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DEFENCE R&D DÉFENSE

A Technology Maturity Measurement System for the Department of National Defence

The TML System

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Project Manager: Cdr W. Rockwell DGMEPM COS (819) 994-8720

Contract Number: NDHQ/DGMEPM Standing Offer Task # IT2367-R

Contract Scientific Authority: Cdr D. Parks, DRDC Atlantic/SMO (902) 426-3100 x159

Defence R&D Canada – Atlantic

Contract Report

DRDC Atlantic CR 2005-279

May 2006

Canada

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Author

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for ~~Mr. Kirk~~ Foster

DRP Chair

Abstract

This report provides an overview of a number of different technology maturity measurement systems in use by Canada's NATO allies. The report then goes on to demonstrate how various systems can be combined into a composite system referred to in the document as the Technology Maturity Level (TML) system. The final section identifies how the TML system would be utilized within the DND Defence Management System to support the development of systems and equipment being considered for acquisition in the Canadian Forces.

Résumé

Le présent rapport présente un aperçu de divers systèmes de mesure de la maturité de la technologie utilisés par les alliés du Canada au sein de l'OTAN. Le rapport montre ensuite de quelle manière divers systèmes peuvent être combinés dans un système composite désigné comme système TML (système d'évaluation de la maturité technologique). La section finale explique comment le système TML serait utilisé dans le cadre du Système de gestion de la Défense du MDN afin d'aider au développement de systèmes et d'équipements dont les Forces canadiennes envisagent l'acquisition.

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Executive summary

Introduction

The Canadian Department of National Defence, (DND) utilizes a system know as the Defence Management System (DMS) for equipment/system acquisition. Under this system, the operational, engineering, scientific, and procurement communities all play major roles and the process involves a series of linear steps where information related to systems and equipments being developed or considered for purchase is systematically passed for action between any and all of these groups. There is no common system that allows all of these organizations to clearly understand the technology maturity level of any system/equipment at any point in the process. This makes assessment of technological maturity (or inversely the risk to productize such systems/equipments) very difficult. There has been a wide body of work completed in the area of technology maturity measurement and a number of different systems have been developed to measure the different aspects of technology maturity of equipment/systems that are being developed for military applications. These systems include Interface Maturity Levels, System Readiness Levels, Design Maturity Levels, Technology Readiness Levels and Manufacturing Readiness Levels. While each of these systems have their merits and value, the problem is that each system only measures one aspect of technological maturity and as such they must be used collectively to gain a better appreciation of the state of maturity of any particular system under development

Principle Results

The introduction of five or six different maturity measurement systems would prove difficult for DND to manage. This report is proposing a prototype system that utilizes the Technology Readiness Level (TRL) system as a baseline but which incorporates the measurement criteria for the other systems into the TRL levels resulting in a single scale named the Technology Maturity Level (TML) system.

Significance of Results

Adopting the TML system would facilitate the management of the interface areas between the Scientific, Engineering and the Environmental Commanders during all phases of technology transition. It is recommended that the Associate Deputy Minister Science and Technology (ADM S&T) forward the details of this prototype TML system to other technology transition partners for consideration.

Future Plans

It is hoped that this report will generate interest in the concept of measuring technological maturity levels and lead to the further development and use of this prototype system by the technology transition partners in the DND.

Hobson, B. 2005. Technology Maturity Measurement for the DND. DRDC Atlantic CR 2005-279. Defence R&D Canada – Atlantic.

Sommaire

Introduction

Le ministère de la Défense nationale du Canada (MDN) utilise le Système de gestion de la Défense (SGD) pour effectuer l'acquisition d'équipements et de systèmes. Dans le cadre de ce système, les collectivités opérationnelles, techniques, scientifiques et des acquisitions jouent chacune un rôle majeur et le processus en jeu se compose d'une série d'étapes linéaires au cours desquelles l'information relative aux systèmes et équipements en cours de développement ou dont on envisage l'achat est transmise systématiquement pour suivi entre tous ces groupes. Il n'y a pas de système partagé qui permette à toutes ces organisations de bien comprendre le niveau de maturité technologique de tout système ou équipement à un point quelconque du processus. Cela rend très ardue l'évaluation de la maturité de la technologie (ou, inversement, le risque que représente la production de ces systèmes ou équipements). De nombreux travaux ont été effectués dans le domaine de la mesure de la maturité de la technologie et divers systèmes ont été développés afin de mesurer les divers aspects de la maturité technologique des équipements et systèmes développés en vue d'applications militaires. Ces systèmes sont fondés sur les niveaux de maturité des interfaces, les niveaux de préparation des systèmes, les niveaux de maturité des conceptions, les niveaux de préparation technologique et les niveaux de préparation à la fabrication. Bien que chacun de ces systèmes ait ses mérites et sa valeur, le problème est que chaque système mesure seulement un aspect de la maturité de la technologie et que, à ce titre, ils doivent être utilisés collectivement afin de dresser une meilleure évaluation de l'état de maturité de tout système particulier en cours de développement.

Principaux résultats

Il serait difficile pour le MDN de gérer la mise en oeuvre de cinq ou six systèmes de mesure de la maturité. Ce rapport propose un prototype de système qui fait appel au système TRL (niveau de préparation de la technologie) comme base, mais qui intègre les critères de mesure des autres systèmes aux niveaux TRL de manière à constituer une seule échelle de mesure, le système d'évaluation de la maturité technologique (TML).

