DEPTH OF EXPERTISE

Systems Engineering Capability to Support Australia’s Future Naval Projects
With the 2012 Defence Capability Plan reinforcing the Australian Government’s intention to undertake a number of strategic naval projects, the focus has turned to the Systems Engineering needed to deliver the capability. With a depth of expertise across complex naval programs and an existing infrastructure underlined by proven processes, Australia’s Defence industry is well-positioned to succeed at the task ahead.
SYSTEMS ENGINEERING CAPABILITY TO SUPPORT NAVAL SHIPBUILDING

Date: 13 August 2012

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EXECUTIVE SUMMARY

1. The Australian Government has designated naval shipbuilding as a Strategic Industry Capability. The 2012 Defence Capability Plan (DCP) outlines the Commonwealth’s intentions to conduct a number of naval shipbuilding projects over the next two decades, including the development of the future submarine. Historical analysis of why projects have failed shows deficiencies in areas associated with Systems Engineering capability. The application of Systems Engineering to the management and execution of large and complex naval shipbuilding projects is now widely acknowledged by defence and commercial industries as a critical factor in achieving project success.

2. The Defence Materiel Organisation (DMO) has engaged defence industry to assist in identifying the ‘systems’ skills required for the future naval shipbuilding projects in Australia (Cawley, 2012). Raytheon’s standpoint, based upon experience gathered internationally and from Australian projects such as the COLLINS Class Submarine and HOBART Class Destroyer projects, is that the required ‘systems’ skills for complex projects, such as the future submarine project, requires an organisation with the following attributes:
   a. A professional workforce skilled in Systems Engineering;
   b. A mature organisational process framework for Systems Engineering; and
   c. A model to measure, guide and improve organisational performance.

3. Core to an organisation’s ‘system’ skills is the skilling of its workforce in Systems Engineering. The Systems Engineering roles and key skills are well understood but vary across industry, based on whether Systems Engineering is treated as a process or a discipline. This inconsistency has not helped the maturing of this capability and Engineering Societies generally do not recognise Systems Engineering outside a process area. Despite this, there are tertiary courses in Systems Engineering, and there are some external providers that provide training and development for some companies. A small number of companies, such as Raytheon Australia, develop their own Systems Engineering capability through internal programs. Within Raytheon Australia, Systems Engineering is regarded as a discipline, and internally has a defined professional development program for the training of its System Engineers.

4. There are a number of Systems Engineering Standards available that provide a framework and principles for the delivery of projects. Defence and Industry have largely adopted EIA-632 for guidance, with most companies able to show a mapping of this standard to their internal processes. Raytheon Australia uses the Raytheon Company Integrated Product Development System (IPDS) as the basis of its process framework. It has been continually developed over the past decade and tailored to take into account local culture, discipline, and behaviours. It has been independently accredited to Capability Maturity Model Integration (CMMI®) Maturity Level 3.

5. Recent US studies have shown that a model to measure, guide and improve an organisation’s performance, such as CMMI®, benefits an organisation’s Systems Engineering capability. There is a strong correlation between an organisation’s Systems Engineering capability and overall project performance. The organisations demonstrating this higher level of Systems Engineering capability utilised the CMMI® Framework to develop this capability. The US Department of Defense now mandates a CMMI® Level 3 capability on defence industry. Raytheon Australia has achieved Company-wide CMMI® Maturity Level 3 accreditation across all process areas. Raytheon’s DMO Scorecard performance, significantly higher than its competitors, reflects the benefits of such a model in an Australian context.
AIM

6. The aim of this paper is to define the Systems Engineering capability required by Australian defence industry for future naval shipbuilding projects, such as the future submarine project.

BACKGROUND

7. Historical analysis in the US and Australian defence sectors are consistent in identifying that the most likely causes of project failure are associated with key Systems Engineering skills such as Architecture, Trade Studies, Technical Solution and Requirements. Other areas also covered within the CMMI® framework such as Integrated Product Management, Project Planning and Risk, also rate highly. This analysis demonstrates the importance of Systems Engineering capability to project success. This becomes even more critical when considering large, complex and high value projects such as the future submarine project.

8. One example of a lack of Systems Engineering capability that caused significant issues in project success relates to the COLLINS Class submarine, with the Case Study detailed below. Whilst the maturity of Systems Engineering to support naval shipbuilding has improved significantly since the mid 1980’s when the project commenced, the case study highlights the importance of the application of Systems Engineering skills from the inception of such programs.

CASE STUDY – COLLINS CLASS SUBMARINES

The COLLINS Class Submarine Project encountered problems early in the program as a result of poor requirements. These problems were caused by both the Commonwealth and Industry. The original Combat System Specification (‘A’ Specification) was quite comprehensive and well structured. The difficulty from the Commonwealth perspective was that history has shown that the Combat System was over specified and therefore unrealistic for the time; it then took industry over ten years to realise this fact, following a number of independent reviews, the final one by the Naval Undersea Warfare Center. The finding of this review indicated that a significant part of the ‘A’ Specification could not be realised with current technology, and as a result the ‘A’ Specification was de-scoped. On industry’s side the contractor had offered a developmental system with more development than originally revealed to the customer. Additionally, the contractor had not conducted their own due diligence to determine those requirements that could not be realised with the technology of the day, a lack of domain knowledge being a significant factor. A de-scoping of the requirements, a change of contractor to one with domain knowledge, and the installation of a proven MOTS design, successfully addressed these issues on the combat system side.

