Comment on the ADAMS transportation requirement estimation methodology

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Materiel Group Operational Research

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Author

R. H. A. David Shaw

Approved by

Paul Desmier
Director Material Group Operational Research

Approved for release by

Dale F. Reding
Director Operational Research (General Analysis)

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Abstract

The transportation requirements estimator provided in the Allied Deployment and Movements System's (ADAMS) Deployment Planning Module (DPM) can lead to questionable estimates for certain manifests. This paper develops an alternate simple estimation methodology and compares the performance of the two techniques to the "optimal" solution on a data set inspired by the Operation ATHENA deployment. The alternative estimator is shown to be more accurate, leading to conservative estimates which are high by around five to ten percent. The impact of other real world constraints on the two estimators is also discussed.

Résumé

L'estimateur des besoins de transport fourni dans le module de planification des déploiement du système Allied Movement and Deployment System (ADAMS) pourrait aboutir des estimations contestables pour certains manifestes. Cet article développe une méthodologie d'estimation alternative simple et compare la performance des deux techniques à la solution «optimale» inspirée par les données du déploiement de l'opération ATHENA. L'estimateur alternatif est vu d'être plus précis, aboutissant à des estimations conservatrices qui sont plus élevées d'environ cinq pourcent. L'impact des autres contraintes du monde réel sur les deux estimateurs est aussi discuté.

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1 Introduction

This report explores the estimates of the number and types of transportation assets required to move a specified manifest of cargo and equipment generated by three different techniques. The relative strengths and weaknesses of each method will be compared and contrasted; conclusions will subsequently be drawn as to the suitability of each method for given problem types.

1.1 Background

The Allied Deployment and Movement System (ADAMS) consists of an interconnected set of software modules developed by the NATO Consultation, Command and Control Agency (NC3A) to facilitate the planning and deconfliction of large scale multinational military movements. ADAMS links with a rather comprehensive database containing information on equipment and forces structures in service with NATO militaries in addition to the relative dimensions and capabilities of a wide variety of typical airlift and sealift asset types. The Deployment Planning Module (DPM) then allows for either rapid estimation of transport requirements or the development of a complete and detailed movement plan.

ADAMS has been extensively used within Directorate Materiel Group Operational Research (DMGOR) in several recent studies of deployment lift [1–3]. In these studies, once the manifest of equipment and supplies that moved during the deployment phase of a given operation was determined, the transportation requirements estimation tool provided in the ADAMS DPM was used to estimate the required number of chalks and possible mixes of transportation assets that would be required to move the entire force into theatre.

In the course of these deployment lift studies, it was determined that ADAMS, while an excellent planning and deconfliction tool, did not afford the user with the opportunity to easily optimize any aspect of the movement. Even relatively simple options analysis was difficult to perform using ADAMS, as it required extensive backtracking to generate a new plan with the desired features before any form of movement analysis could be conducted.

In response to these shortcomings, DMGOR is currently undertaking to develop a set of tools that could be used to supplement the ADAMS software by allowing for optimization of deployment lift problems. One major component of this effort is GALAHAD[1] [4], a software tool developed within DMGOR that uses a combination of simulated annealing and genetic algorithm techniques to derive near-optimal loading plans across a fleet of transportation assets.

As development of the GALAHAD loading module progressed, one logical validation test involved comparing the optimal loading solutions returned from the program with those results obtained from ADAMS for the equipment manifests of Operation ATHENA [1], Operation APOLLO [2], and Operations STRUCTURE and HALO [3]. The results obtained for Operations APOLLO, STRUCTURE, and HALO were generally comparable to,

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[1] Genetic Annealing for Loading of Aircraft, a Heuristic Aiding Deployment

but somewhat lower than, those determined with the ADAMS DPM estimator, which was consistent with our expectation that GALAHAD, as an optimization tool, should outperform the ADAMS estimator by finding more efficient movement solutions.

However, in the case of Operation ATHENA, the minimum constraint surface computed by GALAHAD intersected that returned by ADAMS. The deployment of materiel on Operation ATHENA was accomplished in three phases: a sea lift from Montreal, Canada to Derince, Turkey, a road move within Turkey from the port at Derince to the military airbase at Topel, and an air lift from Topel, Turkey to Kabul, Afghanistan. We shall focus our attention on the air lift phase of the movement, which was accomplished using a mixture of AN 124 and IL 76 TD cargo aircraft. In particular, ADAMS determined that a minimum of six AN 124 sorties were required to move various large pieces of equipment, with the remainder of the equipment requiring 132 IL 76 TD chalks. GALAHAD, by contrast, computed the analogous point as a requirement of seven AN 124 and 183 IL 76 TD chalks. While minor differences in vehicle dimensions and weights were observed between the input data sets for the two programs, these proved insufficient to explain the wide discrepancy in the estimated IL 76 TD requirements.

1.2 Objectives

Given the large discrepancy observed between the ADAMS and GALAHAD results on the Operation ATHENA data set, this paper endeavours to determine how ADAMS calculates its transportation requirement estimate, develop an alternate estimation method where appropriate, and compare the results obtained using both methods to the GALAHAD loading solution.

1.3 Document structure

This report is structured in four sections with one annex. Following the introductory section, the next section explores the prediction obtained from ADAMS on a small cargo manifest, reverse engineers the ADAMS methodology, and proposes an alternative estimation technique. The third section compares the estimates stemming from both the ADAMS and alternative methods with the GALAHAD predictions on an Operation ATHENA-like data set and discusses the strengths, weaknesses, and limitations of all three techniques, while the final section summarizes the findings of the paper and makes recommendations for future analysis and study. The annex provides the precise details of the Operation ATHENA-like data set used in this study for archival purposes.

2 Two estimation techniques

In this section, we will determine how ADAMS computes its transportation requirement estimate and develop an alternative method which offers some advantages over the ADAMS procedure. This exploration and comparison of estimation methodologies will be facilitated by the use of a common, simple data set.

2.1 A simple data set

As the air lift phase of the Operation ATHENA movement was performed with AN 124 and IL 76 TD aircraft, we begin by extracting parameters relevant to these aircraft from the ADAMS database. The cargo bay dimensions and maximum payloads listed for the ADAMS default (i.e., the "AA" asset types) AN 124 and IL 76 TD are presented in Table 1.

Table 1: *An extract of cargo bay dimensions and maximum payloads from the ADAMS database for two common aircraft types.*

	Cargo Bay Dimensions			
Aircraft	Length (m)	Width (m)	Height (m)	Max Payload (kg)
Ilyushin 76 TD	20.0	3.40	3.30	57000
Antonov 124–100	41.5	6.40	4.40	120000

When the inconsistencies between the ADAMS DPM transportation estimate and the loading solutions provided by GALAHAD became apparent, the complete Operation ATHENA manifest was broken down into smaller subsets in an attempt to isolate areas where the differences arose and to identify which program was returning the correct results. The subset with the largest observed discrepancy consists of the items tabulated in Table 2.

Table 2: *A small subset of the Operation ATHENA cargo and equipment manifest.*

Item	Number	Length (m)	Width (m)	Height (m)	Mass (kg)
20ft ISO Shipping Container	300	6.10	2.40	2.40	7000
LSVW with Engine Repair SEV	1	5.61	2.01	2.73	3270
LSVW with IRIS Repair SEV	1	5.61	2.01	2.73	3270
Trailer, 850kg, M102 Cdn	1	3.68	1.88	2.01	670

Consider the problem of estimating the number of sorties required to move the cargo shown in Table 2 with IL-76 TD transport aircraft. ADAMS correctly identifies that all items in this manifest will fit inside the cargo bay of an IL 76 TD, but given an minimum inter-item spacing of 0.15m estimates that 70.79 chalks (i.e., 71 chalks) will be required to move the entire manifest. This is somewhat disconcerting, as both simple geometry and movement planner expertise [5] indicate that no more than three sea containers may be carried by an IL 76 TD in a single chalk. Given the manifest in Table 2, a requirement of about 101 chalks would appear to be more reasonable.

2.2 Reverse engineering the ADAMS estimation method

After some experimentation, it was determined that ADAMS determines its transportation requirements estimate by selecting the more restrictive of the cargo footprint and the weight constraints[2]. In computing the former, ADAMS determines the total effective footprint F_j of cargo to be transported by an asset of type j by the formula

$$F_j = \sum_{i=1}^{C} n_{ij}(l_i + d)(w_i + d), \tag{1}$$

where i indexes the various cargo types, n_{ij} denotes the number of items of type i to be transported by an asset of type j, l_i and w_i represent the length and width of an individual item respectively, d represents the user-specified minimum inter-item spacing, and C is the total number of item types in the cargo manifest. To determine the latter, ADAMS requires the total mass of cargo M_j to be transported by assets of type j, which may be computed by

$$M_j = \sum_{i=1}^{C} n_{ij} m_i, \tag{2}$$

where m_i is the mass of an individual item.

