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A Framework to Support S&T Planning for Royal Australian Navy Capability Acquisition

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ABSTRACT

When the Australian Defence Force (ADF) identifies a capability gap an acquisition process commences, supported by science and technology (S&T) guidance. Though the S&T support requirements are governed by the needs of the acquisition project, the S&T planning process would benefit from the introduction of a framework to improve the robustness and transparency of decision making with regards to the allocation of S&T resources. This report presents an overview of a proposed framework, encompassing the Foresight Planning methodology, to assist in the identification of critical design issues; technology readiness; and research plans for critical technology areas in support of ADF capability acquisition. The iterative application of suitable Foresight Planning methods will enable the S&T requirements and vision to be established, from which a strategic S&T Plan can be developed. The aim of the proposed S&T planning framework is to provide guidance to establish a bespoke vision for each new capability acquisition and facilitate planning for the shape of things to come.

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A Framework to Support S&T Planning for Royal Australian Navy Capability Acquisition

Executive Summary

Foresight Planning is a methodology to examine future possibilities across disciplines such as science, economy and society, to aid in developing policy and action to achieve a desired goal. It is not to be considered a method to forecast the future, instead, the aim of Foresight Planning is to understand the possibilities that may exist in the future and thereby facilitate planning for shaping that future. Each method in Foresight Planning is one step in providing advice for guiding policy and assisting with strategic planning innovation processes. At the commencement of a Foresight Planning exercise the requirements are nebulous, however, through iteration and the application of suitable Foresight Planning methods, the requirements become clearer and a vision established. From this vision a strategic plan can be developed. Foresight Planning, would, therefore, seem ideal for developing strategic guidance for many Australian Defence Force (ADF) capability projects. Specifically, the methodology could prove beneficial in the development of science and technology (S&T) policy and guidance for major capability acquisition.

This report presents an overview of a proposed S&T planning framework, encompassing Foresight Planning, designed to assist the development of S&T Plans for Royal Australian Navy (RAN) capability acquisition. The S&T Planning framework is an attempt to develop and apply a formal procedure that would ensure robust development of the S&T Plans and maintain consistency across RAN acquisition projects. The framework was developed in response to the 2003 Defence Procurement Review (DPR) to initiate change in the ADF acquisition process. As a result of the review, DSTO became responsible for the development of S&T Plans for ADF capability development and approval processes.

The report defines S&T Advice Capabilities (STACs) that may be used in conjunction with Technology Readiness Levels (TRLs) to determine the suitability of technology inclusion during a capability's acquisition phase and service life. Examples of the planning products produced by the framework for a fictitious RAN capability acquisition project are included to assist in the explanation. The S&T planning framework presented in this report focuses primarily on technology issues related to capability major systems and their acquisition, sustainment and upgrade, along with consideration of whether an appropriate S&T advice provider can be identified or needs to be developed/established to support the project.

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The S&T planning framework for RAN acquisition provides a comprehensive, documented and traceable S&T process for key decision-making points during capability acquisition. However, the framework would benefit from further research examining the sensitivity of the methods, the choice of metrics and the subjective inputs provided by participants and demonstration of the framework for a more complete list of the fundamental inputs to RAN capability.

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Glossary

ADF	Australian Defence Force
ADO	Australian Defence Organisation
ASW	Anti Submarine Warfare
ASuW	Anti Surface Warfare
CoA	Commonwealth of Australia
COTS	Commercial-off-the-Shelf
DMO	Defence Materiel Organisation
DoD	Department of Defense
DPR	Defence Procurement Review
DSTO	Defence Science and Technology Organisation
EV	Expected Value
FIC	Fundamental Input to Capability
FORERA	Foresight for the European Research Area
FTA	Free Trade Agreement
GAO	Government Accountability Office
HVAC	Heating, Ventilation and Air-conditioning
ICT	Information and Communication Technologies
ILS	Integrated Logistics Support
IRL	Integration Readiness Level
M&S	Modelling and Simulation
MCM	Mine Counter Measures
MOTS	Military-off-the-Shelf
MPD	Maritime Platforms Division
NATO	North Atlantic Treaty Organisation
NCW	Network Centric Warfare
NGT	Nominal Group Technique
QFD	Quality Function Deployment
PIC	Priority Industry Capability
R&D	Research and Development
RAN	Royal Australian Navy
RPDE	Rapid Prototyping, Development and Evaluation
S&T	Science and Technology
SBA	Simulation Based Acquisition
SME	Subject Matter Expert
SRL	System Readiness Level
STAC	Science and Technology Advice Capability
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
TTCP	The Technical Co-operation Program
UNIDO	United Nations Industrial Development Organization
US	United States (of America)
USA	United States of America
USN	United States Navy
UUV	Unmanned Undersea Vehicle
VTT	<i>Valtion Teknillinen Tutkimuskeskus</i>
WDA	Work Domain Analysis

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1. Introduction

In 2003, the Defence Procurement Review (DPR) was established to initiate change in the Australian Defence Force (ADF) acquisition process [1]. Resulting from this review, the Defence Science and Technology Organisation (DSTO) became responsible for technical risk assessments and the development of Science and Technology (S&T) Plans for ADF capability development and approval processes. Guidance has since been published relating to the development and execution of technical risk assessment, as well as a template for writing S&T Plans that define S&T requirements and the support provided by the DSTO [2, 3]. However, identification of S&T requirements and subsequent DSTO support does not follow a formal procedure that would ensure robust development of the S&T Plan and maintain consistency across ADF acquisition projects. This report provides one approach to develop and apply such a formal procedure as part of a recent acquisition project. In this approach, a conceptual framework was proposed in which Foresight Planning techniques were utilised to systematically identify and prioritise relevant S&T to support capability acquisition and through life.

The motivation for developing this framework was to provide systematic methods for supporting S&T plan development in order to improve the objectivity, accountability and robustness of planning decisions. In this context, objectivity refers to attempts to minimise the influence of parochial motivations by individual research groups; accountability refers to the repeatability and traceability of results; and robustness refers to the ability of the framework to cope with multiple potential futures.

Developing an S&T Plan is akin to strategic and long range planning and numerous tools, such as 'SWOT Analysis', 'Portfolio Analyses' and 'Balanced Scorecard', are available for use in developing those plans. However, these tools do not constitute a formal framework. Instead, Foresight Planning, with a lengthy historical application in examining innovation policy; considering alternative futures; generating a vision of possible futures; and planning and developing actions to achieve desired goals [4, 5, 6], provides the necessary methodology to enable the development of strategic and long range plans. While Foresight Planning methods are not without limitations, they can be utilised as policy tools to complement steering approaches, such as resource management. Subsequently, Foresight Planning has had successful application in government, commercial and defence applications [7, 8, 9]. The Foresight Planning methodology, therefore, appears to provide an ideal basis for use in developing S&T Plans in support of ADF capability acquisition; however it does need to be adapted for use in capability acquisition, as documented in this report.

This report presents an overview of the proposed S&T planning framework designed to assist the development of S&T Plans for Royal Australian Navy (RAN) capability acquisition. Examples of the planning products produced by the framework for a fictitious RAN capability acquisition project are included to assist in the explanation. However, while it is recognised that there are many different fundamental inputs to capability (FIC), the S&T planning framework presented here focuses primarily on the technology issues related to the major systems and their acquisition, sustainment and upgrade, along with consideration of

whether an appropriate S&T advice provider can be identified or needs to be developed/established to support the project.

In Figure 1, the conceptual RAN capability acquisition S&T planning framework is presented. The framework is designed to enable a formal, auditable process to assist in the identification of critical technologies associated with a capability acquisition project and to develop an S&T Plan to manage the requirements for each of the technologies during the acquisition and, potentially, through the service life of the capability. The framework is organised into two groups:

1. the first group, labelled 'Process', constitute the application of Foresight Planning processes to generate and organise the data required for S&T planning purposes; and
2. the second group, labelled 'Outputs', constitute the production of actual S&T Plans.

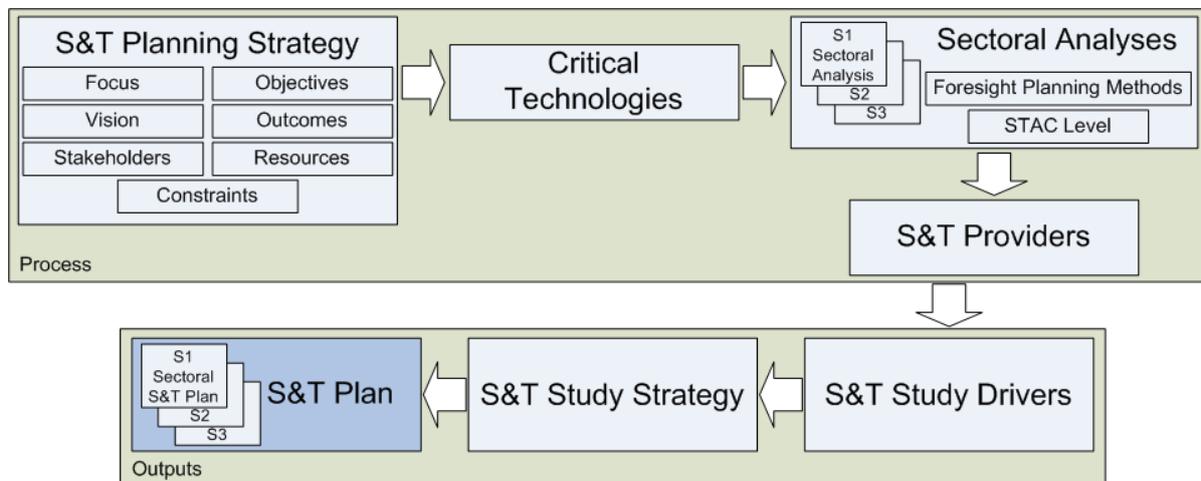


Figure 1: Conceptual RAN capability acquisition S&T planning framework

The application of Foresight Planning within the S&T planning framework differs little from that published in the general literature; however the following aspects are considered somewhat unique:

- the methodology for identifying platform critical technologies;
- the methodology for identifying suitable providers of S&T support; and
- the establishment of a new metric related to the level of S&T advice required during various acquisition phases, known as the S&T Advice Capability (STAC) level.

Outputs from the framework contribute to the identification of S&T study drivers, enabling development of an S&T study strategy and the S&T Plan.

The framework will benefit RAN capability acquisition by providing methods supporting: capability technology options assessment; the identification and prioritisation of critical technical risks; and the analysis and prioritisation of system integration issues. The aim of the framework is to provide a robust, traceable method to ensure objective decision-making during RAN capability acquisition. It is anticipated that such systematic S&T planning will reduce project risk, project costs and scheduling delays.

2. Foresight Planning

Foresight Planning is defined as:

...a participatory, future intelligence gathering and medium-to-long term vision building process that systematically attempts to look into the future of science, the economy and society in order to support present-day decision making and to mobilise joint forces to realise them¹. [4]

Having established a vision for a desired future, the development and application of technology can be guided [10]. However, Foresight Planning is not an exercise in forecasting the future. Forecasting is considered to be an assessment of what is likely to happen in the future [5, 6] and is an input into Foresight Planning [6]. Also, Foresight Planning does not try to create the most probable vision of the future; instead it is an examination of innovation policy [11], used to consider alternative futures and to aid in developing actions to achieve a desired goal [5]. Therefore, Foresight Planning does not assume a fixed future. Some Foresight Planning techniques may consider a possible future and determine the means to achieve that future; however, the future is always in motion and by its nature, unpredictable. The aim of a Foresight Planning exercise is to generate a vision of the possible future and facilitate planning for things to come.

In the context of RAN capability acquisition, multiple potential futures may be introduced from uncertainties such as:

- acquisition models (for example, Military-off-the-Shelf (MOTS), bespoke and evolved designs);
- the introduction of disruptive technologies;
- options to exploit near-mature advanced technologies; and
- the influence of politics on project funding and schedules.

The European organisation, FORERA, provides a methodology for preparing a Foresight Planning exercise [5]; and the European Commission has produced a technical report describing how to perform a Foresight Planning exercise [6]. Foresight Planning, or parts thereof, has been utilised extensively in defence applications, commercial industry and for defining government policy and direction. Examples include:

1. the Department of the Navy, United States of America (USA), in developing their Unmanned Undersea Vehicle (UUV) Master Plan [7];
2. the Australian government's Department of Defence in developing their Network Centric Warfare (NCW) roadmap [12];
3. the American Plastics Council in developing their vision and technology roadmap in automotive markets [13];
4. the Risø National Laboratory Sensor Technology Foresight to determine a strategic outlook for sensor technology within the timeframe of 2000 to 2015 [8]; and

¹ Note, the terms 'intelligence gathering' and 'joint forces' are not being used in a traditional military context. Intelligence gathering refers to the collecting of information; and joint forces is the inclusion of industry, governments, and/or commercial and non-profit organisations.

5. the United Nations Industrial Development Organization (UNIDO) using Foresight Planning to facilitate the development of policies and exploiting emerging/critical technologies for the benefit of developing countries [9].

The Foresight Planning methodology consists of a number of tools and techniques, each of which is one step in providing advice for guiding policy and assisting with the strategic planning innovation process. Figure 2 (adapted from [14]) presents a process funnel implying that at the commencement of a Foresight Planning exercise the requirements are nebulous. Iterative application of suitable Foresight Planning methods will clarify the requirements and a vision is then established, from which a strategic plan can be developed.

Foresight Planning, would, therefore, be ideal for developing strategic guidance for many RAN (and ADF) capability acquisition projects. Specifically, the methodology would benefit the development of S&T policy and guidance for major platform acquisition. To determine the suitability of Foresight Planning for RAN capability acquisition and gain understanding of the methodology, a review of Foresight Planning techniques and methods was performed and a framework defined to enable the identification of critical design issues; technology readiness levels; and research plans for critical technology areas in support platform acquisition. The proposed S&T planning framework will assist in the provision of S&T advice to allow for decision-making and policy guidance. The aim of the proposed framework is to therefore provide guidance to establish a bespoke vision for RAN capability acquisition and facilitate S&T strategic planning.