9. Recent US Studies conducted over the last five years with a sample base of 148 projects (NDIA, 2012), show a strong correlation between an organisation’s Systems Engineering capability and overall project performance; these projects being representative of the large complex projects found in naval shipbuilding. This summary of the study is detailed in Figure 1. This diagram clearly identifies a significant increase in project performance with organisations that have a high level of Systems Engineering Capability (SEC).
10. It is worth noting the subtle point in Figure 1; it specifically correlates performance against demonstrated Systems Engineering capability, not processes or the number of trained people. Capability in this sense reflects the successful application of Systems Engineering skills and processes to real projects.

11. Additionally the higher SEC of Figure 1 is associated with the Process Areas of the CMMI® Model. Developed with Defence and industry by Carnegie Mellon University, Software Engineering Institute (SEI), CMMI® is built from a collection of global best practices in software and systems engineering and is a model based process improvement framework that supports organisational process maturation. The organisations demonstrating this higher level of Systems Engineering capability have utilised the CMMI® framework to develop this capability. The US Department of Defense has a mandated requirement of CMMI® Level 3 capability for defence industry participation\(^1\).

12. It can then be inferred that for industry to provide the required Systems Engineering capability for complex naval shipbuilding projects, such as the future submarines, it must possess the following attributes:
   a. A professional workforce skilled in Systems Engineering;
   b. A mature organisational process framework for Systems Engineering; and
   c. A model to measure, guide and improve organisational performance, such as CMMI®.

13. This paper discusses, in turn, each of the three attributes of an organisation’s Systems Engineering capability with relevant examples based upon the capability and experience resident within Raytheon Australia. Raytheon Australia’s perspectives are also informed through its current role as the Combat Systems System Engineer (CSSE) on the HOBART Class Destroyer Program and its role in support of the COLLINS Class Submarine combat system. Raytheon Australia has invested significantly in the training and development of its System Engineers, the ongoing development of its product development processes, and in establishing and maintaining its CMMI® Maturity Level 3 accreditation at a company level and across all Process Areas.

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\(^1\) Note: The US industry is highly motivated to achieve CMMI® Level 3 accreditation, as in November 2003 the US DoD provided industry with a letter requiring accreditation to a minimum of Level 3 in order to be able to respond to RFTs.
SYSTEM ENGINEERS

INTRODUCTION

14. Industry’s ability to develop and maintain a workforce of appropriately skilled Systems Engineers is essential for future naval shipbuilding projects. This involves the development of a workforce with the breadth of skills required to perform all aspects of the Systems Engineering function.

15. It is necessary to first define what is a ‘System’ followed by ‘Systems Engineering’ in order to be able to then define the Role(s) of the Systems Engineer. These definitions are not universally agreed, but come close in many areas. Individual organisations have either adopted the definitions, as defined in the standards, or created their own definitions to remove any ambiguity in relation to the organisations own Systems Engineering processes. Raytheon's definition of a 'system' aligns with MIL-STD-499 and is detailed below.

RAYTHEON ‘SYSTEM’ DEFINITION

A system is a set of functional elements organised to satisfy user needs. These functional elements include hardware, software, people, facilities, data, and services.

A system includes the product design, and the facilities, equipment, special tooling, or processes for establishing the manufacturing, test, distribution, training, support, operations, and disposal capabilities.

Typically, a system is the major deliverable from a project.

16. At Raytheon, the entire process of developing a system – from initial user need, through design, development, delivery, and eventual disposal – are part of the ‘Systems Engineering’ function. Raytheon’s definition of ‘Systems Engineering’ is detailed below.

RAYTHEON ‘SYSTEMS ENGINEERING’ DEFINITION

Systems Engineering is a multi-faceted discipline, involving human, organisational, and various technical variables that work together to create complex systems.

17. A very important part of the definition of Systems Engineering is that within Raytheon, Systems Engineering is treated as a discipline; this is not the case for all companies. In many cases Systems Engineering is treated as a process performed by a range of people with differing skills from within and outside engineering. It is this latter approach to Systems Engineering that is the cause for the lack of recognition of Systems Engineering in industry. For example, Engineers Australia does not recognise Systems Engineering as a discipline; there is a Technical Society but not a College. When trying to attain Chartered Engineering status Systems Engineers do so within their College affiliation, for example, such as Electrical Engineering or Mechanical Engineering. The general lack of knowledge on what Systems Engineering entails is surprising, given the importance of this discipline to both the defence and commercial industry.
18. The various Systems Engineering ‘Roles’ and their relative place in a project’s Systems Engineering organisational structure or hierarchy is shown in Figure 2.

![Figure 2. Systems Engineering Roles](image)

**Table 1. Description of System Engineering Roles**

<table>
<thead>
<tr>
<th>ROLE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chief Engineer</td>
<td>Oversees all technical aspects of the major program or business area</td>
</tr>
<tr>
<td>Lead Systems Engineer</td>
<td>Acts as the principal Systems Engineer for a program</td>
</tr>
<tr>
<td>Requirements Engineer</td>
<td>Ensures that every requirement is identified and assigned to someone, all requirements are accounted for, the integrity and parent/child traceability (links), versions are maintained, and all changes are tracked and controlled.</td>
</tr>
<tr>
<td>System Architect</td>
<td>Transforms the architectural description into system design</td>
</tr>
<tr>
<td>System Analyst</td>
<td>Determines how well a system can perform its intended function, and expresses results in terms that are quantitative and objective</td>
</tr>
<tr>
<td>Integration Engineer</td>
<td>Ensures that the delivered product functions as designed</td>
</tr>
<tr>
<td>Verification and Validation Engineer</td>
<td>Ensures that the delivered product meets all system requirements and satisfies the needs of the end user</td>
</tr>
<tr>
<td>System Process Engineer</td>
<td>Facilitates the deployment of the Integrated Product Development System (IPDS)</td>
</tr>
<tr>
<td>Specialty Engineer</td>
<td>Overseas various specialty engineering tasks such as reliability, maintainability, supportability and human engineering</td>
</tr>
</tbody>
</table>

19. A brief description of each of the roles detailed in Figure 2 is provided in Table 1.

20. Each of the roles identified in Table 1 are key for a complex program such as the future submarine project. These roles have different behavioural and skill characteristic requirements. The more senior roles, such as the Chief Engineer and Lead System Engineer require general expertise and skills in all role areas.
21. There has been some interest within elements of industry and INCOSE to introduce a Certification Process for Systems Engineers. This idea has not gained general acceptance and is not supported by Raytheon Australia. Raytheon Australia has preferred to use its own competency models and work with Engineers Australia and have systems engineering experience recognised for Chartered Status. Within industry, Chartered status is what counts as it is also an independent recognition of skill.