Given the two results above, in combination with the floor area A_j and maximum payload MPL_j of an asset of type j, the estimated number of sorties N_j of asset type j may then be determined via

$$N_j = \max\left(\frac{F_j}{A_j}, \frac{M_j}{\mathrm{MPL}_j}\right). \tag{3}$$

2.2.1 The ADAMS DPM estimate for the simple data set

For the cargo manifest given in Table 2, assuming that all items are to be transported with IL 76 TD and using a minimum inter-item spacing of $d = 0.15$m, we find

$$\begin{aligned} F_j &= \sum_{i=1}^{4} n_{ij}(l_i + d)(w_i + d) \\ &= 300(6.25\text{m})(2.55\text{m}) + 2(5.76\text{m})(2.16\text{m}) + (3.83\text{m})(2.03\text{m}) \\ &= 4813.91\text{m}^2 \end{aligned} \tag{4}$$

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[2] ADAMS assumes that the cargo bay of any asset type takes the form of a rectangular prism, thereby allowing for reduction to a two-dimensional bin-packing problem. Item heights are only used to determine which asset types can be used to transport the item in question.

and

$$\begin{aligned} M_j &= \sum_{i=1}^{4} n_{ij} m_i \\ &= 300(7000\text{kg}) + 2(3270\text{kg}) + 670\text{kg} \\ &= 2107210\text{kg}. \end{aligned} \tag{5}$$

Drawing from the information in Table 1, we determine the floor area $A_j = (20\text{m})(3.4\text{m}) = 68\text{m}^2$ and the maximum payload $\text{MPL}_j = 57000\text{kg}$ for the IL 76 TD. Using the ADAMS estimator of (3) above, we find

$$\begin{aligned} N_j &= \max\left(\frac{F_j}{A_j}, \frac{M_j}{\text{MPL}_j}\right) \\ &= \max\left(\frac{4813.91\text{m}^2}{68\text{m}^2}, \frac{2107210\text{kg}}{57000\text{kg}}\right) \\ &= \max(70.7928,\ 36.9686) \\ &= 70.7928, \end{aligned} \tag{6}$$

in agreement with the actual result returned by ADAMS. In the case of this simple manifest, it is clear that the binding constraint is the availability of floor space as opposed to the maximum payload of the aircraft.

2.3 A proposed alternative estimator

While the ADAMS DPM estimator given in (3) correctly identifies that availability of floor space is the binding constraint for the ATHENA manifest subset provided above, it still underestimates the required number of IL 76 TD chalks by almost 30%. In the discussion that follows, we shall develop an estimator that is more “geometrically aware” to allow for more refined and accurate estimation of transportation requirements[3].

Let us assume for the time being that each item has only one allowable orientation, with the dimension listed as the “length” aligned parallel with the longitudinal axis of the aircraft cargo bay. Given the length L_j and width W_j of the cargo bay of an asset of type j in combination with the dimensions of each individual cargo type, we may then determine how many items of a particular type may be placed side by side or front to back within the cargo bay. In particular, the maximum number of items of type i that can fit into an asset of type j, denoted by m_{ij}, is given by

$$m_{ij} = \left\lfloor \frac{L_j - d}{l_i + d} \right\rfloor \times \left\lfloor \frac{W_j - d}{w_i + d} \right\rfloor, \tag{7}$$

where $\lfloor \cdot \rfloor$ represents the floor operator defined as

$$\lfloor x \rfloor = \sup\{z \in \mathbb{Z} \text{ such that } z \leq x\}. \tag{8}$$

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[3] In the discussion that follows, we continue to treat items and cargo bays as rectangular prisms.

The first term on the right hand side of (7) represents the number of items that fit from the front to the back of the cargo bay, while the second term determines how many items may be packed side by side. The reduction of the length and width of the cargo bay by the minimum inter-item spacing is necessary to ensure that items are not only appropriately spaced with respect to each other, but also with respect to the bay walls, a subtlety that the ADAMS DPM estimator does not currently handle.

Using the m_{ij} determined above, we may now develop an improved articulation of the transportation requirements imposed by floor space availability. With n_{ij} items to be moved, an improved estimate of the number of chalks required from a floor space perspective $N_{j,\,\text{floor space}}$ is given by

$$N_{j,\,\text{floor space}} = \sum_{i=1}^{C} \frac{n_{ij}}{m_{ij}}. \tag{9}$$

Replacing the $\frac{F_j}{A_j}$ term in (3) with the relation above yields an alternative estimate $\tilde{N}_j$ given by

$$\tilde{N}_j = \max\left(\sum_{i=1}^{C} \frac{n_{ij}}{m_{ij}},\ \frac{M_j}{\text{MPL}_j} \right). \tag{10}$$

2.3.1 Alternative estimate for the simple data set

Returning to the manifest presented in Table 2, we begin by computing the m_{ij} for each of the item types given that they are to be transported by IL 76 TD aircraft. For example, in the case of the 20ft sea containers, we find

$$\begin{aligned} m_{ij} &= \left\lfloor \frac{L_j - d}{l_i + d} \right\rfloor \times \left\lfloor \frac{W_j - d}{w_i + d} \right\rfloor \\ &= \left\lfloor \frac{19.85\text{m}}{6.25\text{m}} \right\rfloor \times \left\lfloor \frac{3.25\text{m}}{2.55\text{m}} \right\rfloor \\ &= \lfloor 3.176 \rfloor \times \lfloor 1.275 \rfloor \\ &= 3, \end{aligned} \tag{11}$$

in agreement with previous movement planner experience [5]. The corresponding results for the other item types in Table 2 are presented in Table 3.

Table 3: *The maximum number of items of a given type that can be transported on a single IL 76 TD chalk.*

Item Type	m_{ij}
20ft ISO Shipping Container	3
LSVW with Engine Repair SEV	3
LSVW with IRIS Repair SEV	3
Trailer, 850kg, M102 Cdn	5

With these results in hand, we may now compute our alternative estimate of the number of IL 76 TD chalks required to move the manifest of items in Table 2. Note that in the calculation that follows, we have suppressed the cargo weight constraint, as we have determined in the previous discussion that it is non-binding for the data set currently under consideration. We find

$$\begin{aligned}\tilde{N}_j &= \sum_{i=1}^{4} \frac{n_{ij}}{m_{ij}} \\ &= 100 + \tfrac{1}{3} + \tfrac{1}{3} + \tfrac{1}{5} \\ &= 100.8667, \end{aligned} \tag{12}$$

which agrees with our earlier estimate of 101 chalks based on movement planner expertise [5].

2.3.2 Accommodating rotatable items

In the preceding discussion, we have assumed that all items have a single preferred orientation. While for vehicles this is most certainly the case, items such as air freight pallets or other small bulk freight objects can be loaded in a number of possible orientations. For simplicity, we shall only consider two possible orientations, namely those with the item's length aligned either parallel with or perpendicular to the longitudinal axis of the cargo bay. Given these two orientations, our expression for m_{ij} given above at (7) must be now rewritten as follows:

$$m_{ij} = \max\left(\left\lfloor \frac{L_j - d}{l_i + d} \right\rfloor \times \left\lfloor \frac{W_j - d}{w_i + d} \right\rfloor, \left\lfloor \frac{L_j - d}{w_i + d} \right\rfloor \times \left\lfloor \frac{W_j - d}{l_i + d} \right\rfloor \right). \tag{13}$$

The above expression considers the maximum number of items of type i that may be loaded into an asset of type j with homogeneous use of either of the two allowed orientations, then selects the more efficient of the two possible solutions.

Unfortunately, when items are rotatable the most efficient packing pattern frequently involves a hybrid of the two (or more) possible orientations. Figure 1 illustrates three possible packing arrangements of 4×3 boxes in a 21×7 container using minimum inter-item spacing $d = 0$. The homogeneous configurations presented in Figure 1a and Figure 1b are both considered by the estimator presented in (13) above, which will return $m_{ij} = 10$, corresponding to the configuration illustrated in Figure 1b. However, through use of a combination of the two orientations, such as the square lattice arrangement shown in Figure 1c, maximally efficient packing solutions with $m_{ij} = 12$ can be obtained.[4]

The problem of determining the optimal packing pattern is in general both strongly dependent on the relative dimensions of the item and the container and computationally intensive, which precludes encapsulating a more sophisticated estimate in a simple closed form result. For the time being we shall use the result of (13), noting that by construction it will lead to conservative transportation requirement estimates.

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[4] With the item and container dimensions specified, it is impossible to pack 13 items into the given area.

