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THE WHOLE SYSTEM TRADES ANALYSIS TOOL FOR AUTONOMOUS GROUND SYSTEMS

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ABSTRACT

An important aspect of any new ground vehicle acquisition program is an analytic understanding of the key performance, cost, risk and growth tradeoffs inherent with the system design. The Whole System Trades Analysis Tool (WSTAT) provides a holistic framework for modeling and understanding these tradeoffs. In this paper, we present the overarching WSTAT methodology and then consider a specific implementation for the Army's Squad Multipurpose Equipment Transport (SMET) autonomous ground vehicle. Emerging results regarding high-level SMET design considerations are provided to demonstrate the types of decision support enabled by the WSTAT capability.

INTRODUCTION

The Department of Defense has a long-standing interest in the development and deployment of autonomous ground systems (AGSs) to provide soldiers with many unique battlefield advantages. These advantages are wide ranging – from easing logistical burdens and lessening dismounted soldier loads to improving intelligence gathering and even performing certain warfighter roles in dangerous situations. Despite significant progress in recent years, the challenges inherent with the development of AGSs are still substantial. As with any new, complex ground system, AGSs present a vast array of design tradeoffs and interdependencies that must be carefully considered in order to maximize effectiveness to the warfighter, minimize long-term maintenance and operational needs, maximize the potential for future upgradability, minimize overall costs to the tax payer, and balance many other goals. These important yet competing design considerations require an unbiased analytic approach that presents decision makers with multiple optimal system alternatives – providing a spectrum of options for best balancing the considerations.

The remainder of this paper is laid out as follows. In the next section, we introduce the Whole System Trades Analysis Tool (WSTAT) developed by Sandia National Laboratories in conjunction with the U.S. Army's Tank Automotive Command (TACOM), the Program Executive Office Ground Combat Systems (PEO GCS), and Booz Allen Hamilton. Next, we provide an overview of the Army's Squad Multipurpose Equipment Transport (SMET) acquisition effort. We then present the capability needs for this program and outline the modeling approaches taken to cast the SMET design architecture into the WSTAT framework – including the SMET technology hierarchy, performance metrics, and user prioritization of capabilities. Finally, we demonstrate some emerging results from the in-depth SMET trade study.

WSTAT OVERVIEW

WSTAT is a holistic system design and tradeoff exploration tool that uses multi-objective optimization [1] to find system configurations that best balance competing design criteria such as performance, cost, and risk. Rather than presenting a single optimized system design, WSTAT provides decision makers with a variety of possible designs – each balancing the competing stakeholder preferences in different ways.

The WSTAT framework is very generalizable and has been successfully applied to a diverse range of systems including the Ground Combat Vehicle, the Armored Multi-Purpose Vehicle family, the Maneuver Support Vessel (Light) aquatic landing craft, the portfolio of robotic Explosive Ordinance Disposal systems, and Contingency Basing Infrastructure base camp design.

When the WSTAT process is applied to a new program, it begins with a thorough understanding of the program needs and requirements – typically guided by a Capability Design Document (CDD) and discussions with subject matter experts (SMEs). These requirements are then mapped to Functional Objectives (FOs) – quantitative or qualitative measures of performance against the system's requirements. In the context of ground vehicles, example FOs might include off-road speed, acoustic signature, protection against under-vehicle attack, etc. Next, the system is conceptually decomposed into its constituent subsystems (collectively referred to as the Product Structure), with each subsystem having multiple potential Technology Options (TOs) with inherent pros and cons. For example, a ground combat system would typically include subsystems such as engine, transmission, hull, armor, weapon system, etc. – any major component for which there exists various potential technology alternatives with different tradeoffs. Once the Functional Objectives and Product Structure are defined, next comes an iterative refinement of the calculations used in the FOs based on further discussion with SMEs and data availability for the TOs. Also during this phase of development, a panel of system users (typically, soldiers who have operated similar systems in the field) is assembled to provide prioritization weightings of the FOs that are aggregated into each optimization dimension. This user elicitation follows the Swing Weight Matrix approach [2] for capturing FO priority – giving highest weights to FOs that have both 1) greater tactical importance and 2) larger variability in possible outcome. The FOs are typically aggregated into 4 to 6 higher-level optimization dimensions such as mission performance, cost, growth potential, etc.