EXAMPLE: RAYTHEON AUSTRALIA ENGINEER CAREER ROAD MAP

Within Raytheon Australia there is a basic six level career profile for professional engineers, including Systems Engineers. At the top end of this profile, a very small number of Principal Engineers are promoted to Engineering Fellow (E44 / E88). The selection of Engineering Fellows is a highly selective competitive process across all of Raytheon Company. Within Raytheon Australia there are 11 Engineering Fellows and 10 of these are in Systems Engineering. The general Career Road Map for engineers is illustrated at Figure 3.

Promotion and career progression of Systems Engineers is competency based so progression from one level to the next requires the respective engineer to satisfy the company Discipline Lead in Systems Engineering that they have demonstrated the required competencies. At the higher levels of E-6 and higher to ensure company wide consistency requires the Engineering and Technology Council (ETC) approval.

In Raytheon Australia the more senior roles, such as Lead System Engineer and Chief Engineer have System Architect backgrounds and have graduated from the Raytheon Certified Architect Program (RCAP). RCAP is a highly selective role specialisation only available to Level E-6, Principal Engineers. The course is conducted over two years and is conducted at Raytheon facilities in the US. To date over 11 Architects have graduated from the RCAP program and a further three are at various stages of training.
KEY SKILLS

22. All of the Systems Engineering roles identified in Table 1, and the skills associated with these roles, are considered key for future naval shipbuilding. However, some of these skills can be viewed as having more influence on the success of a project. A brief review of the ‘Top 10 Reasons Projects Fail’, as shown in Figure 4, provides an initial insight of where to look, (Mink, 2008). The items in red text specifically relate to the Systems Engineering discipline. This correlates with the NDIA Study (Mink, 2008) on the Effectiveness of Systems Engineering. These results are provided in the Summary of Relationships illustrated in Figure 5.

23. It comes as no surprise that Architecture is the Systems Engineering skill that has the highest positive relationship with project success. Architecting the system is the most effective approach to dealing with the increasing complexity of projects. The nature of architecting also changes as the project moves from phase to phase, (Mair et al, 2009).

RAYTHEON EXAMPLE: RCA PROGRAM

Raytheon, through analysis of over 8,000 of its projects, came up with a similar result about the importance of Architecture in project success. This was a key factor in the establishment of the Raytheon Certified Architect Program (RCAP).

24. In Figure 5 the other high ranking correlations to project success for Trade Studies and the Technical Solution should also not be surprising and reflect the need for the early engagement of skilled personnel to ensure early and binding decisions of Trade Studies are made based on a thorough understanding of the required project outcomes.

CONCLUSIONS & CAVEATS

Consistent with “Top 10 Reasons Projects Fail”

1. Lack of user involvement
2. Changing requirements
3. Inadequate specifications
4. Unrealistic project estimates
5. Poor project management
6. Management change control
7. Inexperienced personnel
8. Expectations not properly set
9. Subcontractor failure
10. Poor architectural design

Figure 4. Top 10 Reasons Projects Fail
Figure 5. Relationship between Systems Engineering Capability and Performance

25. As detailed earlier, Table 1 details the key skills required for complex programs such as the future submarine project. Of comparable importance is the correct timing and application of those skills. It is vitally important that there is early engagement of the right skills into the project. Raytheon believes that the following Systems Engineering roles and associated skills need to be engaged early on any complex project:
   a. Chief Engineer
   b. System Architect
   c. Requirements Engineer
   e. Integration Engineer
   f. Verification and Validation Engineer

26. In addition to the System Engineering roles, there is also an essential requirement for User / Operator / Domain Specialists to be part of the team. It is also critical that the Military Systems Integrator (MSI) / CSSE can integrate and co-ordinate not only the Systems Engineering skills, but the other important project skills such as program management etc.
SKILLS DEVELOPMENT

TERTIARY COURSES IN SYSTEMS ENGINEERING

27. The roles and key skills within the Systems Engineering Capability are well understood but vary across industry, based on whether Systems Engineering is treated as a process or a discipline. This inconsistency has not helped the maturing of this capability and Engineering Societies generally do not recognise Systems Engineering outside of a process area.

28. The lack of recognition of Systems Engineering as a discipline is a constraint to skills development. There are currently limited opportunities in Australia to attain formal tertiary qualifications in Systems Engineering. The University of South Australia is the only university with a current undergraduate program in Systems Engineering after the University of Technology Sydney cancelled their undergraduate program some years ago.

29. At the graduate level, only the University of Queensland and University of South Australia have regular programs. Both of these graduate programs were sponsored by Defence. The University of Queensland’s Masters Degree in Systems Engineering was sponsored through the Strategic Industry Development Agreements (SIDAs), initially for the HF Modernisation Project and then the AEW&C Project. In the case of University of South Australia, its Masters Degree in Military Systems Integration has been sponsored through the Skilling Australia’s Defence Industry (SADI) program. The other occasional Post graduate program in Systems Engineering is through the Royal Melbourne Institute of Technology (RMIT).

