Systems Maturity Assessment of the Lithium Ion Battery for Extravehicular Mobility Unit Project

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Abstract. The Long Life (Lithium Ion) Battery (LLB/LIB) is designed to replace the current Extravehicular Mobility Unit (EMU) Silver/Zinc (Ag/Zn) Increased Capacity Battery (ICB), which is used to provide power to the Primary Life Support Subsystem (PLSS) during Extravehicular Activities (EVAs). The LLB (a battery based on commercial lithium ion cell technology) is designed to have the same electrical and mechanical interfaces as the current ICB. The EMU LIB Charger is designed to charge, discharge, and condition the LLB either in a charger-strapped configuration or in an EMU-mounted configuration. This paper will retroactively apply the principles of Systems Maturity Assessment to the LLB project through use of the Integration Readiness Level and Earned Readiness Management. The viability of this methodology will be considered for application to new and existing technology development projects.

Keywords: System Maturity Assessment, lithium ion, Systems Engineering, Technology Readiness Level, System Readiness Level, Integration Readiness Level
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INTRODUCTION

The Long Life (Lithium Ion) Battery (LLB/LIB) is designed to replace the current Extravehicular Mobility Unit (EMU) Silver/Zinc Increased Capacity Battery (ICB), which is used to provide power to the Primary Life Support Subsystem (PLSS) during Extravehicular Activities (EVAs). The resulting system includes a long-life rechargeable battery, a portable Intravehicular Activity (IVA) charger and an accessories kit for cable and fuse storage.

The LLB is an important logistical endeavor by the International Space Station program to reduce the up mass requirements necessary to resupply ICBs, given their short useful life of one calendar year. While the stakeholders include ISS Program Office, EVA crew members, prime contractor, and EVA Program Office, the JSC Engineering Directorate has a principal stake in development of the flight product from design concept through maturation and certification. This paper summarizes the technology development and hardware build project and retroactively applies Systems Maturity Assessment as a means of assessing viability of the project management methodology in the development of critical NASA spaceflight systems.

System Description

This section provides an overview of the battery/charger system from the perspective of technology development. The LLB/LIB system is made up of three discrete elements: battery, charger and data logging software. The battery has been designed to interface with and power the Extravehicular Mobility Unit (EMU), or spacesuit and the charger. The charger has been developed to interface with the LLB and either International Space Station (ISS) or Space Transportation System, Orbiter (Shuttle) power systems. The software is installed on a Space Station Computer (SSC) and interfaces solely with the LIB Charger via a one-way Universal Serial Bus (USB) data interface. The software is not required for nominal operation of the LLB/LIB Charger. A definition of the nominal system interfaces is offered in Figure 1. The data logging software is not shown in this figure since it is not a portion of the nominal system; however, the logging code is designed to operate non-intrusively on the on-orbit laptop and connect directly to the LIB charger via a Universal Serial Bus cable.

