A Monte Carlo Simulation of Air Ambulance Requirements During Major Combat Operations

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ABSTRACT   In this study, we evaluate rules of allocation and planning factors that have an effect on requirements for Army air ambulance companies. The Army uses rules of allocation in scenarios drawn from strategic planning documents to determine how many units of each type are required. Army planners use these rules for determining the number of units required to support specific operational and tactical scenarios. Unrealistic rules result in unrealistic unit requirements. We evaluate quantitatively (via Monte Carlo simulation) planning considerations for air ambulance units during major combat operations (MCO) and estimate that 0.4 airframes per admission would be a reasonable planning factor.

INTRODUCTION

In this article, we evaluate rules of allocation and planning factors for Army air ambulance companies. The Army applies rules of allocation to scenarios drawn from strategic planning documents to quantify requirements of each type of unit, while military planners use these rules to estimate unit requirements for operational and tactical scenarios. Imprecise rules result in unrealistic unit requirements. We evaluate quantitatively (via Monte Carlo simulation) rules that have an effect on air ambulance units during major combat operations (MCO). The bottom line of this study is that the Army's Total Army Analysis (TAA) process may be improved by using better rules of allocation generated by the branch proponents.

This essay unfolds as follows. First, we discuss the Army's process for determining unit requirements, the TAA. Second, we detail some previous findings associated with the Army's TAA, as these findings provide sufficient justification for our study. Third, we provide recent background information regarding rules of allocation associated with air ambulance units. Fourth, we discuss recent rules of allocation affecting air ambulance units. Fifth, we conduct a simple Monte Carlo simulation to estimate a workload-based rule of allocation during a TAA MCO.

The primary significance of this study is that it provides an initial planning factor for air ambulance units in MCOs and highlights potential areas for improvements in terms of data collection. Further, the study provides simulation methodology that might be adopted by decision makers to investigate different TAA scenarios. We begin now with a discussion of the TAA process.

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Total Army Analysis

The TAA is the Army's method for determining and resourcing force structure requirements for all approved Tables of Organization and Equipment (TOEs). "TAA develops requirements and authorizations defining the force structure the Army must build, raise, provision, sustain, maintain, train, and resource."[1] The TAA seeks an affordable, supportable, and executable solution in assessing and resourcing the Army's force structure and provides the link between the current Army and the future Army. The process, therefore, demands significant rigor.[1]

"Requirements determination, the more critical of the two phases, is made up of two separate events: force guidance and quantitative analysis. Accurate planning, consumption and workload factors, threat data, and allocation rules ensure accurate computer developed requirements."[1] The force guidance provides the planning input for the scenarios. The Strategic Planning Guidance (SPG), the Joint Planning Guidance (JPG), and The Army Plan (TAP) provide the basis for planning and assumptions. Organizations that provide data and guidance for the process include Northern Command (NORTHCOM, homeland defense), the Office of the Secretary of Defense (analytic agenda), Combatant Commanders (theater-specific deter missions), the Army G-4 coupled with both Training and Doctrine Command (TRADOC), and U.S. Army Combined Arms Support Command (planning and consumption factors/assumptions). TRADOC also provides the allocation rules used by the Center for Army Analysis (CAA), which conducts the TAA quantitative modeling process.[1]

Allocation rules drive the force requirements. If the rules do not adequately define a unit's capability, then estimates of the supporting force requirements are flawed. Minimizing the error in these rules therefore becomes a primary concern. Training and Doctrine Command along with the functional proponents develop these rules for inclusion in the process.[1]

The current types of allocation rules include direct input (or manual), existence-based rules, and workload-based rules. A fourth rule regarding theater structure (e.g., one theater headquarters per theater) exists in AR 71-11, Total Army

Analysis, but is essentially a special case of the existence-based rules.[2]

From this short discussion, one can readily see that the TAA has the capability of impacting every component of the Army. We turn now to a discussion of recent third-party findings associated with the process.

