Readiness Assessment Report for Mobile-Learning

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I. Executive Summary

This report was written in response to a request of the Software Engineering Department of Monmouth University. In the university's quest to remain technologically pertinent, they have requested that an inquiry be made towards the emerging technology known as mobile learning. The goal of this report is to evaluate the current state of mobile learning technologies that currently available for the Personal Digital Assistant (PDA) and determine if mobile learning via the PDA has reached sufficient maturity to be incorporated into a university-level institution with maximum effectiveness. Areas that will be focused on are the development of the PDA and requisite software applications for mobile learning, the maturity of the aforementioned technologies as assessed by the standardized Technology Readiness Level (TRL) calculator [13], and success stories from other institutions of higher education.

The TRL calculator reported that PDAs in mobile learning achieved up to TRL 9 in the green zone. The highest level that can be achieved is TRL 9. This level of maturity indicates that the technology has been "flight-proven" in operational fields several times. This can readily be justified since PDA hardware and PDA applications have been available on the market for more than a decade. Some questions remain as to the maturity of mobile learning PDA systems since the development of mobile learning-specific applications can still be considered in its infancy, especially since m-learning does not possess an industry standard.

Despite this uncertainty, a fair number of educational institutions have implemented mobile learning systems into their curriculums; several of their stories have been included and demonstrate that it is possible to form successful mobile learning systems with PDA technologies. Nonetheless, it should be kept in mind that due to the immaturity and narrow scope of existing m-learning applications and the lack of an m-learning industry standard, the risk of implementing such a system will only increase without special care.

II. Introduction

On 1 February 2006, the board of trustees of Monmouth University requested the Software Engineering department to develop an assessment of the university's need for technological upgrades. In particular, it was requested that the focus be on mobile learning, and whether the benefits of its adoption would merit the costs and the changes to the university's learning traditions. The primary people involved in producing this report are Ercan Polat and Rita Lee, under the guidance of Dr. Jiacun Wang. Major components of this report are located in sections I (Executive Summary), III (Background), IV (Purposes), V (Limitations), VI (History), VII (Methods), IX (Results), and XII (Appendix). The *Executive Summary* presents a high-level overview of the analysis findings. The *Background* presents several places where m-learning systems were successfully created and/or used. The *Purposes* section describes the purpose of this analysis. *Limitations* spell out limitations to the interpretation of the results from the TRL calculator. *Methods* describes the DoD definitions of the TRL metric. *Results* gives a summarized table of results from the TRL calculator [13]. The *Appendix* contains the full questions and answers used in the TRL calculator.

III. Background

In order to best assess the maturity of PDAs in the classroom for mobile learning, a background must first be presented addressing two essential questions: “Who else is using PDAs in education and how are they being used?” and “What applications for the PDA are available?” Three educational institutions that have successfully integrated PDAs into the classroom are the University of Connecticut’s School of Business Administration, Harvard Medical School, and Ventral Carolina Technical College. The programs these schools started are described briefly below.

In 2001, the University of Connecticut created a three-course program about addressing real-world technology and business issues using PDAs to “push toward a paperless environment both in the classroom and in real-world business environments.” [12] The three courses in question were titled “Paperless/Virtual Office”, “Mobilizing Commerce”, and “Wireless Collaboration”. Students enrolled in this program studied the merits and mechanics of a paperless office, while putting the principles into practice within the classroom at the same time. Paper was banished from the classroom. Tests were taken electronically. Peer evaluations were completed on their Palms and beamed via infrared to professors and other students. Students took notes during class using the SmartPad, and of course, the Palms are used for email and other communications with each other. The equipment lent to the students were a Palm handheld with Palm.Net wireless internet access and a Seiko Instruments SmartPad.