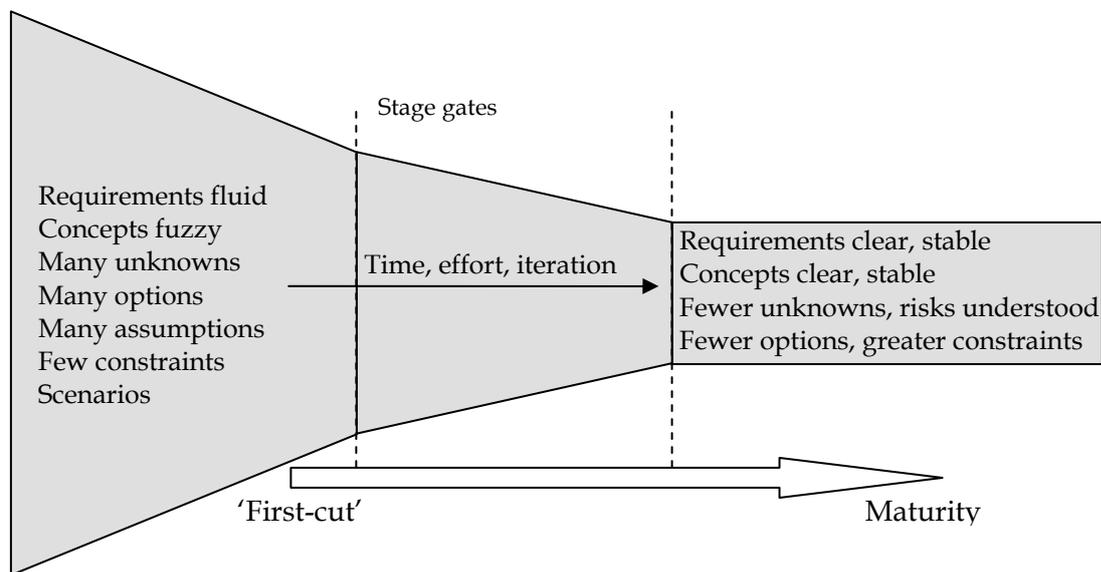


Figure 2: The process funnel of Foresight planning (after [14])

3. Project Life Cycle

The project life cycle, in broad terms, is the materiel system’s capability life cycle from initial identification of a need through to its disposal. The capability life cycle consists of several phases, including identifying and acquiring a new ADF capability. The phases are:

1. Needs: determine capability gaps in relation to strategic guidance, operational concepts and force structure.
2. Requirements: obtain government endorsement and budgetary provision for the proposed solution.
3. Acquisition: acquire the capability solution and enter the solution into service.
4. In-service: where the capability solution is utilised and managed.
5. Disposal: facilitates the withdrawal of a capability or system from service.

The organisational responsibility for managing these phases, as suggested in the 2003 DPR [1] and documented in the Defence Capability Development Handbook [15], is dispersed throughout the Australian Defence Organisation (ADO) as shown in Figure 3. The needs phase is addressed in the ‘strategic assessment’ phase of Figure 3 (prior to the ‘agreement for further analysis’). The requirements phase occurs during the pre-first pass approval and pre-second pass approval points. The 2003 DPR highlights that ‘complex projects may require up to 10% to 15% of project funds be spent prior to approval to proceed to tender’. DSTO’s involvement in defence procurement is presented in the Defence Capability Development Handbook [15].

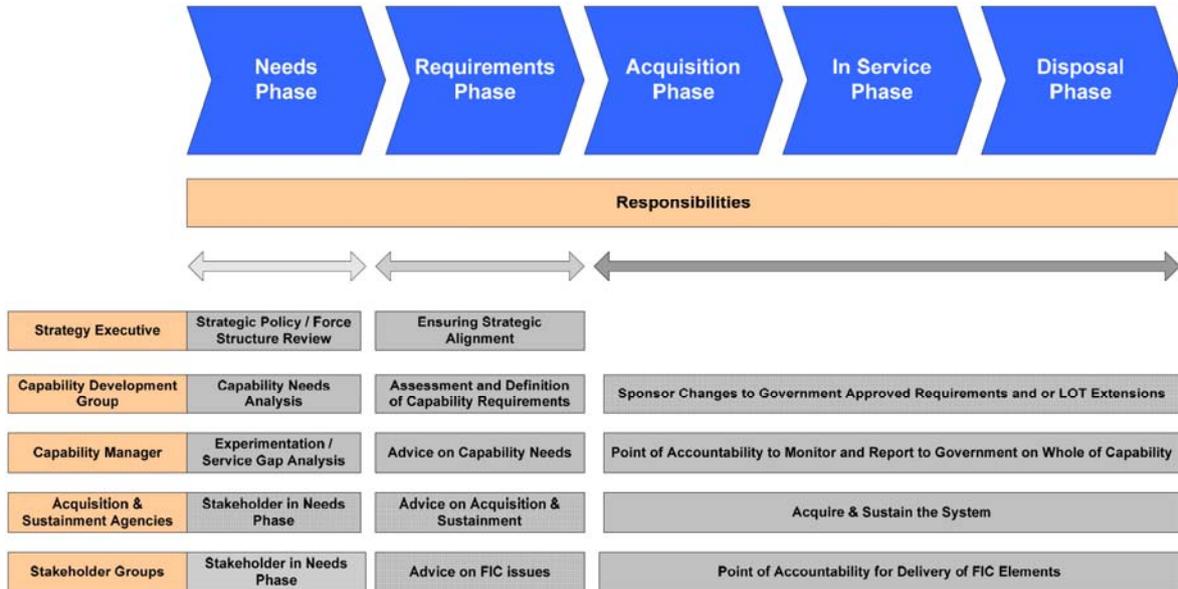


Figure 3: Capability systems life cycle [15]

4. Science and Technology Planning Strategy

The S&T planning framework presents a strategy that is constrained in scope to identify critical technologies and performing a needs analysis in relation to facilities, funding and resource requirements. Therefore, in support of S&T planning for RAN capability acquisition, the framework will facilitate: capability/requirements analysis and effectiveness modelling; technology options identification and assessment; resolution of critical technology technical risk; and resolution of integrated system issues. To achieve this, the first step in the S&T planning framework is to define the planning strategy by identifying, and documenting, the goals of the S&T planning analysis for RAN capability acquisition. This approach follows from the general Foresight Planning methodology documented in the literature [5, 6]. Articulating these definitions ensures that high-level S&T guidance may be aligned with stakeholder requirements (prior to investing effort in performing the Foresight Planning exercise). The following subsections present the major components of the planning strategy document, expanding them for application to RAN capability acquisition. Examples are also provided from applications documented in the literature.

4.1 Focus

The focus defines the core problem for RAN capability acquisition to enable participants to clearly establish and express their expectations [5, 6]. For the RAN, the general focus for the S&T planning framework will facilitate the provision of S&T support to the acquisition project. This will include planning for the S&T capabilities and facilities requirements and co-ordination with relevant S&T providers, including the DSTO, industry and academia.

Consider for example, that the RAN is acquiring a new maritime platform referred to as *Project SEA X*, a potential focus statement would be: *The focus of the S&T planning strategy for Project SEA X is to identify technology and technology trends, including opportunities and threats, spanning the life of the platform. Issues of consideration are: technology influencers and developments; in-country capabilities to provide S&T advice at various levels of expertise; support and test facilities; priority setting for national S&T policy; and enhancing the commercial competitiveness of Australia.*

Example focus statements in the literature include:

1. *Valtion Teknillinen Tutkimuskeskus (VTT)*² defined the focus of their Foresight Planning exercise and roadmap towards innovative applications for Information and Communication Technologies (ICT) in the Nordic countries as: defining and promoting the Nordic way of implementing ICT so that it increases the well-being of society [16].
2. the German Federal Ministry of Education and Research conducted a Foresight Planning exercise 'to identify new priority fields and interdisciplinary themes in research and technology, as well as potentials for strategic partnerships and areas for top priority actions' in order to 'safeguard Germany's long-term innovative capacity as a centre for research and education' [17, 18].

² Translation from Finnish to English: Governmental Technical Research Centre.

3. the focus of Risør's Sensor Technology Foresight Planning exercise was 'to identify and select essential topics related to sensor developments' [8].

4.2 Vision

The vision is an imagined representation, or shared picture, of the future [5, 6]. The vision is defined as:

the process of creating a series of images or visions of the future that are real and compelling enough to motivate and guide people toward focussing their efforts on achieving certain goals.
[19]

Establishment of a vision for S&T planning in support of RAN capability acquisition will enable identification for the level of technological advancement and capabilities of potential systems. It will also facilitate the development of scenarios such as the threat environment. The time-line for the vision may be guided by the *Defence White Paper* [20] and will generally follow the capability life cycle (see Section 3). For *Project SEA X*, the vision statement might be: *The vision of the S&T planning strategy for Project SEA X is to identify the future morphology of the platform, and its systems, to assist development of the long term S&T Plan.*

In the literature, the vision for the United States Navy (USN) UUV Master Plan [7] was to have the capability to:

1. deploy or retrieve devices;
2. gather, transmit or act on all types of information; and
3. engage sea floor, volume³, air or land targets.

In another example, the American Plastics Council [13] defined their vision as:

By 2020, the automotive industry will have established plastics as the material of choice in the design of all major automotive components and systems.

4.3 Stakeholders

Stakeholders include participants and anyone interested in, or affected by, the outcomes [5, 6]. Stakeholders are specific to the acquisition project but will generally consist of: ADO policy makers including the DSTO, the Defence Materiel Organisation (DMO) and the ADF services; knowledge infrastructure; research organisations (primarily the DSTO); capability managers; industry; and end users. For example, the ADF identified stakeholders and their roles associated with the NCW Roadmap, as shown in Figure 4 [12].

³ That is, undersea and surface targets.

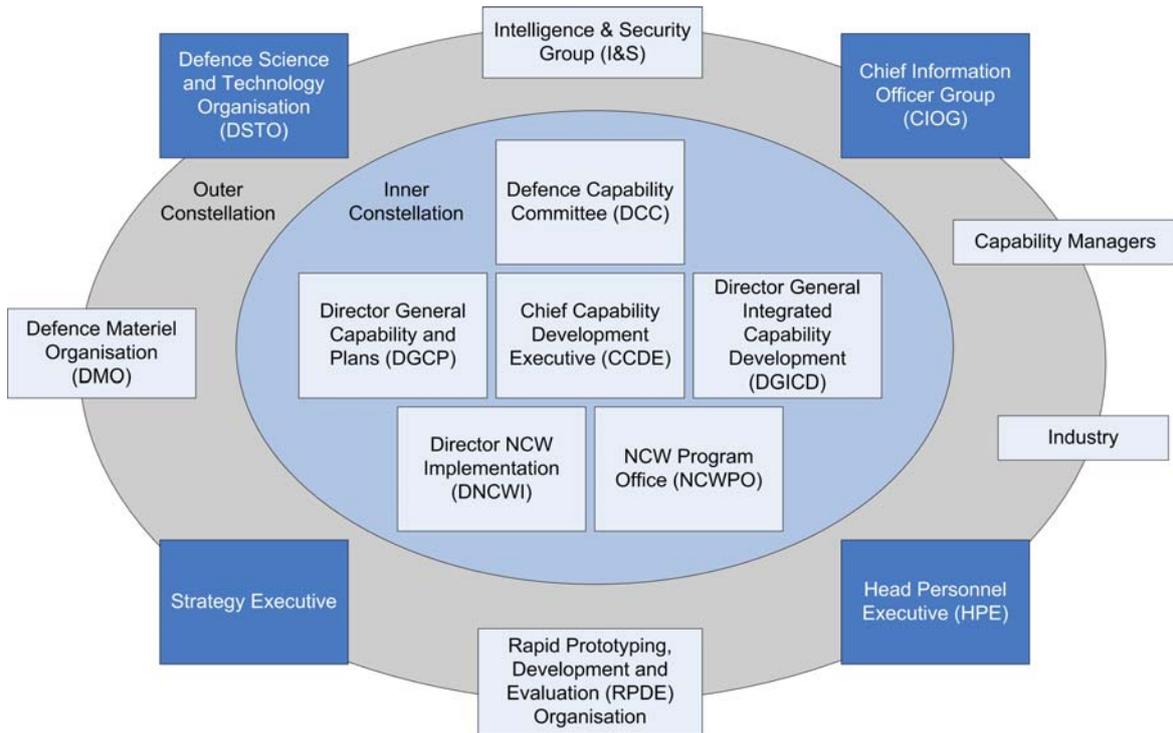


Figure 4: ADF NCW stakeholders [12]

Additionally, a Skill/Will Matrix [21], shown in Figure 5, may be utilised to analyse and identify stakeholder participation in relation to S&T planning. The Skill/Will matrix is a useful aid to identify stakeholder groups that might progress or hinder a project. Elements of a Skill/Will matrix are defined as (after [21]):

1. 'Laggards' are those who lack the skills and are not willing to participate. They will act as followers to the strategy.
2. 'Defendants' have an interest in participation but their objective is to preserve the present situation. Attention should be given to counteract their eventual opposition;
3. 'Supporters' are willing to participate to enable the innovation but lack skills.
4. 'Champions' are the most important participants in the strategy and may even have a leading role. They react positively to innovation and have skills to make the change happen.

