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Decision Support Tool for the Global Reaction Force Outload Process

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Abstract

The 82nd Airborne Division serves as the core of America's strategic response force, and provides the ability to execute global force projection through large scale combat parachute assault operations. A detailed outload plan is necessary to rapidly deploy the Global Response Force (GRF). This outload process involves preparing and prioritizing necessary vehicles for airlift, and then assigning these prioritized vehicles to available aircraft. Throughout the planning process this list and associated priorities can change due to mechanical faults of aircraft/vehicles or due to changing mission requirements. Our team collaborated with the 82nd Airborne Division Operational Research and Systems Analysis (ORSA) Cell in developing an Out-load Decision Support Tool (ODST) that rapidly builds and adjusts the Priority Vehicle List (PVL) and optimizes vehicle assignment to various types of aircraft given a mission profile and a unique brigade vehicle list.

Keywords

Process improvement, Decision analysis, Assignment, MCDA, Heuristics

1. Introduction

The 82nd Airborne Division serves as the core of America's strategic response force. This response force is capable of performing global force projection through parachute assault under short-notice orders. For seventy years the 82nd Airborne Division has been refining its processes and procedures in order to increase its efficiency during any hasty outload process. This project is part of that refinement process.

1.1 Background

In 2008, the Secretary of Defense ordered the 82nd Airborne Division to reassume its full role as the core of the Global Response Force (GRF) to improve the nation's ability to respond rapidly to a range of contingencies. The GRF is capable of executing a wide variety of missions; these mission profiles include airborne operations, non-combatant evacuation operations (NEO), counterinsurgency operations (COIN), decisive action, and domestic civil support operations [2]. Combatant Commands provide planning priorities to the GRF in order to guide joint training and resource prioritization. As a part of the Army's component of the GRF, the 82nd Airborne Division currently provides a Multifunctional Aviation Battalion Task Force, an Indirect Fire capability from the 18th Fires Brigade, an Echelon Above Brigade Headquarters, and an Airborne Brigade Combat Team (BCT), which is comprised of two Infantry Battalions, a Cavalry Squadron, a Fires Battalion, a Special Troops Battalion, and a Support Battalion. These units are quickly deployable and are equipped to contribute to a multiplicity of intended and/or predictable military operations [2].

Over the past thirty years the GRF has deployed on several short-notice contingency operations, including Operation Urgent Fury in Grenada in 1983, Operation Just Cause in Panama in 1989, Operation Desert Storm in Iraq/Kuwait in 1991, as well as disaster relief missions such as Hurricane Katrina and the Haiti earthquake [2]. Since September 11th alone, the GRF has been called upon eighteen times in support of humanitarian missions, special tours in support of operations in Iraq and Afghanistan, and combat operations supporting special operations units [3].

1.2 Problem Definition

The GRF deploys vehicles as part of two distinct echelons. If the mission requires parachute assault, the first echelon will contain vehicles that are rigged with parachutes and are dropped from C130 and/or C17 aircraft. The second echelon contains those vehicles that arrives at an airfield and off-load through normal airfield procedures. If the mission does not require parachute assault, all vehicles are prepared for normal air movement and airfield offload. Due to limited aircraft, staff and commanders must prioritize the hundreds of vehicles that are assigned to an airborne BCT. As a BCT prepares to assume GRF responsibilities, its staff and commanders prepare an initial default Priority Vehicle List (PVL). This PVL serves as the baseline for planning purposes, and drives the selection of vehicles that are rigged with parachutes and prepositioned near the airfield. During actual deployment, this PVL is adjusted based on the specific needs of the contingency operation as well as any maintenance faults discovered on deploying vehicles. The 82nd Airborne Division requested that our team develop a tool to assist planners in building the initial PVL and adjusting this PVL during the outload process. A visual depiction of the tool is shown in Figure 1.