Harvard Medical School sought to mobilize students’ information access due to the fact that its students were constantly moving between classrooms and hospitals. A way was needed to give students access to information. Faculty also needed to be able to keep in contact with students to make sure they were learning the right material, were following the right schedule, enable progress tracking, and other essential functions. Students were given Palm handhelds, allowing them to access personalized course calendars, announcements, and resources such as class notes and syllabi. They also logged important casebook procedures and observations. The faculty could then retrieve the electronic casebook logs in order to monitor and evaluate student progress. In order to establish the infrastructure necessary for this, Harvard Medical School hired ArcStream Solutions, a Palm Solutions Provider, to design and build a mobile information resource for the school, called MyCourses Mobile Platform. It allows students to access information from various school systems via their handhelds through the AvantGo 4.0 MBusiness Server. [4]

Lastly, Central Carolina Technical College wanted to provide wireless access to the school’s website for academic, financial, administrative functions. This was because many of the students were military students from the nearby Shaw Air Force Base who were often on the move even though they remained enrolled at the school. As a result of their PDA initiative, students now can use a Palm handheld to perform tasks such as class registration, applying for admission, browsing course catalogs, checking degree and program information, and accessing news and event calendars. The school is also seeking to use handhelds in other ways, such as for managing work orders in the maintenance department. [1]

The three schools described above tackle the question of using PDAs in schools in three different ways, although there are commonalities in usage. For example, the PDAs are often used as a way to take notes in class, or to write up class work and observations. Wireless communications such as email and text messaging were commonly used; coursework, calendars, announcements, administrative information could all be accessed. However, all these applications are not exactly special-made mobile learning tools. Web browsers, word processors, spreadsheets, graphics/drawing programs, e-book readers and other miscellaneous applications are, collectively, required to make PDAs useful in a classroom environment. According to David Perry of BECTA (British Educational Communications and Technology Agency) ICT Research, "…there are an enormous number of small, classroom specific applications available. But it takes a great deal of time and experimentation to find and evaluate them." [9] One such example of a small classroom specific application is McGraw Hill's Study-to-Go for the Palm and PocketPC. Study-to-Go offers downloadable content that accompanies over fifty titles, providing quizzes, key terms, and flashcards for students to study while on the move. [7] The advantage of this product is that it offers convenient, supplemental study material for students. The downside is that this product is useless if the course does not use McGraw Hill textbooks. There are many small applications for a wide range of disciplines, from Planetarium 2.4, which plots star charts and calculates the position of celestial bodies, to ImagiMath, a mathematics suite with graphing, calculation, and equation solving components, to MusicEar, an ear training program for chords, melodies, scales, and more. [2] All of these can be helpful and interesting, but they are not what the software industry would call the educational 'killer app'; in other words, a 'must have' piece of software that convinces people to invest in a certain type of technology. [11]

Additionally, there currently is no industry standard for mobile learning. [3] The natural result of this is a wide range of incompatible, and thus financially risky, handheld environments (ex. PalmOS, Java, WinCE, Symbian) that inhibit the willingness of software publishers to develop programs for them. [10] Standards, however, are politically very difficult and slow to set, especially when the exact standards that are needed are still unformed.

IV. Purpose

The purpose of this report is to present an overview of Personal Digital Assistants (PDAs), its uses in education as a mobile learning device, and to calculate the readiness of PDA-related hardware and software for mobile learning systems in higher education. The tool used to calculate readiness is a calculator designed by NASA to provide a standardized means of measurement. The metric used is the Technology Readiness Levels metric, as described in the DoD Interim Guidance. However, in addition to the calculator, observations of PDA mobile learning systems implemented in other institutions were included in this report to provide views of successful implementations that the calculator would not be able to show. The ultimate purpose of this report is to provide the material needed for Monmouth University to judge the amount of risk it would incur should it choose to invest in PDA-driven mobile learning technology in its current commercial state.

V. Limitations

The main noticeable limitation was that we did not have one single hardware product and one single software product to assess. Our aim was to keep our scope somewhat restricted (not all m-learning technologies) yet still inclusive (all forms of PDAs and all PDA software that can be used for m-learning). However, the TRL calculator sometimes requires solid yes/no answers to questions in order to advance to the next level, even though the reality is more ambiguous. For example, one question asked for TRL 3 is: “Metrics established”. For the hardware, we can assume metrics have been established since PDAs have been on the market for many years now. However, in terms of applications, while individual programs may have metrics defined, overall, there is no m-learning standard.