30. It should also be noted that both of the Masters Degree Programs are struggling to survive. In the case of the University of Queensland, the majority of students come from outside the defence sector and would have difficulty attaining security clearances. In the case of the University of South Australia, the numbers of enrolments are down and possibly affected by a lack of new projects in the defence sector.

31. The lack of tertiary qualified Systems Engineers is being offset by companies like Raytheon Australia who have an internal competency based model to formally develop and assess the skills of their Systems Engineers. However such internal robust training is not conducted within the majority of companies in defence industry, and is not achievable in Small and Medium Enterprises. As a result, many Systems Engineers are in name only and not through attaining a recognised competency.

COMPANY INTERNAL TRAINING

TRAINING AND DEVELOPMENT

32. Training and development of Systems Engineers in Australia relies primarily on internal company development programs, as well as training provided by industry consulting bodies. Universities offer some graduate programs as already addressed, but only at the more senior levels. The use of outside consultants to provide Systems Engineering training is helping to address the shortage of training by universities and this model is used by a number of defence companies. Raytheon Australia prefers to conduct its own internal training as it also teaches its personnel the internal processes they will actually use in the delivery of projects.

33. Raytheon’s internal professionalisation program for its Engineers is detailed in the following example.
EXAMPLE: RAYTHEON AUSTRALIA INTERNAL TRAINING PROGRAM

Currently Raytheon Australia and most of industry either internally develop their Systems Engineers using company training programs or attracting them from competitors. Raytheon Australia’s Internal Training Program for its Engineering personnel, including Systems Engineers, is illustrated at Figure 6.

In addition to the Engineering Personnel, senior company specialists in each area learn basic skills through the Principles of Systems Engineering (PoSE) course, which is a five day intensive program. This provides Engineers and other program personnel a sound understanding of key Systems Engineering roles and their importance for project success.

In addition to the training shown below, separate process training is a mandatory requirement before being allowed to utilise the company internal processes; this training is conducted by the appropriate Discipline Lead.

The higher level Raytheon Certified Architect Program (RCAP) training is highly selective and conducted in the USA over a period of 12 months followed by qualification and certification on actual projects, which can take a further 1-2 years.

Figure 6. Raytheon Australia Internal Systems Engineer Training Program

In some cases, Raytheon utilises the University of South Australia’s Masters Degree in Defence Systems Integration. This will continue to be utilised into the future, while available.

The company also has a number of new training programs in the areas of Advanced Requirements Engineering, Behaviour Trees, (Powell, 2011), and Test Optimisation as it explores new areas to both improve productivity and Systems Engineering competence.

Raytheon Australia also makes the majority of its Systems Engineering training available to its customers, SME partners and other project contractors at no cost, to encourage an understanding of how the company conducts this aspect of projects. To date over 700 people have been trained on internal PoSE training programs. In general 3-4 courses are conducted each year, based on demand.

The further development of Systems Engineers is through project employments and mentoring by the more senior members of the Systems Engineering discipline; this progress is then measured through regular evaluation against the company competency model for Systems Engineers.
MENTORING

34. Mentoring is another effective mechanism for increasing the number and skill levels of System Engineers. Seeding programs with experienced Systems Engineers in key roles provides an opportunity for on-the-job training and mentoring for less experienced engineers, as well as those new to the company. Strong Technical/Engineering leadership is a key ingredient for mentoring to be most effective, and these leadership skills are therefore critical to motivate, influence, and inspire their team.

RAYTHEON EXAMPLE – SEEDING PROGRAMS

Raytheon Australia has utilised a strategy of always seeding new programs with experienced Systems Engineers in the key roles. Coupled with the corporate and discipline lead support, this has helped to grow the Systems Engineering Capability and address any temporary shortfalls.

In Raytheon Australia, Technical/Engineering leadership is accomplished through the Chief Engineer role, which is also the most senior engineering role on a project and generally filled by an Engineering Fellow with RCAP qualifications and a history of accomplishment. For example, the current Chief Engineer on the AWD Combat System started on the Collin’s Class Submarine Program and over a 20 year period grew and developed into his current role.

At the next level down Raytheon Australia has leadership development programs to identify and groom the future technical leaders, including the Frontline Leadership Courses, and the Management Excellence Program.

CROSS TRAINING

35. Another specific strategy that can increase the Systems Engineering capability is the cross training of other disciplines to become Systems Engineers. This provides greater diversity and flexibility in the workforce, and grows the Systems Engineering capability within the existing workforce.

RAYTHEON EXAMPLE – CROSS TRAINING

Raytheon Australia has cross trained its Software Engineers as Systems Engineers. This has the added benefit of enabling Software Engineers to work in the Systems Engineering space during the early stages of the project before moving into software roles once the project reaches that stage of the lifecycle.

SUMMARY

36. There are a variety of Systems Engineering roles that are required on any complex project, such as the future submarine project. Many of these roles need to be engaged from the start of the project to ensure that the system architecture is developed, technical trade studies are conducted, and requirements are defined. For successful programs, these Systems Engineering skills need to be coordinated and managed with other important project skills such as integrated product teams, project planning and risk management.