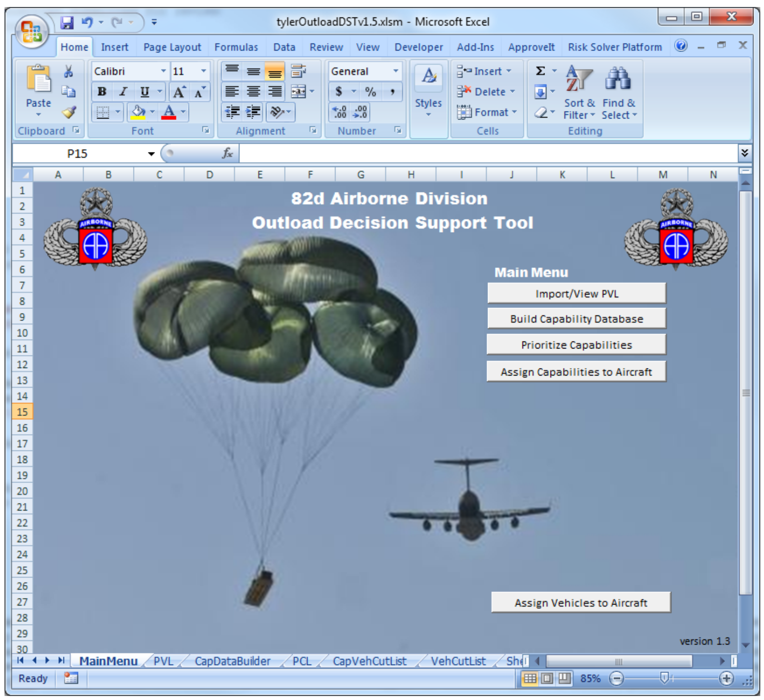

Figure 1: Outload Decision Support Tool

2. Literature Review

We focused our initial literature review on three areas: other units/organizations that rapidly deploy (namely the 75th Ranger Regiment), prioritization models, and assignment models.

2.1 Lessons from the 75th Ranger Regiment

The 75th Ranger Regiment also serves as part of the GRF and often conducts short-notice deployments for contingency operations. Like the 82nd Airborne Division, the 75th Ranger Regiment is prepared to conduct parachute assault operations. In order to gain lessons learned from Ranger deployment procedures, we interviewed several past leaders from the 75th Ranger Regiment (from company through regimental level). Noteworthy among these was our personal interview with Brigadier General Richard Clarke. BG Clarke has served as both a Battalion Commander and the Regimental Commander in the 75th Ranger Regiment. Additionally, he has served as a battalion commander in the 82nd Airborne Division and is familiar with their outload procedures. From these interviews we learned that Ranger deployments differ somewhat from the 82nd Airborne Division. The Ranger Regiment usually conducts short duration deployments as opposed to the longer duration deployments that the 82nd Airborne Division is prepared to conduct.

This eliminates the need for large scale deployment of sustainment vehicles and material. The Ranger Regiment, while also prepared to conduct parachute assault, does not normally plan to air-drop vehicles by parachute. From our interviews, we learned that the Ranger Regiment staff and commanders prioritize their vehicles manually, in a manner similar to the methods employed by the 82nd Airborne Division [1, 4].

2.2 Prioritization

Although Multi-Objective Decision Analysis (MCDA) is a relatively new development, we see glimpses of the science of decision making throughout history. Aristotle (384-322 BC) defines 'preferences' as 'rational desires' in *Nicomachean Ethics*, and Benjamin Franklin outlined a personal decision algorithm that he called 'Moral Algebra' [7]. Noteworthy contributions to modern MCDA include Ward Edwards 1954 and 1961 articles introducing utility theory, Bernard Roy's development of ELECTRA (the earliest 'outranking' approach) and of course George Dantzig and his contribution to mathematical programming. These early contributions have merged into what we know as MCDA [7].

Prioritization falls into the category of MCDA problems in which solutions are explicitly known, which is often called multiple criteria evaluation problems. We focused our research on two evaluative methods for MCDA problems: the weighted additive value model and Analytic Hierarchy Process (AHP).

Weighted additive value models use multiple criteria provided by the stakeholder to measure value in a decision. These criteria are weighted and summed, creating a single criterion used to quantitatively order items by priority. The basic value model is:

$$v(x) = \sum_{i=1}^{n} w_i v_i(x_i)$$

where $v(x)$ is the value of an item, $i = 1$ to n for the number of value measures, x_i is the score of the item on the ith value measure, $v_i(x_i)$ is the single-dimensional value of the item in the ith value measure, w_i is the weight of the ith value measure and $\sum_{i=1}^{n} w_i = 1$. [8]

Analytic Hierarchy Process (AHP) compares alternatives in a stepwise fashion and measures their contribution to the objective. According to Zehedi [12], AHP involves four steps:

1. Setting up decision hierarchy by breaking down the decisions into a hierarchy of interrelated decision elements
2. Collecting input data by pairwise comparisons of decision elements
3. Using the "eigenvalue" method to estimate the relative weights of decision elements
4. Aggregating the relative weights of decision elements to arrive at a set of ratings for the decision alternatives (or priorities)

AHP necessarily consumes time since it requires stakeholders to conduct the pairwise comparison of vehicles and/or capabilities. This method is often criticized for its sensitivity as it is subject to rank reversal when small priorities are changed and is therefore not recommended for prioritizing entities that are subject to last minute change [12]. We primarily pursued AHP as a tool to help staff develop their initial default PVL, but not fully implemented in the ODST since it is not the preferred model for last minute changes.