Once these major modelling elements have been finalized, the system configurations are optimized by a multi-objective genetic algorithm in which the decision variables consist of the choice of Technology Option for each subsystem in the Product Structure. By mixing and matching the various subsystem TOs, many millions of system configurations can be evaluated by the genetic algorithm – learning from and evolving consecutive populations of configurations to generate ever improving sets of designs. The final set of solutions that best balances the competing optimization dimensions is then presented to decision makers by WSTAT, enabling a holistic trade space examination across multiple stakeholders. The WSTAT results engine provides dozens of different filters and views with which to interrogate the resulting trade space. A more detailed overview of WSTAT's methodology and capabilities may be found in [3] and [4].

SMET OVERVIEW

The SMET is an AGS currently being developed for the Program Executive Office Combat Support and Combat Service Support (PEO CS&CSS) as a solution to warfighting challenges centered in Expeditionary Maneuver and Entry Operations as well as Joint Arms Maneuver Operations. The SMET's primary goals are to 1) reduce the load carried by dismounted soldiers, and 2) sustain a squad for an extended time over a larger range without the need for resupply from a parent unit. Conceptually, the SMET is a robotic pack mule that carries a squad's cargo (packs, MREs, water, ammunition, etc.), generates power to recharge batteries, and hosts modular mission payloads while silently maneuvering anywhere a soldier can travel without slowing down the squad's progress. In addition, certain levels of autonomy or semi-autonomy (such as leader-follower or waypoint navigation) are needed to support logistics operations between the dismounted squad and its parent unit. On top of this, the SMET needs to be transportable, reliable, rugged, survivable, upgradable, and cost effective.

Adding to the complexity of the myriad design considerations listed above, the fields of robotics and autonomy are constantly evolving and improving – seemingly at an ever increasing rate. Thus, there exists an extremely rich set of state-of-the-art and near-future technologies that might be employed in an SMET configuration. Understanding which hardware and software technologies should be utilized, along with the tradeoffs thereof, is a matter of fundamental importance to the SMET program. High-level SMET design questions naturally arise such as:

- What type of power solution provides the longest operational endurance, and are hybrid solutions worth the extra cost and complexity?
- What type of running gear should be employed to ensure the best possible mobility in all situations?
- What types of computer vision hardware enable the most robust yet cost effective autonomy solutions?
- If unique SMET variants of different sizes and requirements are desired, which technologies should be in common across the variants and which should be different?

It was for these reasons – both the complex requirements and quickly evolving technology space – that PEO CS&CSS elected to employ a WSTAT approach to support SMET design.

SMET REQUIREMENTS AND CAPABILITIES

The first key step in creating a WSTAT model is a distillation of system requirements into the FOs that will be used by the optimization algorithm to measure the "goodness" of a configuration. As with most WSTAT projects, early drafts of the SMET CDD served as the primary source for FOs, some of which (e.g., Power Offload) map to a single CDD requirement while others (e.g., Semi-Autonomous Navigation) represent the aggregation of multiple distinct requirements. Since the CDD was still in development, SMEs were also consulted to help develop supplementary FOs. For example, there are many accounts of prototype SMET systems getting stuck on the terrain during field tests, so the Maneuverability, Agility, and Trafficability FOs account for these aspects of performance and augment the FOs drawn from the CDD. The full list of 28 SMET performance FOs is outlined in Table 1. Note that all mobility-related FO calculations assume that the SMET is carrying a user-definable Full Combat Configuration (i.e., the packs, MREs, water, and ammunition needed for a dismounted squad mission). Finally, note that this list of FOs is subject to modifications as future CDD drafts are written.

Performance Functional Objectives	**Descriptions**
Transportability	The SMET's ability to be sling loaded under and fit inside vertical lift systems, as well as to fit on a NATO pallet
Time to Setup	The time required to convert an SMET from a stowed configuration to a fully operational configuration, including boot up time, and calibration of sensors
Load Capacity	The number of Modular Lightweight Load-carrying Equipment (MOLLE) packs that the SMET can carry
Recovery Capacity	The SMET's ability to winch a vehicle of similar weight and tow an identical SMET
Power Offload	The amount of AC electrical power the SMET can export while stationary
Burst Speed	The amount of time it takes the SMET to travel 200m starting from a stationary position
Climb and Descend Slopes	The grade of slope the SMET can climb or descend on a dry, hard surface without tipping, slipping, or not having enough propulsion power
Laterally Traverse Slopes	The grade of slope the SMET can laterally traverse on a dry, hard surface without tipping or slipping
Maneuverability	How well the SMET can maneuver around and over objects with respect to turning radius and obstacle height
Agility	How well the SMET can climb over, under, and between obstacles based on its physical dimensions
Cross Trenches and Gaps	The width of a trench that the SMET can cross, relative to its body length
Trafficability	The SMET's ground pressure
Operational Endurance	How long the SMET can operate on a single charge and/or tank of fuel
Operation in Extreme Temperatures	The SMET's ability to operate in extremely cold and hot temperatures
Operation in Water	The SMET's ability to float unloaded or loaded with Full Combat Configuration cargo
Data Integrity	How long the SMET can provide power to its internal computers to secure data during an unexpected shutdown
RAM (Reliability/Availability/ Maintainability)	The mean time between SMET failures
Operation in Restricted Environment	How far the SMET's tether system allows it to operate in GPS-denied and RF-denied environments
OCU Durability	The height that the Operator Control Unit (OCU) can be dropped without being rendered useless
Platform Durability	The amount of deceleration shock that the SMET can withstand
Positional Accuracy	The accuracy of the SMET's GPS