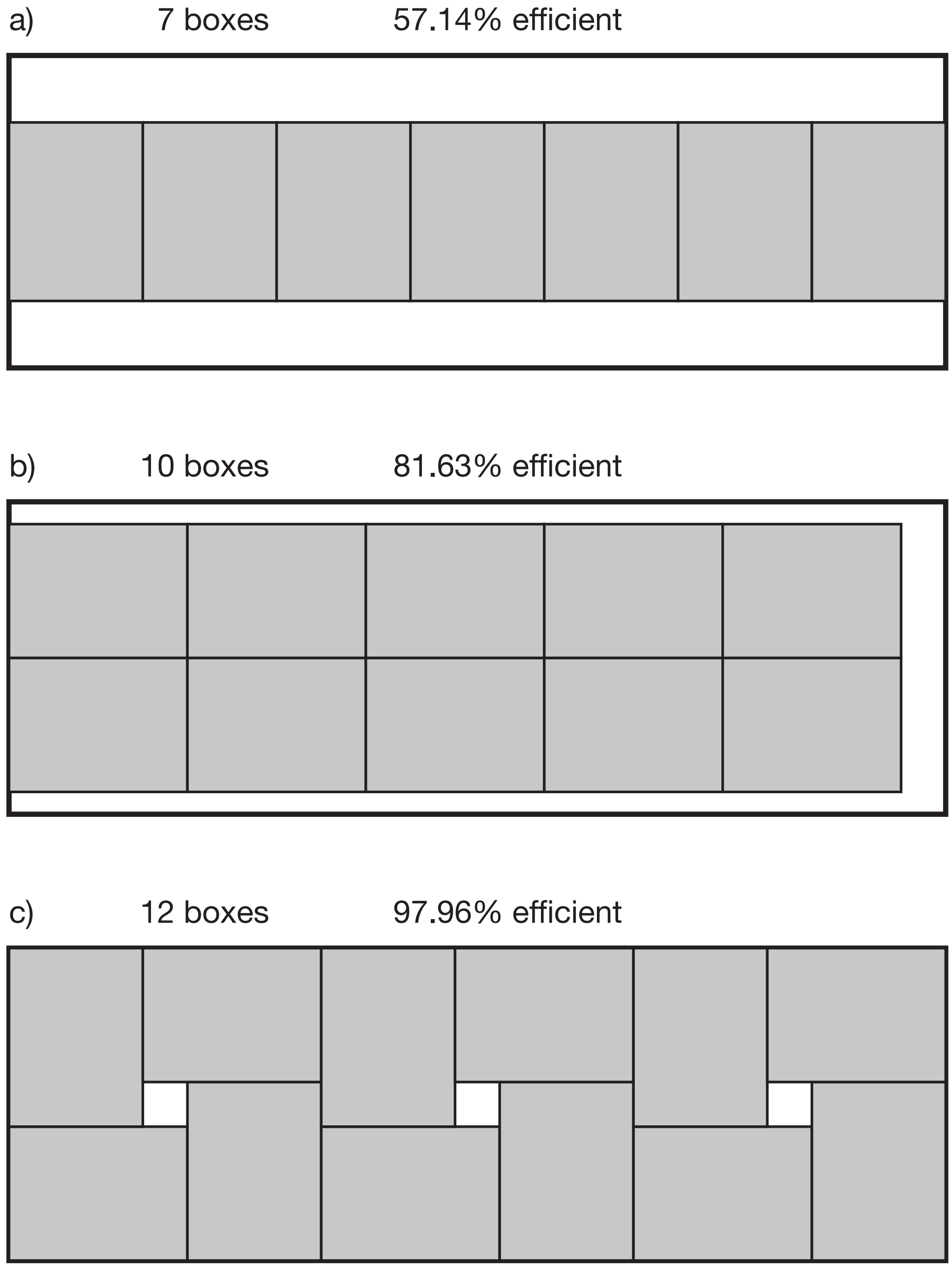

Figure 1: *The effect of rotatable objects on packing efficiency.*

2.4 Discussion

The transportation requirement estimate generated by ADAMS is ultimately a feasibility constraint, giving the absolute minimum number of chalks that would be required in the limit of floor space utilization approaching 100%. For this reason, the ADAMS DPM estimate should be thought of as providing a lower bound on the true movement requirements. While the DPM estimator does allow the user to specify a global footprint inflation factor in order to represent more realistic packing efficiencies, the choice of appropriate factor will be strongly dependent on the makeup of the individual item manifests and therefore difficult to specify *a priori*.

As the alternative estimation technique proposed above takes additional geometrical information into account, it yields an exact estimate of the number of chalks required from both floor space and cargo weight perspectives in the simple case of a single item type with only one allowable orientation. However, as noted above, the extra degree of freedom introduced by rotatable items is not handled by the alternate estimator, which leads to conservative estimates. In addition, as the number of item types increases, the estimator will also begin to overestimate the required number of chalks due to the manner in which it enforces the floor space constraint. Since the estimator considers the requirements at the level of individual item types, it is precluded from considering more efficient loading solutions that could result from the combination of several types of items.

As an example of this effect, consider the following packing problem: eight 12×5 and twelve 10×7 boxes are to be loaded into 54×14 containers using minimum inter-item spacing $d = 0$. The alternative estimator presented in (10) will return an estimated requirement of $2\frac{1}{5}$ containers, which corresponds to the loading solution illustrated in Figure 2a. For each of the item types separately, the loading solutions generated are optimal; however, the heuristic is unable to consider mixed configurations of item types and is therefore incapable of finding the optimal solution shown in Figure 2b.

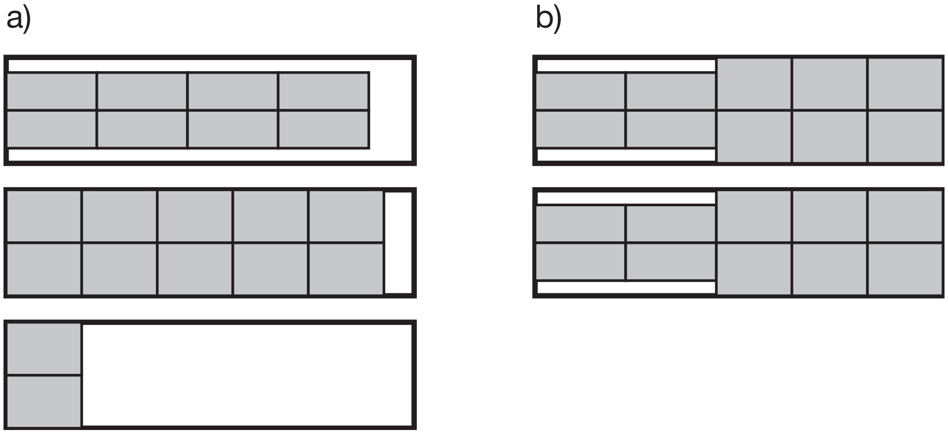

Figure 2: *An illustration of the increased packing efficiencies afforded by allowing mixtures of item types to be loaded in a single container.*

Depending on the particular situation, both estimators provide varying degrees of accuracy in their estimates. The ADAMS DPM estimator will be most accurate in cases where the packing efficiency attained approaches 100%. Such high efficiency is most likely to be attained on manifests with large numbers of rotatable items and/or items whose dimensions are small compared to the dimensions of the cargo bay. Conversely, the alternative estimator of this paper will tend to perform best on manifests containing large numbers of items whose dimensions are on the same order of magnitude as the asset cargo bays.

Used in conjunction, both estimation techniques provide useful information as to the number of chalks required to move a given item manifest; by construction the ADAMS DPM estimator and the alternate estimator of this paper provide lower and upper bounds on the transportation requirements, respectively, with the set of optimal loading solutions situated between the two estimates.

2.5 Further reading

It should be stressed that the two estimators presented in this section sacrifice accuracy for simplicity; indeed, both techniques can be quickly implemented in tools as rudimentary as Excel spreadsheets. The study of two-dimensional bin-packing and cutting-stock problems has generated a rich and extensive literature, with works by Dyckhoff and Finke [6], Dowsland and Dowsland [7], and Lodi *et al.* [8] serving as excellent reviews.

Since the general two-dimensional bin-packing problem is NP-hard[5], the study of high performance upper and lower bounds on the number of bins required is of particular importance, as in general one can only prove a given solution is optimal by demonstrating that the lower and upper bounds coincide.

While the solutions generated by any bin-packing heuristic provide upper bounds on the number of bins required, Chung *et al.* [9] provides a method of generating upper bounds with asymptotic worst-case performance guarantee. Some of the more notable work on improved lower bounds includes that of Martello and Vigo [10].

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[5] In computational complexity theory, a Non-deterministic Polynomial-hard (NP-hard) problem is a member of a difficult class of problems for which no algorithm has been found that will solve the problem in polynomial time.

3 Comparison using an Operation ATHENA-like dataset

In this section, we will compare the estimates generated by the ADAMS DPM estimation methodology, by the alternative estimation approach proposed in the previous section, and by the GALAHAD software on a data set based on the number and types of vehicles and shipping containers that had to be lifted during the deployment phase of Operation ATHENA. We will also discuss some of the limitations imposed on this analysis by the various assumptions made to simplify the problem.

3.1 Comparison

The manifest of equipment and supplies deployed on Operation ATHENA consisted of 350 vehicles and 300 twenty foot ISO containers containing assorted supplies and small pieces of equipment. The dimensions and weights of these items that will be utilized in this study are presented in Annex A, along with a discussion of the differences between the actual Operation ATHENA manifest and the manifest used in this study. For the purposes of this comparison, we will assume a minimum inter-item spacing of about six inches $(d = 0.15\text{m})$ and that both aircraft may be used to their maximum rated payload.

As the Operation ATHENA move was accomplished using a combination of AN 124 and IL 76 TD chalks, one must specify which items in the manifest are to be moved by each asset type before a transportation requirement estimate can be formulated. Determining the optimal allocation of cargo to asset type is unfortunately a difficult problem; indeed, it was precisely for this reason that development of the GALAHAD software package was undertaken.

To avoid this difficulty, we consider only the two extreme cases, corresponding to the minimal and maximal use of AN 124 transportation assets. Examination of the manifest presented at Annex A reveals that while all items can be transported by AN 124, there are 37 items which cannot be moved by IL 76 TD due to their height. These outsize items are listed in Table 4.

Starting with the case where AN 124s are only used to move the outsize cargo, we determine that the weight of the outsize cargo proves to be the binding constraint, so both the ADAMS DPM and the alternate estimators provided above return identical estimates for the number of AN 124s required to move the outsize cargo, namely $N_{\text{AN 124}} = \tilde{N}_{\text{AN 124}} = 7.223$. However the two estimators, while agreeing that the availability of floor space is the binding constraint, return different results for the number of IL 76 TD required to move the remaining 613 items, with the ADAMS DPM estimating $N_{\text{IL 76 TD}} = 129.062$ and the alternate estimator giving $\tilde{N}_{\text{IL 76 TD}} = 203.525$.