2.3 Assignment

In 1947 George Dantzig introduced the simplex method for solving linear programming problems and many quickly leveraged computers to use linear programming to solve real world problems [7]. Optimization is used to determine the best (minimum or maximum) solution to a linear mathematical problem given a finite number of constraints. Optimizing solutions are not always feasible and may require too much effort or expense [8]. In a related military project in Canada, Y. K. Kevin uses linear programming to optimize airlift and airdrop cargo. Kevin uses a set of available manifests made by loadmasters to define the feasible solution space [6].

Heuristics are an approach that uses rules of thumb, or "homemade algorithms" that often prove effective in a given situation. These are considered the most common way that humans take-in and simplify the multifaceted information in a given problem daily. This approach is also used to simplify very complex problems. Heuristic algorithms that find the optimal solution for an objective function come at a price as they do not consider assumptions. This results in optimal solutions that are not the best for the real world problem. Heuristic procedures that can provide improved solutions are often more helpful to the organization as they can easily be implemented [9].

2.4 Data Visualization

The science of displaying data so that it is intuitive to users has come be known as data visualization. Edward Tufte, an expert in this field suggests that "graphical excellence consists of complex ideas communicated with clarity, precision, and efficiency" [10]. Showing the user an accurate and truthful representation of data is essential to the proper and ethical correspondence with stakeholders. Depending on the variables that the author desires to compare, Tufte gives a plethora of examples to make it simpler and idea-provoking for an onlooker.

3. Methodology

Our technical approach primarily employed the Systems Design Process developed by and taught at the Department of Systems Engineering at the United States Military Academy. The SDP is a four phase process developed for complex decision environments. The four phases are *Problem Definition*, *Solution Design*, *Decision Making*, and *Solution Implementation*. During the *Problem Definition* Phase, we visited Fort Bragg, observed an outload rehearsal, and interviewed key leaders in the outload process. This phase ended with the development of the problem definition and functional analysis. During *Solution Design* we designed candidate models for both vehicle prioritization and vehicle assignment. During the *Decision Making* phase we collaborated with the 82nd Airborne Division ORSA team to choose the best model/methodology for vehicle prioritization and vehicle assignment. Following refinement, the *Solution Implementation* phase involved implementing the tool with the 2nd Brigade Combat Team and assisting as necessary in the development of appropriate software documentation and instructions.

3.1 Functional Analysis

The Outload Decision Support Tool (ODST) must accomplish several functions which are outlined in Figure 2. Namely, the ODST assists in building a capability database, importing BCT vehicle data, and associating these vehicles with the capabilities. Having done this, the ODST allows a user to prioritize capabilities, which in turn prioritizes the vehicles. After making any necessary adjustments, the ODST allows the user to assign both echelons of vehicles to aircraft. Finally, the tool creates informative graphics to assist staff and commanders.

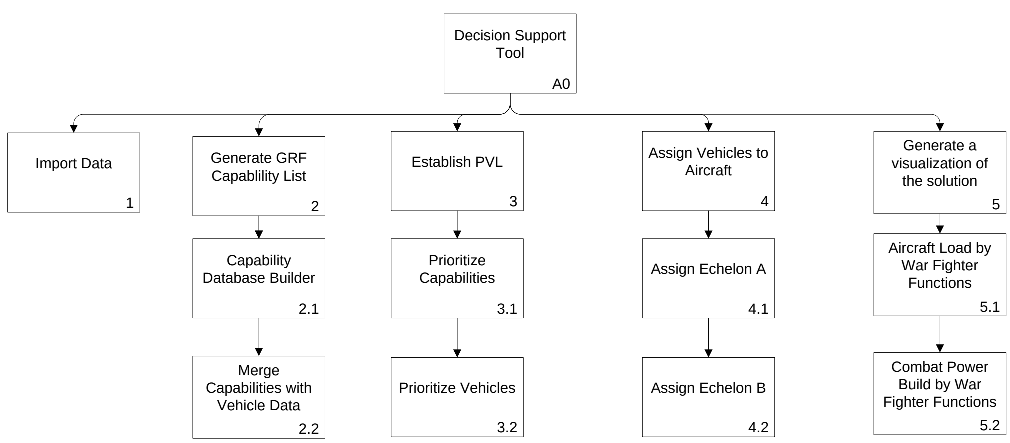

Figure 2: Functional Hierarchy Diagram

3.2 Prioritization

The ODST must assist staff and commanders to prioritize over 200 vehicles. We explored this problem using the additive value model, AHP, as well as other methods that are discussed below.