Relevant Findings

A 2003 report by the Institute of Defense Analysis (IDA) found that, "although the 1996 IDA review pointed out serious problems with outmoded and inappropriate allocation rules, the Army made little progress in the intervening 6 years."[3] This report indicted the process for outdated consumption data and methods for predicting consumption. "The Army needs at least to use combat parameters and consumption rates that appear to be reasonable."[3] This 5-year-old finding provides some credible evidence that estimation might be improved.

We turn now to recent rules and decisions affecting the number of air ambulance companies required.

Rules of Allocation Affecting Air Ambulance Requirements

In 2005, United States Army air ambulance (MEDEVAC) companies were independent numbered units generally assigned to evacuation battalions. As part of restructuring, the Army realigned the numbered companies to lettered subordinates under the General Support Aviation Battalion (GSAB). The Army also reduced the number of aircraft required by Table of Organization and Equipment from 15 to 12.[4,5]

Before the transition to the GSABs, the Army rule of allocation for air ambulance companies was one per division in direct support, one per three separate brigade or armored cavalry regiment (ACR), one for every 2.0 divisions in general support, and one per theater for ship-to-shore and shore-to-ship missions.[6] Assuming a theater containing a single corps with four divisions and an ACR, the total number of aircraft in support of combat would be as follows:

— Theater, 1×15 ship units
— Division, DS, 4×15 ship units
— Division, GS, 2×15 ship units
— ACR/separate brigade, 0 units
— Total units, 7×15 ship units
— Total aircraft required, 105.

After the transition, the allocation of air ambulance companies became a function of the required number of GSABs, as lettered companies generally do not receive separate consideration in the TAA. The current rule of allocation for the GSAB is one per aviation brigade. One of the emerging concepts is for the theater and corps aviation brigades to contain two MEDEVAC companies in their GSABs. Assuming each division contains an aviation brigade, that the corps contains one aviation brigade, and that the theater contains one aviation brigade results in the following estimation of

requirements based upon the previous scenario and emerging concepts:

— Theater, 2×12 ship units
— Corps, 1×12 ship units
— Division, DS, 4×12 ship units
— Total units, 7×12 ship units
— Total aircraft required, 84.

One can see that, given this scenario, the difference in the number of airframes totals 21. By realignment, the rule of allocation affecting air ambulance units was effectively modified. One should note that the current allocation rule for the GSAB does not designate the divisional general support mission (a patient backhaul function) nor does it designate resources for the ship-to-shore/shore-to-ship missions.

CASE STUDY AND METHODS

An analysis linking the "worst-case" MCO from a recent TAA to Operation Iraqi Freedom (OIF) evacuation data suggests that workload-based requirements would largely exceed those generated by a fixed basis of allocation dependent on GSABs. Using a recent TAA MCO hospital admission stream and data from OIF,[7] a Monte Carlo simulation provided evidence that a workload requirement for air ambulance units might be logically set at 0.4 airframes per hospital admission depending on assumptions. This study necessarily assumes that distributions derived from current operations are likely to provide a reasonable empirical basis (albeit imperfect) for analyzing future operations. The distributions of interest include those related to flight time and helicopter hauling characteristics. While we recognize that these characteristics may not be the same in future operations, we postulate that they are unlikely to be radically different unless advances in technology or significant changes in doctrine or general employment occur. Further, we provide flexible simulation parameters for decision makers to manipulate and investigate excursions based upon multiple TAA scenarios. A detailed analysis follows.

Monte Carlo simulations rely on repeated random sampling of distributions to generate estimates of population parameters of interest. These simulations rely on the law of large numbers, which provides that repeated and independent sampling of identically distributed random variables results in convergence to the expected value (or mean) of these variables. Our study follows most Monte Carlo method simulations in that we define our input distributions, randomly generate samples from these distributions, use the results of these samples in calculations, and report our estimates. In our study, we seek to estimate the aircraft required to cover demand by day of operation. In our repetitive sampling, we effectively bracket the mean number of aircraft required. Note: all parameters associated with the simulation are flexible so that alternate scenarios may be investigated as well. We now algorithmically discuss the generation of distributions associated with our workload analysis. For

readers interested in seeing the flowchart first, please skip to Figure 4.