For the case where all cargo is moved by AN 124, the estimators disagree not only on the number of chalks required, but also on the issue of which constraint is binding on the loading. The ADAMS DPM estimator finds that weight is still the binding constraint

Table 4: *Outsize items on the Operation ATHENA manifest*

			Dimensions (m)			
ECC	Nomenclature	Number	Length	Width	Height	Mass (kg)
124443	MLVW Gun Tractor	2	7.09	2.49	3.429	8462
126807	HLVW	7	9.18	2.55	3.65	22423
126808	HLVW w/Winch	1	9.18	2.55	3.65	22676
126811	HLVW Tractor	2	8.2	2.43	3.65	25650
126815	HLVW w/PLS	2	9.34	3.48	4.13	22000
126816	HLVW HMRT	3	9.15	2.55	3.55	23298
126819	HLVW Tanker	2	10.11	2.55	3.65	22970
126820	HLVW Bin Storage	1	9.18	2.55	3.65	14400
126822	HLVW MHC w/Fuel Pod	3	9.18	2.55	3.65	22575
126827	HLVW Refueller	4	9.18	2.55	3.65	22970
126923	HLVW w/PLS & Armour	6	9.22	2.79	3.78	32920
147106	Truck, 15tn, w/PLS	1	10.01	2.44	3.4	29520
162805	Industrial Tractor/Forklift	1	9.55	3	3.35	27150
166237	Road Grader	1	8.4	2.5	3.34	13680
166791	Dump Truck/Snow Plow	1	14.9	3.2	3.53	17219

when the entire manifest is moved by AN 124, with a requirement estimated at $N_{\text{AN 124}} = 40.817$. The alternate estimator, on the other hand, determines that the footprint constraint is binding, and estimates $\tilde{N}_{\text{AN 124}} = 50.290$ chalks will be required.

With the results for these two cases in hand, we can now approximate the constraint surface generated by each method by linearly interpolating between the two endpoints for each integer number of AN 124 chalks and rounding up to the nearest integer. The constraint lines generated in this manner for the ADAMS DPM and the alternate estimator of this paper are shown in Figure 3 as red and green lines, respectively. The black line in Figure 3 represents the constraint surface consisting of the non-dominated loading solutions generated by the GALAHAD software package after 1000 generations of evolution on the Operation ATHENA-like dataset of Annex A.

Figure 3 illustrates that the ADAMS DPM and the alternate estimator act as lower and upper bounds on the actual number of chalks required to move the manifest of equipment as anticipated. The solution set generated by GALAHAD has significantly more substructure than our simplistic linear interpolation between the two endpoints, with the transition between the weight-constrained and footprint-constrained regions clearly evident as a gradual change in the slope of the constraint surface. The lack of substructure in the surfaces returned by the two estimators is not evidence of a problem with the estimators *per se*, but rather of our inability to determine reasonable *a priori* allocations of the various items on the manifest to particular asset types.

For the two extreme cases considered, we may determine the relative difference between the estimates generated and the corresponding optimal loading solution. In each of these comparisons, the number of chalks of one asset remains fixed while the number of chalks

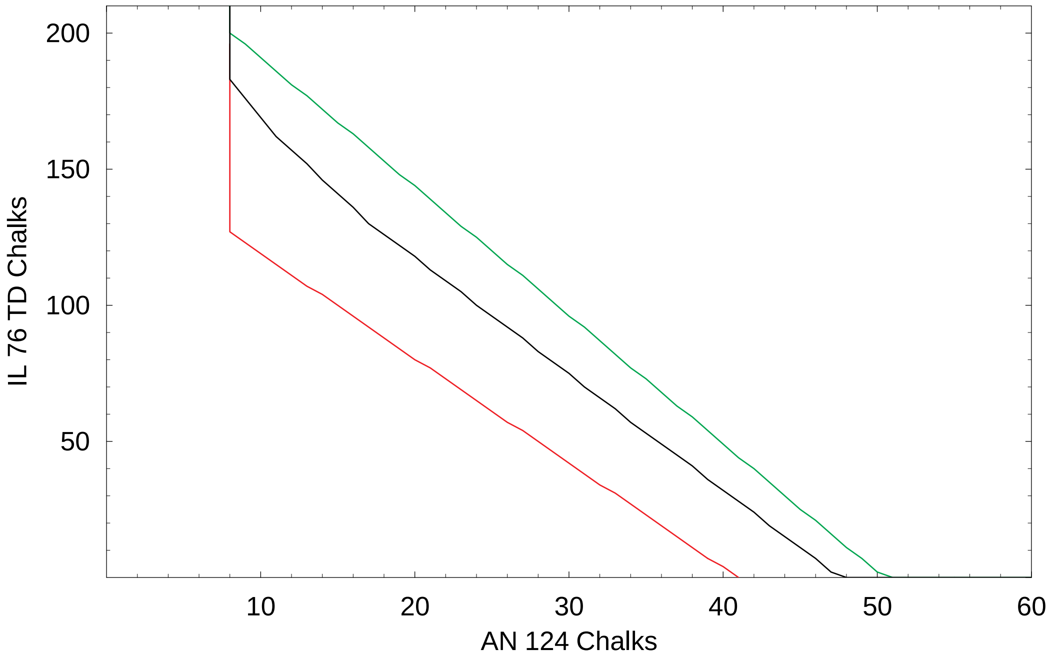

Figure 3: *The transportation requirements estimated by ADAMS (red), the new method proposed in this paper (green) and the optimal solution set provided by* GALAHAD *(black).*

required from the other asset displays considerable variation between estimates. The results of this comparison are tabulated in Table 5. Both Figure 3 and Table 5 suggest that the alternative estimator proposed in this paper tends to be more accurate than the estimator currently provided in the ADAMS DPM for manifests comparable to those used in actual CF deployments, with a tendency to overestimate the actual requirements by around five to ten percent.

Table 5: *Comparison of the difference between the two estimators and the optimal solution for the two extreme cases.*

		Chalks		
Case	Estimator	AN 124	IL 76 TD	Difference
1	Alternative	8	200	+9.3%
	GALAHAD	8	183	
	ADAMS DPM	8	127	−30.6%
2	Alternative	51	0	+6.3%
	GALAHAD	48	0	
	ADAMS DPM	41	0	−14.6%

3.2 Limitations of this analysis

The results obtained in this study using the Operation ATHENA-like dataset presented in Annex A, while generally suggestive as to the actual requirements for movement of the manifest of equipment and supplies, should not be used to judge the optimality of the Operation ATHENA move itself. This study has made no attempt to impose the constraints on aircraft payload, minimum inter-item spacing, or cargo priorities and availabilities that were in effect at the time of the ATHENA deployment, nor has it sought to use the exact weights and dimensions collected for each of the 650 items at the time of loading. Instead, it has simply used an “artificial but realistic” dataset to allow for direct comparisons between three different methodologies for determining the transportation requirements for a specified manifest.

Moreover, in addition to the issues raised above, all three techniques have neglected several factors that will impact the nature of the optimal solution in real world aircraft loading problems. The impact of such factors as load balance, floor strength, cargo tie-down and security, cargo bay shape and dimensions, and cargo compatibility on each of the three estimators is discussed in greater detail in the subsections that follow.

3.2.1 Load balancing

While the ADAMS DPM estimator, the alternative estimator proposed in this paper, and the GALAHAD software package all respect the volume and weight constraints of the individual aircraft, none of the three methods consider the constraints imposed by requiring that each individual aircraft load must be balanced to within a specified tolerances. In order to preserve the aerodynamics of the aircraft and allow for safe flight, the centre of gravity of the cargo must in general be located inside an “envelope” whose size and shape depends on the total weight of the particular load.

Experience with the loading solutions generated by GALAHAD indicates that between 90% and 95% of the individual aircraft load plans can be reconfigured such that the centre of gravity of the load falls within the appropriate envelope. The percentage of loads that can be balanced also appears to be weakly sensitive to the minimum inter-item spacing specified; the extra empty space provided allows for increased flexibility in rearranging items, leading to a larger proportion of loads that can be balanced. Regardless, the number of chalks currently calculated by GALAHAD will likely need to be slightly increased to account for the additional constraint imposed by load balancing.

Although the alternative estimator does not directly consider load balance constraints, the method used to estimate the footprint requirement assumes homogenous, symmetrical combinations of items, which should lead to loading configurations that are easier to balance than the generally random assortment of items appearing in the GALAHAD loading solutions. For this reason, the estimate generated by this alternate method is likely to be fairly robust against changes imposed by load balance constraints.

3.2.2 Floor strength constraints

Another constraint currently omitted from all three calculations is that imposed by the strength of the cargo bay floor. Different regions of the cargo bay floor are able to support different weights, restricting the number of locations where the heavier items on the manifest can be placed within the cargo bay. For particularly heavy items, shoring may be necessary to provide a means of distributing the weight of the item over a large enough area of floor space—with corresponding impact on the effective height and minimum inter-item spacing that must be applied to the item.

Of the three models, ADAMS appears to be the most developed in this regard. While the simple DPM estimator does not take floor-strength issues into account, ADAMS does include information about the rated floor strength for the individual aircraft cargo bays; however, the information is currently represented as a global floor strength, as opposed to a more accurate representation of the variation of the floor strength throughout the bay. Moreover, the vehicle data structure currently utilized by ADAMS does not include the positions of the axles and the corresponding axle loads, rendering it impossible to check whether a particular vehicle loading configuration satisfies the appropriate floor strength constraints.

The floor strength constraint is most likely to cause minor changes to the slope of the minimum constraint surface as heavier cargo items must be allocated to assets with sufficient floor strength to support them. For the particular case of the Operation ATHENA move, the floor strength constraints may lead to a requirement of more than eight AN 124 chalks.

3.2.3 Tie-down constraints

All items transported by air must be properly secured within the aircraft cargo bays to prevent the cargo from shifting in flight. There are only a finite number of permissible tie-down points (usually distributed in a regular grid) available throughout the aircraft cargo bay; similarly, there are a limited number of locations on each vehicle to which tie down chains may be safely attached. This constraint could significantly reduce the degree of freedom available in the placement of various vehicles within the cargo bay.

None of the three estimation methods currently consider this constraint, nor do their architectures offer any means of easily implementing this constraint in the future. However, observing the sensitivity of their estimates to the minimum inter-item spacing should afford some insight into the impact of this constraint on the transportation requirements—increasing the empty space surrounding each item should lead to solutions with fewer potential tie-down conflicts between items.