Additionally, there are many questions that are so detailed that they require in-depth knowledge of a product in order to be answered. Since we were unable to attain the required information for so many products in the amount of time allotted, we had to assume many things, given that the products are already on the market and have been utilized in existing mobile learning systems.

V. History

The invention of the first Personal Digital Assistant (PDA) occurred a little more than three decades ago. However, as a result of the great speed with which digital technology evolves, it is actually quite difficult to pinpoint who invented the first PDA and when it first appeared. According to a chronology of the evolution of PDAs by Evan Koblentz, the precursor to the modern PDA is the programmable calculator with a removable storage via a built-in card reader, developed by Hewlett Packard (HP) in the early 1970's. It is notable because it embodied two key abilities for any computer, much less a portable one; the ability to be programmed, and the ability to save the program on nonvolatile memory. In 1975, Satyan Pitroda secured a US patent for an early PDA. From the mid to late 70's, the calculator improved in complexity with additional features such as an alarm, clock, and scheduler (Casio CQ-1 Primitive PDA); as a handheld video game (Mattel Auto Race); or as calculators with alphanumeric input that output to external printers (TI-58, TI-59). In 1980, Casio introduced the first PDA with character recognition (Casio PF-8000). Also in the late 70's and early 80's, early tablets with touch screens were available. [6]

To avoid misunderstanding, it must be emphasized that none of these early products were "palm-sized". It was only in 1984 that fifth generation Handheld Computers (HHC) were introduced that could be held in a hand. From 1985 to 1990, a flurry of innovations continued to be added to the PDA's repertoire. In 1985, the Casio FX-7000G became the first graphing calculator, introducing a dot-matrix display. In 1986, the HP-18C introduced infrared connections. The following year, the Casio IF-8000 screen expanded two times in both directions and possessed separate text and graphics layers. Then the Panasonic Personal Partner became the first "palmtop" to use a version of DOS; the HP-19B calculator had the choice to choose between six user interface languages; and 1990 saw the introduction of a PDA with a pen GUI and handwriting recognition. [6]

The term "personal digital assistant" was invented by Apple when they marketed their version of the PDA called the Apple Newton, around 1992 or 1993. This name eventually became accepted as the general name for digital handheld computers. After 1994, the evolution of PDAs has continued with new features and functionalities, such as email, fax, pager, and cellular telephone features. The size and weight of PDAs have shrunk while capacity and processing power continue to increase. Currently, an average PDA has almost all the functionalities of a Laptop and even has other features that laptops do not have, such cell phone capabilities. PDAs have an operating system and their own software. It can be used to connect to the Internet wirelessly, watch movies, listen to MP3s, play games, and more. The programmable aspect of the PDA has resulted in a large quantity of software. People do not have to rely on the built-in software that is provided by the manufacturer.

Today a growing number of institutions are incorporating PDAs into mainstream education and training with mobile-learning, whether it be using PDAs as data gathering tools in a lab environment as another form of distance learning, or in a push to make the classroom "paperless". A brief history of mobile learning in education must first begin with distance learning. Distance learning is an educational system or process that connects students with distributed learning resources. The actual implementation can take many different forms, but it is always characterized by a separation in space and/or time between the teacher and student, among students, and/or between students and learning resources. There must be one or more types of media through which interaction takes place between teacher and student and between other students, although it does not necessarily have to be through electronic means. The first distance learning programs were started in the 1970's, in European universities in the United Kingdom, Spain, and Germany. [5] With the innovations and advancements in the telecommunication industry, a new way of distance learning was applied to the educational system. In the late 1970s and early 1980s, cable and satellite television came into use as a delivery medium for distance education courses. [8] Computer conferencing was first used for education in 1981.

With the onset of the personal computer and other electronic media, electronic learning, or e-learning, became the norm for distance learning. E-learning is education delivered through electronic means. With the invention of the World Wide Web (www or internet) came the first wave of the e-learning era, between 1994 and 1999. The second wave came between 2000 and 2005. The technology advances such as rich streaming media, high bandwidth access, and advanced web design had revolutionary impacts in e-learning. In the midst of this progress, wireless technology became widely used. The merging of e-learning and wireless technology have now started shifting educational trends from e-learning to mobile learning (m-learning), which is a type of e-learning that is specifically used with wireless mobile devices. The motto of m-learning is "learning anytime and anywhere". Already there are a number of educational institutions that seek to take advantage of PDA m-learning by mandating its use in schools such as Harvard Medical School, the University of Connecticut, and Central Carolina Technical College.

