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ADVANCING SYSTEM OF SYSTEMS ANALYSIS TOOLSET (SoSAT) AND THE FULLY BURDENED COST TOOL (FBCT) TO JOINTLY ASSESS OPERATIONAL PERFORMANCE, SUSTAINMENT, COST, AND OPERATIONAL ENERGY

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ABSTRACT

The Joint Operational Energy Initiative (JOEI) models energy (and all classes of supply) consumption, generation, and sustainment across a virtual battlefield area of operations utilizing the System of Systems Analysis Toolset (SoSAT) and the Fully Burdened Cost Tool (FBCT). Recent advances in SoSAT provide a capability to model condition-based scenarios that better represent complex dynamic scenario changes and provide more accurate, realistic operational scenario and sustainment modeling. In addition, the JOEI team developed a new operational metric called Combat Effective Operational Endurance (CEOE) using SoSAT system-level outputs to determine unit combat power over time based on system availability and system combat weights. FBCT improvements include increased synchronization with SoSAT and expansion of capabilities to model Class V (ammunition), Class VII (major end item) transport, troop movement, convoy generation and higher fidelity cost allocation. The new SoSAT condition-based scenario capability and FBCT Class-VII capability were recently used by the JOEI team to model dynamic transport operations for crew and equipment transportation and resupply convoys in Phase II operations. Example results for a trailer study involving the Phase II model and for the new CEOE metric are presented.

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1. INTRODUCTION

The Joint Operational Energy Initiative (JOEI) was established to develop, demonstrate and document a modeling and simulation (M&S) toolset and methodology to analyze operational energy (OE) using an integrated, system of systems (SoS) engineering approach, that enables comprehensive energy decision-making throughout the materiel development process. JOEI models energy (and all classes of supply) consumption, generation, and sustainment across a virtual battlefield area of operations. The project utilizes an M&S tool developed by the Department of Energy's Sandia National Laboratories called System-of-System Analysis Toolset (SoSAT) and a U.S. Army developed cost analysis tool called the Fully Burdened Cost Tool (FBCT). Using SoSAT and FBCT, Combat Capabilities Development Command-Ground Vehicle Systems Center (CCDC-GVSC) has developed a capability to assess second order (i.e., sustainment) and third order (i.e., man-hours) impacts of technologies in a multi-level virtual scenario. The JOEI team is developing a library of TRAC-approved Scenario representation models consisting of Maneuver Forces, Logistics Support, and Contingency Bases (Division and below, down to the system/subsystem level). Using these models, the JOEI team can assess energy, sustainment effectiveness, operational availability, logistics, fully burdened costs, and soldier impacts. The JOEI suite of M&S tools provides quantitative evidence to evaluate materiel and non-materiel solutions, inform trade studies, conduct cost-benefit analysis, inform current and future doctrine, inform science and technology investments, and inform current operations.

2. HISTORY

JOEI was formed in 2013 as a partnership between the U.S. Army Program Executive Office Combat Support & Combat Service Support (PEO CS&CSS) and the Tank Automotive Research and Development Engineering Center (TARDEC), now CCDC-GVSC, to address the lack of analytic capability to quantify and understand the second and third order impacts of a technology in a multi-level operational scenario. Prior to JOEI, the Army had limited ability to inform investment and development decisions that could improve the utilization of fuel and water resources and reduce the associated logistics burden.

The initial capabilities of the JOEI toolset included quantifying the logistic impacts of fuel reduction, water generation, and water reuse technologies and assessing the second and third order impacts of ground vehicle system, subsystem, and basecamp system changes using SoSAT. SoSAT could also model and analyze operational materiel availability.

In 2015, JOEI transferred from PEO CS&CSS to Project Manager Expeditionary Energy & Sustainment Systems (PM E2S2) with an eventual transition to TARDEC / CCDC-GVSC in 2016.

In 2015 and 2016, the JOEI team began building a library of TRAC-approved scenario models consisting of Major Combat Operations and Stability/Peacekeeping Operations. In 2018, JOEI added a Seize Initiative Operation to assess the movement and build-up of forces in theater.

In 2016, JOEI also acquired the FBCT from US Army Logistics Innovation Agency (LIA), now US Army Logistics Enterprise Support Agency (USALESA). At that time, FBCT estimated the fully burdened costs and benefits of energy and water for an operational scenario. The FBCT has since been expanded to work together with SoSAT, estimate costs for additional classes of supply (e.g., Ammunition, and Class VII), allocate costs with higher fidelity, and incorporate troop movement.