1. Obtain the Number of Hospital Admissions

A recent TAA MCO provided the daily operating force hospital admission stream for use in this analysis. The TAA hospital admissions are those patients with serious enough injuries/illness to require hospital admission into surgery-capable facilities. We logically assume that these patients receive (among other forms of evacuation) the preferred and primary evacuation means, air ambulance.

2. Estimate the Number of Movements for Each Hospital Admission

The expected number of helicopter aircraft movements for each admitted patient was approximately 1.17 based on in-theater data sources (*n* = 3,763), reflecting that many patients moved multiple times.[8] Note: these air movements are independent of any potential ground movement (e.g., ground ambulance demand.) Since patients move from point of injury to forward surgical intervention to hospital facilities to intertheater evacuation sites, this ratio appears to have some face validity. Simple discrete sampling of the cumulative mass function provided the number of movements for the model. Table I is the distribution of admitted patients.

3. Estimate Flight Hours for Each Patient on the Basis of Number of Movements

Accounting for mission hours was a matter of modeling the flight time from OIF evacuation logs. A screening and compilation of three unit logs of units operating from 2004 to 2006 resulted in *n* = 3,324 usable observations. A histogram revealed that a triangular probability mass function would adequately capture the uncertainty regarding flight hours per mission. The mission hours for both activations then derived from a triangular distribution with a minimum parameter of 0.5, a mode of 1.0, and a maximum of 4.0. See Figure 1.

4. Estimate Demand for Nonadmitted Patients and Supplies

Demand for evacuation aircraft, however, is not restricted to those patients admitted. Two evacuation units provided effective logs of those patients and medical supply missions

categorized as routine. Table II illustrates the breakout for these units. One notes that routine patients generally do not require hospital admission. For purposes of this study, routine patients equated to nonadmission evacuations. A Bernoulli trial with the probability of success equal to 0.48 accounted for those patients transported but not admitted. One logically assumes that, for estimation purposes, nonadmitted patients receive lift only once. This demand converted to flight hours using the same weighting scheme previously discussed.

5. Account for Multiple Patient Transports

The OIF evacuation logs also provided a method for determining the number of patients evacuated per mission. Specifically, an aircraft evacuated only one available patient with probability 0.574, two with probability 0.361, three with probability, 0.049, etc. This distribution reduced the demand for aircraft accordingly. This distribution became a weighting scheme to estimate each patient's contribution to the total hours. For example, if flight hours for an admitted patient were initially 2.5, the following calculation adjusted that value. Expected flight hours per patient, call this $E(h)$, is calculated as follows:

$E(h) = \Sigma_i (h_i/i) \times p(h_i)$ = sum (flight hours per patient × probability of number of patients) = (2.5/1) × 0.574 + (2.5/2) × 0.361 + (2.5/3) × 0.049 + (2.5/4) × 0.013 + (2.5/7) × 0.003 = 1.932 hours vice the original 2.5 hours. Figure 2 provides the distributions.
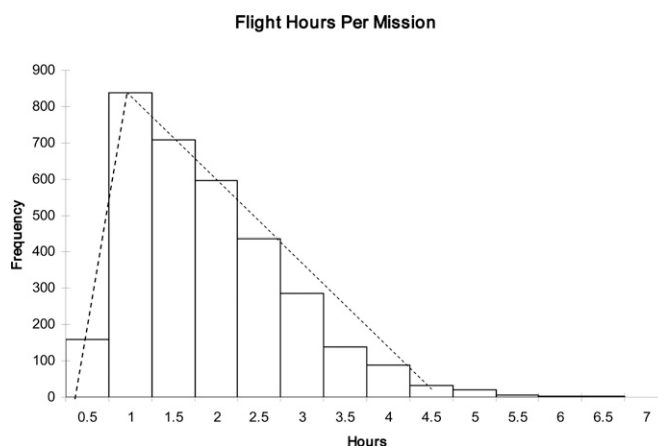

FIGURE 1. Flight hours per mission follow a triangular distribution.