Given that we have already observed that increasing the minimum inter-item spacing in the GALAHAD program leads to loading solutions that are more easily balanced, it appears likely that the impact of the load balance and tie-down constraints will be correlated to a large extent—once a GALAHAD estimate has been appropriately inflated to account for balanced loading, only minimal additional correction to account for cargo tie-downs should be required.

On the other hand, the alternate estimator of this paper, while appearing to be relatively robust against load balance constraints, will likely be more sensitive to tie-down constraints. Depending on the dimensions of individual item types relative to the dimensions of the cargo bay, the load plans upon which the estimate is based can sometimes require very tight packing of cargo. As stated above, observing the sensitivity of the estimate to small variations in the inter-item spacing will be the only way to judge the likely impact of tie-down constraints on the alternate estimator proposed in this paper.

3.2.4 Cargo bay shape and dimensions

All three methods make the assumption that aircraft cargo bays take the form of rectangular prisms with the given dimensions.[6] In the case of the AN 124 in particular, this assumption fails as illustrated in Figure 4. While the cargo bay floor is indeed 6.4 metres wide, the shape of the fuselage restricts the usable height near the outer edges of the cargo bay. The maximum height of 4.4 metres is only attainable over a span of approximately four metres in

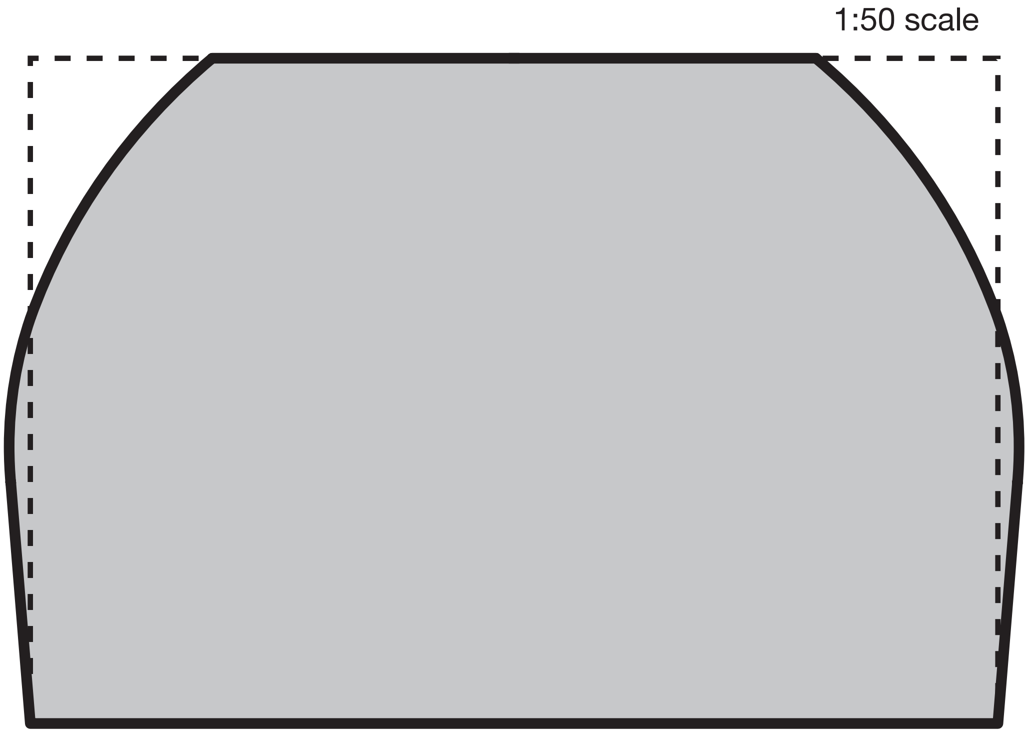

Figure 4: *The actual cross-section of an AN 124 (shaded area) compared to the ADAMS and* GALAHAD *models (dotted lines).*

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[6] Indeed, all cargo items are also assumed to take the form of rectangular prisms.

the middle of bay [11]. The usable height is further constrained by the existence of the load handling cranes that run along rails built in to the roof of the bay. These height restrictions imposed by the shape of cargo bay have major implications on the side by side loading of large cargo such as the Heavy Logistics Vehicle Wheeled (HLVW)—a configuration that currently appears in some of the loading solutions proposed by GALAHAD. While this is unlikely to be a major concern for the ATHENA-like scenario of this paper as the total cargo weight is the binding constraint for the majority of the constraint surface, the precise shapes of items and cargo bays will likely have subtle effects on the optimal solutions, potentially requiring one or two additional chalks on large movements.

In addition, the cargo bay dimensions given in Table 1 above have included the ramp in the overall bay length. While cargo can be indeed be loaded on the ramp, there are stringent floor strength, tie-down, and configuration constraints that must be respected. As discussed above, none of the three techniques apply these constraints in their calculations; however, much as for the load balance and tie-down constraints discussed above, increasing the minimum inter-item spacing used in the calculations will reduce the total amount of cargo allocated to each aircraft, thereby affording greater flexibility in the number of layouts that can be accommodated and increasing the likelihood that the loading solutions can be configured to meet the ramp-specific loading constraints.

3.2.5 Cargo compatibility

Certain types and/or amounts of cargo cannot be simultaneously loaded into the same aircraft. Ammunition is a particularly good example—there are restrictions on both the total net explosive quantity (NEQ) that can be transported on a single chalk and on the types of ammunition that can be transported simultaneously.[7] Similar constraints apply to other dangerous goods that must be transported by air.

Fifty-one of the sea containers used in the Operation ATHENA move contained dangerous goods. Given that this comprises only around a sixth of the total number of containers and less than eight percent of the total cargo moved, it is unlikely that additional chalks would be required to satisfy the cargo compatibility constraints, although the composition of individual chalks within the overall loading solution could change significantly. In cases where dangerous goods comprise a large percentage of the manifest, this constraint could lead to a significant increase in the number of chalks required. Unlike the other constraints considered above, the impact of this constraint cannot be easily estimated via sensitivity analysis on the input parameters for any of the three methodologies considered in this section.

3.3 Discussion

In the absence of the constraints discussed above, both the ADAMS DPM estimator and the alternative estimator of this paper furnish useful information by quickly providing move-

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[7] Some types of ammunition can be transported on the same chalk, but must be located more than a certain distance from one another, imposing yet another constraint on acceptable loading solutions.

ment planners with lower and upper bounds, respectively, on the number of chalks required to move a specified manifest of equipment and supplies. In presence of these loading constraints, the ADAMS DPM estimator continues to act as a lower bound on the actual requirements, but the solutions generated by GALAHAD after a sufficiently large number of generations should provide a tighter, albeit approximate, lower bound on the actual requirements. In addition, under loading constraints the alternate estimator of this paper ceases to function as an upper bound on the transportation requirements; however, given that its estimates only tend to be five to ten percent in excess of the GALAHAD solutions, an order of magnitude comparable to the expected impact of the loading constraints on the transportation requirements, the alternative estimator proposed in this paper should provide movement planners with a realistic "first-order approximation" to the actual range of movement solutions. Given the simplicity of the alternate estimator, it could be particularly well-suited for use in quick staff checks and early option exploration prior to more detailed (and time-consuming) analysis with more sophisticated tools such as GALAHAD, the ADAMS General Deployment Module (GDM), or the ADAMS Deployment Planning Module[8].

The attentive reader may have noticed an apparent inconsistency arising from our contention that the ADAMS DPM estimate provides a lower bound on the actual transportation requirements—after all, as mentioned in the introduction, the GALAHAD loading solutions for the datasets from Operations APOLLO, STRUCTURE, and HALO were observed to outperform those generated by previous DMGOR deployment lift studies [1–3] using the ADAMS DPM transportation requirement estimator. However, the discrepancy is explained by further examination of the precise methodology used in these lift studies.

Recognizing that ADAMS did not fully capture all the loading constraints discussed above, the previous DMGOR lift studies used the actual (non-optimal) movement solutions to calibrate the ADAMS DPM estimator [12] through adjustments to the aircraft payloads, inter-item spacings, and volume inflation factors intended to restrict the amount of cargo loaded on individual chalks. In this manner, it was hoped to generate estimates that approximated the impact of constraints in place at the time of the operations under consideration—at least in the immediate neighbourhood of the actual movement solution implemented. Since the transportation requirements presented in these DMGOR lift studies [1–3] were obtained using this "crippled" ADAMS DPM estimator, it is not altogether unsurprising that these loading solutions are outperformed by the unconstrained near-optimal solutions returned by GALAHAD.

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[8] The DPM itself, as opposed to the DPM estimator, allows the user to manually allocate specific cargo items to individual aircraft and incorporates more sophisticated load configuration checking.

4 Conclusions

Motivated by the observation of questionable transportation requirement estimates generated by the ADAMS DPM module for certain manifests of equipment, this report has examined the methodology behind the ADAMS estimates, developed an alternate methodology, and compared the performance of these two techniques to the near-optimal solution set returned by GALAHAD on an Operation ATHENA-like dataset. A summary of the principal findings and recommendations of this report is presented below.

4.1 Summary of findings

The ADAMS DPM estimator computes the total footprint and weight of the manifest to be moved and compares this with the available floor space and maximum payloads of individual aircraft to determine the absolute minimum number of chalks required to transport the designated equipment; as such, it provides the trivial lower bound on the transportation requirements for any given manifest. The ADAMS estimator will be most accurate when the manifest of items contains a large proportion of rotatable items and/or items with dimensions that are small relative to the dimensions of the aircraft cargo bay, thereby lending itself to packing efficiencies approaching 100%.

Conversely, the alternative estimator proposed in this paper, through consideration of additional geometrical information, ensures that the estimates it generates correspond to feasible aircraft loading plans from the perspective of floor space and weight. However, the solutions generated in this manner are in general sub-optimal and therefore provide an upper bound on the number of chalks required to moved the specified equipment. The estimates generated by the alternative estimator tend to be most accurate when the manifest of items to be moved consists of a large proportion of non-rotatable items whose dimensions are comparable to the size of the aircraft cargo bays.