3. A NEW METRIC: COMBAT EFFECTIVE OPERATIONAL ENDURANCE

In April 2017, the Army held a Demand Reduction Summit sponsored by the Army Capabilities Integration Center at Joint Base Langley-Eustis, Virginia. JOEI attended the summit along with joint services, major Army commands, and other centers of excellence. Discussion centered around an Army desire to enable brigade combat teams (BCTs) to operate independently of the logistics chain in austere environments and across extended distances for extended durations of time (i.e., reducing the need to resupply a BCT with fuel, ammunition, water, energy and other supplies).

Many new concepts and technologies were being considered to accomplish the demand reduction objective. The analysis community was asked to develop a methodology and capability to evaluate science and technology (S&T) investments and advancements against a requirement for a BCT to operate independently for a set number of days without resupply.

JOEI's SoSAT had the capability to produce metrics such as consumption/generation of fuel, power, water, waste, system utilization, operational availability, sustainment availability, and the logistics footprint. However, JOEI did not have a singular metric to assess operational impact of an S&T Initiative, in short, how an initiative improves the Army's ability to fight. To meet this need, JOEI developed a new operational metric called Combat Effective Operational Endurance (CEOE).

CEOE is a metric that measures the operational impact of S&T initiatives on a BCT within an area of operations. CEOE is dependent on individual scenario characteristics such as location, time of year, phase of scenario, and length of combat.

CEOE is calculated using SoSAT system-level outputs to determine unit combat power over time based on system availability and system combat weights. Combat Power of the system is calculated using equation (1) *(*combat weights from the Command and General Staff College at Fort Leavenworth)*.

$$\text{Combat Power}_{\text{System}} = \text{Available Systems} \times \text{Combat Weight}_{\text{System}} \times \text{Class V}_{\text{Unit}} \times \text{Water}_{\text{Unit}}$$

Where

$\text{Available Systems} = \text{Number of systems available for combat}$

$\text{Combat Weight}_{\text{System}} = \text{Combat Power contributed by system}$

$$\text{Class V}_{\text{Unit}} = 1 \text{ if Class V balance at unit} > 0\text{, else } 0$$
$$\text{Water}_{\text{Unit}} = 1 \text{ if Water balance on hand at unit} > 0\text{, else } 0 \quad (1)$$

$$\text{Combat Power}_{\text{Unit}} = \sum_{\text{Unit}} \text{Combat Power}_{\text{System}} \quad (2)$$

Example CEOE results for three modeled ABCTs are presented in Figure *1*, showing that combat power endures and then rapidly diminishes after a few days of operations without resupply. The crosshairs in the figure indicate the point at which combat power has diminished to 70% of its original value which is used as a standard for comparing different alternatives.

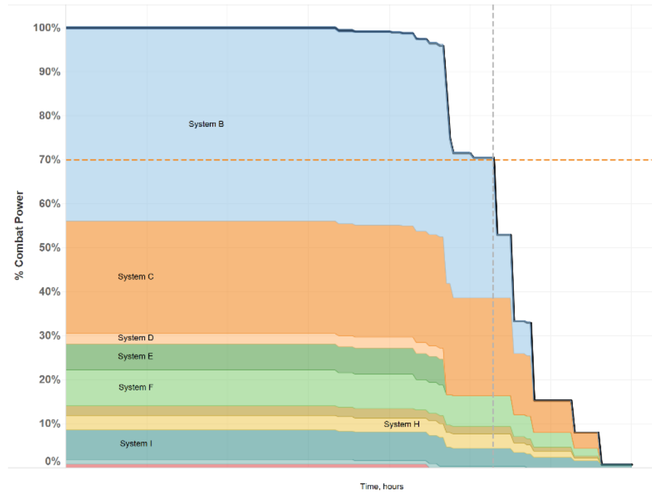

Figure 1: Sample plot of Combat Power (time scale redacted)

With the development of the CEOE metric, JOEI can compare S&T initiatives against a baseline scenario force structure. This metric allows JOEI to measure the days/hours the force can perform the mission with existing Fuel, Ammunitions, and Water supplies and can be used comparatively across different alternatives (i.e., which initiative allows the force to operate the longest).

FBCT outputs can then be paired with the CEOE metric to provide a comparative cost impact assessment of achieving varying levels of CEOE (i.e., which initiative(s) maximize(s) operational time per dollar).

4. MODELING IMPROVEMENTS

As funding continues to grow for unmanned ground vehicles and technology continues to develop, JOEI is continually improving toolsets to be able to analyze new capabilities and how they will operationally affect the Army. Analytical needs spurred recent convoy operations improvements in both SoSAT (conditional scenarios) and the FBCT (automated convoy creation). The FBCT also introduced the ability to analyze costs for transport of major end items (e.g., an Abrams) into theater.