TABLE I. Number of Times Admitted Patients Moved by Air Ambulance

No. of Movements by Patient	No. of Patients	Cumulative Probability
1	3,207	0.852
2	480	0.979
3	68	0.998
4	8	1.000

TABLE II. About 48% of Evacuated Individuals Were Categorized as Routine

	Urgent	Priority	Routine	% Routine
Unit 1	1,001	698	1,430	0.457
Unit 2	373	248	747	0.546
Totals	1,374	946	2,177	0.484

6. Estimate Airframe Demands on the Basis of Competing Standards

The demand for airframes was a function of total flight time for both admitted and nonadmitted patients. Converting flight time to airframes was not straightforward, as the manpower requirements criteria (MARC) suggested that maintenance could support 2.5–2.6 continuous operational hours per airframe per day[9] although operational manuals suggested that 6.0–8.0 operational hours per airframe per day was reasonable.[10] A conservative model (based on uncertainty) employed a uniform random variable with a minimum of 6.0 and a maximum of 8.0 to account for surge capability. Note: this approach includes aircraft downtime. This approach is conservative in that it generates fewer airframe requirements. We also ran an excursion that included 2.5–8.0 operational hours and no routine patients.

7. Calculate the Number of Companies Required on the Basis of Airframes

Finally, the required airframes generated required companies by simple division (12 airframes per company).

8. Simulation and Findings

A simple Monte Carlo analysis of 250 runs provided the estimates for evaluation. We wrote the simulation in Microsoft Excel with Visual Basic for Applications code generating and recording runs. We sampled by using the inverse cumulative distribution function method. All parameters of distributions remained flexible for excursion analysis.

The 250 runs resulted in a median daily 95% confidence interval of 2.6 aircraft in width for the 6.0–8.0 airframe hours per day scenario and 14.6 aircraft in width for the 2.5–8.0 airframe hours per day scenario. Assuming risk at the highest daily peak (a single chaotic event for which extraordinary response would be dictated) and setting requirements at the secondary peak results in a requirement for between 230 and 232 airframes (95% confidence interval) for the more conservative scenario, which is still significantly larger than the undisclosed TAA requirement on the basis of an existence rule. Figure 3 is the chart depicting both scenario simulation runs.

One can see that the conservative scenario generates a mean requirement of 231 airframes at the second peak for a total of 591 admissions. Using this ratio, we estimate the requirement for about 0.4 airframes per admission. Given 12 airframes per company, this planning factor converts to 400 airframes/1,000 admissions or 33 units per 1,000 admissions. If one uses the second peak for planning purposes, then the conservative ratio for units is (33 units/1,000 admissions) × 591 admissions = 20 air ambulance units.

If one assumes that 2.5–8.0 operational hours is more realistic, a planning factor of 0.6 airframes per admission is appropriate as evidenced by Figure 3. We ran several excursions on the basis of operational hours and transport of routine patients. Other excursions generated ranges from 0.3 to 0.6 depending on parameters. Conservative runs resulted in a ratio of 0.4 airframes per admission.

The resultant solution set for the base analysis described here (and other excursions) exceeded by a significant but undisclosed margin the number of GSAB air ambulance units allocated to the scenario in all instances. The existence-based rule provides a known quantity of assets independent of potential workload. Company allocation is therefore dependent upon a unit that does not have the same mission profile or set. One can readily conclude that the application of an existence-based rule to a unit with subordinate elements that are largely workload based is problematic and, in this case, underestimates requirements. The TAA rules of allocation associated with the determination of air ambulance requirements may require additional rigor. This finding is also congruent with the previous Institute for Defense Analysis study
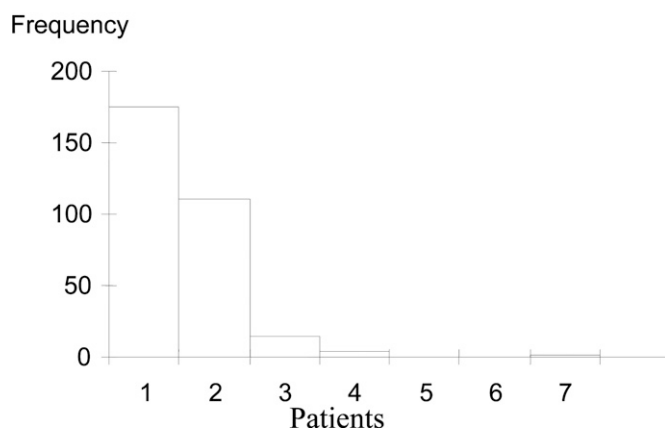
Histogram of Average Patients Per Movement

