Optimizing Marine Security Guard Assignments

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ABSTRACT

The Marine Corps Embassy Security Group (MCESG) assigns 1,500 Marine Security Guards (MSGs) to 149 embassy detachments annually. MCESG attempts to balance MSG experience levels at each detachment and assign MSGs to their preferred posts while fulfilling several billet requirements. Historically, assignments have been made manually in a labor-intensive process requiring more than 6,000 person-hours per year. This article describes the Marine Security Guard Assignment Tool (MSGAT). MSGAT is an Excel-based decision support tool that utilizes a system of workbooks to guide MCESG through a streamlined data collection process and provide high-quality assignments. Assignments are optimized using a multicommodity network flow formulation. This article compares assignments generated by MSGAT to assignments generated manually by MCESG and demonstrates that MSGAT assignments are superior with regard to several measures of effectiveness.

INTRODUCTION

The Marine Security Guard program has existed in its current form since December 1948. Marine Security Guards (MSGs) are responsible for providing ''internal security services at designated United States Diplomatic and Consular facilities to prevent the compromise of classified information and equipment that is vital to national security'' (Department of State, 1999). MSGs currently serve at 149 embassies and consular facilities, henceforth referred to as *detachments*. An MSG's tour typically consists of three one-year posts at three different detachments. Prior to serving at his or her first detachment, each MSG (typically a Lance Corporal with three years of service) receives two to three months of training at MSG School in Quantico, Virginia. MSG School graduates five classes of 80–100 students annually. Following each MSG School graduation, a rotation occurs in which new graduates enter their first posts, MSGs who have served one or two years rotate to new detachments, and MSGs who have served three years leave the MSG program. Thus, there are five rotations of approximately 250–300 MSGs every year, with each rotation corresponding to a graduating class. The life cycle of MSGs is described in detail in the ''Attributes'' subsection of this article.

Prior to each rotation, MSGs are assigned to available billets. Historically, assignments have been generated manually by the Marine Corps Embassy Security Group (MCESG). In assigning MSGs to available billets, MCESG takes into account a number of attributes of MSGs, billets, and detachments.

This article describes a decision support tool designed to assist in the assignment process: the Marine Security Guard Assignment Tool (MSGAT). The goal of MSGAT is to expedite the assignment process while maintaining or improving solution quality relative to manual assignment. The MSG assignment problem is addressed using two integer linear programs (ILPs) that seek to optimize the overall quality of the assignments made. This article describes these models and uses historical data to compare assignments produced by MSGAT to those produced manually by MCESG.

RELATED WORK

A large body of prior work has established the utility of decision support systems for military applications. This section examines recently employed personnel assignment optimization models within the US military and focuses on development techniques that make them successful. It also examines integration of such models with information management systems.

Extensive research has examined the use of network flow models for personnel assignment. Bausch et al. (1991) address assignment optimization with respect to the immediate mobilization of Marine Corps officers. The authors designed and built the Manpower Assignment Recommendation System (MARS). MARS is a decision support tool based on a network flow model that works in conjunction with Marine Corps databases to complete a wartime mobilization involving 40,000 officers and 27,000 billets (Bausch et al., 1991). MARS combines three objectives:

1. Maximize the number of billets filled with qualified officers.

OR METHODS: (Integer) linear programming, Multiobjective optimization, Network methods

APPLICATION AREAS: Resources readiness and training, Manpower and personnel

2. Maximize the fit of the officer to the billet. MARS attempts to obtain a perfect officer-billet fit and avoids sending over- or under-qualified officers to any billet. MSGAT also seeks to maximize the fit of each Marine-billet assignment using similar fit criteria, such as rank and gender.
3. Minimize the amount of movement when filling the billets. That is, MARS aims to keep as many officers in the unit to which they were assigned prior to mobilization.

Two files are critical to the functionality of MARS: the Wartime Officer Slate File (WOSF) and the Wartime Authorized Strength Report (WASR). The WOSF contains information on Marines, whereas the WASR describes billets and their requirements. A conceptual network model of the Marine Corps mobilization problem depicts each officer as a supply node and each billet as a demand node (Bausch et al., 1991). Because a literal implementation of the conceptual model is computationally impractical, MARS employs several important simplifications to the conceptual model (Bausch et al., 1991). Prior to the development of MARS, the previous Marine Corps system took up to four days to complete a mobilization and produced substandard results. MARS produces results in less than 10 minutes and with a significant improvement in all measures of effectiveness (MOEs).