Signification des résultats

L'adoption du système TML faciliterait la gestion des zones d'interface entre les commandants des collectivités scientifiques, techniques et environnementales pendant toutes les phases de transition technologique. Il est recommandé que le sous-ministre adjoint, Science et technologie - SMA(S & T) transmette les détails de ce prototype de système TML à d'autres partenaires intéressés à la transition technologique afin qu'ils l'examinent.

Plans futurs

Nous espérons que ce rapport générera de l'intérêt envers le principe de la mesure des niveaux de maturité de la technologie et mène au développement ultérieur et à l'utilisation de ce prototype par les partenaires dans le domaine de la transition technologique au sein du MDN.

Hobson, B. 2005. Mesure de la maturité de la technologie pour le MDN. DRDC Atlantic CR 2005-279. R & D pour la défense Canada – Atlantique.

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Introduction

Under the current DND system/equipment acquisition process, the operational, engineering, scientific, and procurement communities all play major roles and the technology transition process involves a series of linear steps where information related to systems/ equipments being developed or considered for purchase is systematically passed for action between any and all of these groups. Currently there is no common system that allows all of these organizations to have the same clear understanding of the technology maturity level of any system/equipment at any point in the process. This makes assessment of technological maturity (or inversely the risk to productize such systems/equipments) very difficult and related project team discussions and decisions become equally difficult.

Objective

The objective of this report is to propose a prototype system for measuring the technology maturity level of systems/equipment for the consideration of DND technology transition partners.

Maturity Measurement Concepts

There has been a wide body of work completed with regard to technology maturity measurement in the United States and United Kingdom defence departments. As a result, a number of different systems have been created to measure the technological maturity of equipment/systems being developed for military applications. The following systems were reviewed.

> Technology Readiness Levels (TRL) - The TRL concept originated with National Aeronautics and Space Administration (NASA) in the early 1980s.[1] The system is currently being used for integrated technology planning by that organization[2]. The basic system is also in use by the US and UK navies. It has also been adopted by NATO.[3] This system bases its ratings on demonstrated system performance ie: laboratory proven, field proven, operationally proven;
>
> Interface Maturity Levels (IML)[4] – This system rates an equipment/system on the confidence level that it will successfully integrate with the other equipment/systems that it must interact with in the field;
>
> System Readiness Levels (SRL) - These ratings look beyond the straight technological aspects of getting a system to work and interacting with other systems to reflect the degree to which documentation, training, life cycle support considerations etc have been completed;

Design Maturity Levels (DML) – This system establishes a series of design review targets over the life of a project to improve the chance of project success; and

Manufacturing Readiness Levels (MRL) – As the name implies, this rating scale measures the characteristics necessary for a producible and affordable commercial product. There are a number of different formats that have been developed in this area. The US Missile Defense Agency has developed a five tier measurement system known as Engineering and Manufacturing Readiness Levels (EMRLs).[5] The agency uses this maturity measurement scale to support assessments of the maturity of the design, related materials, tooling, test equipment, manufacturing, quality and reliability levels, and other characteristics necessary for a producible and affordable product. The UK Ministry of Defence has also developed a similar scale but it uses a nine level system;[6]

Further details regarding each of these systems have been included as Annexes A-E.

Technology Maturity Level System

Of all of these systems, the TRL system has found the greatest degree of acceptance and implementation in other navies (US, UK, Australian). Defence Research and Development Canada (DRDC) is also in the process of implementing this system for use with their Technology Demonstration Program[7]. However, as noted by Mr. William Nolte (US Airforce Research Laboratory, Wright Patterson Air Force Base),

> "The TRL scale measures maturity along a single axis, the axis of technology capability demonstration. A full measure of technology maturity, or in the commercial world product maturity, would be a multi-dimensional metric. It's not uncommon to find references to 12 or more dimensions of product or technology maturity. One writer speaks of 16 different dimensions of maturity. The TRL measures only one of the 16."[8]

In an attempt to broaden the scope of technology maturity measurement in DND, a prototype Technology Maturity Level (TML) system has been developed as part of the Maritime Technology Insertion Working Group study[1]. This proposed system utilizes the NATO TRL system as a baseline, but it expands each TRL level to incorporate the measurement criteria for the other systems at the crossover levels

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[1] The Maritime Technology Insertion Working Group was established by the Martime Research and Development Oversight Group in June 2003 to develop recommendations on improving technology transition processes for the Navy and to better leverage Defence Research and Development (DRDC) products into Naval capability.

shown in Table 1. It should be noted that the prototype only incorporates a rough conversion from the US and UK project milestones to Canadian DMS milestones.

It is hoped that this prototype will generate interest in the concept of technological maturity levels and lead to the further development and use of this concept by the technology transition partners in the DND.