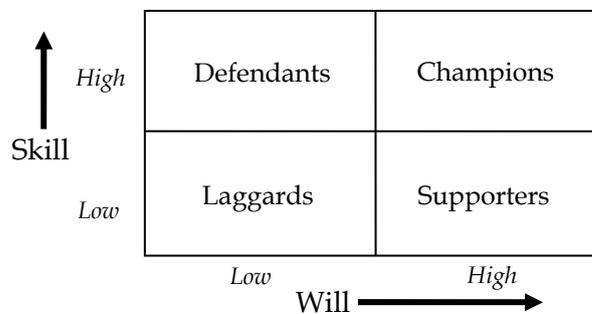


Figure 5: The general format of a Skill/Will Matrix (after [21])

It is important to therefore consider who will be utilising the outcomes and the purposes for which those outcomes will be utilised, since outcomes relevant for one stakeholder group may not be relevant to another stakeholder group. It is also important to involve the stakeholders in performing the S&T planning analysis to enable ownership, resulting in a more 'hands-on-approach' for the analysis. However, publication of the Skill/Will matrix to stakeholders must be handled with care. Stakeholder perceptions of their assigned ratings within the Skill/Will matrix are not addressed within the literature. It is recommended that the use of the Skill/Will matrix be utilised solely by the S&T planners to identify the role of stakeholders and the matrix not be published.

To provide the full range of S&T support, the capability acquisition project might require partnerships to access the full range of skills, knowledge and information. Partnerships between the DSTO and industry have been important during historical acquisition projects and allowed for the combining of complementary capabilities of the two providers. The services of universities are mostly of value in the development of new system concepts, although they may sometimes provide specialist services for testing and diagnostics.

4.4 Constraints

Constraints impede delivery of objectives and are not necessarily limited to lack of resources but may relate to policy and risk mitigation. Documenting constraints ensures stakeholders do not have unrealistic expectations of the acquisition project and/or the platform being acquired. Constraints include: project implementation details; Government policies; program timelines; acquisition, build and sustainment strategies; consideration of which FIC are within planning scope; program costs; through-life capability objectives; survivability requirements; and staffing constraints. Constraints for consideration within an acquisition project are described in the following subsections.

4.4.1 Timeline

The planned S&T activities will be delivered in time to contribute to the decisions that are evolved from the acquisition strategy timeline. Therefore, expected completion dates may be a critical constraint on the S&T program and the S&T objectives will need to reflect this. Decision timeframes may be defined as:

1. *Early*: decisions that need to be made early and are important because they influence many other aspects of the capability design. They have long technology refresh rates and have long development lead-times;
2. *Delay*: decisions that would be more appropriate to make at the latest possible stage in order to exploit ongoing evolution or maturity. They either have lower levels of design interdependency with other technologies/systems or the interdependency can be managed. Even though detailed design for these items⁴ is deferred, allowance for their influences on the overall platform design will need to be made earlier in the

⁴ Including items such as: estimated power, volume and weight budgets; interface requirements; operator and maintainer workload estimates; and upgrade strategy.

design process. There will be some level of design risk that may need to be accepted due to the uncertainty;

3. *At Convenience*: decisions with relatively short lead-times and low interdependencies that can be made at convenience;
4. *Urgent Facilities Required*: it will be necessary to establish facilities (with local investment or via securing access to international facilities) that have a technology refresh rate of five years or more. This is based on the assumption that it will take five years to establish each facility and that development of the technology will require half to one refresh rate cycle to mature any advancement to a suitable level for incorporation into the project; and
5. *Plan Upgrade*: identifies technology areas that are early design items and are subject to obsolescence. This will avoid degraded sustainment of capability due to some technology areas that may require midlife, or earlier, upgrades.

However, it is not possible to be precise with the timing of when particular S&T support will be required until acquisition strategies have been considered, with each strategy having significantly varying requirements in the scope and timing of the required S&T support. In some instances, the capability acquisition project office must decide whether to accept aspects of the S&T program recognising that the results may not eventually be exploited or to risk progressing without that aspect being included in the S&T program.

Having a view of the likely acquisition timeline is particularly useful since it allows consideration of when S&T outputs are able to be introduced into the capability. It is clear that S&T outputs that are unable to be practically introduced in a build or upgrade program are indicative of wasted S&T resources.

4.4.2 Acquisition Strategy

RAN platform build strategies will vary from one capability to the next and will be guided by Australian government policy. The build strategy may need to consider both continuous/evolutionary build processes as well as a batch build process that includes a mid-life upgrade. The S&T program may also need to incorporate activities that consider a MOTS or Modified MOTS option as well as developmental acquisition strategy. Within these build strategy options, various sub-system acquisitions may be considered to be off-the-shelf (that is, non developmental) however, system integration and through-life management issues will need to be considered. Examples of off-the-shelf systems may include:

- propulsion motors;
- generators and power converters;
- combat system sensors and weapons;
- communications systems (internal and external);
- pumps, hoses and cabling;
- galley systems (cooking and food storage); and
- heating, ventilation and air-conditioning (HVAC).

For the continuous/evolutionary build process, it is accepted that later build platforms will receive upgraded systems and the earlier platforms would receive upgrades at suitable times during their service life. This will result in variations in class baselines and will require

ongoing design, integrated logistics support (ILS) and training. Technologies that are included in the continuous/evolutionary build process are assumed to have a separate technology development program from the product development program. This would then make the framework conform to the recommendations by the USA's Government Accountability Office (GAO) in their review of the USA's Department of Defense (DoD) Technology Readiness Assessment (TRA) procedures [22].

Therefore, the acquisition strategy will constrain the S&T program, requiring recognition in the S&T objectives. A lack of an agreed acquisition strategy will result in uncertainty in defining S&T program deliverables and the expected delivery schedule. While this will not in itself interrupt the S&T planning activities, it is possible that S&T resources will be wasted by focussing on S&T issues that are subsequently found to be outside the project scope or are inconsistent with the timing of key decisions. It is assumed that the S&T Plan will provide support for such technologies through the life of the platform.

Even when the acquisition strategy is undecided during the early stages of the project, having potential acquisition models described within the associated time-lines will facilitate the development of S&T plans that are adaptable and relevant to each potential acquisition strategy.

4.4.3 Capability Objectives

Capability objectives will be established during analysis of the *Defence White Paper* [20]. Tools, such as *Decision Maker* [23], to perform trade-off analysis between capability, cost risk, evolvability and capability growth margins may need to be utilised for qualitative and traceable decision making.

4.4.4 International Relationships

It is assumed that the Australian government will provide guidance regarding aspects of Australia's alliance and international relationships that will need to be considered as part of the specific RAN capability acquisition program deliberations.

4.4.5 Free Trade Agreements

It is possible that Australian government policy will establish a minimum level of Australian content for specific acquisition projects and will provide guidance regarding the applicability of, and obligations to, Free Trade Agreements (FTAs).

4.4.6 Minimum Upgrade Cycle Period

It may be assumed that the acquisition program will support regular upgrades of technologies that require upgrades (especially for obsolescence or capability reasons) but these should be packaged so that there is a minimum time frame between each upgrade/replacement activity.

4.4.7 Science and Technology Staffing

Staffing constraints relate to issues such as availability, retention and training. Consider, again, *Project SEA X*. During the capability life-cycle of *Project SEA X*, it might be assumed that up to 8% of ADO staff will depart the organisation, requiring recruitment, redeployment and/or re-training to sustain the *Project SEA X* workforce. The minimum lead-time to develop ADO scientific resources for specialised areas may be assumed to be:

- time to recruit/redeploy/retrain staff: 6 months to 1 year; and
- time to 'skill up' in a specialised area and/or develop client knowledge: up to 5 years, or more.

These lead times were nominally chosen by the authors based on their observation of staff reallocations within DSTO. Refinement of these values would be useful if a suitable evidence based scheme could be established.

4.5 Objectives

Objectives define the desired purpose and goals for the acquisition project [5, 6]. They represent high-level questions to be answered; the desired documentation; the degree of involvement by stakeholders; and the duration of the S&T Plan. Determining the objectives at the outset subsequently allows the S&T planning analysis to be designed with respect to the desired outcomes, outputs and/or constraints. Objectives, guided by the S&T planning focus and vision, incorporate information needs and benefits. Therefore, the objectives for S&T planning for RAN capability acquisition would be to:

1. determine strategic technologies and research and development (R&D) priority areas to enable identification of capability related critical technologies that provide for improved: platform capability edge; survivability; habitability; service life; and through-life costs;
2. develop an S&T planning vision for the capability to identify technology trends and suitable technologies that may be incorporated during the capability's life-cycle. Identification of technology threats is also to be considered. Threats include disruptive technology, that is technology that renders other technology obsolete or those that counteract technology included in the capability design; and
3. facilitate development of S&T policies for the life-of-type, governed by Objectives 1 and 2.

Objectives should incorporate information needs, as well as the benefits of the S&T planning process. For example, the objectives of the ADF's NCW Roadmap were to [12]:

1. define the NCW-related targets and milestones for the ADF;
2. establish the network that will link engagement systems with sensor and command and control systems and provide the underlying information infrastructure upon which the networked force will be developed;
3. develop the human dimensions of the networked force by changing doctrine, training and education to prepare ADF personnel for operating in an NCW environment; and
4. accelerate the process of change and innovation through a Rapid Prototyping, Development and Evaluation (RPDE) capability, in partnership with Industry, in

Objectives of Foresight Planning exercises in the literature include the identification of new commercial products and markets [5, 8] and formulation of national research plans for emerging strategic industries [5].

Objectives will enable the development of strategic S&T policies in support of the development of the capability. For example, there may be an initial need to increase R&D in new technology areas. Later in the capability life-cycle, the research effort may be directed towards life extension of the technology. Resources and related technologies will need to be identified, such as shortfalls in staff knowledge or facilities to conduct appropriate trials testing of technologies.

4.6 Outcomes and Outputs

Outcomes and outputs consist of the intangible effects resulting from the process of performing the S&T planning analysis, as well as the tangible, physical deliverables. Outcomes and outputs are derived from the objectives and contribute to the RAN acquiring a capability utilising state-of-the-art, or at least up-to-date, technology and facilities [5, 6]. The primary output from the RAN capability planning analysis is the actual S&T Plan, however other outcomes and outputs include:

1. recommendations for S&T policy;
2. recommendations for technology areas for inclusion within the capability;
3. critical technology areas and cross impact within the capability;
4. a vision for the future direction for critical technology areas; and
5. identification of key providers of S&T support and advice for the capability.

It is important to relay the outcomes and outputs of the S&T planning analysis to relevant stakeholder groups in a manner appropriate to each group.

5. Critical Technologies

The Foresight Planning processes of the S&T planning framework, Figure 1, identify technology areas that influence acquisition relating to specific capability or sustainment requirements, vulnerabilities or systems. To achieve this, technology areas relevant to the platform capability must be identified, using, for example, such techniques as Work Domain Analysis (WDA) [24]. S&T prioritisation is aided by the definition of criticality measures that relate the technology areas to performance, risk and cost of the provision of capability through life. These definitions are developed by the Foresight Planning practitioner and vary widely in the literature [25], with a set of example measures being presented in Table 1. The next step is to determine the significance of each technology area to capability acquisition, thereby enabling identification of critical technologies. Accordingly, the measures are

assigned values (normalised, say, between zero and ten) by Foresight Planning practitioners working with Subject Matter Experts (SMEs).

For the proposed S&T planning framework presented in this report, assessment of whether a technology area is considered *Critical* is proportional to the *Capability*, *Sustainment* and *Risk* measures. Algorithms developed by the authors to calculate the criticality of each technology area are presented in Appendix A. Criticality thresholds are utilised to establish a nominal subset of technology areas that are critical to the capability. Whilst it might be argued that the inclusion or exclusion of items in the subsets of high-ranking items is based on arbitrary thresholds, the identification of a subset is useful mainly to highlight critical areas. Technology areas that are not identified as critical are considered to be sufficiently managed by technology suppliers or by ad-hoc allocation of S&T effort.

The resulting critical technology list identifies the level of technological capability spanning the near future to the long term future and the priority of each technology for use in a project. This will enable critical technology studies to highlight short-term R&D priorities for RAN capability acquisition decisions makers.

Table 1: Example Measures of Significance (for FIC: “Major Systems” technologies)

Measure of Significance	Definition
Capability	Measures the technology area’s effect on capability. This includes direct influences via the coverage of the technology area on function, as well as indirect influences via functional dependencies.
Cross Impact	Measures the indirect effect that the technology area has on dependent functions. This amounts to how much the technology area is expected to influence the integrated design via its design drivers.
Integration	Measures the degree to which the technology area is subject to influence by other technology areas that have shared functions and design drivers. This can be interpreted as the sensitivity of this technology area to competing demands or conflicting requirements by other systems.
Sustainment	Measures the degree to which the technology area affects sustainment of the capability. A high value indicates that the technology area is vital to ensure cost effective sustainment through-life; whereas a small value may indicate that the technology area is purely driven by the capability itself.
Risk	Measures the potential risk associated with the technology area, comprising the Cross Impact and Integration factors, and allowing for the novelty of proposed technologies in relevant platform applications or the RAN environment in general.
Critical	The critical technology areas are those that are deemed significant according to having a high ranking of <i>Capability</i> , <i>Sustainment</i> or <i>Risk</i> . It is essential that each are well managed for the success of the project.
Cost-effective Edge	Measures the degree to which significant developments in the technology area, that directly resulted in enhanced capability are affordable within the scope of funding by the project. Even if this yields a low score, developments in those technology areas may still become available due to large investment by industry or the greater scientific community.

Consider again *Project SEA X*. Table 2 presents example numerical values (determined by SMEs) for each measure of significance for three *Project SEA X* technology areas. The measures of significance *Capability*, *Sustainment* and *Risk* (defined in Table 1 and utilising the

algorithms in Appendix A) have been used to calculate the single measure *Critical*. In this example, *Project SEA X* technology areas ‘Sensors’ and ‘Hull Materials’ were determined to not be critical; however ‘Corrosion Management’ was deemed to be critical and will therefore appear on the critical technology list identifying technology areas requiring ongoing support during the life of *Project SEA X*.

