A REVIEW OF TECHNOLOGY READINESS LEVEL (TRL) IN DEVELOPING COMMAND AND CONTROL SYSTEM FOR MARITIME OPERATIONS

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ABSTRACT

Maritime system of any origin and purposes are the heart and mind or more appropriately addressed as the core of the command and control it is built and designed for. In this paper it is aimed to elaborate the lessons learnt from the United States Navy in the development of commonality base design and the possibility of applying the use of Technology Readiness Level (TRL) in developing command and control system for maritime based applications. The learning curve expected is to classify the crucial achievement to comprehend the efforts of developing solutions associated to maritime based computer system destined for command and control operations. This review is aimed to draw the framework by applying readily and existing technology allowing development through the use of TRL. It is believed that the same approach could be adapted into the Malaysian environment when necessary.

Keywords: TRL, Command and Control, Maritime Based Application

1. INTRODUCTION

United States Navy (USN) no longer plan to adapt a unique design of a command and control system for its new command and control system as it is expensive to do so. Instead, the USN is making headway to design a common set of software architectures that will ease the modernization and upgrades of their computer system used for command and control function. This is seen as an enabler for an effective budgetary or pricing control measures where such initiatives could initiates as a catalyst to enhance software engineering innovation for warships of any class and design, old and new (Smith, 2013). Traditionally most naval ship either frigates, destroyers etc. are designed in silo, which means the Navy applies unique design specification and does not cater to tailor to system for future expansion and this uniqueness is rather unfriendly when it is time to do some upgrade. To make it worst, independent design for the same class of ships differs by differences caused by time lapse in the building (dealing with obsolescence issues) or by the difference between shipbuilder way of doing things amongst themselves. To remove these complications in the future, a highly effective design trend is deemed necessary for future buildings. Commonality is seen as the solution to these kind of challenges and for command and control system design and development, it is only inevitable to follow suit the trending requirement to eliminate the complex ‘family type’ system design and development and to create a system which is built around common architectures. (Kolodgie, Shuttleworth & Albertson, 2013). TRL can be, the most suitable considerations for Software and Design engineers to consider such efforts in creating command

and control with features that it is adaptable for future upgrades without making huge changes to the base design and architecture.

2. LITERATURE REVIEW

2.1 TRL's Application as a development tool.

Technology readiness level (TRL) was initially used by NASA and is known as a form of measurement tool to gauge the maturity level of a particular technology. Each technology in a project are assessed in comparison to the parameters for each technology level and is then distinguished via a TRL rating based on the project progress. Nine technology readiness levels (TRLs) is commonly applied where, TRL 1 is the lowest in category and TRL 9 being the highest. (Mankins, 1995). The key determination of using TRLs is to assist the organization in making decisions concerning the development and transition of technology. It should be viewed as one of several tools that are needed to manage the progress of research and development action within an organization. Some advantages of TRLs are:

1) Make ready a common understanding of technology status
2) Manage associated risk,
3) Assist in technology funding decision making
4) Assist in transition of technology decision making.

2.2 TRL use in defence acquisition program and beyond.

Academic papers on the use of TRL in defence acquisition program are scarce perhaps due to the confidentiality of defence related program or projects, according to (Sauser, Ramirez-Marquez & Tan, 2009) in 1999, the Department of Defence (DoD) of the USA initiated to use TRL as the metric tool to gauge "the maturity level of a program technologies before its system development begins". This resulted in underlying defence procurement policy to use TRL as a key reference beginning 2001, to accomplish proper demo of maturity level prior to program initiation and ensuing to use an evolutionary or structured approach of developing defence systems. (Olechowski, Eppinger, & Joglekar, 2015) further elaborates that since 2001, the DoD USA requires the application of TRLs in all of its projects expediting the adoption of the TRL. Today the industries besides defence like oil and gas and infrastructure has also engendered customised TRL guidelines as a standard practice. Currently many organisations are reported to have increases the requirement of charting TRL plots to their generic system development process where detailed TRLs are actuality allocated to some or all gates in a development method. (Olechowski et al., 2015)

A DoD sample of TRL scale mapping is shown in Figure 1, "With such a TRL mapping, expectations of technology maturity are consistent and explicit across projects." (Olechowski et al., 2015).

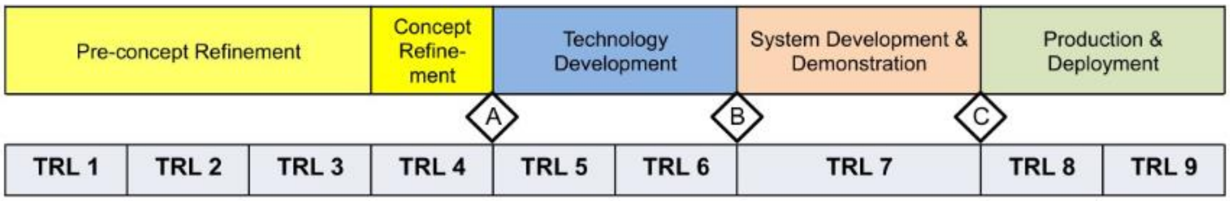

Figure 1: Mapping of technology readiness levels to US Department of Defense System Acquisition Process. Technologies are expected to achieve TRL 4 by milestone A, TRL 6 by milestone B, and TRL 7 by milestone C.