Table 1 - Cross System Integration Levels

Tech Maturity Level (TML)	Tech Readiness Levels (TRL)	Interface Maturity Levels (IML)	Design Maturity Levels (DML)	System Readiness Levels (SRL)	Manufacturing Readiness Levels (MRL)
0	0	1			
1	1	2	1		
2	2	3,4	2		
3	3	5	3	1	3
4	4	6	4	2,3	4
5	5	7	5	4,5	5
6	6	8	6	6	6
7	7	9	7	7	7
8	8		8	8	8
9	9		9	9	9
TML	**T-TRL**	**P-PROGRAMMATICS**			**M - MANUFACTURING**

Each level of the TML scale is comprised of three sub-areas and the criteria in each sub-area must be met before making a TML level determination for any system/ equipment. The first sub-area is the Technology Readiness Level (T). The second sub-area combines the measurement criteria for Interface, Design, and System issues into a category called Programmatics (P). The third area is Manufacturing

Readiness(M). An overview of the resulting Technology Maturity Level (TML) scale is shown in Table 2

Table 2 – Technology Maturity Level Scale

TM Level	**Description** **(T–Technology Readiness, P–Programmatics, M–Manufacturing Readiness)**
0	**T** - Basic Research with future Military Capability in mind. - Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and /or observable facts with only a general notion of military applications or military products in mind. Many levels of scientific activity are included here but share the attribute that the technology readiness is not yet achieved. **P** – No assessment of requirements or impacts done.
1	**T -** Basic Principles Observed and Reported in context of a Military Capability Shortfall. - Lowest level of technology readiness. Scientific research begins to be evaluated for military applications. Examples of R&D outputs might include paper studies of a technology's basic properties and potential for specific utility. **P –** Requirements and impacts understood at concept level - Preliminary discussions conducted with operational and engineering communities about applicability of research.
2	**T** - Technology Concept and / or Application Formulated. Invention begins. Once basic principles are observed, practical applications can be postulated. The application is speculative and there is no proof or detailed analysis to support the assumptions. Example R&D outputs are still mostly paper studies. **P –** Interface requirements specified and understood – Scheme drawings, outline concepts. – Engineering and operational community actively supporting or involved in the research

<table>
<tr><th>TM Level</th><th>Description
(T–Technology Readiness, P–Programmatics, M–Manufacturing Readiness)</th></tr>
<tr><td>3</td><td>T - <u>Analytical and Experimental Critical Function and / or Characteristic Proof of Concept</u> - Analytical studies and laboratory/field studies to physically validate analytical predictions of separate elements of the technology are undertaken. Example R&D outputs include software or hardware components that are not yet integrated or representative of final capability or system.

P – Interfaces demonstrated at modular level in a synthetic environment
Identify Key Design Risks
– Training needs analysis started
– Safety and Environmental user requirements captured
– Overall system availability requirements identified
– High-level human factors analysis completed.

M – Manufacturing Concepts identified.</td></tr>
<tr><td>4</td><td>T - <u>Component and / or “Breadboard” Validation in Laboratory / Field (eg ocean) Environment</u> - Basic technology components are integrated. This is relatively “low fidelity” compared to the eventual system. Examples of R&D results include integration and testing of “ad hoc” hardware in a laboratory/field setting. Often the last stage for R&D (funded) activity.

P – Interfaces partially demonstrated - system/sub-system level in a high fidelity synthetic environment
- System requirements, and Specifications reviews completed.
- Preliminary Safety/Environmental assessments complete
- Supportability work breakdown structure completed
- Sub-system R&M case developed for sub-systems.
- Initial Human Machine Interface design completed
- Key Sub-System schematics completed.
  - All Sub-System Specifications defined
- Engineering and operational communities negotiated a formal commitment to use the results of the research.

M – Laboratory Manufacturing Process demonstrated</td></tr>
</table>

TM Level	**Description** **(T–Technology Readiness, P–Programmatics, M–Manufacturing Readiness)**
5	**T -** Component and / or "Breadboard" Validation in a Relevant (operating) Environment - Fidelity of sub-system representation increases significantly. The basic technological components are integrated with realistic supporting elements so that the technology can be tested in a simulated operational environment. Examples include "high fidelity" laboratory/field integration of components. Rarely an R&D (funded) activity if it is a hardware system of any magnitude or system complexity. **P –** Interfaces demonstrated at systems level in a synthetic/high fidelity environment. Impacts on other systems demonstrated as manageable Preliminary Design Review completed - confirm training needs analysis still valid. - safety/environment management and trials plans completed - hazard mitigation plan complete - Non-economic Level of Repair Analysis (LORA) completed. - through life issues have been identified. (eg. Obsolescence, Disposal, Configuration Management, WLC etc) - Evidence from early testing provided for reliability case to feed logistic and R&M models to confirm results. - Continuing operability trials conducted with end users to refine design - Comparison of operator performance with previous predictions made using HF predictions **M –** Manufacturing processes defined by studies and lab experiments

TM Level	**Description** **(T–Technology Readiness, P–Programmatics, M–Manufacturing Readiness)**
6	**T -** System / Subsystem Model or Prototype Demonstration in a Realistic (operating) Environment or Context - Representative model or prototype system, which is well beyond the representation tested for TML 5, is tested in a more realistic operational environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory/field environment or in simulated operational environment. Rarely an R&D (funded) activity if it is a hardware system of any magnitude or of significant system complexity. **P –** System interfaces demonstrated though test in an operational environment. - Critical Design Review completed for critical sub-systems. - demonstrate training interoperability with other programs - interim logistic support in place for trials - baseline data available for in-service ILS support - Engineering and operational communities actively using results of the research. **M –** Critical Manufacturing Processes prototyped
7	**T -** System Prototype Demonstration in an Operational Environment or Context (eg exercise) - Prototype near or at planned operational system level. Represents a major step up from TML 6, requiring the demonstration of an actual system prototype in an operational environment, such as in a relevant platform or in a "system-of-systems". Information to allow supportability assessments is obtained. Examples include extensive testing of a prototype in a test bed vehicle or use in a military exercise. Not R&D funded although R&D experts may well be involved. **P** - System interface qualified in an operational environment. - Critical system design review completed for all sub-systems Safety target trials and data analysis completed Evaluation of operator performance within the integrated system - Assessment of operator workload and situational awareness - Comparison predicted vs. actual operator performance - integrated system **M –** Prototype Manufacturing System - ready for low rate production