Tivnan (1998) also presents a network flow model, Enlisted Assignment Model-Global (EAM-GLOBAL), that serves to optimize the assignment of enlisted Marines to billets. EAM-GLOBAL seeks to optimize Marine-to-billet fit while balancing staffing shortages, allowing grade and MOS substitutions, and minimizing the monetary cost associated with moving Marines (Tivnan, 1998). Four MOEs are used to determine how well EAM-GLOBAL's assignments satisfy US Marine Corps (USMC) staffing goals:

1. Percentage of filled billets.
2. Number of transcontinental United States transfers.
3. Percentage of filled billets with a perfect fit. The authors define ''perfect fit'' as an exact grade and MOS match between Marine and billet.
4. Number of Marines available but not assigned.

EAM-GLOBAL verifies that the current inventory of enlisted Marines can achieve over 99 percent of the staffing goals.

In a similar model, Dell et al. (2008) use an integer linear program, Optimally Stationing Army Forces (OSAF), to provide optimal stationing of Army units as weapons systems, missions, and operations change over time. The OSAF model prescribes optimal Army stationing by using the existing starting locations, set of installations, and unit requirements to minimize cost associated with Base Realignment and Closure (BRAC) decisions, while maximizing military value (Dell et al., 2008). Each stationing plan satisfies a number of unit requirements, such as the availability of buildings and land for unit training. OSAF has assisted with BRAC decisions since 2005 and has successfully provided the Army with reliable stationing analysis for several years. Although OSAF is a stationing analysis tool, it shares many features with personnel assignment models such as MSGAT (Dell et al., 2008). For example, each assignment solution generated by MSGAT satisfies various MSG and billet requirements identified by MCESG and the region commands.

Similarly, Loerch et al. (1996) develop an integer program to determine efficient stationing solutions for the United States Army in Europe. The authors design their model to achieve the desired objectives of minimizing monetary costs, maintaining unit integrity, and fulfilling unit support requirements (Loerch et al., 1996). Model results were provided as a basis for developing stationing plans throughout Europe.

In a related approach that uses mixed integer programming, Baumgarten (2000) develops the Marine Corps Manpower System (MCMS) to maximize the Marine Corps' operational readiness through the assignment of officers to billets. While attempting to fulfill billet requirements, MCMS simultaneously develops the professional skills that each officer must possess to be assigned to billets as their careers progress (Baumgarten, 2000). Thus, career paths must be designed to reflect the balance of fulfilling billet requirements and developing professional skills. Baumgarten (2000) presents a mixed integer program, the Officer Career Path Selection (OCPS) model, that assigns officers to acceptable career paths in order to meet billet requirements while satisfying professional skill development. OCPS assists in determining the number of officers to assign to various Military Occupational Specialties (MOSs) each year.

Goldschmidt and Boersma (2003) also use integer programming to assign MOSs to all newly commissioned Marine Corps second lieutenants at the Basic School (TBS). The assignment of an MOS is based on the officer's ordinal rank within his or her cohort at TBS and the demands of the Marine Corps. Ordinal rank is a ranking based on academic and leadership grades attained throughout TBS. To ensure quality distribution of officers, each cohort within TBS is divided into thirds based on ordinal rank (Goldschmidt and Boersma, 2003). The MOS vacancies are divided into thirds as well. Goldschmidt and Boersma (2003) develop an information management system, MyMOS, for use by TBS personnel, that assists in the collection of information and the assignment of MOSs to newly commissioned officers. Each MOS assignment model is an integer linear program that optimally assigns an MOS to an officer using the officer's ordinal rank, MOS preferences, the third in which the officer finished within their cohort, and MOS availability. In addition to the numerical improvements realized by linear programming, Goldschmidt and Boersma (2003) achieve substantial cost savings by reducing human involvement in the assignment process.

