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CHALLENGES WITH SPECIFICATION DEVELOPMENT OF LEAD ACID REPLACEMENT BATTERIES

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ABSTRACT
The systems engineering process is clearly defined for not only the department of defense, but for other government entities. Following this process is critical to the overall success of the program and DoD's success to get a best value solution that is applicable to various platforms across multiple services. Ensuring that the requirements phase of the systems engineering process receives its due diligence will provide the design phase the critical details necessary to build a sub-system solution that will be easily integrated, across various platforms This paper will look at this process and show the importance of this process using a case study of the Military 6T start battery. In order to qualify a 6T Lithium Nanophosphate battery as a drop-in-replacement to 6T lead-acid batteries a requirement set and appropriate testing must be conducted. When it comes to battery chemistries Li-Ion chemistry is night and day compared to lead-acid chemistries. When developing a requirement specification for 6T Li-Ion battery it is important to consider omission of certain requirements from lead-acid specs and the addition of certain requirements relating to the specific chemistry and packaging requirements of Li-Ion batteries.

INTRODUCTION

Systems engineering is defined by the McGraw-Hill science and technology dictionary as: *"The design of a complex interrelation of many elements (a system) to maximize an agreed-upon measure of system performance, taking into consideration all of the elements related in any way to the system, including utilization of worker power as well as the characteristics of each of the system's components.[1]"*

There are a number of ways to approach a system design and various DoD entities typically have a systems engineering process/procedure that clearly defines the systems engineering approach. For instance, the Defense Acquisition University (DAU) uses a document entitled, "Systems Engineering Fundamentals, Jan 2001[2]", while NASA uses NASA/SP-2007-6105, "NASA Systems Engineering Handbook.[3]"

The systems engineering approach will typically guide the development team through the steps to realize the preferred system configuration. It gets complicated; however, when the "preferred" system configuration is an "upgrade" to what is currently being used, this often creates confusion because there is often an existing specification for the old system that meets a significant number of the requirements, with some changes. This is complicated because some of these changes can have a large impact on not only the system being designed, but the system in which this sub-system is being integrated. The result is often multiple entities modifying the original specification to meet the individual needs of the program. By developing (often as "drafts") multiple specifications, the design team tries to meet the "hardest" of all of the specifications, which drives up the cost and development time of the program.

This paper will review the first critical steps of the systems engineering process and show how the development and agreement on requirements is critical to the overall process. As an example, we will discuss the current DoD initiative to upgrade its current fleet of 6T lead acid batteries to Lithium Ion and how specification development is critical if the DoD is to successfully integrate lithium ion start batteries into vehicle applications.

Review: Requirements and the System Engineering Process

Figure 1 shows the typical systems engineering process as outlined by the DoD Systems Management College. The process is broken into 3 parts: Requirements loop, Design Loop and Verification. Prior to starting any design (entering the design loop), it is imperative that the requirements are clearly defined and agreed upon by typically the designer and the customer. After all…..how can someone design something that is not clearly defined!? Upon completion of the requirements loop, the design team will enter the design loop which usually consists of a number of design reviews followed by a testing phase (verification). Because the system being designed is often a sub-system that will be integrated into a larger system, it is critical that these steps are followed in order for the overall system to work.

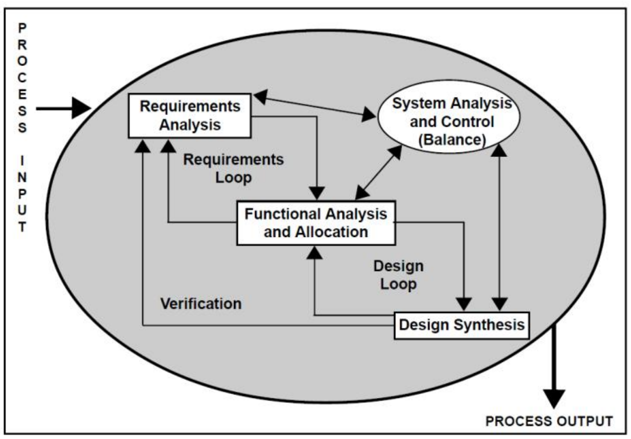

Figure 1. DoD Systems Engineering Process [2]

The NASA Systems engineering handbook shows this process in context of overall project management. This is shown in Figure 2. Again, this process calls out Requirements definition prior to the Technical solution definition.