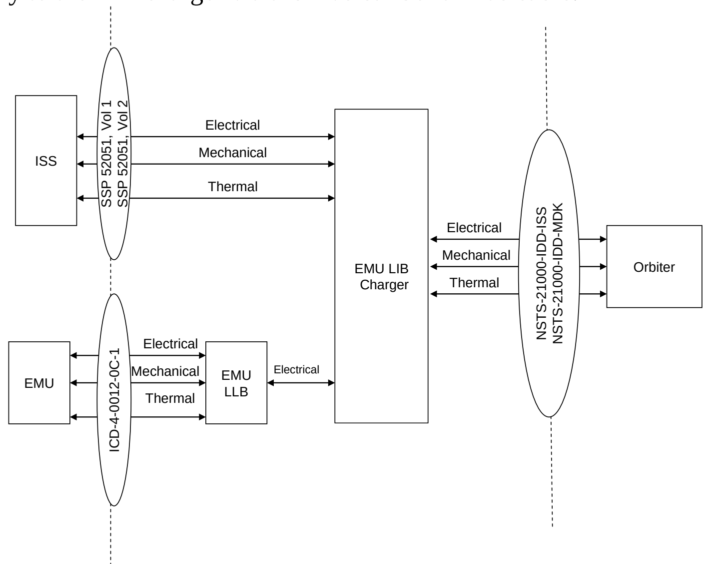

FIGURE 1 – Nominal LLB/LIB Charger Interface Definition

Although each system element functions in concert, the battery is mission critical and serves the EVA mission without the associated charger. The LIB Charger serves the IVA portion of the mission by providing the necessary battery servicing function. For this study, the development and certification of the firmware required for charger operation is considered an inherent portion of charger development and is not singled out for independent consideration herein. The data logging software was developed to aid in troubleshooting should anomalous battery or charger performance occur while on-orbit or during ground operation. The logging software is not required for charger operation nor can the software influence charger operation. Likewise, by design, the logging software is neither required for space station computer operation nor can it influence computer operation. The software does require a 32-bit Windows-based operating system and a USB data interface, facts which are considered in interface definition for off-nominal operation of the LLB/LIB Charger system.

Battery Technology Overview

The battery design went through two iterations to achieve the final product. The initial build approached the challenge through modification of a commercial cell design with limited industrial use but which was based on pouch technology. The pouch design was pursued due to the low internal pressure required to relieve the cell should over-charging occur. Unfortunately, the resulting product was immature and failed to meet the life requirement levied on the long life battery as the project under-estimated the development effort necessary for a complex lithium-ion battery. When the failure was identified, the problem was studied and determined to be incurable with the available budget and schedule. Therefore, in 2007, the battery project was re-commissioned to use a Commercial Off-the-Shelf (COTS) lithium-ion electrochemical cell widely deployed in consumer electronics (laptops, digital cameras, etc). The second generation battery (designated the LLB to distinguish it from the original concept) retained the electrical architecture and hardware infrastructure developed during the first iteration to insure applicability of the LIB charger. In a further effort to minimize repeat failure, the second generation battery build was contracted to the industry leader in on-orbit operation of lithium-ion technology. This paper will discuss the technology and integration readiness development of both the first and second generation battery. A pictographic representation of the design evolution is shown in Figure 2 (note the battery housing is oriented differently in the two pictures).