Semi-Autonomous Navigation	The SMET's ability to operate in semi-autonomous mode on secondary roads while avoiding obstacles and soldiers
OCU Ease of Use	The ease with which the OCU can be used to operate the SMET, based on its physical and technical capabilities
Tele-Operation Distance	The distance that the OCU and platform can communicate under both line-of-sight and non-line-of-sight conditions
Simultaneous Operations	The number of SMETs that can be operated simultaneously in the same area without interference
OCU Nighttime Screen Brightness	The OCU's ability to avoid detection while operating at night
Platform Acoustic Signature	The least amount of noise that the SMET can generate while still being fully operational
Survivability	The SMET's ability to protect interior subsystems from ballistics threats

Table 1: WSTAT SMET performance FOs

The FOs listed in Table 1 are aggregated into a single Performance score, which is one of the five optimization dimensions analyzed in this study. Though these performance FOs are of fundamental importance, each of the other optimization dimensions also has its own set of FOs – allowing analysts to explore tradeoffs among performance and the other four dimensions of:

- Investment Cost – the average acquisition price per SMET system.
- Operations and Maintenance (O&M) Cost – the overall expenses incurred for repairing, maintaining, and fueling an SMET throughout its operational lifetime.
- Growth Potential – the SMET's ability to carry additional weight and volume, and to supply additional power for hosting mission modules (robotic arms, sensors, mine detection payloads, etc.).
- Schedule Risk – the relative maturity of the subsystems employed in the SMET configuration.

In addition to all of the FOs for each optimization dimension, WSTAT can also track a wide range of supplementary metrics for each configuration. For SMET, these metrics include internal frame volume, center of gravity, amount of power required to support all of the system electronics, and the total height of the fully configured system. These metrics are often employed as intermediate steps for many FO calculations, but they also provide important diagnostic information for analyzing the trade space and understanding the underlying rationale for high-level design decisions made by the tool. In total for the SMET WSTAT implementation, there are 34 FOs and 54 metrics that are calculated for each configuration.

SMET ARCHITECTURE

Broadly speaking, WSTAT operates by scoring a candidate configuration based on its selection of subsystems – eventually finding those solutions that best balance the optimization dimensions. Therefore, it is important to properly decompose the system into its constituent subsystems, as these form the fundamental decision variables of the optimization. It is this decomposition architecture, or Product Structure, that forms the basis for WSTAT's conceptual understanding of a configuration. In other words, all FOs and metrics are calculated based on parameters of the subsystems chosen for each configuration.

In general when designing a WSTAT Product Structure, the ideal goal is to find a balance between too much detail (where the optimization progress could get bogged down making choices about subsystems that do not impact the trade space) and too little detail (where there is not enough information for the FOs to capture a rich set of design tradeoffs). In addition, the Product Structure is also heavily influenced by the availability of data for each subsystem and by the ability to freely "mix and match" the subsystems. For example, if there is no reliable source of data for a given subsystem, then including it in the Product Structure is of limited value. Similarly, if two parts cannot be independently selected due to heavily interrelated design restrictions, then the Product Structure should not be decomposed to that level and instead those parts should be aggregated into a single subsystem. Taking all of these considerations into account, the final SMET Product Structure is shown in Figure 1.