Table 2: *Project SEA X*: technology area measures of significance assessment

Technology Area	Capability	Cross Impact	Integration	Sustainment	Risk	Critical	Cost Effective Edge
Sensors	2	1	4	0	3	×	2
Hull Materials	3	6	2	2	3	×	3
Corrosion Management	3	6	2	4	3	✓	3

When assessing the technology areas against the measures of significance, it is important to consider:

1. technology evolution – including refresh rates, permanence and obsolescence issues. Table 3 presents technology evolution characteristics relevant for critical technology analysis; and
2. design influencers – a major factor in determining the timing of design specification and technology de-risking is if the technologies have strong, widely varying demands on major design parameters. Table 4 defines design influence characteristics for *Project SEA X*.

Table 3: *Technology evolution characteristics (for FIC: “Major Systems” technologies)*

Technology Characteristic	Definition
Refresh Rate (static, years)	Measures the rate at which static aspects of the technology undergo major evolution in form, function, major interfaces and system demands. Static aspects are those that are typically built-in to the respective platform and are not upgraded during the life of the platform except, maybe, during major upgrades.
Refresh Rate (upgrade, years)	Measures the rate at which non-static aspects of the technology undergo major evolution in form or function. This relates to items that can be upgraded readily, including software upgrades and modular subsystem replacements.
Permanence	Indicates if the technology influencers on the overall design are (effectively) permanent for the life of the platform.
S&T Cost Effectiveness	Refer to definition for <i>Cost Effective Edge</i> in Table 1.
Novelty for Australia	Identifies if the technology has been implemented in a relevant RAN or platform environment.
Obsolescence Issues	Identifies if the technology area is subject to lack of access to technical expertise, equipment suppliers and replacement parts after several cycles of the technology refresh rate. This can include technology involving replaceable components, non-standard equipment, evolving interface standards and small marketplaces.
New Facilities Required	Identifies if new facilities requiring significant investment or establishment time (of approximately five years) are required in order to provide advice at a required level to the project.

Table 4: Project SEA X design influence characteristics (for capability major system technologies)

Design Influence	Definition
Power and Cooling	Identifies if the technology area relates to the overall power, 'hotel load', cooling and thermal management.
Life Support	Identifies if the technology area relates to major factors governing crewing levels, accommodation and life support.
Weight and Balance	Identifies if the technology area is a significant influencer of the weight and balance, stability, margins and ballasting requirements.
Size, Layout and Form	Considers the overall hull-form, displacement, deck layout and major equipment layout.
Networking and Bus	Considers items involving demands on the data bus, sensor distribution and cabling.

Technology evolution characteristics may be determined in consultation with SMEs, or for greater fidelity, by the use of technology trend analysis techniques such as bibliometrics [26]. Design influence characteristics are expected to be tailored to the particular system by SMEs, based on knowledge of factors involved in fundamental design constraints. Since the scope of influence by the acquisition process on the fundamental design of commercial-off-the-shelf (COTS) and MOTS options is limited, the influence characteristics may be reduced to a small set for COTS/MOTS projects.

Table 5 presents technology evolution characteristics and design influences for the major system being acquired in the *Project SEA X* example. Included is a simple decision timeframe, defined in Section 4, to identify the required timing of planning decisions. Input for this table is derived from SMEs and the application of Foresight Planning methods (presented in Section 6). The table contains two technology areas relevant to *Project SEA X*. Consider *Hull Materials*. Here the refresh rate is 30 years and it is a permanent feature for the capability; it is also an early decision requirement with a need for facilities to perform test and evaluation. Hull material cannot be upgraded during the life of the capability and therefore the refresh rate must be evaluated against the major system's life-of-type requirement. Note, construction of the major system cannot commence until hull material is evaluated; a delay in selecting appropriate material will affect the acquisition strategy schedule.

6. Sectoral Analysis

Sectoral analysis consists of studies conducted by industry and the DSTO in critical technology areas. Sectoral analysis will assist in identification of:

- technology drivers – key features and characteristics, including disruptive technologies; local industry manufacturing skills; and the level of knowledge;
- timing – technology evolution and obsolescence issues; refresh rates; potential key advancements in the technology during the life of the platform; and
- providing S&T advice – the ability of provider sectors to supply advice in relevant technology areas; existing or new facilities required to support the technology area; and intellectual property.

Table 5: Foresight planning analysis: technology evolution characteristics and design influences

Technology Area	Technology Evolution			Other Decision Issues			Design Influence					Decision Timeframe					
	Refresh rate, static (years)	Refresh rate, upgrade (years)	Permanence	S&T cost effectiveness	Novelty for Australia	Obsolescence issues	New facilities required	Power, Cooling	Life Support	Weight and Balance	Size, Layout and Form	Networking and Bus	Early	Delay	At convenience	Urgent Facilities Required	Plan Upgrade
Sensors (Sonar)	8	4	✓	✓	✓			✓		✓	✓	✓	✓				
Hull Materials	30	30	✓	✓			✓		✓	✓		✓				✓	

There are several indicators associated with the provision of S&T advice and for determining the readiness of the technology. The primary indicators are the STAC Level and the Technology Readiness Level (TRL) and they are defined in the following subsections. Other indicators that may prove beneficial, but not documented within this report, are the Manufacturing Readiness Level (MRL) [27], System Readiness Level (SRL) [28, 29] and Integration Readiness Level (IRL) [28]. It is recommended that further study of the literature and the application of MRL, IRL, SRL and other related readiness level metrics be performed to identify their suitability and relevance for application in individual capability acquisition S&T planning.

6.1 Science and Technology Advice Capability (STAC) Level

The concept of the STAC Level was established for the purpose of the S&T planning exercise to assist with identification of knowledge gaps that may need to be addressed. The STAC Levels identify the ability of a technology provider sector to supply specific technology advice. It may not be necessary for DSTO to have high STAC Levels across all relevant platform technology areas, especially when there are trusted support organisations with high STAC Levels. STAC Levels, defined in Table 6, may influence aspirations to develop long term knowledge and in-country capability. Therefore, the STAC Levels can be utilised when applying Foresight Planning methods to identify and investigate relevant and/or critical technology areas specific to the capability acquisition. Minimum STAC Levels for each technology area and acquisition phase are specific to, and determined by the needs of, respective acquisition projects. In particular the acquisition of COTS or MOTS systems involving mature technologies would potentially allow for lower minimum STAC Levels than would a bespoke design.

Table 6: STAC Level definitions

STAC	Definition
0	Insufficient knowledge to provide meaningful advice.
1	There is awareness of the technology and knowledge of advancements in the technology area is being maintained.
2	Along with STAC 1, there is an understanding of the technology such that: the principles of the technology can be explained; there is an ability to operate it; and/or there is an ability to understand the underlying science.
3	Along with STAC 1 and 2, there is the ability to: specify the requirements of the technology; understand what the technology is capable of achieving; and understand what is required of the technology.
4	Along with STAC 1, 2 and 3, there is also the ability to design and perform innovative R&D in the technology area.

Figure 6 presents suggested minimum STAC Levels required for technologies during phases of an RAN capability acquisition project. Included in Figure 6 is consideration of the Priority Industry Capabilities (PICs), which are defined as ‘industry capabilities which would confer an essential strategic capability advantage by being resident in Australia, and which, if not available, would significantly undermine defence self-reliance and ADF operational capability’ [30]. At the time of writing the required minimum STAC Level for the PICs is unknown but is anticipated as being STAC Level 4. Example minimum STAC Levels that may be required by the Commonwealth of Australia (CoA) in order to support project decisions for *Project SEA X* are defined in Table 7. These levels were nominally chosen by the authors in consultation with DSTO group heads and research leaders. Refinement of these values would be useful if a suitable evidence based scheme could be established.

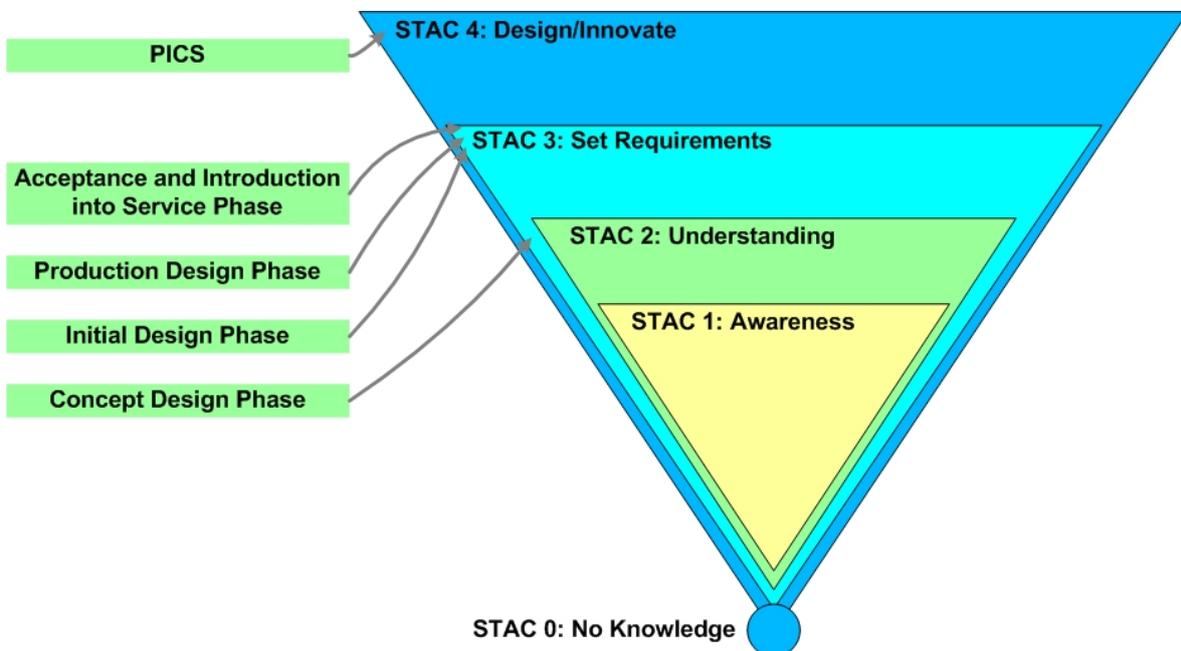


Figure 6: Suggested minimum STAC Level required for technologies during phases of an RAN acquisition project

Table 7: Minimum STAC Level requirements for technologies during phases of Project SEA X

Phase	Importance	Minimum STAC Level Required
Concepts Design	Critically Important Technology	2
	Non-critical Technology	2
Initial Design	Critically Important Technology	3
	Non-critical Technology	3
Acceptance and Introduction into Service	Critically Important Technology	3
	Non-critical Technology	3

6.2 Technology Readiness Level

The TRL is measured on a scale of one to nine to assess the maturity of technology [31, 32]. A brief description of each level is presented in Table 8, with expanded definitions presented in Appendix B. TRLs can be applied during the S&T planning process to determine technology maturity levels and maturation time lines for critical technology. This will assist the decision-making process for the inclusion of relevant technology during a capability's life-cycle.

Table 8: TRL definitions [31, 32]

TRL	Definition
1	Basic principles observed and reported.
2	Technology concept and/or application formulated.
3	Analytical and experimental critical function and/or characteristic proof-of-concept.
4	Component and/or 'test bed' validation in laboratory environment.
5	Component and/or test bed validation in relevant environment.
6	System/subsystem model or prototype demonstration in a relevant environment.
7	System prototype demonstration in an operational environment.
8	Actual system completed and qualified through test and demonstration.
9	Actual system proven through successful mission operations.

The TRL can be utilised when applying Foresight Planning methods to identify and investigate relevant and/or critical technology areas specific to the capability being acquired. Based on the principles of Best Practice from the USA's DoD [22], the suggested minimum TRL required of a technology prior to being considered for inclusion in each stage of a capability acquisition project is presented in Table 9.

Table 9: Suggested minimum TRL requirements for consideration of technology inclusion during RAN capability acquisition project phases

Phase	Requirement	TRL Required
Concepts Design	A Technology Maturation Plan must be established.	≥ 3
Preliminary Design	A Technology Maturation Plan must be established.	≥ 6
Project Design	Technology Maturation Plan.	≥ 7
	No Technology Maturation Plan.	≥ 8

6.3 Foresight Planning Methods

Numerous Foresight Planning methods may be utilised to assist the identification of technology trends, integration issues and priority technology areas that influence key design decisions; capability edge; and capability risk. Foresight Planning methods are well documented in the literature [5, 6] and their application in the development of S&T Plans is not unique. Tools also exist to assist the selection of appropriate Foresight Planning methods [5]. The methods identified as being most suitable in relation to S&T planning and sectoral analyses are described in the following subsections. The final subsection presents a method for selecting appropriate Foresight Planning methods.

Due to resource constraints, only some of the following methods were utilised by the authors when performing the S&T planning exercise for *Project SEA X*. The expanded set of methods is included here since they form a recommended set for consideration in future S&T planning exercises. Production of Foresight Planning data involving subjective judgement by the authors for *Project SEA X*, such as cross-impact matrices, was independently verified by other suitable DSTO staff.

6.3.1 Technology Roadmap

The Technology Roadmap is a tool that allows for detailed projections for the future of S&T, products or the environment [34]. It generally commences with a desired vision of the future and then examines ways to achieve that future. The Technology Roadmap facilitates the linkage of strategic product and technology plans in a graphical or tabular format as the focal point of strategic planning documents or business cases [14]. According to Phaal *et al.* [14], the aim of a technology roadmap is to answer three questions:

1. Where are we going?
2. Where are we now?
3. How do we get there?

Technology Roadmaps can take many forms and have been applied extensively across many disciplines [7, 13, 35]. For example, a Technology Roadmap can be related to product planning for the insertion of critical technologies into a manufactured product. A generic example of the product planning Technology Roadmap is shown in Figure 7. In Figure 7, technology is continuously being developed and may be included in the development of other technologies when mature. The figure also shows that at appropriate times in the development of technologies they will be included in product design.