Initially we explored prioritizing these capabilities with an additive value model. An additive value model allows for the user to prioritize and weight several criteria which are then used to produce values for the entire list of vehicles. The PVL is created when these values are rank ordered. We evaluated vehicles based on three criteria:

- Battalion (Maneuver 1, Maneuver 2, Reconnaissance Squadron, Special Troops Battalion, Brigade Support Battalion)

- Company (A, B, C, D, HHC, FSC)
- War Fighting Function (Mission Command, Fires, Intelligence, Maneuver, Protection, Sustainment)

This model requires staff/commanders to prioritize battalions, and then within battalions to prioritize companies, and finally to prioritize warfighting functions. Warfighting functions are the six doctrinal functions that Army forces provide. We assumed that decision makers could quickly prioritize these three variables to create or adjust a PVL. We used these variables in an additive value model and tried to compare how closely the new PVL compared to historical vehicle lists that were prioritized by staff and commanders. Through this comparison, we could ascertain if the additive value model was able to replicate the priorities assigned manually by staff/commanders. After spending significant time adjusting priorities and weighting, we found the additive value model, while informative, did not sufficiently approximate the staff/commander priorities.

After discussing these methods with staff and commanders, we collaborated with the division ORSA team to develop a manual method that aggregated vehicles by capability, allowing a user to initially prioritize capabilities as opposed to individual vehicles. Prior to assuming the GRF, staff will create capabilities which are associated with vehicles during the data import function. To build a priority vehicle list, staff prioritize the capabilities, and then adjust individual vehicles as necessary. This process allows planning staff to prioritize roughly 40 capabilities as opposed to more than 200 vehicles. Our development effort focused on allowing a user to define, save, and edit capabilities stored in a database, as seen in Figure 3.

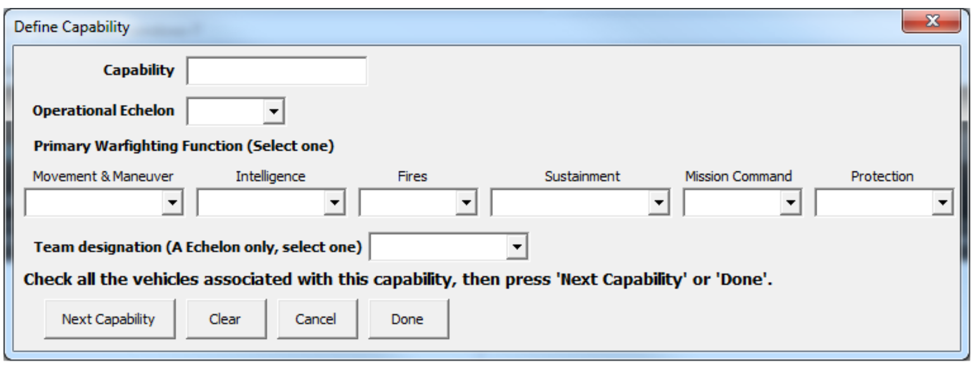

Figure 3: Interface for User Defined Capabilities

3.3 Assignment

The assignment model was designed to take the PVL and allocate each vehicle to a finite number of aircraft. Our first model implemented an integer linear programming model for the purpose of assignment. Our objective function minimized the available space in the aircraft and the aggregate deviation for the sequencing of vehicles. Minimizing the available space on the aircraft ensures that the staff and planner use their limited airlift resources to the fullest. Minimizing changes from the PVL will ensure that the vehicles remain, as close as possible, in the prescribed PVL sequence that supports the mission and the commander's plan. This objective function was subject to four constraints as seen below: (1) each vehicle must be assigned to one and only one aircraft, (2) the cumulative length of vehicles assigned to an aircraft is less than or equal to the total available space in that aircraft, (3) the cumulative weight of vehicles assigned to an aircraft is less than or equal to the load limits of that aircraft, and (4) the decision variables are binary (0- not assigned, 1-assigned).