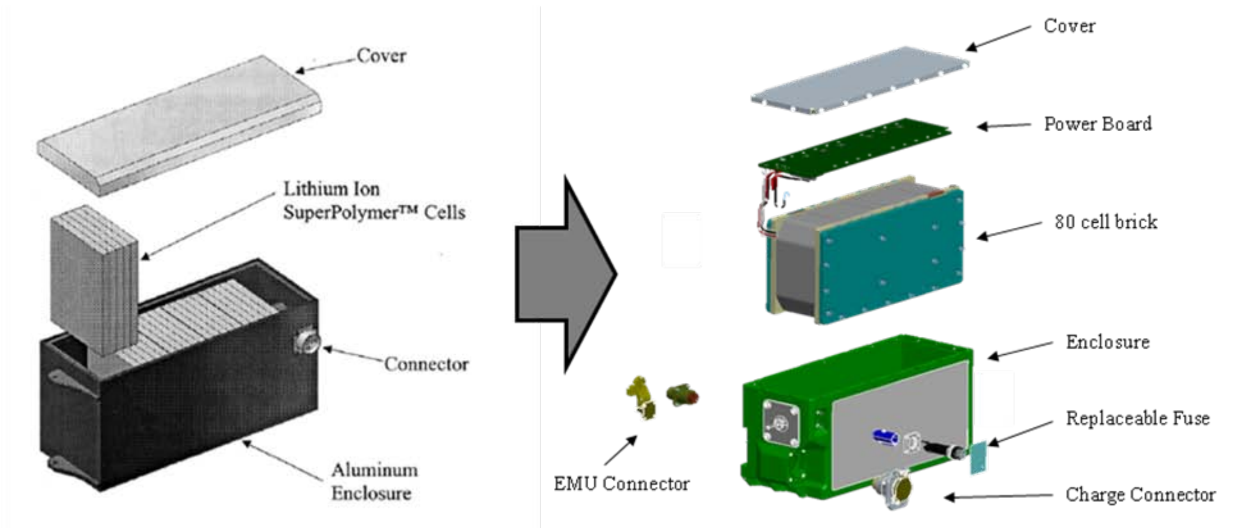

FIGURE 2 - Battery Design Evolution

Charger Technology Development

The charger design progressed on a much more linear path due to the decision to maintain the existing control architecture and interfaces with the second generation lithium battery. Although steady, charger development was not without issue. The design employed the use of COTS microcontrollers in a serial fashion, each regulating voltage over a slightly increased range. In this fashion, three microcontrollers were able to provide the two fault tolerance required of human spaceflight hardware. Since the ISS program does not allow software (in this case, charger firmware) to provide every control, the charger was designed to use a power source incapable of over-charging the lithium ion battery. The resulting complexity of the charger design and the poor quality control of the initial vendor allowed for latent defects to progress undetected through the initial flight acceptance and qualification program. These defects were detected during fleet acceptance testing about the same time as the first generation battery failed the life cycle requirement (ironically, the defects were noted while troubleshooting the failed battery). As a result of this failure, the charger design was revisited, the defects identified, and rigorous methods developed to independently verify each critical charger function. The autonomous operation of the charger, especially when combined with the design requirement that inherent charger function be inaccessible by the user, made detection and verification of critical function operation a challenge. The accessory kit was combined with the charger development effort since it was to reside with the charger on-orbit. The accessory kit development was not without issue due to inappropriate labeling requirements and incorrect material selection. As a part of the charger refurbishment work, the flight kits were modified to satisfy specification requirements. The delivered kit is secured to the charger once on-orbit with a hook-and-loop-fastened strap which allows for securing of two batteries as shown in Figure 3.

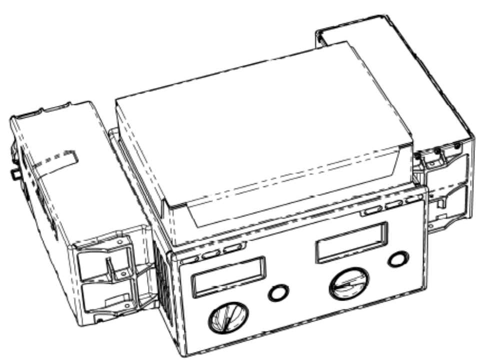

FIGURE 3 - LIB Charger with Accessory Kit and Two Batteries

Data Logging Software Development

The laptop logging software matured on a more optimized path progressing from basic ground test function, to development of a user-friendly Graphical User Interface (GUI), to certification as flight software. The system requirement that LIB charger operational parameters be unchanged by the user resulted in a one-way data connection between the LIB Charger and the companion laptop. Operationally, the data logging software is only required for collection of engineering data should the need arise to troubleshoot an on-orbit or ground problem. Based on this usage scenario and the decision to maintain a stand-alone executable program, NASA classified the flight software as non-safety critical. The combination of classification, and the design decisions to utilize standard drivers in a stand-alone executable, drastically simplified the flight certification process. The use case for the data logging software (LIBSoft) is shown in Figure 4.

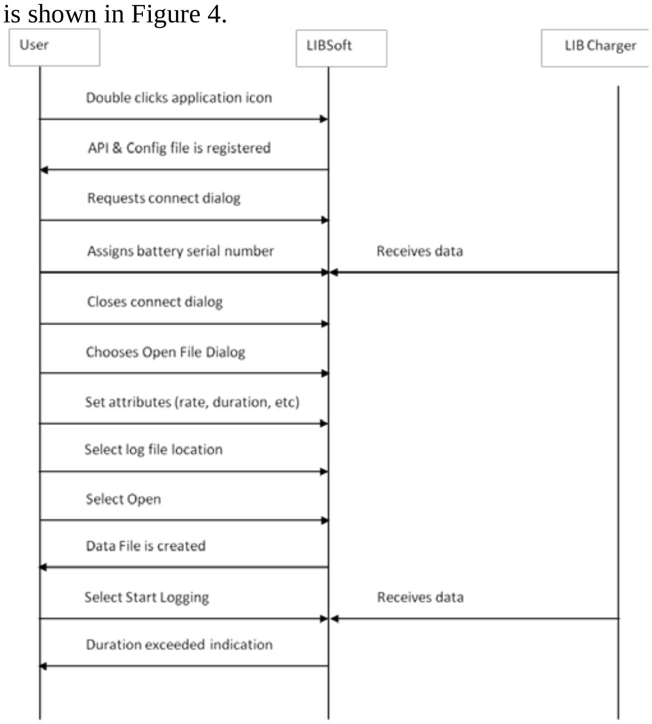

FIGURE 4 - LIB Charger Data Logging Software Use Case Diagram

System Operation

Functional flow development is briefly discussed to foster an understanding of intended use of the system both on-orbit and in ground storage. Nominal battery utilization prepares a battery for EVA, performs a pre-EVA verification, performs the stated mission, and returns the battery to storage condition if necessary (short EVA). Should an anomaly be detected either during servicing or mission use, data logging software is available for us in conjunction with charger operations to assist the ground operations team in determining the nature and significance of the finding. It is assumed that trouble shooting operations will require charge and discharge operations of the charger with data logging enabled. The resulting data file will then be studied and additional ground or on-orbit testing utilized before a decision is made to continue usage of the on-orbit or ground hardware.