Many of the models discussed thus far are successful, in part, because they incorporate persistence. That is, these models account for any existing solution and attempt to minimize disruptions to that solution while meeting new requirements. Incorporation of persistence is beneficial because optimization has the potential to amplify small input changes into drastically different solutions (Brown et al., 1997). This is especially troublesome in a cyclic process such as the MCESG assignment process. In this process, MCESG produces an assignment, the assignment is published, revised MSG or billet data becomes available, MCESG produces a revised assignment, and the revised assignment is published. New assignments that retain features of prior assignments are more desirable to MCESG, as this limits the amount of disruption to MSGs' planned rotations. Thus, MSGAT utilizes a user-defined parameter that limits number of changes between any two sequential assignments.

OPTIMIZATION MODELS

MSGAT implements a multicommodity network flow model called the Balance Model (BALMOD) to optimally assign MSGs to billets. It also implements the Assignment Modification Model (ASMOD), which is an extension of BALMOD that is capable of generating similar assignments using varying sets of input data. Before describing models BALMOD and ASMOD, we first discuss the attributes of MSGs and billets that are relevant in the assignment process.

Attributes

MSGAT considers several attributes when determining goodness of fit between an MSG and a billet. These attributes are summarized in Table 1. Most attributes are applicable to individual MSG/billet pairs; however, two attributes are relevant at the detachment level. The first is *MSG experience level*. Rotating MSGs can be placed into one of four experience levels:

1. *First posters* are transitioning from MSG School to their first detachment.
2. *Second posters* are transitioning from their first detachment to their second detachment.
3. *Third posters* are transitioning from their second detachment to their third detachment.
4. *OPCs* are going Off Program Completely (OPC; i.e., leaving MSG duty).

An individual leaving MSG duty may be doing so for one of three reasons: (1) the MSG may have successfully completed his or her service and is rotating OPC; (2) the MSG may be physically unable to continue duty and is being discharged for the Good of the Service (GOS); or (3) the MSG may be removed from duty for legal reasons or Removed for Cause (RFC). For the purposes of the decision support tool, the term OPC encompasses the OPC, GOS, and RFC conditions. In assigning MSGs to detachments, MSGAT attempts to ensure that each detachment receives a balanced distribution of first, second, and third posters, taking into account any MSGs

Table 1. The set of goals that MSGAT attempts to satisfy when making MSG-billet assignments.

Entity	Attribute	Goal
Detachment	Experience level	MSG experience level should be balanced across all detachments.
	Rank	MSG rank should be balanced across all detachments.
MSG/billet	Tier	MSGs should not be assigned to the same tier more than once.
	Post restrictions	MSGs should not be assigned to detachments in which they are restricted from serving.
	Repeat region	MSGs should not be assigned to the same region more than once.
	Gender	Female MSGs should not be assigned to detachments that are not configured for females.
	DC	Only DC-qualified MSGs should be assigned to DC detachments.
	A/	Only MSGs qualified to serve as an A/ should be assigned to billets requesting an A/.
	SSgt select	Billets needing SSgt selects should receive MSGs selected for the rank of SSgt.
	1/5 posts	All billets in 1/5 posts have priority over billets in more populous detachments.
	Preferences	MSGs should be assigned to one of three detachment preferences or one of two region preferences.

who are not rotating in the current cycle as well as any OPCs leaving MSG duty.

The second attribute that is relevant at the detachment level is *MSG rank*. MSGs range in rank from Lance Corporal (E3) to Staff Sergeant (E6). MSGAT attempts to ensure that each detachment receives a balanced rank structure, again taking into account any MSGs who are not rotating in the current cycle as well as any OPCs leaving MSG duty.

All remaining attributes can be modeled at the level of individual MSG/billet pairs. The first such attribute is *detachment tier*. Each detachment is categorized into one of three tiers based on desirability. Tier designations are determined by the Department of State (1999). Tier 1 detachments are in desirable locations, such as Paris, Rome, and Munich. Tier 3 detachments are in less desirable locations, such as Port Au Prince, Rangoon, and Kiev. Tier 2 detachments are in intermediate locations, such as Mexico City, Ankara, and Kuwait. One goal of the assignment process is to ensure that each MSG receives an equitable distribution of Tier 1, Tier 2, and Tier 3 assignments during his or her 3-year tour of duty; ideally, one year should be spent in each tier.