The formulation for this integer programming model is given below:

Sets:

$a \in A$ Set of Available Aircraft
$v \in V$ Set of Available Vehicles

Data:

$avail.feet_a$	Available Linear Feet for Aircraft a
$avail.weight_a$	Available Weight for Aircraft a
$veh.feet_v$	Length of Platform for Vehicle v
$veh.weight_v$	Weight of Vehicle v
$pvl.prev_{av}$	PVL Preference for Vehicle a to Aircraft a

Decision Variable:

X_{av} Binary Assignment of Vehicle v to Aircraft a

Formulation:

$$\min \quad \sum_{a\in A}\sum_{v\in V} X_{av}pvl.pref_{av} + \sum_{a\in A} avail.feet_a - \sum_{a\in A}\sum_{v\in V} X_{av}veh.feet_v$$

$$\text{subject to} \quad \sum_{a\in A} X_{av} \geq 1 \qquad \forall v \in V \qquad (1)$$

$$\sum_{v\in V} X_{av}veh.feet_v \leq avail.feet_a \qquad \forall a \in A \qquad (2)$$

$$\sum_{v\in V} X_{av}veh.weight_v \leq avail.weight_a \qquad \forall a \in A \qquad (3)$$

$$X_{av} \in \{0,1\} \qquad (4)$$

Note that this model requires the following data: aircraft weight and length restrictions, vehicle length and weight, the PVL, and a preference matrix that is created from the PVL and Aircraft flight schedule. An example of this preference list is given in Table 1.

Table 1: Example matrix used for integer linear optimization: reflects $Vehicle \rightarrow Aircraft$ Preference

	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8	AC9	AC10
Vehicle 1	1	2	3	4	5	6	7	8	9	10
Vehicle 2	1	2	3	4	5	6	7	8	9	10
Vehicle 3	1	2	3	4	5	6	7	8	9	10
Vehicle 4	1	2	3	4	5	6	7	8	9	10
Vehicle 5	2	1	2	3	4	5	6	7	8	9
Vehicle 6	2	1	2	3	4	5	6	7	8	9
Vehicle 7	2	1	2	3	4	5	6	7	8	9
Vehicle 8	2	1	2	3	4	5	6	7	8	9
Vehicle 9	3	2	1	2	3	4	5	6	7	8
Vehicle 10	3	2	1	2	3	4	5	6	7	8
Vehicle 11	3	2	1	1	2	3	4	5	6	7
Vehicle 12	3	2	1	2	3	4	5	6	7	8
Vehicle 13	4	3	2	1	2	3	4	5	6	7
Vehicle 14	4	3	2	1	2	3	4	5	6	7

This integer programming model was implemented in Excel using the OpenSolver for Excel. OpenSolver is an open source solver developed by Andrew Mason and students at University of Auckland, NZ. OpenSolver is a linear and integer progamming solver that extends the capabilities of Excel's built in Solver. In particular, Excel's built-in solver will not allow models with more than 200 decision variables. Our models required more than 3000 decision variables. OpenSolver allowed us to build and solve the model in Excel, even though our model exceeded the allowable ceiling of 200 decision variables.

While optimization uses equations to minimize the empty space and changes from the PVL, we hypothesized that instead of using the integer programming answer, a heuristic model of assignment would do just as well and not require external software (OpenSolver) and data preparation (namely developing the preference matrix given in Table 1). Our heuristic algorithm attempts to replicate the intuitive methods that staff and planner would use to manually assign vehicles to aircraft. The heuristic begins by assigning the first vehicle to the first aircraft. It continues down the list of vehicles assigning each subsequent vehicle to the first aircraft. If an aircraft fills up, it begins filling the second aircraft. Before it places a vehicle on an aircraft, it checks to see if it will fit on any previously filled aircraft. This heuristic is given in Algorithm 1 below:

Algorithm 1 Heuristic Aircraft Assignment Algorithm

```
for each vehicle on the PVL do
  if vehicle is loaded then
    Move on to next vehicle
  else
    for each available aircraft do
      if usable aircraft length > vehicle length and available aircraft weight > vehicle weight then
        usable aircraft length = usable aircraft length − vehicle length
        usable aircraft weight = usable aircraft weight − vehicle weight
        label vehicle with aircraft number
        break
      else
        label vehicle with "Does not Fit"
      end if
    end for
  end if
end for
```

We evaluated these models based on quantitative and qualitative criteria. Quantitatively we evaluated each model based on total empty aircraft space and total deviations from the PVL. These comparisons are given in Table 2 below. The heuristic algorithm matched or exceeded the performance of the integer programming model in both criteria. We also evaluated the models based on their ease of use. The heuristic algorithm proved much easier to use, since it did not require additional software or the creation of the $Vehicle \rightarrow Aircraft$ preference matrix. The ODST therefore implements the heuristic algorithm given above.