37. There are limited, but sufficient, opportunities for tertiary qualifications in Systems Engineering in Australia. This is attributable to the fact that Engineering Societies regard Systems Engineering as a process and not a discipline. Raytheon regards Systems Engineering as a discipline and has an established competency based Systems Engineering professionalisation program. Notwithstanding the constraints around skilling, for the last 10 years, across all programs (including the HOBART Class Destroyer), Raytheon has managed to meet all company requirements through selective recruiting, internal training programs, mentoring and cross training.
38. To date, Australian defence companies have developed their Systems Engineering capabilities to support defence and meet business needs. It is considered that the number of capable Systems Engineers available to meet the future submarine project is sufficient to meet this demand, drawing on the expertise and experience of previous and current projects, such as the COLLINS Class Submarine and the HOBART Class Destroyer projects. The RAND report into lessons learnt from the COLLINS Class project indicates that in the case of the Combat System that there are some 1205 Combat Systems Engineers within the Australian Defence Industry. Most critical for future projects is ensuring that the System Engineering skills are applied at the correct time during the project, which includes early in the capability definition phase.

SYSTEMS ENGINEERING FRAMEWORK

39. In addition to skilled Systems Engineers, organisations also require a business framework that identifies the processes, procedures, and governance mechanisms required for the successful and repeatable delivery of projects. For Systems Engineering, Defence and Industry have largely adopted the EIA-632 Standard for guidance as it was developed from industry and government working groups with industry being represented by INCOSE and its membership. Most companies can show a mapping of this standard to their internal process models.

40. It is very important that standards such as EIA-632 are not mandated upon industry, as they are guidance documents only. In the early use of some of these standards when they were mandated, the immaturity of both the customer and industry lead to a number of project problems caused by blind following of a theory based on the ‘What’ and not the ‘How’. Industry has learnt to adopt the Standards for guidance and develop their own internal procedures and processes to address the ‘How’ in the most cost effective and pragmatic way.

RAYTHEON EXAMPLE - IPDS

Raytheon’s Systems Engineering framework is embedded in its Integrated Product Development System (IPDS). IPDS is a proprietary system for managing defence product development. The IPDS defines and describes the interaction of policy, governance, processes and people to ensure efficient execution of programs. As detailed in Figure 7, the IPDS spans the entire system continuum, from the first emergence of a business opportunity through system design, development, verification, validation, and encompassing production, operations, support, and terminating at project completion and shutdown. The system has evolved over many years and, based on experience in both in Australia and the US, it provides a comprehensive suite of tools and processes specifically aimed at managing the design and development aspects of complex defence programs. This includes:

- business strategy planning and execution
- requirements and architecture development
- system integration, test, verification and validation
- operations and support
- project planning, management and control
- product design and development
- production and deployment

IPDS is particularly well suited to large and technologically advanced projects as it describes logically ordered process components that provide for repeatable and reliable project outcomes of the highest quality. IPDS has been applied successfully to number of complex programs in Australia, including the COLLINS Class Submarine and HOBART Class Destroyer projects which included significant and complex design and development aspects.
41. It should be noted that having an offshore parent with industry best practices in Systems Engineering does not mean this capability can be transferred to the Australia landed company, as it fails to account for the local culture, discipline and behaviours. Recognising this aspect, Raytheon Australia adopted the high level IPDS Life Cycle Model as mandated by Raytheon Company Policy, but then over the last decade developed and tuned the local processes, taking into account the unique attributes of delivering projects in the Australian environment.
PROCESS IMPROVEMENT

42. Recent US studies have shown that organisational commitment to a model that measures, guides and improves an organisation’s performance, such as CMMI®, benefits its Systems Engineering capability, which in turn improves overall project performance. Organisations demonstrating the higher level of Systems Engineering capability utilised the CMMI® Framework to develop their capability. The US Department of Defense mandates a CMMI® Level 3 Maturity on defence industry for participation in projects.

CAPABILITY MATURITY MODEL INTEGRATION (CMMI®)

43. CMMI® is a model based process improvement framework that supports organisational process maturation. CMMI® is built from a collection of global best practices in software and systems engineering. When laid over existing technology processes and systems, CMMI® highlights strengths and weaknesses against its global baseline, and thus creates a catalyst for continuous improvement initiatives. CMMI® is not, on its own, an improvement process. Rather it is a diagnostic model which provides a globally tested benchmark for measuring and defining an organisation’s process maturity.

44. CMMI® addresses capability by considering maturity and integration in four broad process groups:
   a. process management;
   b. project management;
   c. engineering and
d. support.

45. Within these broad groups, the CMMI® framework has analysed and defined the key attributes of 18 different process areas to identify the characteristics that reflect best practice and help an organisation establish and maintain a mature process capability.

46. CMMI® significantly reduces risk and provides efficiency for the customer by providing assurance that all activities on a program will be undertaken completely, and execution will be aligned with recognised best practice. CMMI® also provides efficiency because regardless of the location where work may be undertaken, the customer can be assured that a single set of proven, documented processes exist and personnel who use them have been uniformly trained. Uniformity in training provides both a reduction in training costs, and creates a robust environment where peer review and advancement from lessons learned become genuine performance improvement enablers.

47. The CMMI® Framework, namely CMMI® For Development, is ideally suited for defence industry as not only does it assess an organisations capability in Systems Engineering, it also addresses the capabilities associated with all aspects of the MSI / CSSE role. For example; Process Management, Project Management, Engineering (Systems Engineering, Software Engineering, Hardware Engineering) and Support.
CMMI® IN INDUSTRY

48. The Defence Electronic Systems Sector Strategic Plan (DMO, 2004) recommended that DMO and industry jointly develop goals and a framework for capability improvement in the Defence electronic sector. This recommendation included joint planning and coordination of matters affecting the industry-wide capabilities for the delivery and support of electronic systems for the ADF. To support these objectives the Defence Electronic Sector Development Forum (DESDF) was formed in 2006. One of the outcomes of DESDF was to establish a capability test to assess the eligibility of companies at first solicitation based upon, amongst other areas, a CMMI® assessment. (McKinnie, 2006)

49. Figure 8 provides an overview of the Industry Target (i.e. first stage of the capability test) developed by DESDF. This Industry Target provided the expectation for industry to mature to CMMI® capability levels one to three dependent on the process area in that stage. In addition, this staging approached allowed industry to focus their performance improvement areas on DMO’s priorities as well as meeting their own needs. It should be noted that from the end of year 3 (Figure 8 uses the convention of EoY3), CMMI® capability level 3 was required to be reached and maintained (Note: CMMI® appraisals have a validity of three years and only apply to the business areas assessed).