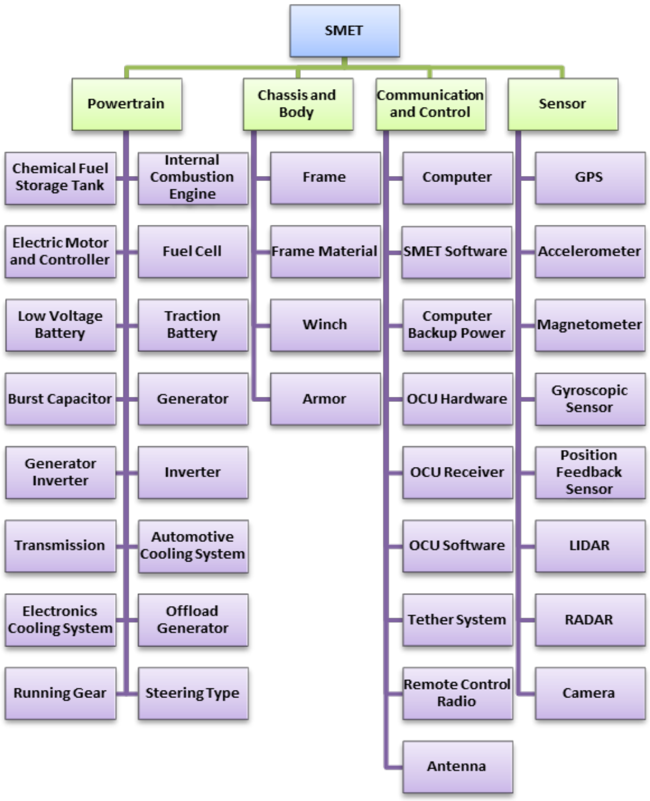


Figure 1: WSTAT SMET Product Structure

Each purple box represents a subsystem in the SMET architecture, with each subsystem having a variety of TO choices from which WSTAT can choose. Note that many of the subsystems are optional (e.g., Armor, Burst Capacitor, LIDAR) and thus include a “None” Technology Option as a design choice. Hence, an SMET configuration may not include every subsystem

Some subsystem choices obviate or necessitate choices in other parts of the configuration. For example, as a general rule the SMET can only contain a single fuel-driven power source (i.e., it can choose either an internal combustion engine or a fuel cell, but not both). Hence the choice of a fuel cell would require the choice of a “None” internal combustion engine. Similarly, choosing a LIDAR also requires the choice of a computer that can support the vision-processing demands of the LIDAR. These types of behaviors are enforced via a judicious application of optimization constraints. With all these considerations in mind, the WSTAT SMET model results in a search space of size 10^{19} possible configurations.

In addition to the tradeable Product Structure subsystems in Figure 1, WSTAT also models several non-tradeable “baseline” subsystems that appear in every configuration. The SMET baseline parts include

- lights,
- speakers,
- a squad radio,
- a high and low voltage power distribution unit,
- and a DC/DC converter.

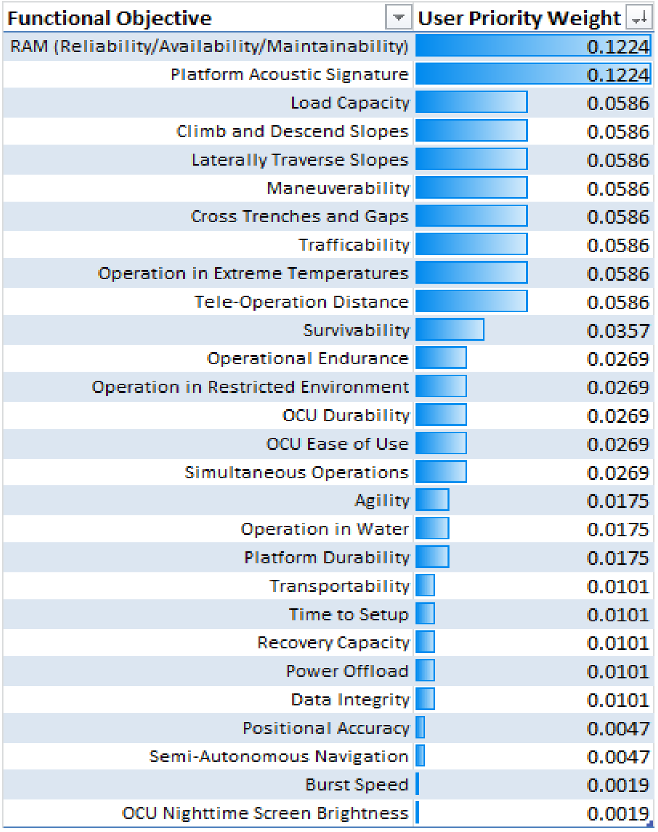
While these baseline parts do not vary from configuration to configuration, it is nevertheless important to capture their cost, weight, power draw, and other effects when calculating the SMET FOs and metrics.