VI. Methods

The method of readiness analysis used for this report is the Technology Readiness Level scale developed by NASA, which adheres to the DoD mandates (Section 804 of the FY2003 Defense Authorization Act and Directive 5000.1) that require all DoD departments to adopt technology maturity assessments in order to reduce cost and schedule over-runs. The first TRL scale originally had seven levels of maturity growth. The new scale in use with NASA essentially is the same scale suggested by the DoD Interim Guidance, which outlines nine levels of maturity. Descriptions of each level are as follows [13]:

- **TRL 1**: Basic principles observed and reported. This is the lowest level of readiness, where research is just starting to be applied and developed. Examples might include paper studies of a technology's basic properties.
- **TRL 2**: Technology concept and/or application formulated. Once basic principles are observed, the invention process for practical applications can begin. What is produced is speculative, with no real proof or detailed analysis. At best, analytic studies are being developed at this level.
- **TRL 3**: Analytical and experimental critical function and/or characteristic proof of concept. At this point, active research and development has begun. Deliverables include analytic studies, laboratory studies, and components that are not yet integrated or representative of the final technology.
- **TRL 4**: Component and/or breadboard validation in laboratory environment. Basic technological components are integrated to establish that they will work together, but do not necessarily represent how the technology will look like or operate in its final stages. Examples of this would be "ad hoc" hardware integration in a laboratory.
- **TRL 5**: Component and/or breadboard validation in relevant environment. Trustworthiness of the breadboard technology increases significantly, and is integrated with realistic supporting elements so it can be tested in a simulated environment.
- **TRL 6**: System/subsystem model or prototype demonstration in a relevant environment. By this point, a representative model/prototype system is ready to be tested in a relevant environment, such as a "high fidelity" laboratory or a simulated operational environment. This level is a significant step up from TRL 5.
- **TRL 7**: System/subsystem model or prototype demonstration in an operational (space) environment. The prototype is near or at completion point. This level requires a demonstration of the system prototype in a non-simulated operational environment, for example, testing a prototype in a test bed aircraft. This is a major step up from TRL 6.
- **TRL 8**: Actual system completed and (flight) qualified through test and demonstration (Ground and Space). The technology has been proven to work in its final form and under expected conditions. In most cases, this level represents the end of true system development.

- **TRL 9**: Actual system (flight) proven through successful mission operations. The final form of the technology is applied under mission conditions, such as those encountered in operational test and evaluation.

VII. Instrumentation

The instrument that was used to calculate a numerical representation of PDA m-learning product readiness was the Technology Readiness calculator. Developed by NASA as a tool to apply Technology Readiness Levels (TRLs) to technology development programs, it is a Microsoft Excel spreadsheet application that lists a series of questions for the user to answer concerning a technology. The questions are grouped according to associated TRL. Once the questions are answered, the calculator displays the overall TRL that has been achieved. The same set of questions is used every time, thus providing a standardized process for evaluating hardware and/or software maturity.

Across the top of the calculator, there is a segmented thermometer displayed across the top of the page. This thermometer will remain present at the top of the page even if the user scrolls down to answer questions. Each numbered segment represents a TRL, and the display segments beneath the TRL numbers change color as data is entered into the spreadsheet. The colors indicate the overall TRL achieved, where red means data was entered but the level was not achieved; yellow means some items have not been completed but if they are not highly important, then the level may be claimed; green means the level has been reached; and no color means no data has been entered. The calculator is set up so that the overall TRL level achieved can be no higher than the lowest TRL level. In other words, if TRL2 is in yellow stage, later levels such as TRL3 and TRL4 will not turn green no matter how many tasks are completed. Only until TRL2 reaches green would TRL2+ be able to reach green.