MSGAT also takes into account any *post restrictions* that may make an MSG ineligible to serve at a particular detachment. One example of a condition that would result in a post restriction is the presence of a close relative of the MSG (e.g., an aunt or an uncle) living near the detachment. For security reasons, MSGs are not permitted to serve at such detachments.

Each detachment belongs to one of nine geographic regions, and MSGs are prohibited from serving at more than one detachment in the same region. Thus, MSGAT attempts to avoid assignments that would result in an MSG serving in a *repeat region*. This attribute is modeled separately from the post restriction attribute because, in some cases, it may be desirable to relax the repeat region requirement while enforcing any restrictions on individual posts.

Most detachments are configured to house both male and female MSGs; however, some detachments are configured for males only. Therefore, MSGAT considers *gender* when assigning MSGs to detachments. Again, gender is considered separately from the post restriction attribute to allow attributes to be emphasized or deemphasized individually.

Three attributes relate to specific designations MSGs may hold. Some detachments, located in *designated countries* and referred to as *DC posts*, require that posted MSGs have a special type of security clearance. Thus, MSGAT considers each MSG's *DC qualification* status. Similar to DC qualification, MSGs must receive a special designation to serve as an assistant detachment commander (A/). Accordingly, MSGAT considers each MSG's *A/status* when making assignments to detachments requesting a new A/. Finally, detachments may also request an MSG who has been selected for promotion to Staff Sergeant (SSgt); these MSGs are referred to as *SSgt select*.

Inevitably, personnel shortages sometimes result in some billets going unfilled. When this occurs, it is desirable that unfilled billets be located at large embassies with many MSGs rather than small embassies with few MSGs. The smallest embassies are configured for one detachment commander and five watchstanders; these are referred to as *1/5 posts*. MSGAT attempts to fill all billets at 1/5 posts.

Finally, *MSG preferences* are taken into account. In each rotation, each MSG is allowed to specify two regions and three individual detachments in which he or she would most like to serve. MSGAT attempts to honor these preferences.

Limitations of the Classical Assignment Model

The classical assignment model matches personnel to billets while minimizing a sum of penalties (or, equivalently, maximizing a sum of utilities) defined for each person-billet pair. As shown in Table 1, MSGAT must satisfy two detachment-level goals: each detachment must receive an equitable distribution of first, second, and third posters, as well as a balanced rank structure. Fortunately, with the exception of rank and experience level, all other attributes are either constant throughout a detachment or are linked to rank. Thus, each detachment can design its billet requests to ensure that it receives a balanced rank structure. However, the classical assignment model must be modified to balance experience levels across detachments. We now describe such a modification.

Model BALMOD

BALMOD solves a multicommodity network flow problem in which MSG experience levels serve as commodities. A schematic diagram of this network is shown in Figure 1.

This network contains four sets of nodes: a set representing MSGs, G; a set representing billets, B; a set representing detachments, D; and a set representing experience levels, E. The first layer of this network, consisting of the nodes in G and B and the arcs connecting them, behaves as a classical assignment model. It assigns MSGs to billets based on attributes unique to MSGs/ billet pairs. The second layer of the network captures the balance of MSG experience levels across detachments.

In this multicommodity model, flow commodities represent MSG experience levels. The arcs connecting nodes in D to nodes in E incur penalties based on the commodity of flow (MSG experience level) and the experience level represented at the destination node. The arc connecting node det in D to node e in E has capacity cap^{e}_{det}, which indicates the number of MSGs with experience level e required at detachment det to balance experience levels across detachments.