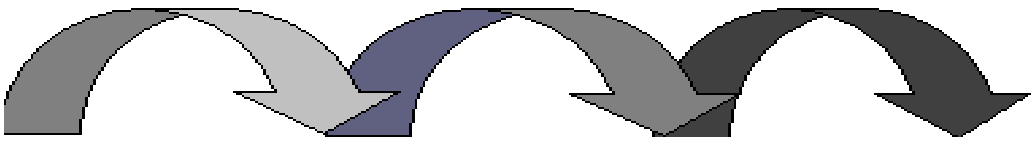
TM Level	**Description** **(T–Technology Readiness, P–Programmatics, M–Manufacturing Readiness)**
8	**T -** Actual System Completed and Qualified through Test and Demonstration - Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TML represents the end of Demonstration. Examples include test and evaluation of the system in its intended weapon system to determine if it meets design specifications, including those relating to supportability. Not R&D funded although R&D experts may well be involved. **P -** Sustainability estimates validated against predicted usage and planning assumptions. - Complete Critical Design Review – System, Detailed design complete - Functional Configuration audit - Production Readiness review (Design Readiness Aspects) - Baseline data ready for in-service ILS (Predicted Reliability, Component Costs, etc) - HATs and some SATs completed. - Any remaining Test Forms completed. - Full Maintenance Plan in operation **M –** Manufacturing Process Maturity Demonstration completed to acceptable yield and producibility levels for pilot line.

TM Level	**Description** **(T–Technology Readiness, P–Programmatics, M–Manufacturing Readiness)**
9	**T -** Actual System Operationally Proven through Successful Mission Operations - Application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation and reliability trials. Examples include using the final system under operational mission conditions. **P -** Training standards in place – course outline/lesson plans complete - Safety and Environmental Operator and user instructions verified and published. - Emergency and contingency arrangements verified and published - In-service support policy agreed and issued. - Adequate in-service R&M data collection & analysis over representative lifetime demonstrates R&M has been achieved - Documentation of human & organizational lessons learnt to inform future capability upgrades and new systems - Full certification achieved to the requirements of Class. - Acceptance-off-Contract achieved and In-Service Date declared. - Remaining SATs and operational trials completed. - All Inspections, Test Forms and Acceptance Trials completed. - All operating procedures and documentation complete. - Physical Configuration Audit conducted M – Manufacturing Processes proven – line running at desired stable level

Applicability to DND Defence Management System

The Defence Management System (DMS – Figure 1) is the primary DND vehicle for bringing new systems and equipment into service, either through the Capital Acquisition Process, or through the In-Service Support stream. [9]

Figure 1 DMS project phases. [10]



IDENTIFICATION	OPTION ANALYSIS	DEFINITION	IMPLEMENTATION	CLOSE-OUT
Identify Capability Deficiency Capability-based Planning Validation	Formulate options Discard invalid options Assess benefits of remaining options Examine risk Decide which option should be pursued Definition Planning	Detailed review, risk assessment and costing of selected option. Implementation planning	Management/ Monitoring, i.e. Initial/Full Operational Capability Milestones Procurement/ Realty Strategies Reports on status of implementation	Full Operational Capability Operational Handover Completion Report Lessons Learned
Decision SS(ID)	**Decision SS(PPA)**	**Decision SS(EPA)**		

The DMS vehicle for seeking program decisions is the Synopsis Sheet (SS). As shown in Figure 1 there are three major decision points, Identification- SS(ID); Provisional Project Approval - SS(PPA); and Effective Project Approval - SS(EPA). In order to utilize any technology maturity measurement system, it must line up with these major decision points. To use the TML system as a tracking tool within the DMS, the linkage shown in Table 3 could be utilized.

Table 3 - TML/DMS Linkage

DMS PHASE/ DECISION POINT	TML LEVEL
IDENTIFICATION	TML 1,2,3
SS (ID)	TML Level 3 confirmed
OPTION ANALYSIS	TML 4,5
SS (PPA)	TML Level 5 Confirmed
DEFINITION	TML 6, 7
SS (EPA)	TML 7 Confirmed
IMPLEMENTATION	TML 8
CLOSE-OUT	TML 9

Summary

This paper introduced the concept of technology maturity measurement and the idea that some form of technology maturity measurement would serve the DND acquistion system participants well. This introduction was followed by brief descriptions of some of the major systems currently in use in the US and the UK to measure different aspects of technology maturity. It was then argued that no single system, adequately presents a complete picture of technological maturity. On that basis, the prototype Technology Maturity Level (TML) system was introduced as being a composite of the Technology Readiness Level system and the major maturity sub-measurement systems : Design, Integration, Interface, System and Manufacturing Readiness. The paper then went on to demonstrate how the TML system could be utilized under the Defence Management System.