Using the SMET Product Structure together with the baseline subsystems, WSTAT is able to holistically and quantitatively explore the impacts of a broad host of design decisions. These decisions include choice of power plants (conventional vs. fuel cell vs. electric vs. hybrid), running gears (wheels vs. tracks vs. mattracks), steering types (Ackerman vs. skid vs. pivot), and autonomy levels (ranging from no autonomy to full autonomy, including capabilities such as leader-follower and waypoint navigation).

USER PRIORITY WEIGHTS AND UTILITY SCORES

The penultimate step in the WSTAT development process (prior to running the optimization) maps each “raw” FO value into a common 0 to 100 utility score and takes a weighted sum of these scores for each optimization dimension. As mentioned earlier, the Performance dimension consists of a diverse set of 28 FOs, each with unique units of measure such as “ground pressure pounds per square inch” for Trafficability and “seconds needed to move 200m” for Burst Speed. Mapping these raw FO units into utility scores allows 1) an apples-to-apples comparison between different FO scores and 2) a means by which to take a weighted sum to aggregate the multiple FOs into a single Performance score. This utility mapping is done via analyst-specified walkaway, threshold, and objective values (taken from the CDD where appropriate) where the raw walkaway value translates to a utility score of 0, raw threshold translates to 70, and raw objective translates to 100 (with linear interpolation between these values). Thus, WSTAT has the freedom to explore below-threshold trades in individual FOs in order to find good overall performance or to find solutions that excel in other optimization dimensions.

The 28 performance FO utility scores are added together using priority weights elicited from SMET experts and users during an in-person panel using the Swing Weight Matrix method [2] – ranking each FO based on 1) how important it is to SMET usability in the field, and 2) how much possible variation it exhibits. FOs having the greatest importance and the most variation are given the highest weight, while those with the least importance and variation are given the lowest. The final outcome of the SMET user panel elicitation is shown in Figure 2. Note that the 28 weights sum to 1, meaning that if *every* FO is at objective value then the configuration would get a total Performance score of 100. These weights are subject to change with further refinements to the SMET CDD, but they are the weights used in the analysis results in the next section.



Functional Objective	User Priority Weight
RAM (Reliability/Availability/Maintainability)	0.1224
Platform Acoustic Signature	0.1224
Load Capacity	0.0586
Climb and Descend Slopes	0.0586
Laterally Traverse Slopes	0.0586
Maneuverability	0.0586
Cross Trenches and Gaps	0.0586
Trafficability	0.0586
Operation in Extreme Temperatures	0.0586
Tele-Operation Distance	0.0586
Survivability	0.0357
Operational Endurance	0.0269
Operation in Restricted Environment	0.0269
OCU Durability	0.0269
OCU Ease of Use	0.0269
Simultaneous Operations	0.0269
Agility	0.0175
Operation in Water	0.0175
Platform Durability	0.0175
Transportability	0.0101
Time to Setup	0.0101
Recovery Capacity	0.0101
Power Offload	0.0101
Data Integrity	0.0101
Positional Accuracy	0.0047
Semi-Autonomous Navigation	0.0047
Burst Speed	0.0019
OCU Nighttime Screen Brightness	0.0019

Figure 2: WSTAT SMET performance FO user priority weights

It is interesting to observe the priorities given to various aspects of performance. For example, the users greatly value a highly reliable, maintainable and quiet SMET as paramount design considerations. Second tier considerations include various aspects of mobility, load carrying capacity, allowable environment temperatures, and operable distance between the SMET and the controller. Very low priority design aspects include the desire for autonomy, fast burst speed, and a dim screen for nighttime use. Not surprisingly, these FO weightings have a significant impact on the final solutions reported by WSTAT, and more details on these impacts will be examined in the following section.

SMET TRADE STUDY RESULTS

Once all preceding modeling activities are complete, the final step is running the Genetic Algorithm to obtain a representative sample of the Pareto trade space of optimal configurations. Algorithm run time varies from problem to problem depending on the size of the search space and the number of problem constraints – usually taking between an hour and a day to achieve satisfactory convergence. The SMET results presented in this section are gathered from a three hour run of the large SMET variant, which has stricter load carry, transportability, and growth requirements than the medium and small variants.