The principle, permits technology maturity to be carefully thought of, the milestones shown in figure 1 are reviews that need special attention which are essential to the decision process from milestones to milestone. Although there are numbers of explanations why organisations implemented the TRL ruler for their expertise development valuation, the key advantage denoted is the common consideration of technology risk and advantage. To elaborate further, the levels are a typical communication to deliberate the technology readiness transversely between organization and inter disciplines. Amongst dissimilar group, the levels are evidently useful in planning of the technology handover, for example, between R&D team and Project Team. To add a methodical modelling for technology intensive system development provisions are made possible with the TRL as guideline. As evidence, a study of 62 US DoD programs, it was formalised that programs which had reached TRL 7 or greater since the beginning of the system's development finishes virtually on time and on cost, against those with technologies below TRL 7 which saw increases in development cost by 32%, purchase cost per unit cost increase of 30% and delay of 20 months. In another study of 37 DoD weapon system program, proof that TRL guideline have momentous effect on the unscheduled overrun of these systems, promulgated added examination of TRL usage in existing practices. Growing roles of independent advisors and accreditors and the inscription of new standards are apparent that safety critical industries like defence, oil and gas and aerospace are gradually acclimating TRL as an instrument to qualify technology readiness and qualification. Further growth is stimulated through introduction of grants and funding or policies that requires the use of TRL as a criterion of worthiness (Olechowski et al., 2015).

2.3 TRL evolution review.

Origins of TRL, the tradition of the aerospace technology is primarily focussed on the safe flight and fit to fly state of aircraft. It is virtually a procedural trend to meticulously check and double check critical components of planes, a process in aviation better known as flight readiness review. People at NASA makes habit of such ritual ever since the first space programs (Héder, 2017). When Apollo program was at its pinnacle, NASA was already making progress to launch space stations and to assess readiness of technology in that aspect, a technology readiness review was made known then but it actually took two decades later for a group of experts at NASA to officially came with a paper on the concept of readiness level but the term Technology readiness level was not spelled out then. The paper spoke mainly about a new technology development strategy of NASA in collaboration with civil, commercial as well as international partners in the quest of available technology for their program. The paper familiarizes Supporting Research Technology (SRT) and Advance Research Technology (ART) as categories of new work idea in a pre-TRL era, in which, saw the ART transition failed recurrently. Nevertheless, in cases where the ART was successfully, technology transfer was considered successful and ART pursued a higher level of maturity aimed at achieving flight readiness. NASA management analysed a number of fruitful and failed technology transfer projects, resulting in, those cases when the technology transfer was successful, the ART project pursued a higher level of maturity, aimed to achieve something close to flight readiness (Héder, 2017).

The experts then proposed a mutual categorisation arrangement amid SRT and ART creating a scale of seven levels derived as in Table 1:

Table 1: SRT and ART Scale of Seven Levels (Source: Heder, 2017)

Levels	Descriptions
1	Basic principles observed and reported
2	Potential application validated
3	Proof-of-Concept demonstrated analytically and experimentally
4	Component and/or breadboard laboratory validated
5	Component and/or breadboard validated in simulated or real-space environment
6	System adequacy validated in simulated environment
7	System adequacy validated in space

Two years beyond the introduction of the 7 levels, NASA continues to refine the levels of maturity and in 1995, John C Mankins wrote a white paper refining the Levels of maturity known as Technology Readiness Level, TRL as shown in Table 2.

Table 2 – Mankin’s TRL 9 Levels (Source: Mankins, 1995)

TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL 7	System prototype demonstration in a space environment
TRL 8	Actual system completed and “flight qualified” through test and demonstration (ground or space)
TRL 9	Actual system “flight proven” through successful mission operations

2.4 Beyond TRL.

Sauser, Verma, Ramirez-Marquez, & Gove (2006), reiterates NASA’s introduction to TRL operation does not imply the concluding actions of denoting system readiness, this are owed to the subsequent governing facts:

- TRL is only a degree of a discrete technology but not systems readiness;
- There is no technique for integrating TRLs mentioned; and
- There is no verified, tried, organized directory of systems readiness

For that there are two extension beyond TRL dully recognised System Readiness Level (SRL) and Integration Readiness Level (IRL).

2.4.1 The System Readiness Level (SRL)

Sauser et al., (2006), elaborates that SRL is an index of the applied maturity at system’s level with correlation to suitable systems engineering organisation principles. SRL is debated not being a function of distinct TRL within a given system and the maturities of the associations amid them, defined based on a scale of integration readiness levels (IRLs). TRL and IRL respectively are utilised to convert qualitative descriptions into quantitative maturity levels this are important to understand the ever-changing aspects of SRL.