4.1. Conditional Scenarios

Historically, SoSAT used time phased convoy operations. A timeline for convoy operations would be developed or model input would determine the frequency at which resupply convoys would take place. Through utilization and consumption calculations and knowledge of the force structure and available convoy assets, a Subject Matter Expert (SME) would schedule convoys and the SoSAT tool would account for asset availability.

Through extensive development and improvement of SoSAT, JOEI has implemented a conditional scenario capability that can generate convoys dynamically based on a set of conditions being satisfied. The conditional scenarios capability can better represent complex, dynamic scenario changes and circumstances, and more accurately and realistically model operational scenario and sustainment activities.

SoSAT has been used extensively to model operational and materiel availability and resupply operations for time-based Operational Mode Summary/Mission Profile (OMS/MP) and other scenario operation utilizations. However, although these time-based utilizations can be complex, they could only change at prescribed times; they could not change according to non-time-based conditions such as system, equipment, or resource availability; completion of required, dynamic scenario segments; or other potentially complicated SoS conditions. Due to the complexity of SoSAT and its SoS dependencies, connections, and redundancies, implementation of the ability to model conditional scenarios required significant development effort.

In the prior versions of SoSAT, scenarios were divided into a series of scenario segments that defined what actions each system would be assigned to perform. These scenario segments were defined with a time duration that dictates exactly when in the simulation a segment would end and the next segment begin. Conditional scenarios now allow scenario segments to instead wait on trigger conditions to become true before ending a segment.

Trigger functionality is a new, user definable, "if-this then-that" capability added to the core SoSAT functionality that allows defined actions to occur when a defined condition is met. For example, "if inventory drops below a defined threshold, then start an emergency convoy action." Triggers can also be used to change model parameters such as "if the availability of the command and control or reconnaissance unit drops below a defined level, then increase the combat damage probability of the combat unit." Trigger functionality provides a flexible capability to define new conditions and actions that can be added as analysis needs arise.

One specific use of conditional scenarios and triggers was a trailer study that modeled unit transport during Phase II operations. These operations involve transport of heavy equipment on trailers and the self-transport of unit systems and personnel. Triggers are used to force self-transferred units to wait until heavy equipment convoy resources are available before the transport operations can begin. It also allowed for prioritization of units for transport and limiting the number of units to be transported according to conditions, convoy support center capacity in this case. Example results for the trailer analysis are shown in Section 4.3.

This new conditions-based capability expands our analytical trade space. It provides more accurate, realistic operational scenario and sustainment modeling. It enables detailed transport and movement operations that can be condition-based in addition to time-based. This capability allows for more model flexibility to include modeling a defined "if-then-else' operation that was not previously available. Furthermore, it allows JOEI increased levels of detail. JOEI can now model operations that are not based on fixed durations; the model can adapt to changing conditions like threats, availability and attrition.

4.2. Automated Convoy Capability in the Fully Burdened Cost Tool

Improved convoy operations are currently being implemented within the FBCT as well. FBCT cost estimates are most representative when the full theater supply chain is modeled. Historically, the FBCT has required users to manually define convoys or relied on convoy data from SoSAT. However, given the data required, it is not always practical for SoSAT to model the entire theater supply chain.

To support captures of total supply chain costs, an FBCT automated convoy capability is being implemented that will enable quick extension of the supply chain using either custom parameters or parameters synchronized with imported SoSAT convoy data. Users can specify convoy characteristics by route (or globally) such as force protection levels, expected commodity loss, and specific convoy system selections. The FBCT will then automatically generate convoys along selected routes using the provided convoy parameters. The automated convoy capability can be used in conjunction with SoSAT model outputs or independently. The automated convoy capability will significantly improve JOEI's ability to assess the full costs of logistic activities and simplify time requirements to model scenarios independently within the FBCT or extend scenarios imported from SoSAT.

4.3. Trailer Analysis and Transport Costs

The new SoSAT conditional scenario capability and FBCT Class-VII capability were recently used by the JOEI team to conduct a demonstration study for Product Manager Heavy Tactical Systems. The study showed how SoSAT can be used to analyze the effects of different trailer fleet system mixes on the build-up of Combat Power in theater to support the Army's Heavy Trailer Modernization Strategy efforts. This study involved modeling dynamic transport operations for transportation of crews and equipment and resupply convoys in Phase II operations, with the analysis objectives being to determine: the time and resources required to complete the transport operations; operational costs; and impacts of different transport systems, potential capacities, and reliability improvements.