System Development Timeline

The project timeline shown in Figure 5 maps systems development as a function of time and significant project milestone and illustrates the rigor required to develop this particular system. The project timeline is developed based on lifecycle review and significant program events as these are well-documented milestones. It may be interesting to note that significant events occurred after the design phase suggesting that there is no substitute for hardware when attempting to develop and mature a system.

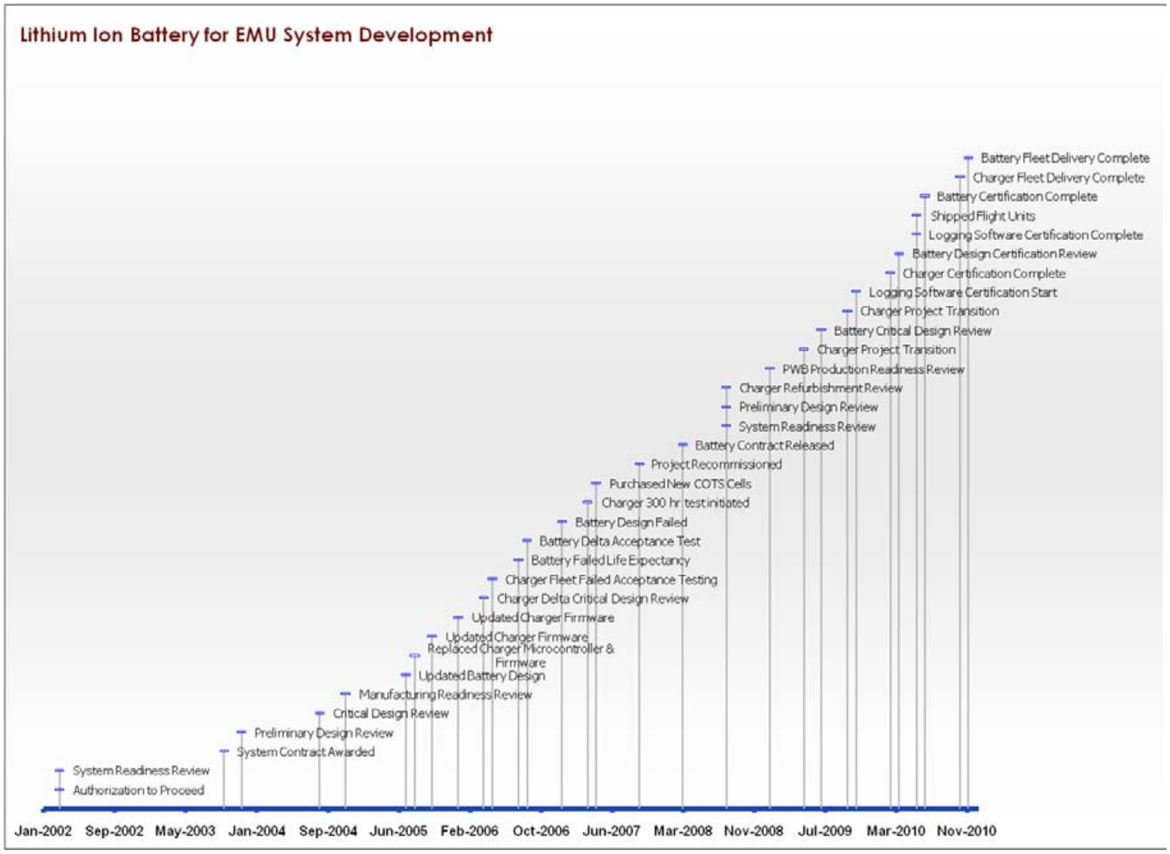

FIGURE 5 - Lithium Ion Battery for EMU System Development Timeline

System Maturation Assessment

This paper retroactively applies the principles of System Maturation Assessment (SMA) (Whitfield, 2010) to the three principal components of the LIB/LLB system, the battery, the charger and the data logging software. To simply this assessment, each system element is considered a single technology as defined herein. SMA requires the use of both Technology Readiness Level (TRL) and Integration Readiness Level (IRL) to compute a composite Systems Readiness Level (SRL) (Sauser, 2008). While TRL focuses purely on technology readiness, IRL focuses on the integration readiness of developing technologies. Knowing these assessment levels, a composite SRL can be computed which provides a quantitative maturity assessment for the developing system. This section applies the principles of SMA to the LLB/LIB project at each project milestone indentified in Figure 5.