Technology Roadmaps provide clarity of detail, relevance and a focal point for the information displayed.

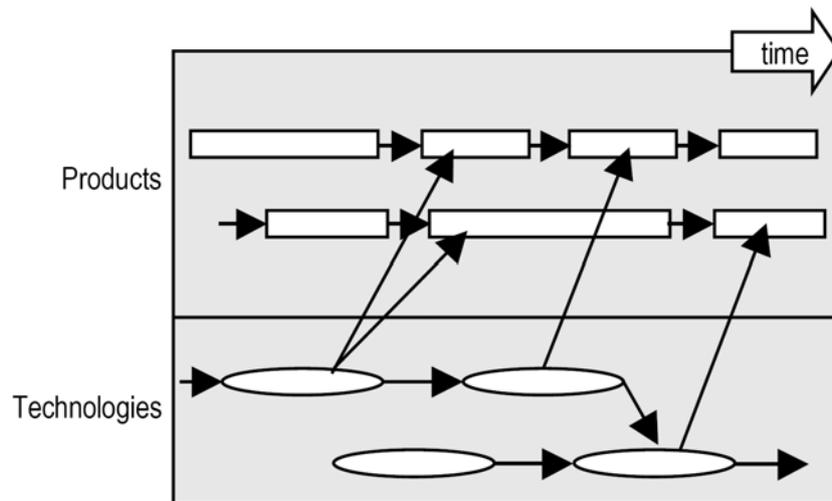


Figure 7: A product planning technology roadmap [36]

6.3.2 Delphi Survey and Nominal Group Technique

A Delphi Survey is a consensus technique drawing upon input from its participants, usually SMEs, thereby forming a collective opinion of the future. The Delphi Survey is conducted over several rounds, with each round refining the opinion of the previous round [34]. During the Delphi Survey, SMEs complete a questionnaire and provide reasons for their forecasts. The results of the surveys are then presented to the participants and they are requested to respond, hopefully providing new information relating to another SME's response [37].

A Delphi Survey is resource intensive – requiring time, labour and SME preparation. For example, a single survey round can take up to three weeks. However, including preparation time, several rounds of questionnaires and collation of results, a Delphi Survey can take half a year to complete [34]. If there are time constraints, or the pool of SMEs is limited, a Nominal Group Technique (NGT) may be applied [38]. NGT consists of a set of procedures for structuring group meetings to 'brainstorm' and initiate group decision-making to facilitate the generation of ideas and identify issues. The procedure consists of five steps [38]:

1. participants independently and silently generate a list of ideas;
2. the facilitator records one idea at a time from participants in a round-robin format until all participants have completed their list;
3. participants discuss each idea for clarification only, without critical evaluation or lobbying;
4. participants independently rate and rank the ideas; and
5. the group decides the priority ordering of the alternatives based on voting and mathematical pooling of the individual rankings.

When performing the Foresight Planning exercise in relation to *Project SEA X*, the authors surveyed SMEs within the DSTO and industry representatives at a relevant science and technology conference and exhibition, enabling them to collect data for further analysis.

6.3.3 Environmental Scanning and Monitoring

Environmental scanning and monitoring involves identifying early warning signals regarding important future technological changes, such as threats or opportunities [34, 39]. Environmental scanning and monitoring is not necessarily a Foresight Planning method as such but it can form the basis of a Foresight Planning exercise [34]. The process of environmental scanning and monitoring involves: reading the news; reading 'web logs'; attending conferences and events; site visits; searching the world wide web; preparation of literature reviews; and scanning for triggers that may have a future technological impact.

6.3.4 Scenario Building and Analysis

Scenario Building develops a series of alternative futures or aspects of possible futures [34, 40]. Scenarios are used to reveal the choices available and the consequences of each choice, based on assumptions, facts and trends. This allows decision-makers to consider the range of plausible futures, the implications and to simulate the impact of their decisions. The method usually identifies future scenarios, ranked according to impact and likelihood. *Scenarios Europe 2010* [41] and *Air Force 2025* [42] provide examples of scenario building and the method of application.

6.3.5 Trend Extrapolation and Hindsight

The aim of trend extrapolation is to identify historical trends and project them into the future, utilising data on rates of change and the extent of the change [34].

Hindsight is a method used to identify crucial factors in the successful development of technologies. For example, hindsight has been used by the United States (US) Army to examine critical technology events in the development of four current US Army weapons systems (M1 Abrams tanks, AH-64 Apache helicopter and the FIM-92 Stinger and FGM-148 Javelin missiles) to understand the reasons behind their successful development [43].

6.3.6 Backcasting

Backcasting is a technique that analyses a desirable future and determines the possible solutions to achieve such a future [34, 44]. The reasoning being, having defined a strategic objective, it would be possible to work backwards and determine the policies required leading to that desired objective. It is a method usually utilised in complex situations involving many stakeholders and the means of achieving a future vision is unclear. The outputs include a shared vision of the future; pathways to that future; and an in-depth economic, cultural and technological analysis of the pathways [34].

6.3.7 Expert Panels

This is a method to obtain SME knowledge. Expert Panels usually consist of groups of twelve to twenty SMEs who are given three to eighteen months to deliberate upon the future of a given topic [34]. Even though the output is a consensus of key issues or a means to identify

priorities, the Expert Panels method is expensive (budget and resources) and is difficult to perform.

6.3.8 Modelling and Simulation

Modelling and Simulation (M&S) is the use of mathematical models to mimic real world systems. A model is a simplified representation of the real world system, incorporating a set of assumptions relating to the system [45]. A simulation is the temporal imitation of the operation of a real world system, involving the generation of an artificial history to analyse the operating characteristics of the real world system [45].

Simulation Based Acquisition (SBA) [46] is a concept being utilised in commercial organisations, and some defence organisations, to manage M&S resources during the acquisition and through-life support phases of a project. The benefits include the [46]:

- continuous evaluation of system development;
- rapid evaluation of concept design;
- reduction and delayed need for physical prototypes;
- efficient development and evaluation of manufacturing plans;
- re-use of system software and hardware in system simulators; and
- ability to test the proposed system at sub-component, component and system level.

The application of SBA assists in attaining and monitoring required knowledge levels during a project's development and through-life to disposal.

6.3.9 System Dynamics

System Dynamics investigates and models complex problems in terms of stocks, flows and feedback loops [34]. It is used to find the conditions under which a system will evolve and in what direction, looking at the inter-relationships between the components rather than looking at the components in isolation [34]. The aim is to identify causes for system behaviour within the system. System Dynamics models cause and effects and could be used as a practical tool during the policy making phase to determine future funding and resource requirements.

6.3.10 Cross Impact Matrix

Cross Impact Matrices consider events and developments and their influences on each other [34, 47, 48, 49]. The method explores future behaviour of a given system, utilising a systematic description of all the potential modes of interaction between the variables of the system and analysing the inter-relationships. It is used to evaluate changes in probability of occurrence of a given set of events based on the occurrence of any one of them [34]. An example layout for a Cross Impact Matrix is given in Table 10 [49].

In Table 10 there are four events, each with an initial probability of occurring. If an event occurs, there is a probability of it triggering a follow-on event. For example, if Event 3 occurs there is a 0.60 probability of it triggering Event 4. Further matrices are then developed from the Cross Impact Probability Matrix in order to develop a model of event interaction tracing the chain of events resulting from a given cause.

Table 10: Cross Impact Probability Matrix [49]

If This Event	Initial Probability	1	2	3	4
Event 1	0.25		0.50	0.85	0.40
Event 2	0.40	0.60		0.60	0.55
Event 3	0.75	0.15	0.50		0.60
Event 4	0.50	0.25	0.70	0.55	

6.3.11 Structural Analysis

Structural Analysis highlights key variables that influence the problem space. The method makes use of Cross Impact Matrices to determine the causal relationships between the variables [34]. It is a method used to understand the inter-dependencies of each technology area and thereby understand integration costs, the overall performance and timing of inputs and key decisions. It also allows for estimation of the integrated system complexities. In some applications, Structural Analysis is used to analyse the overall system structure (including market forces and consumer behaviour).

6.3.12 Morphological Analysis

Similar to Backcasting, Morphological Analysis commences with a desired future and the aim is to then identify the solutions (such as circumstances, actions and/or technologies) required to achieve that future [34, 50].

Morphological Analysis involves mapping options to obtain a perspective of possible solutions, that is identifying and investigating the set of configurations in a given problem space. It is a technique useful for identifying new product opportunities. Morphological analysis involves the use of a multidimensional matrix containing all existing and future possible solutions [19, 50]. Analysing the matrix will identify those configurations that are possible, viable, practical and/or interesting [51]. Table 11 presents a morphological analysis matrix for a Swedish Airborne Combat Capability [52]. The matrix consists of those fields deemed necessary for an Airborne Combat Capability (across the top) and the blue shaded cells represent one possible configuration of the Airborne Combat Capability. The red shaded cell signifies a compulsory capability requirement. The matrix allows for the determination of requisite knowledge that may have been lacking and what systems of variables are dependent on how the Airborne Combat Capability should be configured.

6.3.13 Relevance Trees

Relevance Trees also commence with a desired future and the aim is to identify the solutions (such as circumstances, actions and/or technologies) required to achieve that future [34, 50]. Relevance Trees decompose a broad topic into smaller subtopics, revealing all possible paths to an objective. It should also provide a forecast of costs, durations and probabilities for each element [34].

Table 11: Morphological matrix for a Swedish Airborne Combat Capability [51]

Task and milieu for Airborne Unit as whole	Task and milieu for Airborne Ground Combat (AGCU)	Combat system for ACGU	Number of combat helicopters (75% availability)	Unit's effective Range	Command and Control (C&C)	Degree of collective training	Personnel and preparedness time	External support: time and degree of precision	External support: range
Engage mechanised brigade in open terrain	Retard armoured tank units in open and covered and partially covered terrain	Light infantry	2 companies (16 helicopters)	Up to 100km	Single overall organisational C&C unit	High	Full time employed 48 hours	Precision strikes within minutes	100km
Engage all units in open and partially covered terrain	Engage advanced units in urban milieu	Combat system 2005-2010	1 company (8 helicopters)	Up to 150km	No overall organisational C&C unit	Medium	Conscripts 10 days	Precision strikes within a few hours	150km
Take and hold terrain in urban and partially covered milieu	Take bridgehead. Partially covered and urban terrain	Combat system 2015-2010	None	Up to 200km		Low	Contract 30 days	Saturation strikes within minutes	200km
Engage advanced units in urban terrain	Relief/rescue operation			> 200km				Saturation strikes within a few hours	> 200km
Rescue and evacuate	Surface surveillance - Target designation								
Supervise and support mission in open and partially open terrain									

Figure 8 presents a relevance tree developed by the US Office of Technology Assessment used in an assessment of alternative economic stockpiling policies [53]. This particular relevance tree examines the question of 'why stockpile?' while other relevance trees might examine how stockpiling might be accomplished and/or the alternatives to stockpiling.

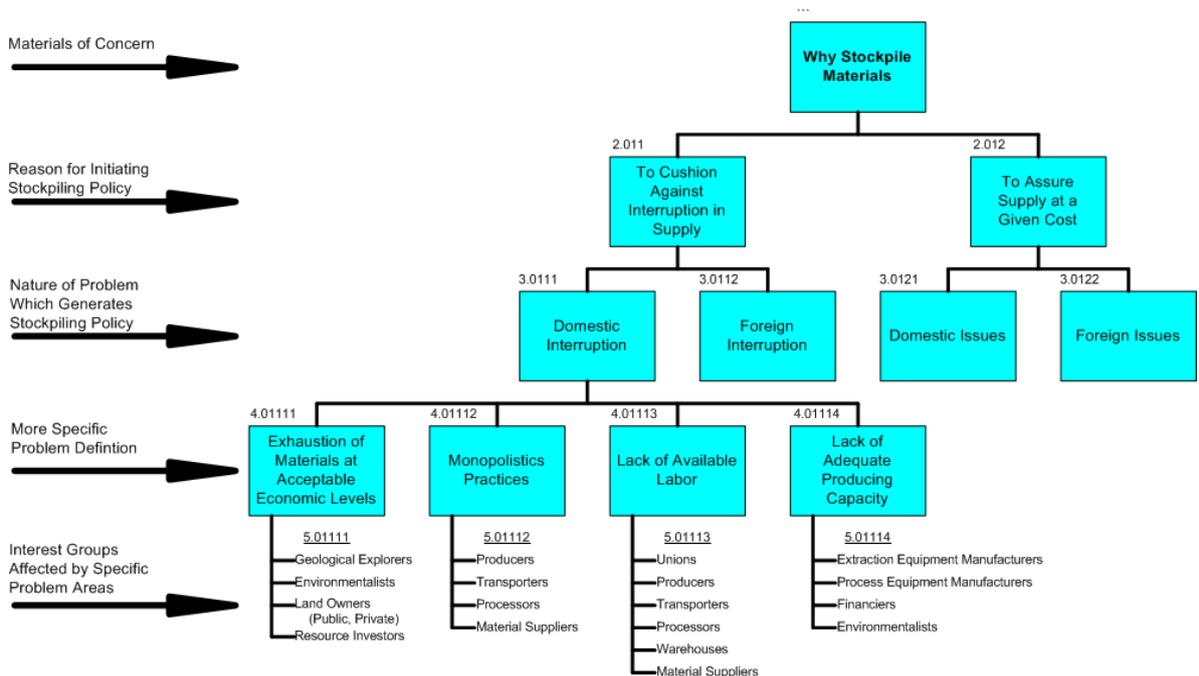


Figure 8: Relevance tree used in assessing alternative stockpiling policies [53]

6.3.14 Portfolio

The portfolio method is a multi-variable graph designed to highlight the relative importance of emerging technologies and their potential for success during a given time frame. Portfolio management assists with project prioritisation and resource allocation when there are number

of projects in development [54, 55]. Cooper and Edgett [54] define four goals in portfolio management:

1. maximising the value of a portfolio;
2. seeking the right balance of projects;
3. ensuring that the portfolio is strategically aligned; and
4. ensuring there are not too many projects for the limited resources.