Both estimation techniques were used to generate approximate transportation requirement constraint surfaces for an Operation ATHENA-like manifest of equipment and supplies. The results obtained using these two estimators were then compared with the near-optimal loading solutions generated by GALAHAD on the same dataset. The GALAHAD solution fell between the surfaces generated by the other two techniques as expected. Relative to the near-optimal solutions generated by GALAHAD, the alternative estimator proposed in this paper generated transportation requirement estimates that were high by around five to ten percent, while the ADAMS DPM module underestimated the actual requirements by fifteen to thirty percent.

All three methods of estimating transportation requirements have neglected constraints such as load balance, floor strength, cargo tie-down and security, cargo bay shape, and cargo compatibility that affect real-world aircraft loading problems. In general, as cargo is packed ever more tightly within a given aircraft, these additional constraints gain importance. Some insight into the sensitivity of the estimates to these constraints can consequently be gained through adjustment of the minimum inter-item spacing or other parameters that restrict the total amount of cargo loaded into each aircraft; indeed, this is the approach that has been taken to date in other DMGOR studies.

In light of these additional constraints, the GALAHAD solutions may be thought of as providing a tighter, but approximate, lower bound than the ADAMS DPM estimates on the number of chalks required to transport a given manifest of equipment. Similarly, the alternative estimator proposed in this paper, while slightly conservative in the unconstrained case, is likely to represent a fairly accurate estimate of transportation requirements for the constrained loading problem. This fact, coupled with its relative computational simplicity, suggests that the alternative estimator is well-suited to rapid staff checks and exploratory analysis prior to conducting more detailed and time consuming analysis with more sophisticated movements planning tools such as GALAHAD, the ADAMS DPM, or the ADAMS GDM.

4.2 Recommendations

At the time of the previous DMGOR lift studies [1–3], ADAMS was the only tool available for lift analysis. Use of ADAMS as the primary analysis tool imposed some limitations on the detail and accuracy of the transportation requirements generated. As the introduction and ongoing development of the GALAHAD software package now allows for more sophisticated analysis of deployment lift solutions, it is recommended that the deployment lift studies conducted for Operations ATHENA, APOLLO, STRUCTURE, and HALO be revisited with the GALAHAD program.

The reexamination of these studies with GALAHAD would allow for more accurate determination of the optimal movement solutions under the constraints existing at the time of the respective movements. If any significant differences are discovered, some of the findings and recommendations of the previous studies could require amendment. The revisit should also conduct detailed sensitivity analysis should also be conducted on such input parameters as the inter-item spacing and the maximum allowable aircraft payload in order to determine the driving factors for real-world CF airlift requirements and to provide insight into the potential impact of additional aircraft loading constraints not currently considered by the model.

Given the low computational overhead associated with the alternative estimator of this paper, inquiries should be made to NC3A as to the possibility of including the alternative estimator of this paper within the ADAMS DPM module, thereby providing ADAMS users with both lower and upper bounds on the actual transportation requirements.

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Annex A
The Operation ATHENA dataset

Section 3 compared the results of two different transportation requirement estimation methodologies on an Operation ATHENA-like dataset. In this annex, Table A.1 presents the complete list of items, with corresponding dimensions and masses.

While the equipment manifest consists of the same numbers and types of equipment as that tabulated in [1], it is strictly speaking only an “ATHENA-like” data set, in that the exact dimensions and weight of each individual vehicle or container were not available to the author while the study was ongoing. The data set used in this paper consequently assumes that all vehicles within a given ECC have identical dimensions and mass. While this is likely a good approximation in the case of dimensions, there will likely be considerable variation in the masses of vehicles within the same ECC, as the available space within vehicles is generally used to various degrees to hold assorted small freight items. Likewise, the container weights are strongly dependent on the types of freight loaded within them—ammunition tends to weigh substantially more than clothing stores, for example.

The dimension and mass data provided at Table A.1 was extracted from the Fleet Management System (FMS) via the Defence Total Asset Visibility (DTAV) interface [13]. For the purposes of this comparison, the gross weights[9] of the vehicles (i.e., including standard equipment and a full cargo load) were used, as this allows for worst-case scenario planning in terms of the total weight that must be moved.

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[9] Technically, these are masses, as they are given in kilograms instead of Newtons or pounds.

Table A.1: *The Operation ATHENA equipment manifest.*

ECC	Nomenclature	Number	Dimensions (m)			Mass (kg)
			Length	Width	Height	
109507	TRUCK, LIFT, FORK, BOOM TYPE, MATERIAL HANDLER, DED, ROUGH TERRAIN, AIR TRANSPORTABLE, MILITARY PATTERN, 9000 LB CAPACITY	5	5.08	2.54	2.54	12510
112304	CAR, ARMOURED, INFANTRY SECTION CARRIER, WHEELED, 8X8, DIESEL, BISON	12	6.48	2.59	2.44	12909
112306	CAR, ARMOURED, MOBILE REPAIR TEAM, WHEELED, 8X8, DIESEL, BISON	3	7.277	2.858	3.06	13538
112307	LIGHT ARMOURED VEHICLE, WITH MAST MOUNTED SURVEILLANCE SENSORS, BRIGADE VARIANT, W/E APCL L-30-601-000/LC-000, COYOTE	4	6.45	2.66	2.69	14890
112308	LIGHT ARMOURED VEHICLE, WITH GROUND MOUNTED SURVEILLANCE PACKAGE, (GRD), W/E APCL L30-602-000/LC-000, COYOTE	4	6.45	2.66	2.69	14890
112309	CAR, ARMD, AMBULANCE, WHLED, 8X8, DIESEL, BISON	5	6.706	2.858	2.935	12450
112310	CAR, ARMD. CP, WHLED, 8X8, DIESEL, BISON	3	6.48	2.59	2.67	13000
112311	LIGHT ARMOURED VEHICLE, (COMMAND), W/E APCL L-30-303/LC-000, COYOTE	3	6.45	2.66	2.69	14890
112401	LIGHT ARMOURED VEHICLE (LAV III), ARMOURED PERSONNEL CARRIER, DESIGNATED AS INFANTRY SECTION CARRIER (ISC), 8X8, DIESEL, AS PER CHECK LIST L-30-560-000/LC-000	14	6.98	2.7	2.63	16896
112402	LIGHT ARMOURED VEHICLE (LAV III), ARMOURED PERSONNEL CARRIER, DESIGNATED AS COMMAND POST VARIANT A, 8X8, DIESEL, AS PER CHECK LIST L-30-560-000/LC-000	6	6.98	2.7	2.63	16896

Table A.1: *The Operation ATHENA equipment manifest (cont'd).*

ECC	Nomenclature	Number	Dimensions (m)			Mass (kg)
			Length	Width	Height	
114230	CARRIER, PERSONNEL, FULL TRKD, ARMD, AMPH, M113A2CDN, W/EXTERNAL FUEL TANKS	3	5.32	2.68	2.22	11750
121501	TRUCK, UTILITY, LIGHT, 4X4, MIL DESIGN, ILTIS CDN BASIC	82	3.982	1.52	1.837	2550
121511	TRUCK, TOW SYSTEM LAUNCHER, LIGHT, 4X4, MIL DESIGN, ILTIS CDN.	3	3.982	1.85	1.837	2680
121512	TRUCK, TOW MISSILE CARRIER, LIGHT, 4X4, MIL DESIGN, ILTIS CDN	1	3.982	1.85	1.837	2680
121519	TRUCK UTILITY LIGHT 4X4 MILITARY DESIGN ILTIS CANADIAN WITH TAIL GATE	5	3.982	1.52	1.837	2550
121527	TRUCK UTILITY, LIGHT, 4X4, MILITARY DESIGN, ILTIS CANADIAN, W/MILITARY POLICE KIT	7	3.982	1.85	1.83	2550
123120	TRUCK, CARGO, 1.5 TONNE, 4X4, MILITARY DESIGN LSVW, W/TARP AND SUPERSTRUCTURE	1	5.56	2.04	2.69	5250
123121	TRUCK, CARGO, 1.5 TONNE, 4X4, MILITARY DESIGN, LSVW, W/SUPERSTRUCTURE AND TARP AND SECURITY SCREEN	1	5.61	2.04	2.59	5250
123122	TRUCK, CARGO, 1.5 TONNE, 4X4, MILITARY DESIGN LSVW, TROOP CARRIER, W/SUPERSTRUCTURE AND TARP, TROOP SEATS AND PERSONNEL HEATER	6	5.69	2.04	2.59	5250
123123	TRUCK, CARGO, 1.5 TONNE, 4X4, MILITARY DESIGN LSVW, TROOP CARRIER W/TARP AND SUPERSTRUCTURE, TROOP SEATS AND PERSONNEL HEATER AND SECURITY SCREEN	4	5.61	2.04	2.59	5250
123124	TRUCK, CARGO, 1.5 TONNE, 4X4, MILITARY DESIGN LSVW, WELDING SEV, W/TARP AND SUPERSTRUCTURE	1	5.69	2.04	2.59	5250