Readiness Level Definition

In addition to the widely accepted Technology Readiness Level (TRL), the lesser known Integration Readiness Level (IRL) is required to complete SMA. Guidance for selection of the IRL metrics for developing technology integration is offered in Table 1.

Table 1 - Integration Readiness Level Definition[1]

IRL	Definition
9	Integration is Mission Proven through successful mission operations.
8	Actual integration is completed and Mission Qualified through test and demonstration, in the system environment.
7	The integration of technologies has been Verified and Validated with sufficient detail to be actionable.
6	The integrating technologies can Accept, Translate, and Structure Information for its intended application.
5	There is sufficient Control between technologies necessary to establish, manage, and terminate the integration.
4	There is sufficient detail in the Quality and Assurance of the integration between technologies.
3	There is Compatibility (i.e., common language) between technologies to orderly and efficiently integrate and interact.
2	There is some level of specificity to characterize the Interaction (i.e., ability to influence) between technologies through their interface.
1	An Interface between technologies has been identified with sufficient detail to allow characterization of the relationship.

[1]Sauser, 2008

To test applicability of the methodology without undue burden, each system element is considered a single technology. This decision limits integration between elements as shown in Figure 6 with a common technology serving as the linkage for the other two. Figure 6 also depicts the directional nature of the technology interaction, although integration direction is not considered in this work.

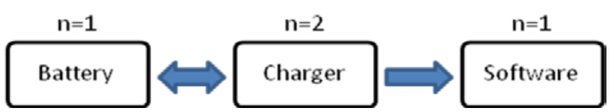

FIGURE 6 - Technology Interactions of the LLB/LIB System

In order to compute SRL, a technology and integration assessment must be provided at each point of measurement. Derived from conventional definitions of Technology Readiness Level and Integration Readiness Level, readiness level is considered to generally progress through system development as shown in Table 2. However, when assigning integration assessment level, development of the integrated technologies must be considered in that the slowest developing technology will pace the corresponding integration readiness. Although slightly over-reaching for a true SMA, the definitions stated herein allow retroactive SMA evaluation given available data, for a system of three technologies and two integrations where development of each technology was largely pursued separately from the others.

Table 2 - Readiness Level Progression with Project Phase

Project Phase	TRL	IRL
Requirements Definition	1	0
Concept of Operations*	2	1
Preliminary Design Complete	3	2
Critical Design Complete	4	3
Manufacturing Readiness Complete	5	4
Final Design Iteration*	6	5
Hardware Acceptance Complete	7	6
Mission Certified	8	7
Mission Complete	9	8

**Note: These events were finalized out of the conventional sequence due to programmatic changes and events experienced during execution*