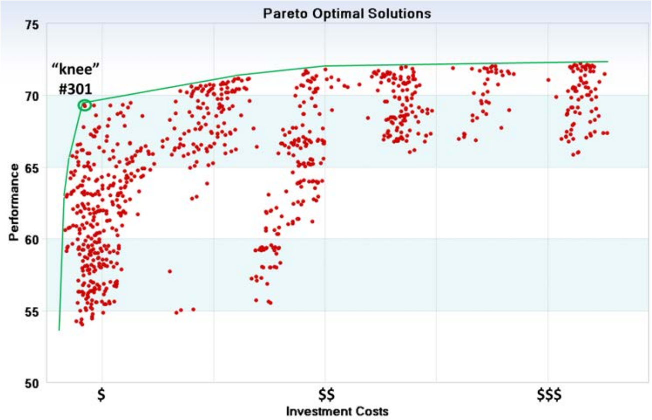


Figure 3: Pareto frontier of optimal SMET solutions

Figure 3 shows a plot of Investment Costs (x-axis) vs. Performance (y-axis) for the Pareto frontier of optimal solutions – each point representing an optimal SMET design. Cheaper solutions are on the left and more expensive solutions are towards the right; performance varies from roughly 54 to 72 (out of a possible 100). The green line indicates the “bleeding edge” of the cost-performance tradeoff and highlights a distinct “knee” near the relatively inexpensive solutions; further increases in price beyond this knee buy only marginally improved performance.

Every configuration in Figure 3, including those well below the green line, is optimal; each solution strikes a unique balance in the five optimization dimensions. For example, solutions that are relatively high-cost and low-performing have a tradeoff in that they score well in O&M cost, growth, or risk. This spectrum of solutions provides an analytically-driven basis for multiple stakeholder insights and, ultimately, decisions.

A simple yet powerful analytic capability built into WSTAT is the ability to highlight the optimal solutions by their choice of subsystem technology. For example, Figure 4 shows the cost- performance trade space colored by running gear selection: four-wheeled options are red, six-wheeled are blue, oval tracks are green, and neither trapezoid tracks, parallelogram tracks, nor mattracks are selected in the Pareto set. Interestingly, only a small set of the cheapest solutions select an oval track. These solutions are “bare bones” configurations, and oval tracks provide a cheap way to score very well in the Trafficability FO (due to much lower ground PSI) compared to wheeled solutions. The rest of the trade space is dominated by wheeled solutions, as these have much better rolling resistance, cost, and reliability. Six-wheeled options are common in the most expensive solutions since they are more costly yet outperform 4-wheeled solutions in most mobility-related FOs.

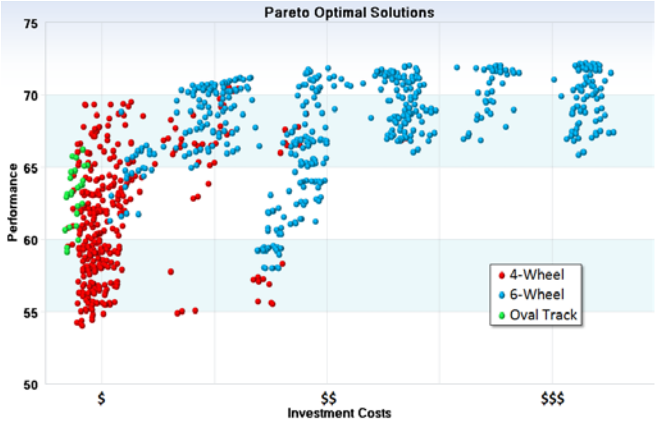


Figure 4: Pareto frontier colored by choice of Running Gear

Figure 5 again highlights the cost-performance trade space – this time coloring by choice of power plant architecture which is determined by multiple subsystem selections in the Powertrain section of the Product Structure. Like running gear, the choice of internal combustion only (red), electric only (blue), or hybrid (purple) power plants is of fundamental importance and will have downstream effects on many FOs. Notice that the internal combustion solutions have a lower average performance than either the electric or hybrid solutions. This is driven primarily by the inferior acoustic signature of the internal combustion engines (recall that the Acoustic Signature FO has highest weight). The electric only solutions tend to be very inexpensive due to the fact that the available battery technologies cannot support a large electronics power draw or a prolonged operational endurance. Thus electric only solutions are relegated to relatively bare bones configurations that excel in mobility. The highest performing solutions all utilize a hybrid power plant, which enables good acoustic signature, operational endurance, and supports more electronics power draw. The tradeoff, naturally, is that these more complex hybrid solutions are more expensive.