Conclusions

The DND currently has no system to measure and report technology maturity levels between the various NDHQ organizations who collectively progress the development, procurement and acquisition of systems and equipment. Canada's major defence allies (US, UK) are developing and implementing a number of different systems to provide this common tracibility for their acquisitions. While these systems are in their early stages, the US and UK are each grappling with the implementation of several of the different components of maturity measurement. Trying to directly follow their lead would be difficult for the DND, given its relative size. It is therefore concluded that a combined system such as this prototype TML would be a good starting point for DND to add such a capability into the development and acquisition process of systems being progressed through the DMS.

Recommendation

It is recommended that ADM S&T support the further development of the TML system through the engagement of ADM (MAT), ADM (IM) and the Environmental Chiefs in a project to introduce the TML system into service.

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United States, Department of Defence/Under Secretary of Defence, Managers Guide to Technology Transition in an Evolutionary Acquisition Environment Ver 1, Jan 31, 2003, pgs 57,58.

List of symbols/ abbreviations/ acronyms/ initialisms

ADM IM	Associate Deputy Minister Information Management
ADM MAT	Associate Deputy Minister Materiel
ADM S&T	Associate Deputy Minister Science and Technology
AMS	Acquisition Management System
CF	Canadian Forces
DML	Design Maturity Level
DMS	Defence Management System
DND	Department of National Defence
DOD	US Department of Defence
DRDC	Defence Research and Development Canada
EMRL	Engineering and Manufacturing Maturity Level
IML	Interface Maturity Level
MOD	Ministry of Defence (UK)
MRL	Manufacturing Readiness Level
NDHQ	National Defence Headquarters
SPI	Smart Procurement Initiative
SRL	System Readiness Level
SS (EPA)	Synopsis Sheet (Effective Project Approval)
SS (ID)	Synopsis Sheet (Identification)
SS (PPA)	Synopsis Sheet (Preliminary Project Approval)
TML	Technology Maturity Level
TRL	Technology Readiness Level

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Annex A

NATO Technology Readiness Levels[2]

NATO Technology Readiness Level		Description
0	Basic Research with future Military Capability in mind	Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and /or observable facts with only a general notion of military applications or military products in mind. Many levels of scientific activity are included here but share the attribute that the technology readiness is not yet achieved.
1	Basic Principles Observed and Reported in context of a Military Capability Shortfall	Lowest level of technology readiness. Scientific research begins to be evaluated for military applications. Examples of R&T outputs might include paper studies of a technology's basic properties and potential for specific utility.
2	Concept and / or Application Formulated	Invention begins. Once basic principles are observed, practical applications can be postulated. The application is speculative and there is no proof or detailed analysis to support the assumptions. Example R&T outputs are still mostly paper studies.
3	Analytical and Experimental Critical Function and/or Characteristic Proof of Concept	Analytical studies and laboratory/field studies to physically validate analytical predictions of separate elements of the technology are undertaken. Example R&T outputs include software or hardware components that are not yet integrated or representative of final capability or system.
4	Component and/or Breadboard Validation in Laboratory / Field (eg ocean) Environment	Basic technology components are integrated. This is relatively low fidelity compared to the eventual system. Examples of R&T results include integration and testing of ad hoc hardware in a laboratory/field setting. Often the last stage for R&T (funded) activity.
5	Component and/or Breadboard Validation in a Relevant (operating) Environment	Fidelity of sub-system representation increases significantly. The basic technological components are integrated with realistic supporting elements so that the technology can be tested in a simulated operational environment. Examples include high fidelity laboratory/field integration of components. Rarely an R&T (funded) activity if it is a hardware system of any magnitude or system complexity.
6	System / Subsystem Model or Prototype Demonstration in a Realistic (operating) Environment or Context	Representative model or prototype system, which is well beyond the representation tested for TRL 5, is tested in a more realistic operational environment. Represents a major step up in a technologys demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory/field environment or in simulated operational environment. Rarely an R&T (funded) activity if it is a hardware system of any magnitude or of significant system complexity.

2 North Atlantic Treaty Organization/Undersea Research Laboratory, Technology Readiness Levels, 2004, available Internet http://www.saclantc.nato.int/trl.html, 9 March 2006.

7	System Prototype Demonstration in an Operational Environment or Context (eg exercise)	Prototype near or at planned operational system level. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in a relevant platform or in a system-of-systems. Information to allow supportability assessments is obtained. Examples include extensive testing of a prototype in a test bed vehicle or use in a military exercise. Not R&T funded although R&T experts may well be involved.
8	Actual System Completed and 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 Demonstration. Examples include test and evaluation of the system in its intended weapon system to determine if it meets design specifications, including those relating to supportability. Not R&T funded although R&T experts may well be involved.
9	Actual System Operationally Proven through Successful Mission Operations	Application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation and reliability trials. Examples include using the final system under operational mission conditions.

Interface Maturity Levels[3]

Interface Maturity Levels (IMLs) were introduced within the Astute Class nuclear-propelled submarine program as a structured means of indicating the level of understanding of the interfaces and the confidence level of achieving successful integration.

Summary of Levels

Low levels (IMLs 1 to 3) relate to a high-level system design, with some theoretical analysis of interaction between sub-systems.

Medium levels (IMLs 4 to 6) indicate a greater understanding, through the use of modelling in a synthetic environment, of the interface requirements and the impacts on other sub-systems and on the overall system.