Readiness Level Assessment

		TRL			IRL		SRL	
Date	Event	Battery	Charger	Software	Charger-Battery	Charger-Software	Composite	*Normalized*
Mar-02	Authorization to Proceed	0	0	0	0	0	0.00	*0.00*
Mar-02	System Readiness Review	1	1	0	0	0	0.06	*0.05*
Oct-03	System Contract Awarded	2	1	1	0	0	0.13	*0.11*
Dec-03	Preliminary Design Review	3	2	1	1	1	0.20	*0.17*
Sep-04	Critical Design Review	4	3	2	2	2	0.33	*0.27*
Dec-04	Manufacturing Readiness Review	5	4	2	3	2	0.42	*0.35*
Jul-05	Updated Battery Design	6	4	2	3	2	0.45	*0.38*
Aug-05	Replaced Charger Microcontroller & Firmware	6	4	3	3	3	0.51	*0.42*
Oct-05	Updated Charger Firmware	6	4	3	3	3	0.51	*0.42*
Jan-06	Updated Charger Firmware	6	4	3	3	3	0.51	*0.42*
Apr-06	Charger Delta Critical Design Review	6	5	4	4	3	0.61	*0.51*
May-06	Charger Fleet Failed Acceptance Testing	6	5	4	4	3	0.61	*0.51*
Aug-06	Battery Failed Life Expectancy	7	5	4	4	3	0.64	*0.54*
Sep-06	Battery Delta Acceptance Test	7	5	4	4	3	0.64	*0.54*
Jan-07	Battery Design Failed	7	5	4	4	3	0.64	*0.54*
Apr-07	Charger 300 hr test initiated	1	5	5	4	4	0.48	*0.40*
May-07	Purchased New COTS Cells	1	5	5	4	4	0.48	*0.40*
Oct-07	Project Recommissioned	1	5	5	4	4	0.48	*0.40*
Mar-08	Battery Contract Released	2	5	5	4	4	0.52	*0.43*
Aug-08	System Readiness Review	3	5	5	4	4	0.55	*0.46*
Aug-08	Preliminary Design Review	3	5	5	4	4	0.55	*0.46*
Aug-08	Charger Refurbishment Review	3	6	6	5	5	0.69	*0.58*
Jan-09	PWB Production Readiness Review	4	6	6	5	5	0.73	*0.61*
May-09	Charger Project Transition	5	6	6	5	5	0.77	*0.64*
Jul-09	Battery Critical Design Review	6	6	6	5	5	0.80	*0.67*
Oct-09	Charger Project Transition	6	7	6	5	5	0.86	*0.72*
Nov-09	Logging Software Certification Start	6	7	7	5	6	0.93	*0.77*
Mar-10	Charger Certification Complete	6	8	7	5	6	0.99	*0.83*
Apr-10	Battery Design Certification Review	7	8	7	6	6	1.06	*0.88*
Jun-10	Logging Software Certification Complete	7	8	8	6	7	1.13	*0.94*
Jun-10	Shipped Flight Units	7	8	8	6	7	1.13	*0.94*
Jul-10	Battery Certification Complete	8	8	8	7	7	1.20	*1.00*
Nov-10	Charger Fleet Delivery Complete	8	8	8	7	7	1.20	*1.00*
Dec-10	Battery Fleet Delivery Complete	8	8	8	7	7	1.20	*1.00*

FIGURE 7 – Readiness Level Assessment for LLB/LIB System

Applying readiness levels to each technology and integration at given project milestones allows computation of the composite SRL. Specifically, SRL is the vector product of normalized TRL and IRL values (Sauser, 2008). Per the guidelines established for SRL computation, technology integration with itself is given an IRL value of 9 (normalized to 1) and technology integration where none exists is given an IRL value of 0 (Sauser, 2008). The composite SRL is computed by averaging the quotient of each technology SRL and the number of interactions associated the integration (Sauser, 2008). As is shown in Figure 6, the number of integrations for this system is 1 for both the battery and software, and 2 for the charger. The assigned TRL and IRL assessment levels for each technology and project phase are shown in Figure 7 as is the resulting SRL value. Since the composite SRL exceeded unity, a normalized result is also provided to scale the resulting composite SRL from 0 to 1 since the composite value exceeded one. This decision is discussed in greater detail later in this work.

Technology Readiness Progression

For the project assessment provided in Figure 7, technology readiness largely progressed as expected based on the definitions previously developed. The definitions imposed in this study are reflected in the data, namely that the battery design, considered as a single technology, progressed more rapidly than the charger yet suffered from the long term capacity retention failure which necessitated a redesign. The redesigned battery rapidly progressed in technology development based on selection of mature lithium-ion technology, the corporate knowledge and experience of the selected battery vender, and the foundations laid by the initial development. Meanwhile, the charger technology advanced much more slowly. This should have been expected during the early project phases based on the dependence of the charger design on the evolving battery design and the complexity imposed on the charger. The moderate charger maturation rate slowed while the design became mired in fleet burn-in testing necessary to indentify latent design defects resulting from a combination of design shortcomings and poor workmanship standards of the equipment supplier. However, once solutions were identified, and after a short term responsibility transfer to the JSC on-site support contractor, design maturation accelerated and the technology progressed relatively quickly and efficiently through repair and certification of the charger fleet. Software technology development followed a similar subservient path as did the charger and battery; however, the software was dependent entirely on charger development. The software, as a sole technology, developed quickly in the initial phases albeit in machine language. Evolving the software into a more user-friendly form required several iterations involving a user representative, with the final cycle occurring after the project had gained traction on the charger refurbishment. Once the certification effort was commissioned, software development continued to move quickly with the threat of constant cancellation if code alteration was required. The code architecture and the non-safety-critical usage requirements supported this hard line approach and facilitate rapid maturation of the software technology in the final stages of the project.