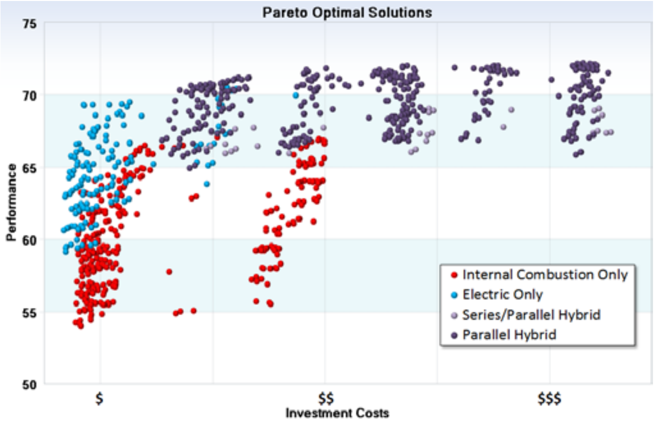


Figure 5: Pareto frontier colored by power architecture

WSTAT can display the optimal solutions plotted by any choice of x and y-axis including optimization dimensions, FOs, and metrics – enabling visualization of any 2D “slice” of the trade space. Along these lines, Figure 6 plots the Platform Weight metric vs Performance dimension. For the large SMET variant, configurations weigh between 1,070 and 3,000 pounds. Notice that while the platform weight itself is not a dimension of optimality, there nevertheless exists an implicit tradeoff between performance and weight;

there are high performing solutions that are light weight (bare bones configurations with excellent mobility), but there are not heavy solutions with low performance. The optimization chooses to build heavy solutions with more/heavier subsystems only if reasonable capability can be acquired by incurring that weight. Interestingly, note that the highest performance solutions exist in the middle of the weight range, suggesting that the absolute best performance is achieved by a compromise between nimble and fully “decked out” configurations.

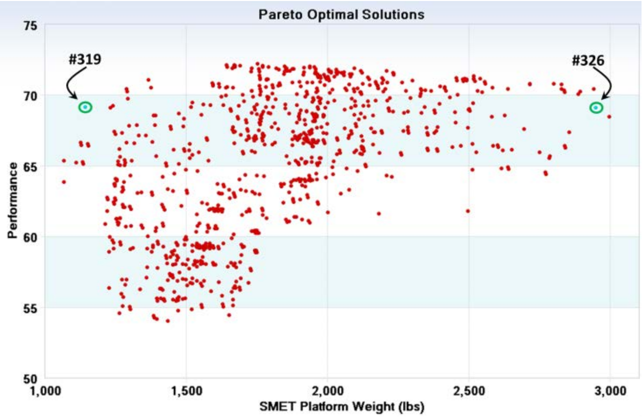


Figure 6: Platform Weight (lbs) vs. Performance for optimal SMET configurations

To examine this in more detail, two solutions in Figure 6 are highlighted (#319 and #326) that have nearly identical overall performance but whose weights are at opposite ends of the scale. These solutions typify two very different SMET design philosophies. The light weight solution #319 is an electric only SMET with a 4-wheeled running gear, and a small carbon fiber frame. In contrast, solution #326 is a hybrid SMET (having a fuel tank, internal combustion engine, automotive cooling system, generator, generator inverter, and transmission – parts not needed in #319), a 6-wheeled running gear, and a large armored steel frame more than twice the internal volume of #319’s frame.

Despite having nearly identical *overall* performance, these two solutions behave very differently in *individual* FOs. Figure 7 depicts a “tornado chart” comparison between these two solutions. A red bar on the left indicates the light weight #319 performs better in that FO; conversely a blue bar on the right indicates that the heavy #326 performs better. Due to having fewer and more robust parts, #319 wins in Extreme Temperatures and RAM. Not surprisingly, the more nimble #319 also wins in the mobility categories of Maneuverability, Agility, Gap Crossing, and Trafficability (despite having only 4 wheels vs. 6, #319’s lower weight gives it a lower overall ground pressure). Lastly, since #319 is purely electric, it has the quietest possible acoustic signature. The heavy hybrid #326, on the other hand, with its gas tank *and* battery has much better operational endurance and can offload much more power via its internal generator. #326 also has a backup power supply so that it outperforms in Data Integrity. And lastly, #326’s heavy steel armored frame provides much better survivability. Despite their differences however, the total lengths of the blue bars is nearly identical to the total lengths of the red – again indicating the two solutions have roughly equal overall performance despite very different design approaches.