2.4.2 Integration Readiness Level (IRL)

IRL are defined as “a systematic measurement of the interfacing of compatible interactions for various technologies and the constant assessment of the maturity amid integration points”. IRL are suggested to elaborate the integration maturity of a developing technology contra to another technology development or maturity. To add, IRLs offers an assessment of where the technology is at, on the integration readiness scale providing access to risks of integration connected with emerging technologies. Studies has confirmed that TRL does not apprehend the risk involved in adopting technology and showed that there can be architecture mismatch risk related to integration (Sauser et al., 2006).

2.4.3 Incose Survey On Trl Users

Tomaschek, Olechowski, Eppinger, & Joglekar (2018), concluded that the 9800 members of the global organisation enthusiastic to the progression of system engineering took ingenuities to induct a first kind survey efforts involving TRL studies. Sampling was extracted from all members of INCOSE through the regional chapter presidents garnering support from a total of 34 presidents agreeing to disseminate invitation to conduct of survey to its members. This resulted in 5370 INCOSE members invited to the survey, in effort to warrant that no TRL users were exempted from the survey a link was also informed in TRL related discussion groups at LinkedIn and sampling were thrown by providing TRL users to disseminate the survey to other known professional with experience in TRLs. Almost 200 respondents submitted in a time frame of two months i.e. between July thru September 2015. Redundant submissions and non TRL respondent and incomplete submissions were omitted from the survey giving a good respond from 167 people.

The survey was design in three parts structure. 1st part discloses the circumstantial information of respondent to segregate the character of TRL user community. 2nd is the core probing the qualified arrangement of the challenge adapting Best Worst Scaling (BWS) method. Last part was about open-ended question concerning supplementary TRL challenges. The uniqueness of the survey exposes detailed data in the second and last part and feedback captured from only skilled TRL users. For the less experienced TRL users, the survey finishes on completion of demographic survey in Part 1. Average timing for the questionnaires was about 15 minutes. In general, the pertinent results drawn from the survey showed, from the Organizational TRL practice point of view, 43% of these organizations require the use of TRLs, while the same fraction (43%) of respondents use them on irregular basis. The obligation to use TRLs is profoundly determined by customers, with 45% of the respondents (75 of 167) chooses that TRLs are essential by clienteles in a multiple-choice question on the motive for the TRL use inside the organization.

Results of this first its kind empirical research closes the gap between TRL and Systems Engineering literature as well as examines in detail TRL application practices, the study added emphasize in prioritization of perceived importance in TRL challenges. A common ground for forthcoming academic studies and guide to researchers in this subject with many selections on investigation area are established, benefited by TRL users on the findings. It is apparent for the study to extract the insights of individual TRL expert's judgement in organisations where TRLs are utilised for technology management. Aerospace, Defence and Government Agencies are dominant TRL users due to their unique a complex technology application. As compliment, it is learnt that manufacturing and professional services are rather new to TRL, nevertheless, complex technology development and innovations are progressively constructing competition and feebleness in partaking unsuitable risk management tool will elevates the attention of more industries in approaches like TRLs. It shall be imperative for managers of large organisation to know whether TRL energies or deter inspired thinking and amalgamation of effective innovative efforts in organisations.

3. RECOMMENDATION

Complex system like command and control system particularly for maritime based applications will dwell in technology readiness issues. Colombi et. al., (2012), reported that in 2005, the DoD US made 54 assessment of defence acquisition program and found that only 15% of them was initiated with adequate mature technologies. A year later a report made by Government Accountability Office, GAO specified that out of 23 major programs they assessed, 75% began system development with immature technologies and during the following year 62 weapon system program assessed with only 16% were entirely matured in technologies, conferring to distinct standards preceding to system development. Alarmingly 32.3 % of the programs suffered cost growth against 2.6% cost growth for project that took off with mature technology. Based on these inputs and the profound known history of system development in maritime based command and control application which usually does not ensures technology maturity prior to development and the wastages in many project delays. Zamrady & Arof (2019), mentions that TRL balances manufacturing readiness consequently it is important for a pragmatic study of the TRLs to be applied in development of indigenous Combat Management System (CMS) for the Malaysian Navy Command and Control System. A gap investigation actions like Delphi (Arof & Khadzi, 2018) combined with AHP (Arof, 2015) are recommended methodologies aimed to create a list of variables, AHP applies as the succeeding phase to regulate the weightage of the selected variables and develop decision making models.

4. CONCLUSION

Ever since its introduction, TRL has been an enabler to safeguard maturity in technology that contributes in ensuring the project or program are conducted with mitigation of risks. Other benefits of TRL have evidently proof that cost overruns could be avoided hence delays are circumvented as well. System developed with TRLs applied are more manageable and is much easier to manage during the design and development phase. Interestingly, new readiness level emerges and evolves around TRL too. These propagates healthier control measures and appropriate documentation can be attained for future improvements. TRL can also be regarded as a preventive measure against project incompletion and future upgrades can be made in a more expedient way especially when it comes to deal with obsolescence's issue, as available records of TRL in place will ensue better technology upgrades instead of holding on to stale blocks tech or worst case backwards technology.

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