Below the thermometer display are the questions to be answered. The TRL calculator being used for this assessment groups all the questions together according to increasing TRL; other versions may group the questions according to category. This version also does not provide weighted TRLs. Some questions in the Question area consist of radio buttons; only one response can be chosen out of a group of possible responses. The majority of the questions are checkbox questions. Checking a box indicates that the task referred to in the question is 100% complete. The answer can also be modified to indicate a partial percentage of completeness, using the slider bar next to each checkbox question. Once the percent complete equals or exceeds the threshold value assigned by the user, the task is counted as done in the calculator's computation, just as if the check box had been checked. The threshold for Green is set at 100% completion. The threshold for Yellow is set at 67% completion. Also, for each level's group of checkbox questions, a shortcut is provided to the user to assume full completion of questions for a level.

At the top of the calculator, there is a button labeled "Summary" which will take the user to the summary results page. Here the user can define thresholds for Green and Yellow, and view the overall calculated TRL achieved by the program and/or technology.

VIII. Results

We used the TRL calculator for Technology Readiness Assessment only; we omitted questions related to Manufacturing and Programmatic Readiness. We also included questions for both hardware and software. By default, the indicator for Green Readiness color required 100% completion. The TRL calculator results are summarized as follows:

TRL Level	**# Criteria Total**	**# Criteria Met**	**Readiness Color**
1	9	9	Green
2	16	16	Green
3	19	19	Green
4	19	19	Green
5	17	17	Green
6	16	16	Green
7	9	9	Green
8	9	9	Green
9	4	4	Green

Summary Results	**TRL Level**
Top Level View – Demonstration Environment	9
Green Level Achieved	9

Evaluation details for each TRL are given in the Appendix.

IX. Concluding Remarks

Monmouth University is considering the implementation of a mobile learning system via Personal Digital Assistants (PDAs), and has requested that a readiness assessment be conducted to judge the maturity of PDA technologies. In terms of hardware, the modern PDA has been in the commercial market for more than a decade and can easily be considered mature. However, while basic PDA software such as word processing has been in the market as long as PDAs have been, specific mobile learning software technologies are only just emerging. There are a myriad of small classroom-specific applications for the PDA that collectively may serve the purpose of effective mobile learning, but no one "killer" application that can easily be assessed for maturity. Despite this uncertainty, according to the Technology Readiness Level (TRL) calculator employed to measure readiness, PDA technologies for mobile learning earned Green readiness color up to TRL 9, the highest level that can be achieved. The criterion for green readiness was set to 100% completion per level, which means that all questions in the calculator must be answered with 100% completion for green to be earned.

Nonetheless, the myriad of small applications for the PDA can be at times confusing, overwhelming, and directionless. Additionally, because there is no mobile learning industry standard, the success of a mobile learning system would be strongly dependent on faculty, and restricted by their personal skill development, their confidence and awareness of available applications, and their limits in being able to develop applications themselves.

X. References:

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XI. Appendix

The tables below depict the questions that were asked by the TRL calculator in order t determine a technology's readiness level. The TOP LEVEL VIEW table directly below indicates the user's perception of the technology's readiness. The rest of the tables determine the technology's true readiness depending on how the user answers each question put forth.

	TOP LEVEL VIEW -- Demonstration Environment (Start at top and pick the first correct answer)
◉	Has an identical unit been successful an on operational mission (space or launch) in an identical configuration?
○	Has an identical unit been demonstrated on an operational mission, but in a different configuration/system architecture?
○	Has an identical unit been mission (flight) qualified but not operationally demonstrated (space or launch)?
○	Has a prototype unit been demonstrated in the operational environment (space or launch)?
○	Has a prototype been demonstrated in a relevant environment, on the target or surrogate platform?
○	Has a breadboard unit been demonstrated in a relevant (typical; not necessarily stressing) environment?
○	Has a breadboard unit been demonstrated in a laboratory (controlled) environment?
○	Has analytical and experimental proof-of-concept been demonstrated?
○	Has a concept or application been formulated?
○	Have basic principles been observed and reported?
○	None of the above

Both hardware-related and software-related questions were asked, as indicated by the far left column in the tables below. "B" stands for "Both", "S" stands for "Software", and "H" stands for "Hardware". In other words, this TRL calculator has been adjusted in order to calculate the combined readiness of a technology's hardware components and software components.