Table A.1: *The Operation ATHENA equipment manifest (cont'd).*

			Dimensions (m)			
ECC	Nomenclature	Number	Length	Width	Height	Mass (kg)
123125	TRUCK, CARGO, 1.5 TONNE, 4X4, MILITARY DESIGN LSVW, CABLE LAYER SEV, W/WINCH.	2	5.85	2.04	2.69	5250
123126	TRUCK, CARGO, 1.5 TONNE, 4X4, MILITARY DESIGN LSVW, MOBILE REPAIR TEAM SEV, W/SECURITY SCREEN AND W/WINCH	4	5.61	2.04	2.59	5250
123128	TRUCK, CARGO 1.5 TONNE, 4X4, MILITARY DESIGN, LSVW, MODIFIED TO ACCEPT SHELTER S250	1	5.69	2.01	2.7	5250
123133	TRUCK, CARGO, 1.5 TONNE, 4X4, MIL DESIGN, LSVW, MILITARY POLICE W/TARP, TROOP SEATS, PERSONNEL, HEATER AND SECURITY SCREEN	2	5.69	2.01	2.69	5250
123348	TRUCK, VAN, 1.5 TONNE, 4X4, MILITARY DESIGN, LSVW, W/AMBULANCE SEV	3	5.69	2.03	2.99	5250
123349	TRUCK, VAN, 1.5 TONNE, 4X4, MILITARY DESIGN, LSVW, W/SIDE MOUNTED BOARD AND FRONT MOUNTED RADIOS, OPS A.	13	5.69	2.01	2.73	5250
123350	TRUCK, VAN, 1.5 TONNE, 4X4, MILITARY DESIGN, LSVW, W/SIDE MOUNTED BOARD AND RACK MOUNTED RADIOS, OPS B	1	5.61	2.04	2.73	5250
123359	TRUCK, VAN.1.5 TONNE, 4X4, MILITARY DESIGN, LSVW, RADIO STATION A W/SHELF MOUNTED RADIOS	1	5.61	2.13	2.73	5250
123360	TRUCK, VAN.1.5 TONNE, 4X4, MILITARY DESIGN, LSVW, RADIO STATION B W/SHELF MOUNTED RADIOS.	2	5.61	2.13	2.73	5250
123361	TRUCK, VAN.1.5 TONNE, 4X4, MILITARY DESIGN, LSVW, AUTOMOTIVE AND INTERNAL COMBUSTION ENGINE MAINT.	1	5.61	2.01	2.73	5250
123362	TRUCK, VAN.1.5 TONNE, 4X4, MILITARY DESIGN, LSVW, WEAPONS REPAIR, LIGHT	1	5.61	2.01	2.73	5250

Table A.1: *The Operation ATHENA equipment manifest (cont'd).*

			Dimensions (m)			
ECC	Nomenclature	Number	Length	Width	Height	Mass (kg)
123365	TRUCK, VAN.1.5 TONNE, 4X4, MILITARY DESIGN, LSVW, TELEPRINTER REPAIR	1	5.61	2.01	2.73	5250
123372	TRUCK, VAN 1.5 TONNE 4X4 MILITARY DESIGN LSVW ELECTRO MECHANICAL EQUIPMENT REPAIR	3	5.61	2.04	2.73	5250
123379	TRUCK, VAN.1.5 TONNE, 4X4, MILITARY DESIGN, LSVW, ARTILLERY COMMAND POST.	1	5.61	2.01	2.73	5250
123394	TRUCK, VAN, 1.5 TONNE, 4X4, MILITARY DESIGN, LSVW, IRIS LIGHT SYSTEM REPAIR VEHICLE MODEL L289	4	5.61	2.01	2.73	5250
123556	LIGHT ARMOURED VEHICLE, MINE RESISTANT, NYALA	1	6.1	2.25	2.7	8400
124035	TRUCK, CARGO, 2-1/2 TON 6X6, M35CDN, 154 IN WHEELBASE, W/O WINCH	4	7.09	2.49	3.25	8777
124036	TRUCK, CARGO.2-1/2 TON 6X6, M36CDN, 190 IN WHEELBASE, W/O WINCH	1	8.32	2.44	3.25	9292
124037	TRUCK, CARGO, 2-1/2 TON 6X6, M35CDN, 154 IN WHEELBASE, W/O WINCH	1	7.09	2.49	3.25	8777
124039	TRUCK, CARGO.2-1/2 TON, 6X6, M35 CDN, 154 INCH WHEELBASE, W/SIDERACKS, W/SUPERSTRUCTURE AND TARPAULIN W/O WINCH	1	7.09	2.49	3.25	9292
124043	TRUCK, CARGO.2-1/2 TON, 6X6, M35 CDN, 154 INCH WHEELBASE, W/SIDERACKS, W/SUPERSTRUCTURE AND TARPAULIN, W/TROOP SEATS, W/O WINCH	1	7.09	2.49	3.25	9292
124044	TRUCK, CARGO, 2 1/2 TON, 6X6, M35CDN, 154 IN WHEELBASE, W/O WINCH, LAND COMBAT SYSTEMS STORAGE SEV	1	8.249	2.479	2.649	11504

Table A.1: *The Operation ATHENA equipment manifest (cont'd).*

			Dimensions (m)			
ECC	Nomenclature	Number	Length	Width	Height	Mass (kg)
124135	TRUCK, CARGO, 2-1/2 TON, 6X6 M35CDN 154 IN WHEELBASE W/WINCH.	1	7.09	2.49	3.25	8777
124443	TRUCK, CARGO; 2 1/2 TON, 6X6 M35 CDN, 154 INCH WHEELBASE, W/SIDERACKS, W/SUPERSTRUCTURE AND TARPAULIN, W/O WINCH, W/SEV ARTILLERY GUN TRACTOR	2	7.09	2.49	3.429	8462
124445	TRUCK, CARGO; 2 1/2 TON, 6X6 M35 CDN, 154 INCH WHEELBASE, W/SIDERACKS, W/SUPERSTRUCTURE AND TARPAULIN, W/O WINCH, W/SEV KITCHEN RATIONS CANADIAN	2	7.09	2.48	3.24	8645
124448	TRUCK, CARGO.2-1/2 TON, 6X6, M35 CDN, 154 INCH WHEELBASE, W/SIDERACKS, W/SUPERSTRUCTURE AND TARPAULIN, W/TROOP SEATS, W/O WINCH	2	8.249	2.479	2.649	9430
124543	TRUCK, CARGO; 2 1/2 TON, 6X6 M35 CDN, 154 INCH WHEELBASE, W/SIDERACKS, W/SUPERSTRUCTURE AND TARPAULIN, W/WINCH, W/SEV ARTILLERY GUN TRACTOR	2	7.09	2.49	2.65	8104
124545	TRUCK, CARGO; 2 1/2 TON, 6X6 M35 CDN, 154 INCH WHEELBASE, W/SIDERACKS, W/SUPERSTRUCTURE AND TARPAULIN, W/WINCH, W/SEV KITCHEN RATIONS CANADIAN	1	7.09	2.49	2.65	8462
124606	TRUCK, CARGO, FIELD ENGINEERING SECTION 2 1/2 TON 6X6 M36 CDN, 190 INCH WHEELBASE, W/WINCH	2	7.09	2.49	2.29	9630
126807	TRUCK, CARGO, 10 TONNE, 6X6, MILITARY DESIGN, HLVW, CDN	7	9.18	2.55	3.65	22423
126808	TRUCK, CARGO, 10 TONNE, 6X6, MILITARY DESIGN, HLVW, CDN, W/SELF-RECOVERY WINCH	1	9.18	2.55	3.65	22676
126809	TRUCK, CARGO, 10 TONNE, 6X6, MILITARY DESIGN, HLVW, CDN, W/SELF RECOVERY WINCH AND MATERIAL HANDLING CRANE	4	9.18	2.55	3.29	22575

Table A.1: *The Operation ATHENA equipment manifest (cont'd).*

			Dimensions (m)			
ECC	Nomenclature	Number	Length	Width	Height	Mass (kg)
126811	TRUCK, TRACTOR, 10 TONNE, 6X6, MILITARY DESIGN, HLVW, CDN	2	8.2	2.43	3.65	25650
126813	TRUCK, WRECKER, 10 TONNE, 6X6, MILITARY DESIGN, HLVW, CDN, W/EXTENDED FRAME	2	9.449	2.5	3.255	25540
126815	TRUCK, TRANSPORTER, PALLETIZED LOADING SYSTEM, 10 TM, 6X6, MILITARY DESIGN, HLVW, CDN, FOR MEDIUM FLOATING BRIDGE, LAUNCH AND RETRIEVAL, W/WINCH	2	9.34	3.48	4.13	22000
126816	TRUCK, HEAVY MOBILE REPAIR TEAM, 10 TONNE, 6X6, MILITARY DESIGN, HLVW, CDN	3	9.15	2.55	3.55	23298
126819	TRUCK, TANK, WATER, 10 TONNE, 6X6, MILITARY DESIGN, HLVW, CDN, MODEL H818, WITH WATER HEATER AND SELF RECOVERY WINCH	2	10.11	2.55	3.65	22970
126820	TRUCK, CARGO, 10 TONNE, BIN STORAGE AND SECURITY SCREEN, 6X6, MILITARY DESIGN, HLVW, CDN, MODEL H820, WITHOUT SELF RECOVERY WINCH	1	9.18	2.55	3.65	14400
126822	TRUCK, CARGO, WITH MATERIAL HANDLING CRANE, WITH FUEL POD, 10 TONNE, 6X6, HLVW, MODEL H822	3	9.18	2.55	3.65	22575
126827	TRUCK, TANK, LAND VEHICLE REFUELLER, 10TM, 6X6, 7000 LITRE TANK, 650 LITRE PER MINUTE PUMPING UNIT, HLVW, CDN	4	9.18	2.55	3.65	22970
126909	TRUCK, CARGO, 10 TONNE, 6X6, MILITARY DESIGN, HLVW, CDN, W/SELF RECOVERY WINCH, W/MATERIAL HANDLING CRANE, W/ARMOUR CAPABILITY	1	9.18	2.55	3.29	24475