High levels (IMLs 7 to 9) represent practical demonstration in a high fidelity or operational environment that successful integration can be achieved and overall requirements met.

Relation to Technology Readiness

IMLs complement TRLs in the management of risk during acquisition. TRLs can be demonstrated in any system, provided that the environment is relevant. In contrast, IMLs relate specifically to the system under consideration. In general, TRLs tend to mature earlier than IMLs.

Applying IMLs in Acquisition

For the introduction of a new capability or technology into any complex system, it will be necessary to consider integration with other member sub-systems as well as the impact on the overall system. Each should be considered separately against the descriptions below. A judgment should then be taken on which is the driving factor (i.e. the highest risk) for the particular capability or technology, to arrive at an overall IML assessment. As with TRLs, it is important that the reasoning behind the assessment is documented.

[3] United Kingdom, Ministry of Defence, Acquisition Management System, March 2006 release (v10.1) available Internet, http://www.ams.mod.uk/ams/content/docs/trl_guide/trlguide.pdf, 9 March 2006.

Concept Phase[4]

During the Concept Phase, system consideration will be at a high level. The aim should be to achieve an IML of at least 3 by the end of the Phase.

Assessment Phase

During the Assessment Phase, impacts on overall system parameters are examined to establish that these are acceptable, as well as gaining a more detailed understanding of interface requirements. Aim to achieve an IML of at least 5 by the end of the Phase.

Demonstration Phase

During the Demonstration Phase, more detailed and representative modelling and practical demonstration is used to build confidence that the integration can be successfully achieved and requirements met. The aim should be to achieve an IML of at least 6, and preferably 7, by the end of this Phase, together with confirmation that requirements are understood and agreed. A description of the various level requirements in shown in the table below

IML Descriptions

IML	Definition Statement	Description
1	No/minimal assessment of the interface requirements undertaken. No/minimal assessment of the impact on other systems	System looked at in the perceptive of achieving functionality assuming all system needs will be met by other systems with no consideration of how.
2	Interface requirements understood at concept level only. Impact on other systems is understood at a concept level only	The system view is now broadened to look at how the systems needs are to be delivered and what the concept system's needs will place on other systems
3	Analytical assessment conducted to establish interface requirements. Analytical assessments conducted to establish impact on other systems.	Analytical analysis, assessments and possible trials as necessary are conducted to determine precisely what the interface requirements are and the likely impact on the systems to be interfaced. This analysis may require modification of the conceptual system to make the interface needs more palatable to the interfacing system.

[4] Note: These phases are component parts of the UK Ministry of Defence System that is their equivalent to the DND DMS. It is known to the MOD as the CADMID cycle (Concept, Assessment, Demo, Manufacture, In Service and Disposal)

4	Interface requirements specified and understood. The likely impact on interfaced systems is generally understood but the ability of the impacted systems to cope is not understood.	Analysis has been completed, redesign taken place, and the requirements are specified and understood. What has not been established is the interfaced systems' ability to withstand the impact of the introduction of this system.
5	Interfaces demonstrated at modular level in a synthetic environment. Impacts on other systems are understood and have been specified as being achievable.	A degree of interfacing has been conducted at modular level in a synthetic environment. This modular level may be at card level and the synthetic environment may be no more than on a bench. The impacts on the impacted systems are now known and are believed to be acceptable, but at this point not quantifiable.
6	Interfaces partially demonstrated at System/Sub-system level in a synthetic environment. Impact on other systems is understood, specified and quantified and assessed to be minimal or manageable.	Progressive integration will be taking place with emulators/stimulators being used to partially demonstrate the system, including the interfaces, at System/Subsystem level in a synthetic environment. As a result of further work the impact on the other systems is understood and quantified. Having been quantified, an assessment is made on whether the impacts are minimal and can be dealt with during normal business, or achievable with a higher level of project and managerial control.
7	Interfaces demonstrated at system level in a synthetic/high-fidelity environment. Evidence is available that demonstrates the impact on the impacted systems is manageable.	At level 7, the systems interfaces will have been demonstrated at System level in a high fidelity environment. Level of impact maturity will have progressed such that there is evidence available that demonstrates the impact on the impacted systems is sustainable. This is essentially a move from an assessment of being achievable in level 6 to being supported by hard facts and experience of the same or similar work.
8	System interfaces demonstrated through test in an operational environment. Evidence available that all systems impacted on are able to meet the requirement needs of the system in a high fidelity environment.	At this level the system, and hence its interfaces will have been demonstrated through test in an operational environment. There will be evidence that all the impacted systems will meet the requirement needs of the system in a high fidelity environment.
9	System interfaces qualified in an operational environment. Detailed evidence available that all systems impacted on will meet the requirement needs of the system in an operational environment.	Highest level of maturity with all system interfaces qualified in an operational environment together with there being detailed evidence available that all systems impacted will meet the requirement needs of the system in an operational environment.

Annex C

Design Maturity Levels[5]

The establishment and review of the design at particular stages during a project improves the chances of project success. To aid this process, the following Design Maturity levels are suggested, as are Maturity targets at each stage of the CADMID cycle.