![Industry Target Staging](image)

**Figure 8. DMO Industry Targets for CMMI® Maturity against Key Process Areas**

50. Defence’s ‘Capability Test’ did not eventuate as a specific test, however, companies were required to provide their CMMI® profiles and forward strategies for achieving a CMMI® Level 3, as part of Request For Tender (RFT) responses. However, the DMO did not formally continue the program and most companies focused only on a selected number of Process Areas but not the complete set. Raytheon Australia is the notable exception, as it did achieve the complete set of the required Process Areas within the target period to achieve CMMI® Level 3 accreditation.
RAYTHEON EXAMPLE – CMMI® LEVEL 3 CERTIFICATION

In 2004, Raytheon Australia established a funded CMMI®-Based Process Improvement Strategy to, in part, support the Electronic Systems Sector Strategic Plan and, in part, to support Raytheon Australia’s projected growth. Raytheon Australia’s CMMI®-Based Process Improvement Strategy was refined over time where Raytheon Australia used a number of small appraisals. Due to Raytheon Australia’s growth it became evident that the strategy had to change from a business unit capability to that of a company capability. Whilst this set the bar higher than DESDF, this approach has proven to be resilient to growth, changes in structure and gave the ability for new and current projects, irrespective of business unit, to benefit from the increased maturity of the organisation.

In 2009, Raytheon Australia achieved CMMI® capability level 3 and hence met the Industry Target. Since that time Raytheon Australia has maintained the CMMI® capability and in 2011 (Figure 9 refers) Raytheon Australia was appraised to meet CMMI® maturity level 3 as well as capability level 3 for, the DMO sponsored, Safety Engineering and Safety Management CMMI® extension. This also confirmed for Raytheon Australia the correlation between SE capability and project performance analysis provided at Figure 1, and the DMO Industry Scorecard.

Figure 9. Raytheon Australia CMMI® Maturity Level Scorecard

Raytheon Australia’s success has been built upon its IPDS, which is a CMMI® level 5 capable structure. With over 8000 active projects, Raytheon has used the processes within the CMMI® Framework to fine tune the IPDS such that it now represents best practice for industry and the customer. Over the last decade Raytheon Australia has continually tailored and improved its IPDS based upon a decade of experience delivering large, complex projects to the Australian customer. Raytheon Australia then sought independent accreditation of its IPDS to CMMI® Maturity Level 3 in 2009, and it was re-accredited in 2011 for a second 3 year period.

Raytheon Australia has used the IPDS in the Australian context of a CSSE as well as for development of Support Systems. The pedigree of IPDS and the tailoring of IPDS has allowed Raytheon Australia to improve its performance whilst meeting and integrating with DMOs industry targets for development and sustainment projects.

Since the Defence Electronic Systems Sector Strategic Plan and the DESDF initiative, Carnegie Mellon University Software Engineering Institute has released CMMI® for Services. CMMI® for Services provides guidance for applying CMMI® best practices in a service provider organization. Best practices in the model focus on activities for providing quality services to customers and end users. (Chrissis, Konard and Shrum, 2009)

Consistent with Raytheon Australia’s approach taken in 2004, Raytheon Australia is leveraging off Raytheon Company’s development in the services area, tailoring that work and integrating it into current and future projects.

In essence, CMMI® for Services ensures that strategy, the engineering of the Support System and the execution of that system (i.e. delivery of the service) is aligned and developed and delivered in a mature manner. With that alignment and development this ensures that the Mission System and the Support Systems are developed in concert to meet the overall requirements in the design phase. (Schank et al, 2011) CMMI® appraisals provide an independent assessment of the company’s capability in terms of process maturity against best practise.
51. As discussed earlier in the document, US studies have demonstrated that organisational commitment to a framework for such as CMMI® increases an organisation’s Systems Engineering capability, as it encourages the use of mature business processes and continuous improvement across all process areas. This then directly relates to improved project performance. The US Department of Defence understand the importance of this capability, and since November 2003 have mandated that industry require accreditation to a minimum of Level 3 in order to be able to respond to RFTs.

52. In an Australian context, the benefit of CMMI® accreditation in Industry has been reflected by Raytheon Australia’s customer assessed project performance which is reflected in its DMO Company Scorecard, as detailed in the following example.

RAYTHEON EXAMPLE – DMO COMPANY SCORECARD

Raytheon Australia achieved Defence’s Industry Target of CMMI® Capability level 3 in 2009, and was again re-accredited in 2011. Raytheon’s industry leading project performance as measured by the DMO Company Scorecard Benchmark Report supports the US Industry studies results of strong correlation between Systems Engineering capability, strengthened by CMMI® accreditation, and project performance. The latest DMO Company Scorecard benchmark Report is provided in Figure 10.