When the requirements development portion of the process is not followed critically, it can create problems during the development process. One common pitfall in this process is trying to use a "draft" or previous document that is either poorly worded, or defines a "similar" but not exact system. This leaves a number of requirements subject to opinion, or causes individual entities to provide various definitions to critical requirements, which often results in a unique product that cannot be used across the DoD fleet.

Battery Requirements

Energy storage is so critical to the department of defense's future that the Deputy Secretary of Defense released a document in March 2012 entitled, "Energy for the Warfighter: Operational Energy Strategy." [4]

There are a number of energy storage devices that are in common use on today's battlefield. These include batteries, fuel cells, capacitors, flywheels and gasoline. To make the situation more complex, there are various types of each of these energy storage devices, each with a different strength and weakness. For instance, vehicle start batteries typically use lead acid because of their low cost, high energy density and demonstrated robustness despite their weight and cycle life (compared to other technologies). Soldier batteries, however, include lithium ion versions to lighten the load of the Warfighter, but typically cost more than other technologies. This shows that each application needs to have a very defined set of requirements in order to meet the individual system needs on the battlefield.

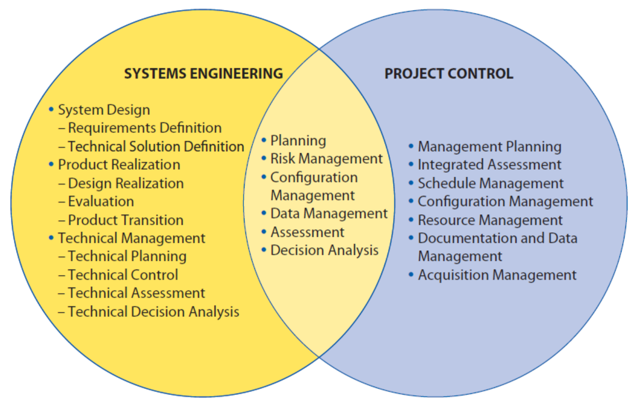

Figure 2. NASA Systems engineering in context of overall project management

Critical parameters when defining energy storage are shown in Table 1. Whether upgrading from one type to another (for example a primary battery to a rechargeable), it is essential that, at a minimum, these requirements are clearly defined as they apply to the system in which they are being integrated.

Table 1. Typical Military Energy Storage Requirements

Critical Energy Storage Requirements
Capacity – How much energy the device retains
Power Capability – How much energy can be delivered in a certain amount of time (sometimes varies by temperature0
Size – Defined by the system in which it is being integrated
Weight – Weight is critical for fuel efficiency and the warfighter's capability to carry it
Cycle life – how long will the battery last
Operating Temperature – Different energy storage

devices have strengths/weaknesses at excessively high and low temperatures
Storage Temperature – At what temperature will the device be stored and for how long
Voltage – Military standards dictate a very specific voltage window during use
Peak Currents – Goes hand in hand with Power Capability; usually critical for "pulsed" systems
Communications interface – Does the battery communicate with the rest of the system
Charge Acceptance – How quickly can the energy storage device be charged
Safety – Ensuring a safe solution during use is critical to protection of our warfighters and their equipment

The requirements shown in Table 1 are a high level look at those things that need to be considered during the requirements phase. Finding a balance that meets the clearly defined requirements for the system in which the energy storage is being integrated to is critical prior to entering the design phase.