Integration Readiness Assessment

Assessing the integration readiness using the guidelines put forth previously requires additional consideration. For example, integration readiness between the battery and charger requires successful maturation of both technologies in order for the integration between the two to advance to the next highest level. For this study, technology definition has been simplified to only three and each is linked by the common charger technology. This results in only two integrations, battery-charger and charger-software. The battery-charger integration progress suffered as a result of the charger design issues experienced early in the project, second by the battery design issues experienced at roughly the same time, and third by charger design issues late in the project development cycle. As refurbishing the charger fleet occurred at roughly the same rate as the second battery design iteration, integration readiness between these two technologies progressed smoothly through the final stages of system development and certification. Charger-software integration readiness was paced by both technological and programmatic effects. Correction of the charger design and workmanship issues provided technological development pacing while the programmatic decision to post-pone software certification delayed software development. The decision to delay software readiness was due to a resource limitation and the fact that software deployment was not depending on a space vehicle launch. However, this programmatic decision to delay software certification was ultimately over-ridden as the result of a negotiation for additional funding to complete charger refurbishment. Based on the negotiation, the software was certified entirely on in-house funding, and to reduce cost, on a very compressed schedule. For these reasons, integration readiness of the charger-software largely mirrors that of the battery-charger integration readiness in final project stages. Charger-software integration readiness was achieved before that of the battery-charger due to the charger-battery integration dependence on battery certification which occurred after both the software and charger efforts were completed.

System Readiness Assessment

The computed composite SRL provides an indication of how well the system is progressing to maturity as shown in Table 3 (Sauser, 2008). The assessment accurately conveys the lagging hardware development activity early in the charger and battery technology development activity but moves rapidly into the realm of system maturity. To constrain SRL to a maximum of 1, the composite SRL was normalized to the maximum calculated value shown in Figure 7. The composite SRL computed for the battery/charger/software system reflects the rise-and-fall-and-rise of the battery technology development, the slow rate of charger technology development, and the rapid closure of the software and battery technologies.

Table 3 - System Readiness Level[1]

SRL	Acquisition Phase	Definition
0.90 to 1.00	Operations & Support	Execute a support program that meets operational support performance requirements and sustains the system in the most cost-effective manner over its total lifecycle.
0.70 to 0.89	Production	Achieve operational capability that satisfies mission needs.
0.60 to 0.79	System Development & Demonstration	Develop system capability or (increments thereof); reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for production; ensure affordability and protection of critical program information; and demonstrate system integration, interoperability, safety and utility.
0.40 to 0.59	Technology Development	Reduce technology risks and determine appropriate set of technologies to integrate into a full system.
0.10 to 0.39	Concept Refinement	Refine initial concept; develop system/technology strategy.

[1]Sauser, 2008

Review of the computed SRL values for each project phase of Figure 8 demonstrates a possible mismatch between the suggested values of Table 3 and certification of flight readiness for NASA spaceflight hardware, specifically in the areas of Operations and Support. This mismatch is likely caused by definition specific to NASA Johnson Space Center (JSC); specially, the separation of hardware acceptance and certification. If these two items were considered to occur simultaneously, maturation would indeed reach the final stage with hardware acceptance.

Table 4 - SRL Comparison

Acquisition Phase	Proposed SRL	Composite SRL	Normalized SRL
Operations & Support	0.90 - 1.00	1.20	1.0
Production	0.70 - 0.89	0.77	0.64
System Development & Demonstration	0.60 - 0.79	0.64	0.54
Technology Development	0.40 - 0.59	0.51	0.42
Concept Refinement	0.10 - 0.39	0.33	0.27

To better understand the maturation of SRL for this project, the project composite and normalized values are displayed with the proposed SRL range per acquisition phase in Table 4. Although the project composite SRL appears to progress prematurely into the operations and support phase, the SRL values computed for earlier acquisition phases agrees well with the proposed SRL range. The normalized SRL value appears to be of less value as there is no theoretical basis for performing this computation and the resulting values appear to stifle the system development quantification. Based on this comparison, normalization offers no additional system insight and need not be considered in future studies. It is also worth noting, that for NASA JSC projects, a decision based solely on achieving a System Readiness Level of 1 may lead to premature system deployment. This finding is a result of the readiness level definitions provided previously which reflect the NASA culture and separates hardware acceptance and certification activities.

