and minimising human error in transposing them. The results can also be promulgated to Projects to update constituent system or component performance targets.

Scenario analysis contributes to the V&V of the Capability in service and de-risks T&E activities by determining expected outcomes and guiding the setting up of the T&E activities at both the Program and Project level. The T&E results can then be used as input parameters to the analysis of the effectiveness of the Capability against that desired. This is especially useful where Product or supporting element performance is less than expected during testing and the impact of this lower performance can be assessed at Program Capability level to determine impact on operations and if remedial work is required.

Program-level dependences on Programs and Projects outside of their direct control is an ongoing concern. Risks are regularly being identified in Defence regarding the ability of Projects to deliver on time and to the expected performance levels. The impacts are not always analysed and mitigated well by the receiving / dependant Project or Program. An additional benefit provided by the Model-Based approach here is that the “what if” studies can include the potential slippages and performance compromises likely to be made by the constituent Projects. From this Capability impact, is easy to see and mitigate measures or escalations up the Capability Manager hierarchy.

It is expected that once the Program-level descriptive and analytical model elements have been initially populated, the analysis of scenarios to answer the "what if" questions and undertake trade / trade-off studies can easily be done by a desk officer within the Program team.

The availability of a suitable MBSE tool on the Defence networks, and therefore accessible by desk officers, is not deemed to be impossible in the short term but may require a "white listing" activity before being readily available. Development of MBSE tools is an ongoing activity by the vendors and recent additions of simulation methods, such as Monte Carlo Analysis, as opposed to exporting models to a separate analysis tool provides the means for the methodology proposed in this paper to be readily implemented by Programs within Defence.

A WORKED EXAMPLE

To illustrate and to test the feasibility of the methodology, a worked example was developed, in the Vitech GENESYS MBSE tool, based on historical events and utilising open source information. The example is based around the UK's Air Defence Network during World War II; commonly known as "The Dowding System" after its Chief Systems Architect - Air Chief Marshall Sir Hugh Dowding (Imperial War Museums, n.d.). The Dowding System, illustrated in Figure 4, is a perfect example of a Directed SoS (SEBoK, 2017) clearly designed and managed to fulfil a specific purpose with the constituent systems subordinated to the SoS; although able to operate independently, the constituent system's normal operational mode in the defence of the UK was subordinated and controlled through the Air Defence Network. The design of the SoS enabled the rapid and frequent evolution needed through the course of the Battle of Britain (Bungay 2001, Holland 2011), and the evolution, at differing rates, throughout the rest of World War II right up to the end of the Cold War.

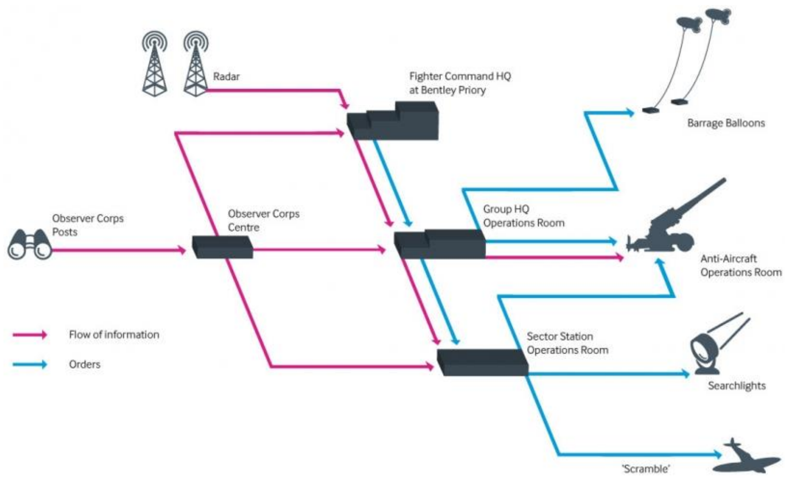

Figure 4. The Dowding System (Imperial War Museums, n.d.).