Case study: NATO 6T vehicle start battery Lithium Ion upgrade

A lithium-ion 6T starter battery is not the first new technology to be introduced into the military market and certainly will not be the least. However, the chemical, electrical and mechanical relationships introduced in the integration of a lithium-ion 6T create a complex system requiring a complex set of requirements. It is important to be aware that the current lead acid 6T is used in different military vehicles spanning from small tactical wheeled vehicles to large combat vehicles. Applications for the Lead acid 6T vary from just starting lighting and igniting (SLI) to powering auxiliary loads during silent watch missions. 6T lithium-ion requirements must be written to consider all current Lead acid applications, plus future military vehicle applications, i.e. JLTV and GCV. The case study presented in this paper will address the difficulty with specifying the proposed lithium-ion 6T requirements, and trade-offs considered.

Military Vehicles (NATO 6T)
M1 Abrams
M2/M3 Bradley
M113
First Support Platforms
Stryker FoV
HMMWV
Medium Tactical Trucks
Heavy Tactical Trucks
Armored Security Veh.
MRAP Vehicles

Comparing Lithium technology to Lead acid

The vehicles operating on today's battlefield require a battery that is used for more than just starting, lighting and ignition (SLI). Today's vehicles also require the battery to provide power for radios, tracking systems and weapon systems as well as many other applications while the vehicle is "off". These systems typically require high power and highlight the Warfighter's dependence and need for a reliable system when operating in harm's way. These batteries typically provide power to the vehicle during "silent watch" applications where the vehicle engine is off and all of the necessary systems are demanding power from the battery. Due to the dependence on the batteries for soldier protection and because lead acid battery cycle life and weight are a significant logistics burden, a new, improved battery (i.e Lithium Ion Battery) that fulfills this need is required to fight on today's battlefield. There are many benefits of using Li-ion batteries over Pb-acid for most military vehicles. These advantages include longer cycle and calendar life, consistent power over batteries State of Charge (SOC), re-charge at higher C rates, and the ability to perform full depth of discharge without degrading life or performance of the battery. One of the inherent drawbacks

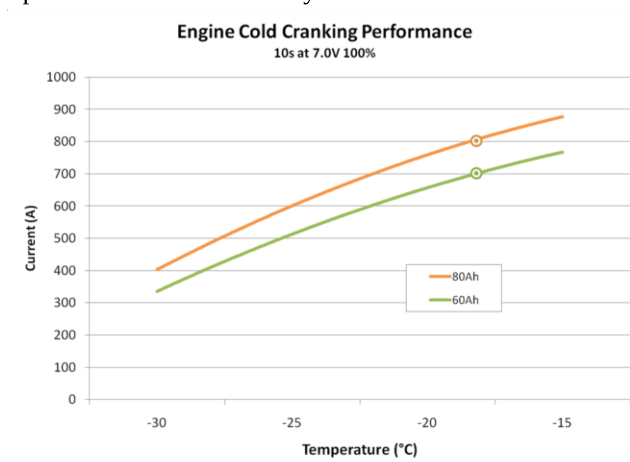

Figure 1: Nanophosphate EXT CCA Test Results

of Li-ion technology is the relatively low power at low temperature and up-front cost. However, A123 Systems with their Nanophosphate EXT is designed to deliver a 20-30 percent improvement over traditional nanophosphate, putting it on par with the highest-performance absorbent glass mat (AGM) lead acid batteries available today. Figure 2 shows the capability of 60 and 80Ah Nanophosphate EXT starter batteries across a range of temperatures. For comparison, typical AGM performance on the standard EN cold cranking test at minus 18 degrees Celsius is also shown. Nanophosphate EXT has similar cold cranking capability, eliminating the only performance advantage of advanced lead acid batteries for SLI applications.

6T Requirements Comparison

Common sense would tell you if a Li-ion battery is designed to displace a lead acid battery then it must be qualified to the lead-acid specification it is displacing. In the case of a Military 6T lead-acid batteries the requirements document is MIL-PRF-32143B for 12V lead-acid batteries. On the surface this makes sense, however if a manufacturer tests to only the lead-acid specification then validation of key requirements, such as Electro-Magnetic Interference (EMI) MIL-STD-461F, and environmental requirements found in MIL-STD-810G (Drop Test and Mechanical Shock), would be missed.