H/SW Both	Ques Catgry	% Complete		TRL 1 (Check all that apply or use slider for % complete)
		☐ Do you want to assume completion of TRL 1?		
B	T	100	☑	"Back of envelope" environment
B	T	100	☑	Physical laws and assumptions used in new technologies defined
S	T	100	☑	Have some concept in mind that may be realizable in software
S	T	100	☑	Know what software needs to do in general terms
B	T	100	☑	Paper studies confirm basic principles
S	T	100	☑	Mathematical formulations of concepts that might be realizable in software
S	T	100	☑	Have an idea that captures the basic principles of a possible algorithm
B	T	100	☑	Basic scientific principles observed
B	T	100	☑	Research hypothesis formulated

H/SW Both	Ques Catgry	% Complete		☐ Do you want to assume completion of TRL 2? TRL 2 (Check all that apply or use slider for % complete)
B	T	100	☑	Potential system or component application(s) have been identified
B	T	100	☑	Paper studies show that application is feasible
B	T	100	☑	An apparent theoretical or empirical design solution identified
H	T	100	☑	Basic elements of technology have been identified
B	T	100	☑	Desktop environment
H	T	100	☑	Components of technology have been partially characterized
H	T	100	☑	Performance predictions made for each element
S	T	100	☑	Some coding to confirm basic principles
B	T	100	☑	Initial analysis shows what major functions need to be done
H	T	100	☑	Modeling & Simulation only used to verify physical principles
S	T	100	☑	Experiments performed with synthetic data
B	T	100	☑	Rigorous analytical studies confirm basic principles
B	T	100	☑	Individual parts of the technology work (No real attempt at integration)
S	T	100	☑	Know what hardware software will be hosted on
B	T	100	☑	Know what output devices are available
B	T	100	☑	Know what experiments you need to do (research approach)

H/SW Both	Ques Catgry	% Complete		☐ Do you want to assume completion of TRL 3? TRL 3 (Check all that apply or use slider for % complete)
B	T	100	☑	Academic environment
H	T	100	☑	Predictions of elements of technology capability validated by Analytical Studies
S	T	100	☑	Analytical studies verify predictions, produce algorithms
H	T	100	☑	Science known to extent that mathematical and/or computer models and simulations are possible
S	T	100	☑	Outline of software algorithms available
H	T	100	☑	Predictions of elements of technology capability validated by Modeling and Simulation
S	T	100	☑	Preliminary coding verifies that software can satisfy an operational need
B	T	100	☑	Laboratory experiments verify feasibility of application
H	T	100	☑	Predictions of elements of technology capability validated by Laboratory Experiments
B	T	100	☑	Cross technology effects (if any) have begun to be identified
B	T	100	☑	Paper studies indicate that system components ought to work together
B	T	100	☑	Metrics established
S	T	100	☑	Experiments carried out with small representative data sets
S	T	100	☑	Algorithms run on surrogate processor in a laboratory environment
S	T	100	☑	Know what software is presently available that does similar task (100% = Inventory completed)
S	T	100	☑	Existing software examined for possible reuse
S	T	100	☑	Know limitations of presently available software (Analysis of current software completed)
B	T	100	☑	Scientific feasibility fully demonstrated
B	T	100	☑	Analysis of present state of the art shows that technology fills a need

Both	Catgry	% Complete		TRL 4 (Check all that apply or use slider for % complete)
B	T	100	☑	Cross technology issues (if any) have been fully identified
H	T	100	☑	Individual components tested in laboratory/by supplier (contractor's component acceptance testing)
H	T	100	☑	M&S used to simulate some components and interfaces between components
S	T	100	☑	Formal system architecture development begins
B	T	100	☑	Overall system requirements for end user's application are known
S	T	100	☑	Analysis provides detailed knowledge of specific functions software needs to perform
H	T	100	☑	Laboratory experiments with available components show that they work together (lab kludge)
S	T	100	☑	Requirements for each function established
S	T	100	☑	Algorithms converted to pseudocode
S	T	100	☑	Analysis of data requirements and formats completed
S	T	100	☑	Stand-alone modules follow preliminary system architecture plan
H	T	100	☑	Hardware in the loop/computer in the loop tools to establish component compatibility
B	T	100	☑	Technology demonstrates basic functionality in simplified environment
B	T	100	☑	Controlled laboratory environment
S	T	100	☑	Experiments with full scale problems and representative data sets
S	T	100	☑	Individual functions or modules demonstrated in a laboratory environment
S	T	100	☑	Some ad hoc integration of functions or modules demonstrates that they will work together
B	T	100	☑	Low fidelity technology "system" integration and engineering completed in a lab environment
B	T	100	☑	Functional work breakdown structure developed