The system comprised Fighter Command HQ with four group HQs, multiple sector HQ stations per group, and multiple airfields and fighter squadrons per station. All HQ's at each level had an operations room with a large map of the UK for monitoring the tracks of incoming raids and the intercepting fighter squadrons. Fighter Command HQ at the top had a Filter room in which all incoming sensor information was combined and analysed to form a clear operational picture for distribution to Groups and Sectors. Each group was essentially an instance of the Dowding System including a range of sub-systems and people.

To test the feasibility of the proposed methodology, the Dowding System architecture and its behaviour, was modelled within the Vitech GENESYS MBSE tool together with a tailored version of the Scenario, shown in Figure 3 earlier with aspects detailed in Figure 5 and Figure 6, representing the Defence of the UK during the Battle of Britain. To align the feasibility study with SE practice the following Critical Operational Issues (COIs) and Measures of Effectiveness (MOEs) were defined to determine how well the Dowding System worked and the impacts of changing constituent elements, tactics, and threat/bomber performance and the effects of damage to, or performance degradation of, constituent elements.

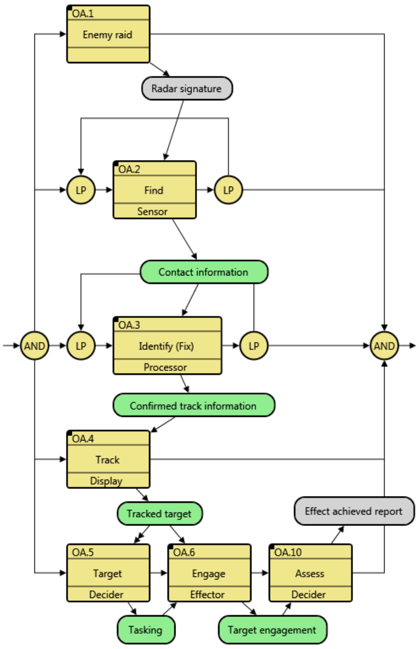

Figure 5. Operate phase example – Single enemy raid

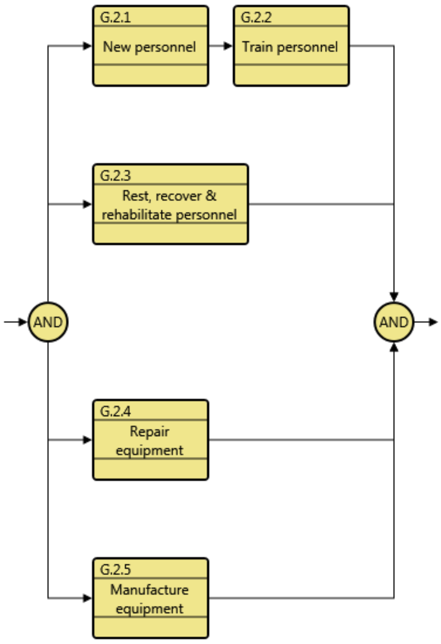

Figure 6. Raise, Train and Sustain phase

The following COIs and related MOEs were defined:

COI 1 – Does the Air Defence Network reduce the efficacy of enemy attacks on High Value or populated areas?

> MOE 1 – Percentage reduction in bomber raid efficacy during a single multi-bomber raid.

COI 2 – Can the Air Defence Network effectiveness be sustained over an extended period?

> MOE 2 – Length of time the Air Defence Network can maintain operational assets on or above critical levels.

COI 3 – Can the Air Defence Network be readily adapted to counter changes in enemy weapons and tactics?

> MOE 3 – Length of time taken to adapt the Air Defence Network to changes in enemy tactics.

> MOE 4 – Length of time taken to adapt the Air Defence network to changes in enemy weapons.

Table 2 shows some of the input parameters used to define the scenario and the "what if" variation studies conducted using the simulation engine in GENESYS. These are based on historical information and are therefore representative of the performance of the components within the Air Defence Network at that time, although simplistic in nature. In order to understand the base effect of a variation from the baseline capability, only one parameter change was made per simulation run (Monte Carlo / multi-variant analysis was not undertaken due to time limitations) i.e. only the sensor range or the number of fighters was changed. Table 3 provides the MOE 1 scores for the baseline condition and a sample set of the Capability and threat variants simulated.