To assist with portfolio management the use of 'bubble diagrams' and pie charts facilitate in determining the allocation of resources across the projects in the portfolio. Figure 9 shows an example bubble diagram developed by the RAND Corporation on behalf of the US Operations Analysis Program of the Office of Naval Research. This bubble diagram represents, for example, the value of a capability to the military; the extent to which the performance potential matches the capability requirement; and the probability of transitioning the project to the military [54]. These three factors contribute towards an Expected Value (EV) highlighting the overall value of each project. The size of the bubbles adds an extra dimension to the portfolio and can, for example, represent the level of investment in a project [55]. In the case of Figure 9, the bubble indicates the spread of values for each project [55]. In Figure 9, Projects 3 and 6 are high valued capabilities with good probability of transition and are therefore good investments. Project 1 is a high valued capability but has low probability of transition. The decision then needs to be made if investing in the project will improve the probability of transition.

A portfolio chart that may be useful in relation to RAN capability acquisition, presents the portfolio items on axes of capability versus STAC Level. Given that it is expected that the STAC Level should be proportional to capability, then this chart would indicate at a glance those S&T areas that over or under resourced.

6.3.15 Quality Function Deployment

Quality Function Deployment (QFD) is not strictly a Foresight Planning tool but it does allow for identifying and translating customer requirements into technical specifications for product planning, design, process and production [56, 57, 58, 59, 60]. The general QFD method consists of [56, 60]:

1. determining the qualities desired by the customer;
2. determining the functions required to provide those qualities; and
3. identifying the process for deploying the resources to provide those qualities.

To achieve this, a QFD matrix provides a framework for representing and analysing the relevant information. An example of applying QFD can be found in the USA's DoD SBA briefing [61].

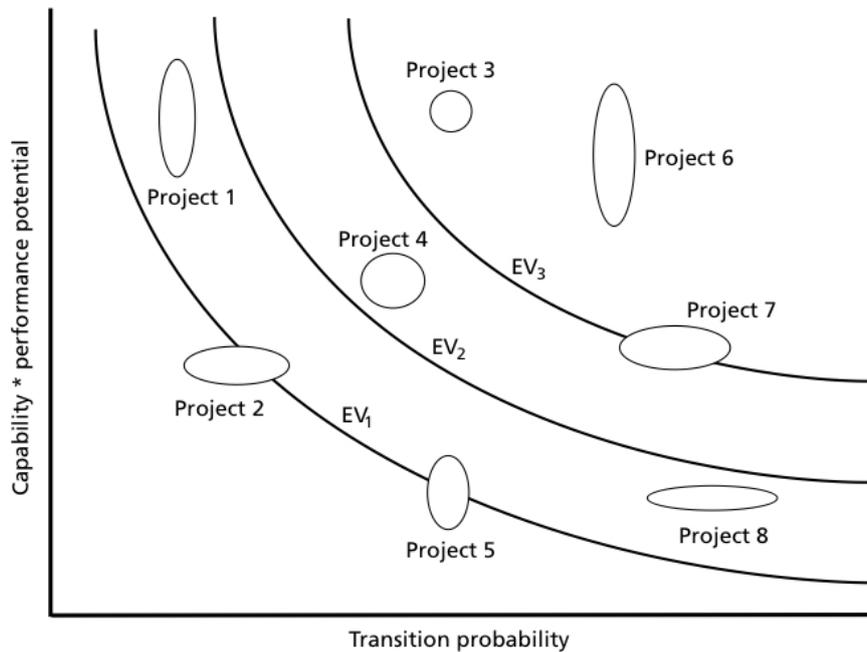


Figure 9: Portfolio of probability of transitioning an R&D developed capability into service [55]

6.3.16 Mind Maps

Mind Maps are a method for note-taking and the generation of ideas by association. A Mind Map consists of a main idea from which stems an organised structure of key words and images. In this way, information is organised with the intention of mimicking the brain's natural way of thinking [62, 63]. Figure 10 shows an example Mind Map generated for the preparation of this report. Within this Mind Map, each 'cloud' represents a set of ideas that are to be presented in the report. Mind Maps are not static and evolve as required.

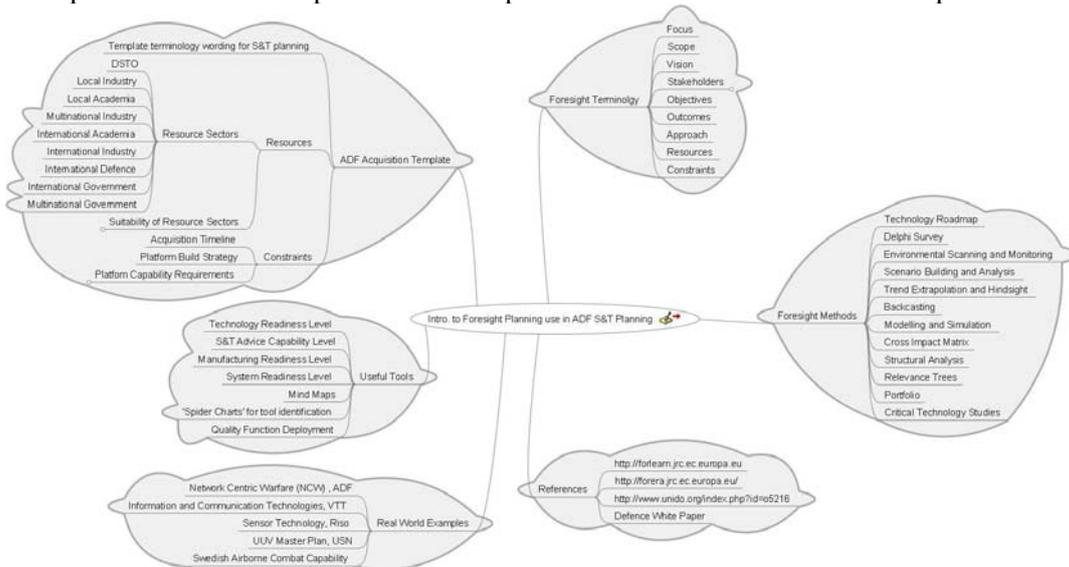


Figure 10: Mind Map showing subject areas and sub-topics to be presented within this report

6.4 Selecting Appropriate Foresight Planning Methods

An evaluation tool, provided by *Forelearn* [33], utilises ‘spider charts’⁵ to graphically represent performance areas of, for example, an organisation, product or method by highlighting strengths and weaknesses within the various performance areas. The same spider charts may then be utilised to also include the strengths and weaknesses of the various Foresight Planning methods. Comparison of the performance areas of the organisation, product or method with the strengths and weaknesses of the Foresight Planning method enables easy selection of an appropriate Foresight Planning method to achieve the desired goals for the performance areas of the organisation, product or method. An example of such a spider chart is presented in Figure 11 with Table 12 presenting the performance areas of relevance to potential Foresight Planning methods for use in capability acquisition S&T planning analysis [33]. Here the solid red and blue areas represent the strength and weakness for the Foresight Planning method ‘Technology Roadmap’. The lightly shaded areas in Figure 11 represent the performance areas for the objectives (the spider chart on the left in Figure 11) and constraints (the spider chart on the right in Figure 11) of an organisation, project or method. In this case, the lightly shade areas of Figure 11 represents the performance requirements for *Project SEA X* and the performance areas listed in Table 12 are exemplars representative of the possible objectives of the acquisition project [33]. Table 13 presents the exemplars representative of the possible constraints of the acquisition project [33]. Further examples for other Foresight Planning methods are presented in [33].

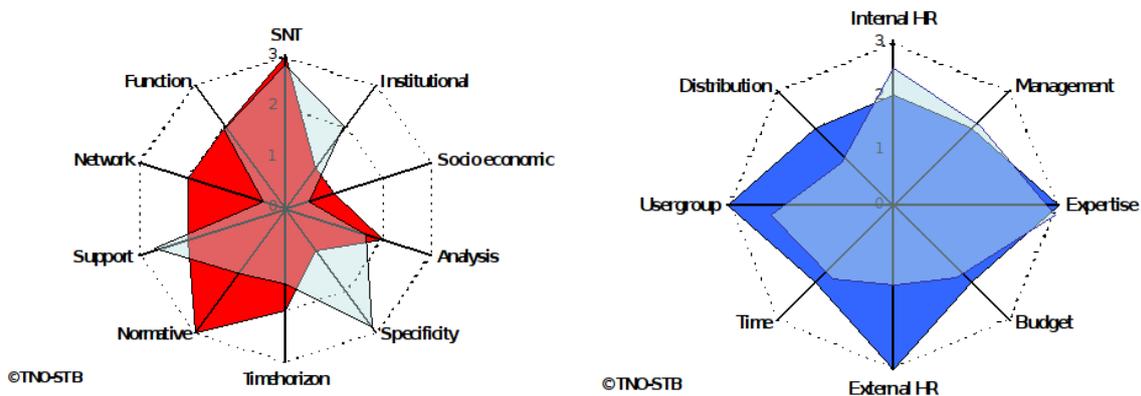


Figure 11: Spider chart for Technology Roadmap [33]

⁵ Also known as a kiviati diagram, cobweb chart, radar chart and star chart, amongst others.

Table 12: Performance areas, representing objectives, for measuring the relevance of Foresight Planning methods to the RAN acquisition project [33]

Dimension		Description
Objects	S&T	The extent views on main S&T developments are the objective.
	Institutional Aspects	The extent the institutional dimensions are perceived as important objectives.
	Social-economic aspects	The extent social and economic aspects are perceived important objectives.
Content	Level of Specificity	The level of specificity about the object of foresight needed as input in the policy process.
	Level of Analysis	The level of strategic analysis needed as input in the policy process.
	Level of Normativity	The level of normative values by which policy is driven and a desired future is already set.
	Time Horizon	Time horizons of the policy central to the exercise.
Process	Development of Support	The importance of development of policy support among the main stakeholders?
	Network Development	How important is the development of new interactions and networks?
	Role in Policy Process	How will the results be used in the policy process? Information, strategic intelligence, decision making?

Table 13: Performance areas, representing constraints, for measuring the relevance of Foresight Planning methods to the RAN acquisition project [33]

Dimension		Description
Stakeholders	Management Involvement	The level of management involved in the policy processes (and will be in the foresight exercise).
	Level of expertise	The level of expertise involved in the policy processes (and will be involved in the foresight exercise).
	Commitment of Stakeholders	The extent involvement of external actors/stakeholders is required.
	Geographical Distribution	The geographical distribution of the stakeholders.
Resources	Involvement of External Actors	The extent external stakeholders are able/willing to invest time in the Foresight Planning exercise.
	Internal Human Resources	The amount of internal human resources available to the foresight exercise.
	Budget	The available budget for the foresight exercise.
	Time Scheme	The time available for the foresight exercise.

7. Science and Technology Providers

Resources define boundaries that limit objectives and preclude some activities. Resources to support S&T activities originate from a number of provider sectors, each having unique strengths, characteristics and constraints. Categories of provider sectors to be considered for RAN capability acquisition are presented in Table 14, with the suitability of provider sectors to supply S&T resources determined by considering the constraints defined in Table 15. Identification of suitable providers that can service each S&T area supports the appropriate allocation of resources such that expenditure is cost effective (an obligation for publicly funded projects), that access to S&T advice as required may be secured, and that issues of security and intellectual property access may be appropriately managed.

Requirements analysis of critical technologies, such as performing sectoral analyses and application of Foresight Planning methods, will provide the necessary information for considering each constraint in Table 15. Evaluating potential provider sectors, for respective critical technology areas, is a relationship that may be expressed, in simplified form, as:

$$\text{Provider Sector Applicability} = \frac{\text{STACAppl.}(\text{Free} + \text{Critical.C}_w + \text{Risk.R}_w + \text{CommercialValue.CV}_w + \text{ThroughLifeSupport.TLS}_w + \text{Security.Sec}_w)}{\text{TechAppl}}$$

where:

- *STACAppl* – Boolean to indicate there is a technology STAC Level requirement;
- *Free*, *Critical*, *Risk*, *Commercial Value*, *Through Life Support* and *Security* – criticality measures derived from the analysis described in Section 3 and defined Table 15;
- C_w , R_w , CV_w , TLS_w and Sec_w – weightings (subjectively assigned) indicating applicability of respective constraints to the provider sector; and
- *TechAppl* – number of technology constraints satisfied for each critical technology area.

Table 14: Sectors capable of providing S&T resources

Provider Sector	Definition
DSTO	The Defence Science and Technology Organisation
National Industry	Australian based industry and multinational industry with an established local presence in Australia.
National Academia	Australian academic and research organisations.
Multinational Industry	Foreign industry (to Australia) with a multinational presence but not in Australia.
International Academia	International academia and government funded research organisations.
International Industry	International industry, with no local presence in Australia.
International Defence	International defence industries.
International Government	International government departments and in-country research organisations equivalent to the DSTO.
Multinational Government	Multinational technical and research organisations, for example: The Technical Co-operation Program (TTCP) and the North Atlantic Treat Organisation (NATO).