At this point you may be asking, why would a battery require EMI testing, there's no electronics in a battery? When it comes to Li-ion chemistry a minimal amount of electronics are required to balance the cells within the battery to preserve battery life and performance as well as to provide the Warfighter with critical battery information (state of charge, state of health, etc.) during use. Therefore, not only does a Li-ion battery introduce a new chemistry but it also introduces electronics internal to a battery enclosure. Anytime you introduce an electronics product into the Military it must pass applicable EMI and environmental requirements.

In addition to cell balancing and monitoring, most manufacturers design in the capability of over/under voltage protection (OVP/UVP), temperature protection, and safety algorithms. The internal battery management system (BMS) not only monitors and reports the status of the battery, but it safe guards the battery from being placed into an unsafe condition and protects the battery if it does.

The Military has solicited a common Battery Monitoring System specification ATPD-2406, which is separate electronics unit designed to monitor lead-acid batteries and provide diagnostics information via the CAN bus. Incorporation and applicability of pieces of the ATPD-2406 requirements are appropriate for Li-Ion 6T batteries, such as EMI and environmental requirements found in MIL-STD-810G. Due to unique characteristics of Li-Ion chemistries it is important to ensure safety mechanisms are in place to prevent a catastrophic failure mode to exist. Requirements need to be written around the necessity for Li-Ion 6T batteries to withstand any events due to overcharge, over discharge, short circuit, and over temperature. Neither the lead-acid specification nor the Battery Monitoring System specifications contain these requirements.

Performance Requirements

Performance requirements associated with a Li-ion 6T requirement specification center around cell performance and BMS performance. Most of the base performance requirements can be drawn from the MIL-PRF-32143B document. Specifically Cold Cranking Amps (CCAs), full charge capacity, deep cycle capacity, retention of charge, and life-cycle capacity. However, you cannot take the requirements verbatim from the specification and apply them to Li-ion. Due to known and established chemistry differences between Li-ion and Pb-acid, deep cycle capacity and life-cycle capacity is drastically improved when using Li-ion chemistry. Taking this into consideration it is recommended that the military increase deep discharge cycle requirement of two hundred deep discharge cycles

CONCLUSION

Although various government entities have different systems engineering procedures, what they all have in common is that the requirements phase is the foundation of which the program sets. Without clearly defined requirements, it is very difficult to build a solution that is cost effective, especially if it is to be used across various platforms or systems. Even if the system is an upgrade to an existing system, a clearly defined requirement document is essential to define and evaluate the existing performance as well as the improvements considered for the design.

The paper includes a case study that shows how critical the systems engineering process (specifically requirements) is when upgrading batteries from Lead Acid to Lithium Ion. Although the specification is typically used to evaluate the the comparable characteristics of the current solution, it does not address and define the improvements or expectations of these improvements in a coordinated manner. Because this battery is used across multiple platforms, and multiple entities within the DoD, having a clearly defined, agreed upon document will ensure the best value solution that best supports our Warfighters currently operating in harm's way.

REFERENCES

[1] Mcgraw Hill Science and Technology dictionary, http://www.answers.com/topic/systems-engineering

[2] Department of Defense Systems Management College, "Systems Engineering Fundamentals." Jan 2001

[3] National Aeronautics and Space Administration (NASA), "NASA Systems Engineering Handbook." NASA/SP-2007-6105, Rev. 1. 2007

[4] Deputy Secretary of Defense, "Energy for the Warfighter: Operational Energy Strategy", March 2012.

[5] MIL-PRF-32143B 6T Lead acid Specification

[6] Battery Monitoring Specification ATPD-2406

[7] Battery Specification for MATV (Group 31 and Group 34 Li-Ion Battery)

[8] USMC Improved Battery Specification (IBS)

[9] MIL-STD-810G

[10]MIL-STD-1275