Table 2. Simulation parameter variants

Parameter	Baseline	Variant 1	Variant 2
Enemy raid: Formation speed	250 mph	500 mph	
System time: sense to scramble	360s	300s	600s
System time: intercept	840s	720s	960s
Fighter: attack pass time	30 – 180s		
# Fighters	48	36	60
Sensor range	50 miles	100 miles	150 miles

Table 3. Simulation results for selected Capability variants – MOE 1

Capability Variation	MOE 1 score Baseline bomber speed	MOE 1 score Variant 1 Bomber speed
Baseline	32%	9%
Sensor range variant 1	49%	7%
Sensor range variant 2	58%	8%
Fighters variant 1	25%	5%
Fighters variant 2	45%	10%

The important thing to note from the scores is that the relative score and rankings identifies priority improvements or critical weaknesses within the Capability. For instance, the MOE 1 scores for the two different bomber speeds (provided by the change from propellors to jet engines) highlights the impact of step changes in technology and how quickly the capability goes from reasonable effectiveness to very poor effectiveness. In this context, the speed advantage that the fighters had which allowed them to attack the bomber formation several times before the formation reached its target was neutralised and only a single near-head-on firing run could be conducted. Once this has been clearly identified ,the desk officer can look at the options available to increase the effectiveness back up to acceptable levels. The obvious option is to increase the speed of the fighters but they could also investigate other changes such as ground based weapons, additional weapons on the fighters (adapting ground attack rockets), numbers of fighters or changes in tactics. Each of these options could then be assessed in the scenario and the most effective identified quickly and pursued.

CONCLUSIONS

This paper argues that a key aspect of a successfully-managed Program in an austere environment is scenario-based analysis as an ongoing activity. Such analysis can be used to aid the exploration of the needs of the Program and to define, design, procure, evolve, maintain, sustain and assure an effective

Defence Capability that can contribute to single and Joint Force operations.

The paper outlines an MBSE descriptive and analytical modelling-based approach to defining and assessing Program-level Capabilities and determining effective courses of action to improve or better maintain Capability Effectiveness over time using low-fidelity simulation of Capabilities in scenarios against which they have been defined. It notes that low-fidelity simulation provides a means to rank options for improvements in changing environments and provide performance targets for constituent systems to be supplied by Projects. It also acknowledges the role of detailed or high-fidelity simulations at the Project level.

The worked example shows the feasibility of undertaking low fidelity simulation of a Program-level Capability as an “out of the box” capability of modern MBSE tools. It highlights the power of quick “what if” simulations at the Program level to determine the impacts on the capability of changes to the component parts or evolution of adversary technology and tactics. It also highlights that the number of parameters and variables used within the simulation can quickly become large in number and make the setting up of simulations onerous for Program Team members therefore the Systems Engineers initially populating the description and analytic models need to pay carefully attention to the definition of the parameters and variables that can be modified and studied directly by the Program Team.

The take away messages from this paper are:

- In an austere environment, as faced by Program teams within Defence, it is critical that a robust method is adopted to design, assess and maintain Program-level Capabilities;
- MBSE techniques provide a way to design, assess, maintain, manage risks and understand the impacts of change on Program-level capabilities and that Project-level lessons and techniques can readily be adapted to the Program-level;
- Program-level scenarios and analysis of capabilities using them encourages integration by design as well as supporting the V&V and T&E activities; and
- Scenarios are the “first place to start”, and the “last place to stop” when analysing Program-level Capabilities.

It is worth noting that although this paper concentrates on the Defence Program Management level, the methodology can be equally well applied at Force Design and Project levels as well as to other domains such as transportation. It is particularly useful for complex system of systems Capabilities exist that need to improve or maintain effectiveness in a changing environment.

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ISBN for SETE2018: 978-1-925627-15-2