Figure 10. DMO Company Benchmark Report (Rounds 18-23)

53. The lack of CMMI® accreditation in Australian Industry indicates that there is significant room for improvement in terms of Systems Engineering capability for most companies. The Priority Industry Capability (PIC) in the area of ‘High End System, and System of Systems Integration’, may offer some insights into the Systems Engineering capability of Australian industry when the Health Check is completed, however, these Health Checks tend to be subjective assessments only. To capture current Systems Engineering capability, the task within the Australian Defence Industry is to then have a universal and independent measure of Systems Engineering Capability, to enable the overall industries capability to be assessed.
54. The CMMI® Framework that was initially sponsored by the DMO under the DESDF remains the most effective means of measuring an organisation’s ability to undertake complex projects, such as the future submarine project. Any measure of the Systems Engineering capability of Australian defence industry would need to draw on the CMMI® Framework, or look for another relevant measure.

55. The strong correlation between Systems Engineering capability and project performance provides some insight for the DMO in trying to determine the Systems Engineering capability of Australian defence companies. The DMO Company Scorecards, which summarises project performance for an organisation, would provide some indication of the Systems Engineering and CSSE capability, in terms of skills and workforce, of that organisation.

OTHER FACTORS AFFECTING PROJECT PERFORMANCE AND SUCCESS

INFRASTRUCTURE

56. Project infrastructure should be established early in the project and reflect the contracting model to reduce cost and risk to the project. For example, an Alliance model needs to have a thin Alliance layer and at the next layer down be based on the main contractor’s Management Systems. This minimises impact and also enables the contractors to preserve ISO 9001, CMMI® and other accreditations, while enabling the individual company to draw upon and retain existing procedures and processes.

TOOLS

57. The selection of project specific tools can be a costly and time consuming activity that leads to a project within a project, causing unnecessary cost and risk to the project. Where possible the main contractors should utilise their existing tools and licenses, where they have developed significant skill, knowledge and expertise.

58. In some areas, such as in the case of requirements, there will be a need to share data between organisations. For these instances, early decisions need to be made to either standardise the tools or share the data across tools. In the area of requirements DOORS would be the most likely selection, but in other areas such as CM / DM this may not be the case. However, informed decisions early in the project may lead to organisations using their existing tools in such areas as CM / DM without the need to try and fit all areas of the Project into a common CM / DM system.

PROCESSES AND PROCEDURES

59. Mature organisations will generally have mature processes. The project should make all efforts to draw on these existing procedures and processes, only tailoring where necessary. A number of benefits can be gained from existing processes including existing training and support. Additionally, the project should let the main contractors remain under their existing accreditations for ISO 9001 and CMMI® as these can then be leveraged and provide an overall benefit to the remainder of the project. This is achieved by the company using its existing Management System within the project.

RAYTHEON EXAMPLE - GOVERNANCE

As MSI/CSSE, Raytheon Australia provides separate independent technical reviews as part of lead-up activities for all major Project Milestone reviews. This is a governance requirement of the company and this process provides further risk mitigation to the project over and above any contract requirement.
TEAM EXPERIENCE

60. The use of a tried and tested project team would always be the preference if circumstances allowed. In the case of Raytheon Australia this has been achieved to some extent by drawing upon the experience of teams used in earlier projects. In practice not all members of the team will have worked together before, some being new hires, however, provided the key roles have worked together then this is generally the best solution.

61. Drawing together a team of experienced people to work together for the first time will always create problems but in some cases this cannot be avoided. The normal issue is not the proven skills and capability but the behavioural fit. In cases where there is not a fit, it can take up valuable time to come to this conclusion.

62. An additional issue that also arises is when major contractors come together, for example, the Platform Designer and the CSSE; the separate organisations can have major cultural differences and ways of working. In these cases early establishment of Integrated Product Teams, with a common goal, formed with representatives of the key stakeholders in the project provides an excellent platform for success.

63. Early engagement of key personnel in small numbers can help to build up the trust and relationships that is very important for project success. The engagement of professional facilitators also helps if engaged early. A well-organised and open management team also sets a good example for the next layers down, and generally the behaviour of the lower levels will reflect what they see at senior levels.

LEARNING FROM EXPERIENCE

64. The COLLINS Class Submarine Program has been the most complex project undertaken within the Australian defence industry, primarily due to the level of design undertaken, as compared with the lower risk approach of using MOTS / COTS products in the Combat System of the HOBART Class Destroyer Project and other projects.

65. Recently, the RAND Report, ‘Lessons from Australia’s Collin’s Submarine Program’, (Schank et al, 2011), has provided some fresh insights that resonate with other reports; Systems Engineering Effectiveness, (Mink, 2008) and the Lesson’s Learned section of, (ANAO, 2011) and (ANAO, 2010). Key observations on a selective basis are captured as follows:

a. All appropriate organisations, commands, and personnel should be involved in the program from the beginning. Note: a further observation here was the absence of the technical community during the early stages of the program.

b. Successful Programs involve having experienced people in key management positions. This requires a strategy to grow people so they are experienced in various disciplines.

c. Program managers must understand the current state of technology in those areas that apply to their program.

d. Program managers must understand how a platform’s operational requirements affect technology, risks and costs.

e. Program managers must understand that when they specify an operational requirement they must also specify how to test for the achievement of that requirement.