Table 15: Technology applicability constraints to determine provider sector suitability

Constraint	Definition
Critical	Identifies if the technology is established as of critical significance (see Section 3).
Risk	Identifies if application of the technology is associated with significant potential risk (see Table 1).
Commercial Value	Identifies significant commercial value for application outside the acquisition project, to identify areas where investment by the acquisition project may have national wealth building benefits. It is also attractive for industry with non-Defence customers; or export potential is likely to be more cost-effective and robust.
Through-life Support	Identifies if access to advice concerning the technology area is expected throughout the platform's life. Through-life applicability is assumed to be directly related to whether the technology area is significant with respect to sustainment.
Security	Identifies if the technology area includes designs, systems, specifications, trade secrets and security-sensitive elements requiring management of special access arrangements.
(Free)	Items are unbounded by technology area provider applicability constraints.

The rules governing the relationship between technology constraints and the characteristics of each provider sector are applied to each critical technology area and filtered by the ability of the provider to supply S&T advice at a given STAC Level. The result is a unitless, unbounded value for each provider sector and the greater the value, the more suitable the provider. Where the value is low, the provider is deemed less suitable but may be available if the technology applicability constraints are managed. This results in a provider applicability table, see Table 16, showing the degree to which each provider is suitable for advising the platform acquisition project in each technology area. So, in Table 16, continuing with the *Project SEA X* example, hull material for this platform was deemed to be critical, with no significant technological risk but having commercial value and through-life support requirements. Therefore there were three applicable technology constraints (that is, $TechAppl = 3$). Also, analysts for *Project SEA X* had set a minimum STAC Level requirement for the technology. Application of the aforementioned equation yielded the values presented in Table 16 for the applicability of each provider sector. Here, the DSTO was identified as being the most suitable S&T provider, however various other providers, particularly local Australian industry and academia, may also provide suitable S&T support.

Table 16: Foresight Analysis: alignment of provider sectors with technology areas

Technology Area	Technology Applicability						Provider Applicability								
	Critical	Risk	Commercial value	Through-life Support	Security	(Free)	DSTO	Local Industry	Local Academia	Multinational Industry	International Academia	International Industry	International Defence	International Government	Multinational Government
Sensors	✓	✓					2.0	2.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0
Hull Materials	✓		✓	✓			1.5	1.3	1.3	0.8	0.3	0.2	0.4	0.0	0.6

The process and associated rules and equations to determine provider applicability are presented in Appendix C.

8. Science and Technology Study Drivers

S&T study drivers distil the results from the S&T planning analysis, focussing on: early design decisions with high bearing on the platform acquisition strategy; ability to provide cost effective capability edge; and identifying areas of high risk. Study drivers identify platform requirements and technology provider sectors, for each critical technology area, which may, for example, enable leverage from Australia's allies or identify technology areas best suited for in-country development. Five study driver categories, defined in Table 17, may be used to document the relevant information.

Table 17: Definitions of S&T study driver categories

Category	Definition
Vision	A summary of goals to be achieved by the acquisition project's S&T effort in the technology area.
Significance	Summarises the significance the technology area has on the acquisition project in terms of: capability; sustainment; and risk. It will identify if the technology area compels early design decision making.
Advice Capability	Assesses immediate and ongoing STAC requirements and actual capabilities within the DSTO, national industry and academia. Capability gaps are identified and highlighted for action to build-up. Where the actual capabilities are deficient, potential S&T advice providers are identified by sector. Where there is excess capability, potential areas for trade-off are identified.
New Facilities	Summarises new facilities, including experimental facilities and large-scale modelling and simulation projects, identified as being required for providing S&T advice for the specification, design and assessment acquisition phases. Facilities required to be established in the short term are highlighted. Facilities may not need to be built if access to an equivalent facility elsewhere can be secured.
Options	Available technology options that are expected to be topics of research and assessment.

The S&T study driver summaries present an overview of the special significance of each technology area; the vision for technology development as it applies to the respective acquisition projects; technology options; and the current and required STAC Levels. Furthermore, the S&T study drivers recommend broad courses of action in the short and medium term regarding the development of facilities and improving STAC Levels. The S&T study drivers should be progressively expanded and individually scrutinised in consultation with stakeholders and SMEs as the acquisition project requirements and resource constraints mature.

9. Science and Technology Study Strategy

The S&T study strategy is a document that may evolve during capability acquisition and will be subject to refinement as capability requirements are defined. The S&T study strategy is developed by SMEs and Foresight Planning practitioners in response to the S&T study drivers, and expands the S&T planning strategy document described in Section 4. The S&T study strategy assists development of the S&T Plan and presents the agreed high level objectives, constraints and rationale for the acquisition program:

1. constraints, such as acquisition project timelines; and resource allocation (such as the likelihood and timeliness of the release of funds for S&T activities);
2. aspirations, such as the benefits to Australia; and identifying a capability effectiveness model, including capability/performance trade-offs; and
3. rationale, the logic to determine STAC Levels and TRLs (such as defined in Tables 7 and 9).

10. Science and Technology Plan

The S&T Plan, developed by SMEs in collaboration with acquisition project stakeholders, recommends the short and medium term development of facilities and advice capability to assist in registering and managing high risk areas. It summarises the S&T strategy to be implemented by individual sectoral S&T Plans. Sectoral S&T Plans correspond to individual critical technology areas, outlining the significance and vision for technology development and technology options and present specific objectives and justification of the S&T activities. Respective S&T programs will include industry engagement, international engagement, knowledge maintenance, Technology Maturation Programs and, where appropriate, facilities investment. In support of the sectoral S&T planning, the following criteria may be used to assist in identifying low priority S&T activities, thereby freeing resources for more effective allocation elsewhere:

- S&T activities for non-critical technologies;
- technologies for which there is already a sufficient STAC Level;
- technologies with TRL that will mature without acquisition project investment;
- technologies that have not been approved due to resource limitations; and
- technologies that have not been approved due to disagreement on the level of risk.

11. Conclusion

The Defence Procurement Review [1] recommended that new ADF acquisitions undergo a two-pass system with 'government considerations dependent on comprehensive analyses of technology, cost (prime and whole-of-life) and schedule risks subjected to external verification'. The proposed S&T planning framework, outlined in Figure 1, is designed to provide a formal, systematic approach for the identification of critical technologies that require investigation in the short to medium term of a capability acquisition project.

Sectoral analysis, and the application of the Foresight Planning methods, enables identification of study drivers for these critical technology areas, as well as highlighting costs, facilities, resource requirements, the scope of work and associated goals contributing to the study strategy. It is from the study strategy that the capability acquisition S&T Plan will evolve, documenting S&T analyses to be performed in each of the critical technology areas.

The S&T planning framework for RAN acquisition provides a comprehensive, documented and traceable S&T process for key decision-making points during capability acquisition. While this report provided examples of S&T planning products for the major systems technology aspects of a fictitious *Project SEA X*, the framework would benefit from further research examining the sensitivity of the methods, the choice of metrics and the subjective inputs provided by participants and demonstration of the framework for a more complete list of the fundamental inputs to RAN capability.

With refinement and further research, the S&T planning framework described in this report may be adapted for use in capability acquisition across the whole of the ADF, as well as for S&T planning in other research organisations.

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Appendix A: Equations for Determining Measures of Significance

This appendix presents equations and algorithms used in analysis and identification of critical technologies associated with Royal Australian Navy capability acquisition. To calculate the criticality of a technology requires identification of capability functional areas (using techniques like WDA, for example) and calculation of the relative importance of functional areas and technology areas contributing to the capability's potential mission roles. The following subsections present a sequential process that enables calculation of number of factors that enable calculation of the measures of significance *Capability*, *Cross Impact*, *Systems Integration* and *Sustainment* (as defined in Table 1, Section 5) that then contribute toward identification of critical technologies. Some of the equations will require an initial weighting to indicate the importance of a capability's mission role or functional area. With suitable resources (namely, time and SMEs) a robust set of initial weightings should be calculated.

A.1 Mission Capability Metric

The Mission Capability metric considers the capability's functional areas (such as: propulsion and energy systems and combat systems) to determine the relative importance of each potential mission role (such as: anti-submarine warfare, mine counter measures and intelligence gathering) for the capability. Platform functional areas may be determine utilising WDA techniques utilising a set of potential mission roles. Table A1 presents potential mission roles expected of RAN maritime capabilities.

The Mission Capability measure is then utilised in subsequent calculations that will ultimately enable identification critical technologies. The Mission Capability measure for the j^{th} functional area, $C_c[j]$, is given in equation A1, where:

i	is the i^{th} mission role;
$C_w[i]$	is the initial weighting of the i^{th} mission role (as determined by SME);
j	is the j^{th} functional area;
$F_w[j]$	is the initial weighting of the j^{th} functional area (as determined by SME);
$C_b[i, j]$	is a boolean for the i^{th} mission capability indicating if the j^{th} functional area contributes towards the mission capability; and
W_{av}	is the average weighting of the functional areas.

$$\forall j \quad C_c[j] = F_w^2[j] \cdot \frac{\sum_i C_w[i] \cdot C_b[i, j]}{W_{av} \sum_i C_w[i]} \quad (\text{A1})$$

Table A1: Example capability mission roles

Mission	Definition
Intelligence Gathering	Collection of intelligence and surveillance data enabling battlespace awareness.
Anti Surface Warfare (ASuW)	Weapons, sensors and/or operations to attack/limit effectiveness of an adversary surface combatant.
Anti Submarine Warfare (ASW)	Weapons, sensors and/or operations to attack/limit effectiveness of an adversary submarine.
Strike	Maritime or land strike to reduce adversary's ability to fight, preventing adversary's reinforcement or sustainment of deployed units and attempting operations by sea or land.
Special Forces	Covert insertion, support and extraction of special forces.
Mine Laying	Mine laying to prevent an adversary from conducting operations.
Environmental Assessment	Assessment of an area of operations enabling battlespace awareness.
Electronic Warfare	Use of electromagnetic spectrum to control the spectrum, attack an adversary or impede an adversary's attack in the spectrum.
Cover	Support to less capable forces to ensure protection and the completion of their tasking without interference from an adversary.
Containment	Threatening an adversary's critical vulnerabilities to force the diversion of their maritime forces into defensive roles and thereby preventing their use for offensive operations.
Mine Countermeasures (MCM)	Making safe an area of operations from the threat of sea mines.
Barrier Defence	Defending an area of operations.
Advanced Forces	Conducting operations ahead of a main force to make safe the area of operations.

A.2 Functional Cross Impact Metric

Once the Mission Capability metric, C_c , for the functional areas has been calculated, it is then possible to calculate the importance of the capabilities functional area, in terms of the number of technology areas that are required for correct operation of respective functional areas. The functional areas that a technology area might influence are identified utilising Foresight Planning methods and sectoral analysis; and there will be a number of technology areas that each contribute to a capability's functional area. The Functional Cross Impact metric for the j^{th} functional area, $CI[j]$, is presented in equation A2, where:

i is the i^{th} technology area;
 j is the j^{th} functional area;
 $C_c[j]$ is the Mission Capability measure for the j^{th} functional area (equation A1); and
 $\text{count}[i, j]$ is the number of technology areas that contribute towards a functional area.

$$\forall j \quad CI[j] = C_c[j] \cdot \sum_i \text{count}[i, j] \quad (\text{A2})$$

A.3 Technology Metric

The Technology metric is a weighting that takes into consideration the contribution of each technology area towards a given capability's functional area. In this weighting, the number of technology areas that directly affect a functional area is considered. The functional areas that a technology area directly affects are identified utilising the Foresight Planning and sectoral analyses. The Technology metric weighting, $T[i]$, for the i^{th} technology area is presented in equation A3, where:

i is the i^{th} technology area;
 j is the j^{th} functional area;
 $C_c[j]$ is the combined mission capability weighting of the j^{th} functional area (equation A1); and
 $TF[i, j]$ is a boolean indicating if a technology area contributes towards a functional area.

$$\forall i \quad T[i] = \sum_j TF[i, j].C_c[j] \quad (\text{A3})$$

A.4 Technology Cross Impact Metric

Next it is necessary to calculate the technology cross impact. This measure takes into consideration the technology areas that influence (directly or indirectly) a functional area. As determined by utilising Foresight Planning and sectoral analyses. The technology cross impact metric, $TI[i]$, for the i^{th} technology area is presented in equation A4, where:

i is the i^{th} technology area;
 j is the j^{th} functional area;
 $C_c[j]$ is the combined mission capability weighting of the j^{th} functional area (equation A1); and
 $TCI[i, j]$ is a boolean indicating if a technology area has a cross impact on a functional area.

$$\forall i \quad TI[i] = \sum_j TCI[i, j].C_c[j] \quad (\text{A4})$$

A.5 System Integration Metric

The next step is to calculate the relative importance of each technology area contributing to capability systems integration. This is done by comparing the technology areas against the capability functional areas and applying the cross impact weighting. The relative importance for the i^{th} technology area contributing towards capability systems integration, $SI[i]$, is presented in equation A5, where:

i is the i^{th} technology area;

j is the j^{th} functional area;
 $CI[i]$ is the cross impact weighting (equation A2); and
 $TF[i, j]$ is a boolean value indicating if a technology area contributes towards a functional area.

$$\forall i \quad SI[i] = \sum_j TF[i, j].CI[i] \quad (\text{A5})$$

A.6 Capability Sustainment Metric

The relative importance of each technology area in relation to sustainment is also required. The relative importance for the i^{th} technology area contributing towards sustainment of the capability, $S[i]$, is presented in equation A6, where:

i is the i^{th} technology area;
 j is the j^{th} functional area;
 $F_w[j]$ is the functional area sustainment weighting (as determined by SME);
 and
 $TF[i, j]$ is a boolean indicating if a technology area contributes towards a functional area.