With size increases (weight and dimensions) resulting from ongoing modernization efforts, tracked systems are becoming too large to be trailered efficiently by the current fleet of Army trailers – due to both system limitations as well as road network restrictions. The Heavy Trailer Modernization Strategy seeks to address this challenge by modernizing the trailer fleet in both types and quantity of trailer systems available to transport tracked vehicles. SoSAT provides a TRADOC scenario based simulation of movement of combat units to/from prescribed locations in theater using specified sustainment (transportation) units. Using the definition of combat power described previously, the simulation can show how quickly combat power can be built up over time as assets are transported from one area to another in a theater of operations and how efficiently the transportation systems are used for a variety of system capabilities and quantities. The demonstration focused on the movement of the heavy equipment of two ABCTs by a Sustainment Brigade from a Training Area through a Convoy Support Center (for refueling and driver rest) to a Tactical Assembly Area. It highlighted the tool's ability to automatically adapt to changing the mix of moving equipment available in the Sustainment Brigade.

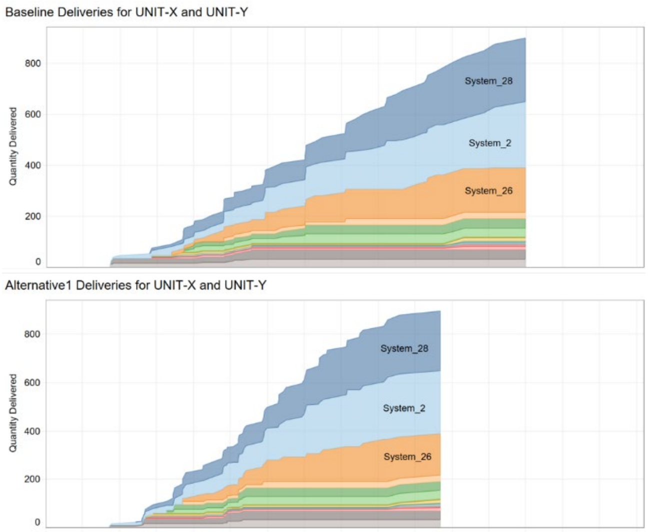

Figure 2: Comparison combat systems delivered at a Tactical Assembly Area using different combinations of trailer systems for movement (time-scale redacted)

Figure 2 shows one of the primary results of the demonstration. It compares the number of combat systems delivered for the Baseline case – using assets from the current trailer fleet – versus an Alternative case using a hypothetical set of upgraded trailers. The Alternative case showed a >16% reduction in the time required to move all the heavy combat equipment and personnel for both ABCTs. This utilization of the tool demonstrated that the capabilities added to the tool could effectively be used to provide additional analysis capability and provide unique results to Army decision makers.

The FBCT was also expanded to include the capability to calculate the fully burdened costs associated with transporting major end items (e.g., Abrams Tank), or FBC-Class VII. This capability was exercised as part of the demonstration study supporting the Heavy Trailer Modernization Strategy as well as an excursion looking at a non-trailered (self-mobile) option.

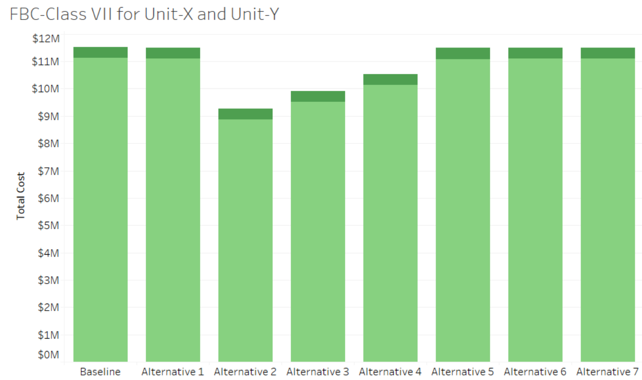

Figure 3: Comparison of FBC-Class VII costs using different combinations of trailer systems for movement

The impacts of system cost-uncertainty on FBC-Class VII for a potential tractor-trailer combination were calculated showing how the FBCT could be used to assess where system cost savings could have the largest impact in overall scenario cost. Sample results are shown in Figure 3.

5. Conclusions

The new CEOE metric allows JOEI to assess combat power and measure the days/hours the force can perform the mission with existing fuel, ammunitions, and water supplies and can be used comparatively across different alternatives (i.e., which initiative allows the force to operate the longest). Conditional scenarios and triggers functionality added to SoSAT provide more realistic modeling and analysis of sustainment and transport convoy operations for manned as well as unmanned and autonomous systems and provides additional capabilities to support assessment of S&T investments and AoAs. The FBCT automated convoy capability allows scenario costs for the full supply chain to be captured while FBC-Class VII enables the FBCT to more accurately represent Phase II scenarios and better inform major system acquisition from a cost perspective (e.g., what mix of trailers is optimal for both performance and cost).