Table A.1: *The Operation ATHENA equipment manifest (cont'd).*

ECC	Nomenclature	Number	Dimensions (m) Length	Width	Height	Mass (kg)
126923	TRUCK, PALLETIZED LOADING SYSTEM, 16 TONNE, 6X6, HLVW, CDN, MODEL H823, W/SELF RECOVERY WINCH, W/SLAVE HYDRAULIC SYSTEM, W/CONTAINER HANDLING UNIT, W/ARMOUR CAPABILITY	6	9.22	2.79	3.78	32920
130109	LAUNDRY UNIT, TRAILER MOUNTED	4	6	2.44	2.16	4077
132501	TRAILER, CARGO. 850 KG (1875 LBS) CAPACITY 2 WH, CDN1, SMP	5	3.68	1.88	2.01	1632
132502	TRAILER CARGO 850 KG 2 WHEEL CDN 1 W/5KW TQG DIESEL GENERATOR MTD AND ITEMS AS PER CHECK LIST L-30-830-001/LC-000	12	4.04	1.98	2.01	1520
132506	TRAILER, CARGO, 850KG, 2WH, SMP, W/SECURITY SCREEN AND WELDING SHOP ARC T16 AND M16, U/W ECC 123124	1	4.04	1.98	2.01	1520
132508	TRAILER, CARGO, 850KG, 2WH, SMP, W/GENERATOR SET DED 5KW AND COMPRESSOR U/W ECC 123361	1	4.04	1.98	2.01	1520
133305	TRAILER, TANK, WATER, 1 1/2 TON, 2 WH, M106A1 CDN2, 330 GB, WINTERIZED WITH GAS OPERATED, WATER HEATER	2	4.22	2.11	1.98	3590
133401	TRAILER, CARGO, 1-1/2 TON, 2-WH, M104 CDN 4	6	4.22	2.11	1.47	2425
133705	KITCHEN, TRAILER MOUNTED, 1-1/2 TON MODIFIED M102 CDN3 MANAC AND M104 CDN4 DEW TRAILER, AS PER CHECK LIST L-90-188-000/LC-000	4	4.58	2.39	2.53	2990
133721	TRAILER, 1 1/2 TON, M104 CDN 4, GEOMATICS SHOP EQUIPMENT, W/10 KW TQG	1	4.14	2.11	2.515	2500
133813	GENERATOR SET 10KW DED 1-1/2 TON M104 CDN3 TLR MTD, W/SECURITY SCREEN	1	4.11	2.11	2.54	2500

Table A.1: *The Operation ATHENA equipment manifest (cont'd).*

			Dimensions (m)			
ECC	Nomenclature	Number	Length	Width	Height	Mass (kg)
133904	TRAILER, CARGO, SMP, 1 1/2 TON M104 CDN4 W/10 KW GENERATOR SET TQG	1	4.19	2.11	2.5	2152
133906	TRAILER CARGO 1.5T 2WHL M104CDN3 W/10 KW TQG MODIFIED FOR RADAR AND UNIT FCS MAINTENANCE	1	4.19	2.11	2.52	2254
134107	GENERATOR SET, DIESEL ENGINE, TRAILER MOUNTED, 30 KW	8	4.191	2.4	2.15	2404
134302	CHASSIS, TRAILER, 2-1/2-TON, 2 WHEEL, M200CDN.	2	4.41	2.41	2.37	3704
137201	TRAILER, PALLETIZED, LOADING SYSTEM, 15 TONNE CAPACITY, 2 AXLE, 4 WHEEL, W/STEERABLE FRONT AXLE	3	8.29	2.59	1.44	20180
140301	ALL TERRAIN VEHICLE, 4 WHEEL, SINGLE PAX	6	2.06	1.16	1.21	267
147106	TRUCK, PALLET LOADING, 15 TON, DED, 6X6, SINGLE WHEELS, COMPLETE WITH PALLETIZED LOADING SYSTEM	1	10.01	2.44	3.4	29520
157106	TRAILER, PALLETIZED LOADING, FULL, 15 TON, WAGON TYPE, C/W PALLETIZED LOADING SYSTEM	3	8.3	2.51	3.2	20000
158122	TRAILER, FLAT BED, BEAVER TAIL, TILT DECK, 30000 LB TANDEM, SPRING SUSPENSION, AIR BRAKES, DUAL SMP/COMMERCIAL LIGHTS	1	6.85	2.43	1.21	22264
161615	CRANE, WHEEL MOUNTED, ALL TERRAIN, DED, HYDRAULIC, 22 TONNES AT 3 M, 360 DEGREE OP.21 M BOOM EXT, 13 M BOOM JIB W/LATTICE EXTENSION AND RECOVERY WINCH.	1	10.03	2.44	3.28	24180
162805	TRACTOR, WHEELED, INDUSTRIAL, HIGH MOBILITY, 4X4, LOADER, ARMOURED CAB, 60 KMH SPEED, 3 CU M 4 IN 1 BUCKET, WINCH, HPTO, TIRE CHAINS, QUICK CONNECT, FORKLIFT ATTACHMENT	1	9.55	3	3.35	27150

Table A.1: *The Operation ATHENA equipment manifest (cont'd).*

			Dimensions (m)			
ECC	Nomenclature	Number	Length	Width	Height	Mass (kg)
166237	GRADER, ROAD, MOTORIZED, 6X6 TDM, 150 NET FLYWHEEL HP, AIR TRANSPORTABLE, ARTICULATED, REMOVABLE ROPS CAB, HPTO, W/SCARIFIER, VEE PLOW, REAR MTD WINGS, DOZER BLADE AND TIRE CHAINS.	1	8.4	2.5	3.34	13680
166791	TRUCK, DUMP, HYDRAULIC, 6X6, SINGLE WHEEL, SNOW PLOW ONE-WAY, MILITARIZED	1	14.9	3.2	3.53	17219
172507	SHELTER SEV GEOMATICS SUPPORT TEAM	1	3.73	2.32	2.41	2860
172702	SHELTER NON-EXPANDABLE, SEV, 12 FOOT, GPS, WITH IMPROVED LAND MINE DETECTION SYSTEM (ILDS)	1	3.73	2.32	2.41	1837
174131	SHELTER, SEV, GPS 14FT, LAND COMBAT SYSTEMS	1	4.3	2.32	2.41	3400
175002	ISO SHIPPING CONTAINER, 20 FT, WATERBAGGING SYSTEM	1	6.13	2.45	2.591	8657
253101	GUN, 105 MILLIMETER, LG1, MK 2	6	5.32	2	1.52	1520
N/A	20 FT ISO CONTAINER SUPPLIES	300	6.1	2.44	2.59	6500

List of symbols/abbreviations/acronyms/initialisms

ADAMS	Allied Deployment and Movement System
AN 124	Antonov 124
CF	Canadian Forces
DMGOR	Directorate Materiel Group Operational Research
DPM	Deployment Planning Module
DTAV	Defence Total Asset Visibility
ECC	Equipment Configuration Code
FMS	Fleet Management System
GALAHAD	Genetic Annealing for Loading Aircraft, a Heuristic Aiding Deployment
GDM	General Deployment Module
HLVW	Heavy Logistics Vehicle Wheeled
IL 76 TD	Ilyushin 76 (TD variant)
ISO	International Standards Organisation
LSVW	Light Support Vehicle Wheeled
NATO	North Atlantic Treaty Organization
NC3A	NATO Consultation, Command and Control Agency
NEQ	Net Explosive Quantity
SEV	Special Equipment Vehicle
sup	supremum (mathematical operator)
$\mathbb{Z}$	the set of integers

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Distribution List

Comment on the ADAMS transportation requirement estimation methodology

Reference: R. H. A. David Shaw, *Comment on the ADAMS transportation requirement estimation methodology*, DRDC CORA TN 2005–011, October 2005 (enclosed).

1. Please find enclosed the Defence Research and Development Canada—Centre for Operational Research and Analysis Technical Note DRDC CORA TN 2005–011, entitled *Comment on the ADAMS transportation requirement estimation methodology*. The report compares the relative performance of three methods of estimating the number and types of airlift assets required to move a specified manifest of cargo and equipment.

2. The transportation requirements estimator provided in the Allied Deployment and Movements System's Deployment Planning Module can lead to questionable estimates for certain manifests. This paper develops an alternate simple estimation methodology and compares the performance of the two techniques to the "optimal" solution on a data set based on a historical Canadian Forces deployment. The alternative estimator is shown to be more accurate, leading to conservative estimates which are high by around five to ten percent. The impact of other real world constraints on the two estimators is also discussed.

3. The alternative estimator proposed in this paper is well-suited to rapid staff checks and exploratory analysis prior to more detailed planning with more sophisticated tools. Questions or comments are welcomed and may be addressed to David Shaw at (613) 996-3664 or by e-mail at *Shaw.D@forces.gc.ca*. Electronic copies of this report are available upon request (*Repsys.R@forces.gc.ca*) or directly from the ORD intranet site (*http://ord.mil.ca/pages/corporate/library_e.asp*).

D. F. Reding
Director Operational Research (General Analysis)

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Operational Research Division
NATO Consultation, Command and Control Agency
P.O. Box 174
2501 CD The Hague
Netherlands

Michael Rafter
AMCC ADAMS Manager
Supreme Headquarters Allied Powers Europe
7010 Casteau
Belgium

Peter Rinck
J4 INCC
Supreme Headquarters Allied Powers Europe
7010 Casteau
Belgium

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The transportation requirements estimator provided in the Allied Deployment and Movements System's (ADAMS) Deployment Planning Module (DPM) can lead to questionable estimates for certain manifests. This paper develops an alternate simple estimation methodology and compares the performance of the two techniques to the "optimal" solution on a data set inspired by the Operation ATHENA deployment. The alternative estimator is shown to be more accurate, leading to conservative estimates which are high by around five to ten percent. The impact of other real world constraints on the two estimators is also discussed.

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