Sensitivity Study

Table 5 - SRL Sensitivity

Study Cases	TRL Battery	TRL Charger	TRL Software	IRL Battery-Charger	IRL Charger-Software	SRL
Hold all but one	2.6	5.4	2.6	0.9	0.9	1.0
Interaction Case 1	7.0	8.0	7.0	5.0	5.0	1.0
Interaction Case 2	7.0	7.0	7.0	6.0	6.0	1.0

To facilitate an understanding of the relationship between technology readiness, integration readiness and composite system readiness for this simple system, a basic sensitivity study is performed, the results of which are shown in Table 5. The study answers two basic questions, a) could a mature system with one infantile element still achieve a high SRL, and b) what is the impact of interaction on the resulting IRL necessary to compute an SRL of 1. Although each violates the definitions established previously, the first question is answered by reducing a single project assessment from the final level to the lowest possible value to achieve a composite SRL of 1.0. The resulting minimum assessment value is shown in Table 5 for each technology and integration readiness level of the project. The second question was answered by holding the technologies with a single interaction at a modest TRL of 7 and changing the technology with the greatest number of interactions (Charger) between 7 and 8 and predicting consistent system integration readiness levels to deliver an SRL of 1. This study predictably shows that an early maturation of the technology with the highest interactions will allow a lower integration level for the same SRL. It is worth noting the previously established definitions of TRL and IRL were abandoned to complete this study.

Conclusion

The Long Life Battery, Lithium Ion Battery Charger and companion data logging software have been developed by NASA JSC to enable long term, reliable support of Extravehicular Activity from the International Space Station or Space Transportation System. The project has been summarized herein and a retroactive Systems Maturity Assessment performed based on major project milestones and established readiness level definition. The results of this assessment were performed to sufficient depth to understand applicability of SMA methodology to NASA system development programs.

System Maturity Assessment is based on quantification of Technology and Integration Readiness Levels. The computation provides a single measure of systems maturity, the Systems Readiness Level. This study compared the predicted SRL to the typical range expected for hardware development demonstrating both applicability of the methodology and a possible disconnect in established definition. The over development of SRL during the final stages of this project may reflect the additional burden placed on critical NASA spaceflight hardware development as compared to maturation of conventional systems. Stated another way, very little hardware development occurs between acceptance and certification for NASA hardware as this final stage is largely based on documentation close out. Since this additional activity is a critical element in the NASA development culture, an over-representation of SRL in the final stages is warranted. Therefore, it is recommended that SMA application to NASA human spaceflight hardware either consider this finding and strive for an SRL greater than 1, or consider a more hardware-centric assessment level definition than that used in this work. Although academic, the simple sensitivity study serves as a reminder that strict adherence to the established assessment methodology is required to ensure a consistent maturation assessment, a fact especially true for systems with technologies of high interaction. Given these conclusions, SMA methodology appears to be a valuable tool worthy of consideration in development of complex systems.

Future developments would benefit from application of this methodology at lower levels than employed in this study. Conversely, during each stage of hardware development, surveillance within each technology could serve useful in determining readiness for progressing through the next project milestone and achieve incremental maturation growth. Therefore, it is recommended that SRL assessment be considered as a Technical Performance Metric in new and existing projects responsible for developing and maturing a complex system.

ACRONYMS

COTS	-	Commercial off the Shelf
EMU	-	Extravehicular Mobility Unit
EVA	-	Extravehicular Activity
GUI	-	Graphical User Interface
ICB	-	Increased Capacity Battery
IRL	-	Integration Readiness Level
ISS	-	International Space Station
IVA	-	Intravehicular Activity
JSC	-	Johnson Space Center
LIB	-	Lithium Ion Battery
LLB	-	Long Life Battery
NASA	-	National Aeronautics and Space Administration
PLSS	-	Portable Life Support System
PWB	-	Printed Wiring Board
SMA	-	System Maturity Assessment
SRL	-	System Readiness Level
SSC	-	Space Station Computer
TRL	-	Technology Readiness Level
USB	-	Universal Serial Bus

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