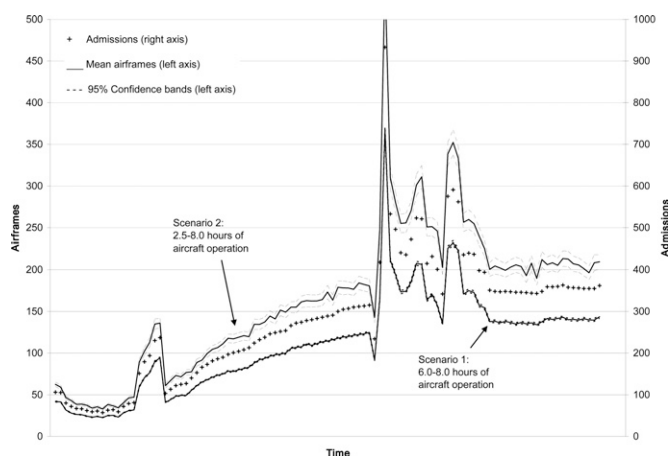**FIGURE 2.** Average number of patients per aircraft movement.

FIGURE 3. Results of the Monte Carlo simulation based on a uniform distribution of daily operational flight hours, 6.0 to 8.0 hours for scenario 1 and 2.5 to 8.0 hours for scenario 2. The left vertical axis provides the number of airframes required, while the right axis provides the number of admissions observed. The horizontal axis reflects the number of days in the simulation.
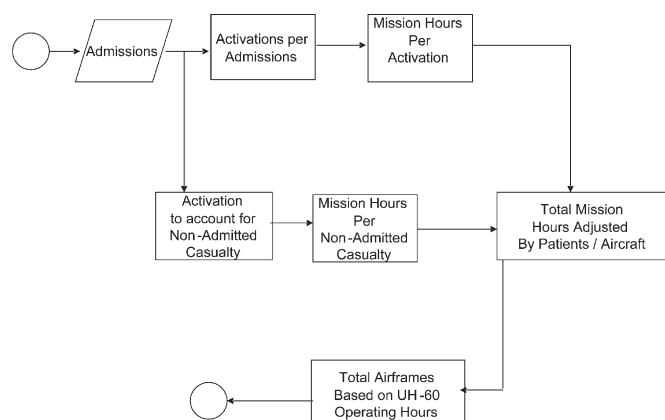
FIGURE 4. Simulation flowchart for air ambulance requirements.

mentioned earlier.[3] Figure 4 provides a graphical depiction of the simulation.

— From this analysis, we note that the existence rule is not congruent with a workload-based rule. Which is better? Because of the requirements determination impact on Army force structure, actual workload analysis should be preferred. Subordinating a unit with a workload factor to an existence rule may not be advisable.

— One might generalize the results of this analysis to other units. Consider, for example, the medical logistics company in a multifunctional medical battalion. Subordinating this company to a battalion diminishes the inherent workload-based requirement. We should note that recent work by the Directorate for Combat Developments and Doctrine (DCDD) at the Army Medical Department relies largely on workload-based analysis (e.g., the new combat support hospital augmentation team analysis.)

LIMITATIONS

In this study, we illustrated how existence-based rules and workload-based rules may not be compatible. While our study is limited to air ambulance units, we believe that other existence rules require additional scrutiny. We also realize this

analysis derives from ongoing operations that may not entirely match future operations.

CONCLUSIONS AND RECOMMENDATIONS

Analysis of unit requirements should include workload-based rules even for small organizations. If small units are subordinate to an entity (e.g., a battalion) that does not share the same demand characteristics, leaders should consider evaluating these units' requirements separately. Further, we estimate that a planning factor of 0.4 air ambulance airframes per hospital admission during MCO would be reasonable.

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