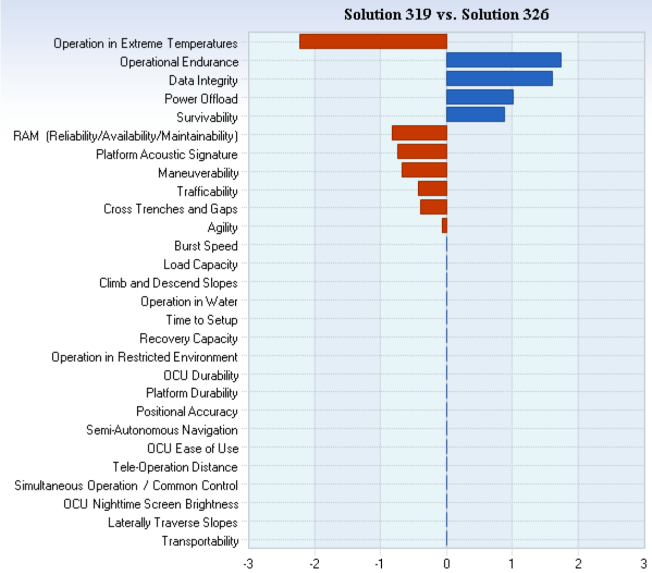


Figure 7: Tornado chart FO comparison of configurations #319 and #326, which have nearly identical overall performance but very different platform weights

As previously mentioned, FO weightings can have a significant impact on the final solutions reported by WSTAT. For example, recall that the Semi-Autonomous Navigation FO is ranked extremely low in Figure 2 by the SMET user panel. In fact, no solution in the Pareto set choses subsystems that enable autonomy (e.g., LIDAR, RADAR, Cameras, and advanced Computers) since these add weight and power draw that negatively affects other more highly weighted FOs. To see this more explicitly, consider the solution #301 from Figure 3 near the “knee” in the cost-performance tradeoff. We create a “clone” of this solution (called #301-A) and then manually alter the clone to include RADAR, LIDAR, and an advanced computer for processing streaming vision data. Performing these alterations to #301-A ensures that it will have an excellent Semi-Autonomous Navigation score, and Figure 8 illuminates the differences in FO scores between these two.

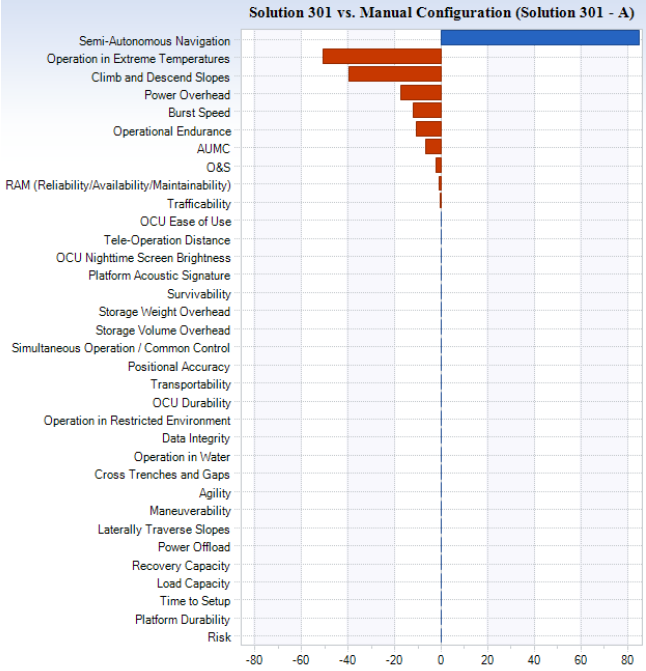


Figure 8: Comparison of configuration #301 and #301-A – a clone of #301 except with autonomy hardware

Notice that while #301-A indeed has better autonomy, it loses to #301 in several other FOs: #301-A has worse Extreme Temperatures because LIDAR is more sensitive to hot and cold, it has worse slope climb because the LIDAR and RADAR draw power from the power plant and also increase the center of gravity, it has worse Power Overhead, Burst Speed and Operational Endurance again due to the increased power draw of the autonomy hardware, it is more expensive to procure and to operate over its lifetime, and it has slightly worse reliability. Given all of these negative tradeoffs together with the FO priority weightings, solution #301-A has a significantly worse overall performance than #301. This tradeoff exists in general, not just for solution #301, and therefore WSTAT chooses not to pursue highly autonomous systems. There is a point, however, where increasing the Semi-Autonomous Navigation priority weight would cause #301-A to outperform #301. WSTAT provides the insight into this tipping point, and informs decision makers that semi-autonomy is only chosen in optimal solutions if that FO is given a larger priority weight.

SUMMARY

The SMET design problem involves a complex intertwining of competing requirements and technology options. Understand the relationship between these requirements and technologies is of fundamental importance to the success of the SMET program. In this paper, we present the general WSTAT process that enables holistic insights into these tradeoffs, along with the specific modeling approaches utilized to cast the SMET architecture within the WSTAT framework. We then outlined some emerging results about important SMET design decisions.

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