Stage	**Level**	Design Maturity Description
Concept	1/ 2/ 3	Design is advanced enough to support Initial Gate Operational Effectiveness and Investment Appraisal analysis, e.g. Draft URD, Outline SRD, Scheme Drawings, Outline Concepts, Product Architecture, Initial Cost estimates. Identify key design risks.
Assessment	4	Complete System Requirements Review/Specification Review.
	5	Complete Preliminary Design Review.
	6	Complete Critical Design Review for Critical Sub-Systems (e.g. Long Lead Time Items).
Demo	7	Complete Critical Design Review (all Sub-Systems).
	8	Complete Critical Design Review (System), (Detail Design Complete). Build and Test Pre-production model. Functional Configuration Audit. Production Readiness Review (Design Readiness Aspects).
Manufacture	9	Physical Configuration Audit.

The framework is provided as guidance and proposes maturity levels that should be achieved before each investment decision point, although the specific implementation of maturity reviews and maturity assessment techniques should be achieved through

[5] United Kingdom, Ministry of Defence, Acquisition Management System, March 2006 release (v10.1) available Internet, http://www.ams.mod.uk/ams/content/docs/prodmaty.htm, 9 March 2006.

negotiation with the contractor. However, management of the risks with mitigation action should be considered where it is not sensible to mature the design before an investment decision point (*e.g.* to avoid prematurely establishing a design baseline in a volatile technology area, to reduce the risk of obsolescence). Similarly, it may be necessary to advance the maturity of critical sub-systems, where these sub-systems are identified as being particularly important to the overall success of the project.

In PFI projects, it should be noted that Critical Design Reviews usually take place in the Demonstration Phase.

Clearly, it is important to ensure that the right design maturity is achieved at the right time and design uncertainty and risk is managed. In order to achieve this, projects have realized the benefit of utilizing a process to measure the Design Maturity. By measuring the maturity of the design, it is possible to plan Design Reviews to take place, only when the design is mature enough, which should improve the likelihood of successfully completing each Design Review. Design maturity measurement also enables the tracking of the design maturity and allows the improved management of the design process, by providing greater granularity of design information.

Design Maturity Measurement Process

Experience has shown that Design Maturity should be measured using carefully selected metrics. This measurement of Design Maturity should facilitate a greater appreciation of the status of the design, thus improving the tracking of progress and prediction of Design Maturity. Therefore the decision to hold any design review can be based on a clear understanding of the likelihood of success.

This guidance is intended to propose potential processes for measuring Design Maturity, although the precise technique that is used, should be agreed through negotiation with the contractor, but it should enable a critical evaluation of the design. It is suggested that the initial assessment of Design Maturity should be made from a "systems" perspective (unless the equipment is simple enough for a "whole equipment" assessment to be made). The following list is intended to provide some indication of the design characteristics that could be used to construct a view of Design Maturity:

> **Definition.** How complete is the definition of the system being measured? How much of the systems remain to be defined?
>
> **Interconnectedness.** How much does the system under consideration affect other systems interfaces? This is a measure of the sub-system design independence. Also, how much is the system dependent on establishment of robust interfaces with other systems?

Change. What is the likelihood that the sub-system will be the subject of change? This could be generated from requirements changes or technical uncertainties within the current sub-system design. What is the risk of change and the impact of that change?

A set of standard questions may be generated that seek to provide insight into the level of maturity that the system possesses. Other characteristics may be considered to be more appropriate as measures of maturity, depending on the design that it is being applied to. The assessment of Design Maturity based solely on the number of drawings that have been issued does not represent a useful measure of maturity, because it ignores many of the factors that are important contributors to maturity.

Alternatively, pre-defined descriptions of what defines *(e.g.)* "low", "medium" and "high" maturity for each system, may be generated separately, against which the actual status of the design may be tested (in which case the design characteristics would not be assessed against a standard list of characteristics).

The output of this assessment should be an overall view of the Design Maturity of the equipment, based on individual assessments of each system/sub-system. The mechanism for reporting design maturity should be simple (*e.g.* "high", "medium", "low") to ensure that the information can be clearly presented, however each maturity "level" must be underpinned by robust criteria, against which the design may be assessed.

Following the initial assessment of Design Maturity, it is necessary to develop a plan to manage the improvement of the maturity of each system. Progress against the plan can be monitored and managed using the Maturity Measurement Process. Only when the system design has been assessed as being mature enough, should design reviews be held or the final decision to move into production be made.

System Readiness Levels[6]

DPA ‘Stocktake’ identified the need for a more consistent approach across the agency to project review. A Project Performance Review and Assurance (PPRA) ‘Dashboard’ was developed, consisting of a series of ‘traffic lights’ to indicate the health of a project. Each traffic light represents a Key Performance Indicator, one of which is System Maturity (SM).

System Readiness Levels (SRLs) were developed as a tool for projects to assess SM and to communicate this in a consistent manner. They provide a taxonomy or scale mapped against the generic systems engineering ‘V diagram’.

Nine SRL stages are defined **. For each stage a list of the main systems engineering activities and outputs are given in a column entitled Systems Engineering Drivers. Additional columns are aligned in the table and fall into two categories:

- Key Integration Parameters (KIPs), which detail good practice in key system disciplines such as Reliability & Maintainability, Human Factors Integration.

- Domain Specific (DS) guidance is presented for the Maritime, Air Certification and Information Systems.

The table contains descriptions of the key outputs (and enabling activities) considered good practice, and if used pragmatically, will provide an assessment of System Maturity.