$$\forall i \quad S[i] = \sum_j TF[i, j].F_w[j] \quad (\text{A6})$$

A.7 Measure of Significance - Capability

The measure of significance *Capability* is defined in Table 1, Section 5. The *Capability* measure of significance for each technology area is presented in equation A7, where:

i is the i^{th} technology area;
 j is the j^{th} functional area;
 $T[i]$ is the Technology metric for the i^{th} technology area (equation A3);
 $TI[i]$ is the Technology Cross Impact metric for the i^{th} technology area (equation A4); and
 C_{mix} expresses the contribution of capability impacts arising from indirect capability effects. That is, the capability enabled by this technology area through its functional interdependence on other technology areas. The authors used $C_{\text{mix}} = 0.3$ in their capability acquisition S&T planning study.

$$\forall i \quad \text{Capability}[i] = \frac{T[i] + TI[i].C_{\text{mix}}}{\max(\forall(T[i] + TI[i].C_{\text{mix}}))}.10 \quad (\text{A7})$$

A.8 Measure of Significance - Cross Impact

The measure of significance *Cross Impact* is defined in Table 1, Section 5. To calculate the *Cross Impact* measure of significance, the total number of platform functional areas that a technology area contributes towards needs to be calculated. Note, a technology area may contribute to a number of capability functional areas. The equation for the *Cross Impact* measure of significance is presented in equation A8, where:

i is the i^{th} technology area; and
 $Count[i]$ is the number of functional areas to which the i^{th} technology area contributes.

$$\forall i \quad Cross\ Impact[i] = \frac{Count[i]}{\max(\forall Count[i])}.10 \quad (A8)$$

A.9 Measure of Significance - Integration

The measure of significance *Integration* is defined in Table 1, Section 5. To calculate the *Integration* measure of significance, the system integration metric (equation A5) for each technology and platform functional is required. The *Integration* measure of significance is presented in equation A9, where

i is the i^{th} technology area;
 $SI[i]$ is the System Integration metric (equation A5).

$$\forall i \quad Integration[i] = \frac{\frac{SI[i]}{2}}{\max\left(\forall \frac{SI[i]}{2}\right)}.10 \quad (A9)$$

A.10 Measure of Significance - Sustainment

The measure of significance *Sustainment* is defined in Table 1, Section 5. The *Sustainment* measure of significance is calculated using equation A10, where:

i is the i^{th} technology area; and
 $S[i]$ is the relative importance of the i^{th} technology contributing towards sustainment of the capability (equation A6).

$$\forall i \quad Sustainment[i] = \frac{S[i]}{\max(\forall S[i])}.10 \quad (A10)$$

A.11 Measure of Significance - Risk

The measure of significance *Risk* is defined in Table 1, Section 5. *Risk* is calculated in the following manner. Firstly, the risk weighting needs to be calculated and it is the normalisation of the risk weighting that enables calculation of the *Risk* measure of significance.

Let:

i	be the i^{th} technology area;
$N[i]$	be a boealan indicating if the i^{th} technology area represented is a novelty for Australia (defined in Table 3, Section 5);
N_r	be the novelty risk weighting (as determined by SME). The authors used $N_r = 5$ in their capability acquisition S&T planning study;
$Cross\ Impact[i]$	be the <i>Cross Impact</i> measure of significance (equation A8);
$Integration[i]$	be the <i>Integration</i> measure of significance (equation A9); and
R_{mix}	expresses the relative proportion of risk arising from the integration and cross impact measures of significance. The authors used $R_{mix} = 0.3$ in their capability acquisition S&T planning study.

The risk weighting, R_w , is presented in equation A11.

$$\forall i \quad R_w[i] = Integration[i].(1-R_{mix}) + R_{mix}.Cross\ Impact[i] + N[i].N_{risk} \quad (A11)$$

The *Risk* measure of significance is the normalisation of the risk weighting, R_w , and is calculated using equation A12.

$$\forall i \quad Risk[i] = \frac{R_w[i]}{\max(\forall R_w[i])}.10 \quad (A12)$$

A.12 Measure of Significance - Cost Effective Edge

The measure of significance *Cost Effective Edge* is defined in Table 1, Section 5. The *Cost Effective Edge* measure of significance takes into consideration the *Capability* measure of significance and the S&T cost effectiveness described in Table 3, Section 5. The *Cost Effective Edge* measure of significance is calculated using equation A13, where:

i	is the i^{th} technology area;
$C_c[i]$	is the combined mission capability weighting (equation A1); and
$S\&T_{ce}[i]$	is a boealan indicating if the i^{th} technology area represents S&T cost effectiveness (for Australia).

$$\forall i \quad Cost\ Effective\ Edge[i] = C_c[i].S\&T_{ce}[i] \quad (A13)$$

A.13 Measure of Significance - Critical

The *Critical* measure of significance for each technology area is described in Table 1, Section 5. The measure is calculated by comparing the measures of significance *Capability*, *Sustainment* and *Risk* to respective thresholds. The thresholds will be defined by Foresight Planning practitioners and SMEs associated with the acquisition project. The algorithm to determine if a technology area is *Critical* is defined as follows.

Let:

i be the i^{th} technology area;
 T_C be the threshold for the *Capability* measure of significance;
 T_S be the threshold for the *Sustainment* measure of significance;
 T_R be the threshold for the *Risk* measure of significance;
 $Capability[i]$ be the *Capability* measure of significance of the i^{th} technology area (equation A7);
 $Sustainment[i]$ be the *Sustainment* measure of significance of the i^{th} technology area (equation A10);
 $Risk[i]$ be the *Risk* measure of significance of the i^{th} technology area (equation A11);
 $Critical[i]$ be the *Critical* measure of significance and is boolean indicating if the i^{th} technology area is critical; and
count be a counter, starting at 0.

```

 $\forall i$ 
if  $Capability[i] > T_c$  then
    count = count + 1;
end if;

if  $Sustainment[i] > T_s$  then
    count = count + 1;
end if;

if  $Risk[i] > T_x$  then
    count = count + 1;
end if;

if count > 0 then
     $Critical[i] = \text{TRUE}$ 
else
     $Critical[i] = \text{FALSE}$ ;
end if;

```

In situations where $Critical[i]$ is true, then the associated technology area is a critical technology for the capability and requires identification in the capability acquisition project S&T Plan as a technology area of significance.

Appendix B: Technology Readiness Levels

This appendix presents detailed descriptions of each TRL [32].

TRL1 *Basic principles observed and reported*

Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Example might include paper studies of a technology's basic properties.

TRL2 *Technology concept and/or application formulated*

Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.

TRL3 *Analytical and experimental critical function and/or characteristic proof of concept*

Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.

TRL4 *Component and/or breadboard validation in laboratory environment*

Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of 'ad hoc' hardware in a laboratory.

TRL5 *Component and/or breadboard validation in relevant environment*

Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include 'high fidelity' laboratory integration of components.

TRL6 *System/subsystem model or prototype demonstration in a relevant environment*

Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.

TRL7 *System prototype demonstration in an operational environment*

The prototype is near or at planned operational level readiness. This represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft or vehicle.

TRL8 *Actual system completed and 'flight qualified' through test and demonstration*

Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.

TRL9 Actual system '*flight proven*' through successful mission operations

Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.

Appendix C: Rules Governing the Relationship between Technology Constraints and Provider Sector

This appendix presents equations used to calculate the applicability of technology provider sectors in providing S&T support to a capability acquisition project. As well as utilising technology applicability constraints presented Table 15, Section 7, the equations for determining provider applicability also take into consideration STAC Level applicability. That is, does the provider have the ability to supply S&T advice at a specified STAC Level?

Firstly it is necessary to identify if each provider sector, such as those presented in Table 14, are constrained (as defined in Table 15). The technology constraints *Risk* and *Through-life Support* are boolean values determined by using the critical technology *Risk* and *Sustainment* measures of significance (as defined in Table 1 and calculated using equations in Appendix A). The algorithm to determine the technology applicability constraints *Risk* and *Through-life Support* follows, where:

i	is the individual technology areas;
$Sustainment_{CT}$	is the critical technology <i>Sustainment</i> measure of performance (equation A10);
$Through-life_{PA}$	is a boolean representing the provider applicability constraint <i>Through-life Support</i> (defined in Table 15);
$Sustainment_{threshold}$	threshold for the <i>Sustainment</i> measure of significance (threshold level is set by SME);
$Risk_{CT}$	be the critical technology <i>Risk</i> measure of significance (equation A12);
$Risk_{PA}$	is a boolean representing the provider applicability constraint <i>Through-life Support</i> (defined in Table 15); and
$Risk_{threshold}$	threshold for the <i>Risk</i> measure of significance (threshold level is set by SME).

```

 $\forall i$ 
if  $Risk_{CT}[i] > Risk_{threshold}$  then
     $Risk_{PA}[i] = 1$ 
else
     $Risk_{PA}[i] = 0;$ 
end if;

if  $Sustainment_{CT}[i] > Sustainment_{threshold}$  then
     $Through-life_{PA}[i] = 1$ 
else
     $Through-life_{PA}[i] = 0;$ 
end if;

```

The calculation for the technology applicability constraint *Critical* is presented in Appendix A. The technology applicability constraints *Commercial Value* and *Security* are determined by SMEs.

For each provider sector there will be a number of determinants to assist in the identification of suitability to provide S&T support. Table E1 presents simple, example determinants.

Table C1: Example provider sector determinants

Determinant	Meaning
Unconstrained Access	This determinant is to identify if Australia has unlimited access to intellectual property (for example) associated with the technology.
Classified Technology Transfer	Some countries, such as the USA, have export restrictions in place for certain technologies. This determinant is used to identify if the technology provider has such restrictions in place.
Supports Australian National Capability	Identify if the technology provider will enable Australian capability growth in the technology area
Reliability	Identifies if there are historical issues relating to the provision of support by the technology provider.
Australian Security Vetting	Identifies if the technology provider has appropriate Australian security credentials.
System-wide Integration Knowledge	Identifies if the technology provider has the knowledge and ability to handle capability system integration issues.
Commercial Interests/Conflicts	Determinant to identify if the technology provider has a commercial interest in the technology

It is now necessary to apply the technology applicability constraints to each of the determinants. This is performed using equation E1, where:

i	is the i^{th} provider sector determinant;
j	is the j^{th} technology applicability constraint;
k	is the k^{th} technology support provider;
$P[i, k]$	is boolean indicating if the technology applicability constraint applies to the provider sector (determined by SME);
$C[i, j]$	is boolean indicating if the j^{th} technology applicability constraint is relevant to the to the i^{th} provider sector determinant (determined by SME);
Total	is the total number of determinants associated with each technology applicability constraints (determined by summing $C[i, j]$ for each j); and
TechApp[j, k]	is the applicability of each technology constraint to a technology support provider.

$$\forall i \forall j \forall k \quad \text{TechApp}[j, k] = \frac{\sum P[i, k].C[i, j]}{\text{Total}} \quad (\text{E1})$$

Finally, to determine the applicability of technology support provider, equation E2 is used, where:

i	is the i^{th} technology area;
j	is the j^{th} technology applicability constraint;
k	is the k^{th} provider sector;
STACAppl[i, k]	is the applicability of a STAC Level requirement of the i^{th} technology area and k^{th} technology support provider (determined by SME);

Free[i]	is boolean indicating if the i^{th} technology area is free of provider applicability constraints;
C[i]	is boolean indicating if the i^{th} technology area is <i>Critical</i> (Appendix A);
C _{app} [k]	is a weight indicating the applicability of the <i>Critical</i> constraint to the k^{th} technology support provider;
R[i]	is Risk _{PA} [i], a boolean indicating if the i^{th} technology area is a <i>Risk</i> ;
R _{app} [k]	is a weight indicating the applicability of the <i>Risk</i> constraint to the k^{th} technology support provider;
CV[i]	is boolean to indicate if the i^{th} technology area is of <i>Commercial Value</i> (determined by SME);
CV _{app} [k]	is a weight indicating the applicability of the <i>Commercial Value</i> constraint to the k^{th} technology support provider;
TLS[i]	is Through-life _{PA} [i], a boolean indicating if the i^{th} technology area requires <i>Through-life Support</i> ;
TLS _{app} [k]	is a weight indicating the applicability of the <i>Through-life Support</i> constraint to the k^{th} technology support provider;
Sec[i]	is boolean indicating if the i^{th} technology area is a <i>Security</i> concern (determined by SME);
Sec _{app} [k]	is a weight indicating the applicability of the <i>Security</i> constraint to the k^{th} technology support provider; and
TechAppI[j, k]	is the applicability of each technology constraint to a technology support provider.

$$\forall i \forall j \quad \text{Provider Applicability} = \frac{STCAppl[i, j] \cdot (Free[i] + C[i] \cdot C_{app}[j] + R[i] \cdot R_{app}[j] + CV[i] \cdot CV_{app}[j] + TLS[i] \cdot TLS_{app}[j] + Sec[i] \cdot Sec_{app}[j])}{\sum_{k=1}^n TechAppI[j, k]} \quad (E2)$$

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19. ABSTRACT When the Australian Defence Force (ADF) identifies a capability gap an acquisition process commences, supported by science and technology (S&T) guidance. Though the S&T support requirements are governed by the needs of the acquisition project, the S&T planning process would benefit from the introduction of a framework to improve the robustness and transparency of decision making with regards to the allocation of S&T resources. This report presents an overview of a proposed framework, encompassing the Foresight Planning methodology, to assist in the identification of critical design issues; technology readiness; and research plans for critical technology areas in support of ADF capability acquisition. The iterative application of suitable Foresight Planning methods will enable the S&T requirements and vision to be established, from which a strategic S&T Plan can be developed. The aim of the proposed S&T planning framework is to provide guidance to establish a bespoke vision for each new capability acquisition and facilitate planning for the shape of things to come.					