Table 2: Comparison of Linear Optimization to the Heuristic Algorithm

	Heuristic Algorithm	Integer Programming
Number of AC	26	26
Empty Space	48 feet	48 feet
Sum of Deviations from Original PVL	34	486

3.4 Data Visualization

We developed several visualizations of the final outload that we thought would inform commanders and planners. We solicited feedback from staff and commanders and implemented the graphics that they valued. We spent significant time exploring various data visualizations that would help senior leaders in the 82nd Airborne Division quickly understand the outload situation, challenges, and decision points. One of these is illustrated in Figure 4. This graphic provides a visualization of combat build by warfighting function. The independent variable is flight numbers, and the dependent variable is cumulative vehicles by warfighting function. This graphic allows commanders to visualize the total number of vehicles by category available at various times during the mission, stimulating re-prioritization if the mix of vehicles is not appropriate for a given time frame.

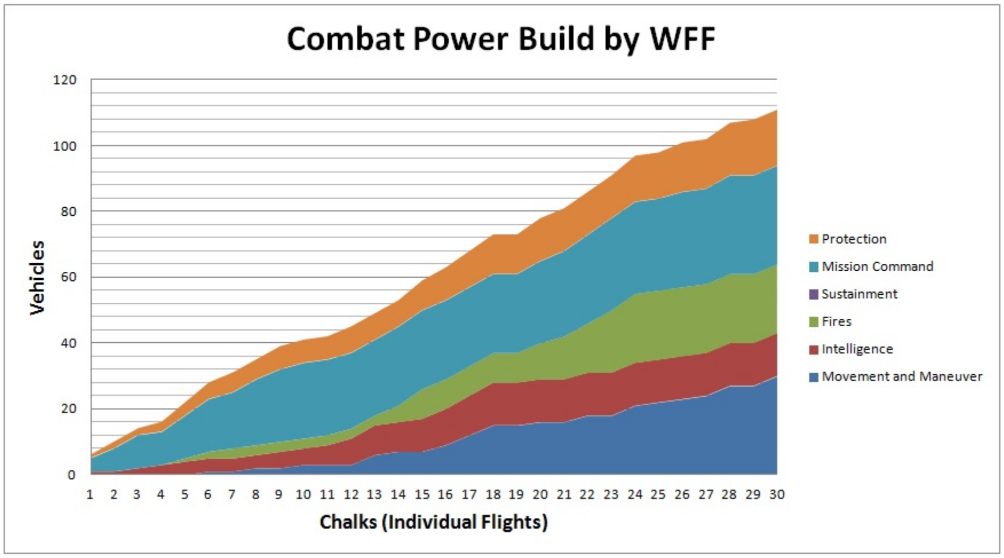

Figure 4: Combat Power Build by Warfighting Function (*Note: this was produced with randomly generated numbers and does not represent real or proposed deployment planning*)

4. Implementation and Way Forward

The 2nd Brigade Combat Team will test and evaluate the ODST as they prepare to take over responsibilities of the GRF. The 2nd BCT is the first brigade of the 82nd Airborne Division to transition to the new "Brigade Combat Team 2020." This restructure will cause them to spend additional time re-evaluating their priority vehicle list. The ODST will provide them a tool to quickly explore possibilities. As they train up to assume the responsibilities as the designated global response brigade, we will test and evaluate the ODST during an outload practice exercise.

In this paper we outline our proposed design of the Outload Decision Support Tool (ODST) to be used by leaders within the Global Response Force. This tool implements data merge and data management functions, vehicle prioritization through aggregation by vehicle capability, and assignment of vehicles to aircraft with a heuristic algorithm. The ODST solution is rendered in several graphics which assist commanders in visualizing the outload process and associated combat power build in theatre.

This project is a great example of the value of systems engineering for the Army at the tactical (Division and below) level. Following thirteen years of war, operations research and systems analysts at the Division level are often associated with combat assessment. While not minimizing the importance of combat assessments, this project highlights an ORSA's value in process improvement and decision analysis.

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