Both	Catgry	% Complete		TRL 5 (Check all that apply or use sliders)
B	T	100	☑	Cross technology effects (if any) identified and established through analysis
B	T	100	☑	System interface requirements known
S	T	100	☑	System software architecture established
S	T	100	☑	External interfaces described as to source, format, structure, content, and method of support
S	T	100	☑	Analysis of internal interface requirements completed
B	T	100	☑	Interfaces between components/subsystems are realistic (Breadboard with realistic interfaces)
S	T	100	☑	Coding of individual functions/modules completed
B	T	100	☑	High fidelity lab integration of system completed, ready for test in realistic/simulated environments
H	T	100	☑	Fidelity of system mock-up improves from breadboard to brassboard
B	T	100	☑	Laboratory environment modified to approximate operational environment
S	T	100	☑	Functions integrated into modules
S	T	100	☑	Individual functions tested to verify that they work
S	T	100	☑	Individual modules and functions tested for bugs
S	T	100	☑	Integration of modules/functions demonstrated in a laboratory environment
S	T	100	☑	Algorithms run on processor with characteristics representative of target environment
B	T	100	☑	IPT develops requirements matrix with thresholds and objectives
B	T	100	☑	Physical work breakdown structure available

Both	Catgry	% Complete		TRL 6 (Check all that apply or use sliders)
B	T	100	☑	Cross technology issue measurement and performance characteristic validations completed
B	T	100	☑	Operating environment for eventual system known
B	T	100	☑	M&S used to simulate system performance in an operational environment
H	T	100	☑	Factory acceptance testing of laboratory system in laboratory setting
B	T	100	☑	Representative model / prototype tested in high-fidelity lab / simulated operational environment
B	T	100	☑	Realistic environment outside the lab, but not the eventual operating environment
S	T	100	☑	Inventory of external interfaces completed
S	T	100	☑	Analysis of timing constraints completed
S	T	100	☑	Analysis of database structures and interfaces completed
S	T	100	☑	Prototype implementation includes functionality to handle large scale realistic problems
S	T	100	☑	Algorithms parially integrated with existing hardware / software systems
S	T	100	☑	Individual modules tested to verify that the module components (functions) work together
S	T	100	☑	Representative software system or prototype demonstrated in a laboratory environment
B	T	100	☑	Laboratory system is high-fidelity functional prototype of operational system
S	T	100	☑	Limited software documentation available
B	T	100	☑	Engineering feasibility fully demonstrated

Both	Catgry	% Complete		TRL 7 (Check all that apply or use sliders)
H	T	100	☑	M&S used to simulate some unavailable elements of system, but these instances are rare
B	T	100	☑	Each system/software interface tested individually under stressed and anomalous conditions
S	T	100	☑	Algorithms run on processor(s) in operating environment
B	T	100	☑	Operational environment, but not the eventual platform, e.g., test-bed aircraft
H	T	100	☑	Components are representative of production components
B	T	100	☑	Most functionality available for demonstration in simulated operational environment
B	T	100	☑	Operational/flight testing of laboratory system in representational environment
B	T	100	☑	Fully integrated prototype demonstrated in actual or simulated operational environment
B	T	100	☑	System prototype successfully tested in a field environment.

Both	Catgry	% Complete		TRL 9 (Check all that apply or use sliders)
B	T	100	☑	Operational Concept has been implemented successfully
B	T	100	☑	System has been installed and deployed in intended weapon system platform
B	T	100	☑	Actual system fully demonstrated
B	T	100	☑	Actual mission system "flight proven" through successful mission operations (OT&E completed)