66. The above list is not exhaustive but there is sufficient detail to identify that the early engagement of an experienced MSI / CSSE would help address these concerns.
IMPROVING SYSTEMS ENGINEERING PRODUCTIVITY

67. There are many sources of productivity improvement within Systems Engineering as well as within the overall projects themselves. A short but not exhaustive list is provided as follows:

   a. Early engagement of industry by the customer of the key Systems Engineering skills such as, Chief Engineers, Systems Architects, Systems Analysts, Requirements Engineers.

   b. Ensure there are effective organisational structures for project execution from the commencement of a project, for example the use of Integrated Product Teams (IPTs).

   c. Clearly define the roles and responsibilities at all levels of the project.

   d. Ensure early agreement and provision of well defined and effective project infrastructure and tools.

   e. Where possible, structure the project to take advantage of existing company approved and proven processes, company accreditations as well as tools. For example, the Combat System on the HOBART Class Destroyer is part of the Raytheon Australia Management System and can draw on any Raytheon Australia processes that are available.

   f. Provide continuity of key personnel and their roles from the start of the project to the later stages. For example, the Chief Engineer and System Architect roles have continuity through all stages of the project.

   g. Select key contractors, such as the Combat System Systems Engineer (CSSE) / Mission System Integrator (MSI), based on capability as early as possible to allow them to assist in the development of key project documents, such as the Operational Concept Document (OCD), Function and Performance Specification (FPS) and Test Concept Document (TCD), to ensure these documents are of the highest quality.

   h. Adopt a CSSE / MSI model similar to that used on the HOBART Class Destroyer project.

   i. Adopt a pragmatic approach to the use of MOTS / COTS Products, changing parent requirements to reflect selected and agreed MOTS / COTS function and performance (including non functional requirements). In general it is the non-functional requirements that pose the greatest risk.

   j. During project start-up there should be an Enterprise Architect IPT comprised of the Commonwealth, the Platform Designer, and the CSSE.

   k. Make extensive use of Modelling and Simulation to support capability trade studies.

   l. Ensure all OCD scenarios have been modelled and characterised and remain available throughout the Project Life Cycle.

   m. Ensure a realistic Cost Model is developed and maintained throughout the Project Life Cycle and that this model is an element of capability trade studies as well as down track product selections.

   n. Ensure requirements traceability is developed at the early stages of the project to include OCD, FPS, TCD and Statement of Work (SOW) and that this is maintained throughout the project.

   o. Apply a Behaviour Trees approach to the modelling of Operational Views in the development of the OCD, (Powell, 2012).

   p. Apply advanced requirements analysis, such as Behaviour Tree, to improve consistency and minimise requirement errors.

   q. Ensure that both the Mission and Support Systems are developed in parallel, as well as the overall cost model, through the Life of Type.

   r. Allow project sell-off at Segment level through individual Segments Specifications.

   s. Be prepared to spend more time involved in the front end activities of the project, where the real cost savings exist on the overall Project Life Cycle.
CONCLUSION

68. Australian defence industry requires a mature level of Systems Engineering Capability to enable the future naval shipbuilding projects, including the future submarine. This is supported by both lessons learnt from programs such as the COLLINS Class Submarine project (as detailed in the RAND report) and through overseas studies that have shown a strong correlation between Systems Engineering capability and overall project performance.

69. An organisation’s Systems Engineering capability comprises a skilled workforce of Systems Engineers, a mature organisational Systems Engineering framework for the delivery of projects, and a model for the measurement and improvement of this framework, such as CMMI®. Systems Engineering skills have been improving within Australian Industry, primarily through initiatives sponsored by the DMO and the internal development by organisations associated with such frameworks as CMMI®.

70. The level and number of Systems Engineering skilled people required within Australian industry to support the future submarine project are available within industry, especially if existing Systems Engineers with experience on the COLLINS Class Submarine and HOBART Class Destroyer projects are leveraged. The sources for training in Systems Engineering, both internal to companies and from external providers, are more than sufficient to meet industry needs, however this training needs to be consolidated through ongoing development and mentoring programs within industry on complex projects.

71. The use of a core of experienced personnel with mature Systems Engineering skills and capability to seed complex projects is considered the most pragmatic outside of the use of already established teams in the specific domain areas. However, when treated in isolation both of these approaches ignore the very important integration of skills to form the overall CSSE Capability. Within the CSSE the Program Management and Systems Engineering skills are linked and co-dependent and, when working together, effectively drive successful projects.

72. An organisation’s internal product development processes need to reflect the experience and lessons learnt from project delivery in Australia. Raytheon’s experience is that product development systems require modification to account for landed company use to account for the unique differences in doing business in Australia. Raytheon Australia’s IPDS, based upon that of Raytheon Company, has been tailored for Australia, reflects lessons learnt from Australian naval shipbuilding programs, and has been separately CMMI® accredited.

73. The CMMI® Framework initially sponsored by the DMO through the DESDF provides the most effective means of assessing an organisation’s Systems Engineering Capability. For those organisations that don’t have this accreditation, Systems Engineering capability could be extracted from project performance based upon their DMO Industry Scorecard.

74. There is a range of approaches available to improve the Systems Engineering productivity within the Project Life Cycle. These improvements increase in benefit the earlier in the project life cycle that they are implemented.
RECOMMENDATIONS

75. The following recommendations are made:
   a. That the lessons learned from major Defence projects and the COLLINS Class Submarine project be applied to the future submarine project.
   b. That the DMO continue to support the development and recognition of Systems Engineering as a discipline within defence and with the Engineers of Australia to achieve Chartered status.
   c. That the DESDF forums between the DMO and defence industry be re-instated to support the achievement of CMMI® Maturity Level 3 across defence industry.
   d. That the DMO look for overall productivity improvements, not just within the Systems Engineering Capability but across the wider responsibilities of the CSSE, recognising that the greater benefits will be realised from the earliest application of these improvements.
   e. That together with industry, DMO looks to agree on those key Systems Engineering capabilities that define the respective roles of Systems Engineers, as well as defining the skills profile for the future submarine project.
   f. That the DMO draw on successful Systems Engineering capability models from industry and not seek to impose a model, thereby utilising proven industry models.
   g. That when initiating large and complex projects, the preservation of industry Management Systems be a factor in determining the overall organisational structure. This applies to tools, procedures and processes.
   h. That the Commonwealth engage industry Systems Engineering capability early in the establishment of the future submarine project.
REFERENCES