While SM levels are not mandated, guidance for Initial Gate (IG) approval is SRL1 and for Main Gate (MG) approval is SRL4. The assessments will be evidence based and should be supplemented by project and risk plans, which demonstrate a clear understanding of the technical and managerial issues to take the project forward.

The KIP and DS guidance is aligned against the SRL definitions, but it is not practical for most projects to progress uniformly against all relevant KIPs and DS columns. For this reason, an SRL assurance expert is listed against each of the KIP and DS columns, to provide specialist guidance on a case-by-case basis. In addition, each column has a hypertext link to more detailed guidance.

** Author’s Note: The tables themselves are too large to fit into this report. They can be viewed at the following link. http://www.ams.mod.uk/ams/content/docs/srl/srl.pdf

[6] United Kingdom, Ministry of Defence, Acquisition Management System, March 2006 release (v10.1) available Internet, http://www.ams.mod.uk/ams/content/docs/srl/srl.pdf, 9 March 2006.

Annex E
Manufacturing Readiness Levels

The following is an extract from the Transition Readiness Calculator developed by Mr William Nolte of Air Force Research Laboratory, Wright Patterson Air Force Base reprinted with Mr Nolte's permission.

The concept of manufacturing readiness levels (MRL) has been invented to expand the TRL idea so that it can incorporate producibility concerns. The MRL approach addresses producibility concerns early in the development phase. In this way, the MRL helps acquisition program managers comply with the DoDD 5000.1 mandates, "Advanced technology shall be integrated into producible systems and deployed in the shortest time practicable," and, "They shall reduce manufacturing risk and demonstrate producibility prior to full-rate production." MRLs are a metric used to assess the system engineering/design process and maturity of a technology's associated manufacturing processes to enable rapid, affordable transition to acquisition programs. When used with software technologies, MRLs measure quality concerns because manufacturing is rarely a problem in software development.

In general, technologies at TRL 1 and 2 are not mature enough to define a manufacturing process. For this reason, the MRL definitions drafted by Mr. Dan Cundiff and the staff at OSD/AT&L begin with MRL 3. The MRL numbering runs from 3 through 9, and is analogous to TRLs 3 through 9. In computing the overall TRL using the AFRL TRL Calculator, MRL definitions and manufacturing questions are embedded with the associated TRL.

The MRL definitions used in the TRL Calculator were compiled from industry and government standards. The definitions may be tailored to apply at the individual component, sub-system, or system level. The definitions provide metrics that capture the engineering design and manufacturing knowledge maturity of a technology for use during the System Development and Demonstration (SDD) and Production phases of an acquisition program. Since MRLs begin at TRL 3, however, they are useful earlier than that, even during S&T prior to transition to an acquisition program.

Manufacturing Readiness Levels

TRL	MRL
1	**N/A**
2	**N/A**
3	**Manufacturing Concepts Identified.** Assessment of current manufacturability concepts or producibility needs for key breadboard components.
4	**Laboratory Manufacturing Process Demonstration.** Key processes identified and assessed in lab. Mitigation strategies identified to address manufacturing/producibility shortfalls. Cost as an independent variable (CAIV) targets set and initial cost drivers identified.
5	**Manufacturing Process Development.** Trade studies and lab experiments define key manufacturing processes and sigma levels needed to satisfy CAIV targets. Initial assessment of assembly needs conducted. Process, tooling, inspection, and test equipment in development. Significant engineering and design changes. Quality and reliability levels not yet established. Tooling and machines demonstrated in lab. Physical and functional interfaces have not been completely defined.
6	**Critical Manufacturing Processes Prototyped.** Critical manufacturing processes prototyped, targets for improved yield established. Process and tooling mature. Frequent design changes still occur. Investments in machining and tooling identified. Quality and reliability levels identified. Design to cost goals identified
7	**Prototype Manufacturing System.** Prototype system built on soft tooling, initial sigma levels established. Ready for low rate initial production (LRIP). Design changes decrease significantly. Process tooling and inspection and test equipment demonstrated in production environment. Manufacturing processes generally well understood. Machines and tooling proven. Materials initially demonstrated in production and manufacturing process and procedures initially demonstrated. Design to cost goals validated.
8	**Manufacturing Process Maturity Demonstration.** Manufacturing processes demonstrate acceptable yield and producibility levels for pilot line, LRIP, or similar item production. All design requirements satisfied. Manufacturing process well understood and controlled to 4-sigma or appropriate quality level. Minimal investment in machine and tooling - machines and tooling should have completed demonstration in production environment. All materials are in production and readily available. Cost estimates <125% cost goals (e.g., design to cost goals met for LRIP).
9	**Manufacturing Processes Proven.** Manufacturing line operating at desired initial sigma level. Stable production. Design stable, few or no design changes. All manufacturing processes controlled to six-sigma or appropriate quality level. Affordability issues built into initial production and evolutionary acquisition milestones. Cost estimates <110% cost goals or meet cost goals (e.g., design to cost goals met).

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This report provides an overview of a number of different technology maturity measurement systems in use by Canada's NATO allies. The report then goes on to demonstrate how various systems can be combined into a composite system referred to in the document as the Technology Maturity Level (TML) system. The final section identifies how the TML system would be utilized within the CF Defence Management System to support the development of systems and equipment being considered for acquisition in the Canadian Forces.

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Technology Maturity Measurement System, Technology Readiness Level, System Readiness Level, Design Maturity Level, Interface Maturity Level. Manufacturing Readiness Level.

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