The capacities cap^{e}_{det} are calculated as follows. Denote the overall fraction of MSGs with experience level e, including rotating and nonrotating MSGs but not OPCs, by $frac_e$. Denote the number of MSGs with experience level e that are not rotating out of detachment det by S^{det}_{e}. Finally, denote the set of open billets at detachment det by $B(det)$. MSGAT uses the following calculation to set the detachment experience demands cap^{e}_{det}:

$$cap^{3}_{det} = \max\left(0, \lfloor frac_3 |B(det)| \rfloor - S^{det}_{3}\right)$$

$$cap^{2}_{det} = \max\left(0, \lfloor frac_2 |B(det)| \rfloor - S^{det}_{2}\right)$$

$$cap^{1}_{det} = |B(det)| - cap^{2}_{det} - cap^{3}_{det}$$

This demand calculation attempts to evenly distribute experience levels over all detachments. Future improvements to MSGAT may include a more sophisticated calculation of cap^{e}_{det}. We will henceforth refer to each unit of MSG experience demand as a *slot*. In other words, if $cap^{3}_{A} = 5$, we say that there are five slots available for third posters at detachment A.

BALMOD allows the user to control assignments of individual MSGs to detachments through the use of a binary matrix f, which has

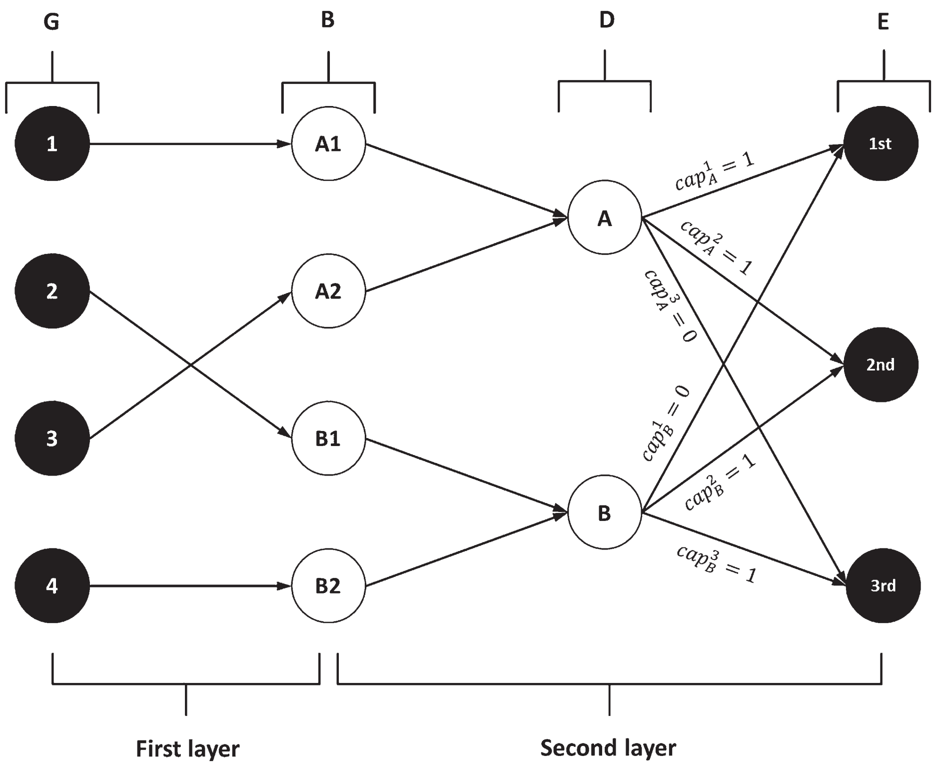

Figure 1. BALMOD solves a two-layer multicommodity network flow problem. The network contains four sets of nodes (G, B, D, and E) and three edge sets. The first layer minimizes MSG-billet cost with respect to attributes unique to MSGs and billets. The second layer balances MSG experience across detachments.

components $f_{g,b}$. This matrix, called the *force/forbid matrix*, allows the user to either force or forbid the assignment of an MSG to a specific detachment by placing capacities on the arcs connecting nodes in G to nodes in B. Initially, the force/forbid matrix allows any MSG to be assigned to any billet, i.e., $f_{g,b} = 1 \; \forall g,b$. However, the user may enter certain requirements that result in modifications to the force/forbid matrix:

- If the user forces MSG g to be assigned to detachment *det*, then $f_{g,b} = 1$ for all $b \in B(det)$, and $f_{g,b} = 0$ for all $b \notin B(det)$. This allows MSG g to be assigned to any billet within detachment *det* and *not* to any billet outside detachment *det*. Because each MSG is required to be assigned to some billet, the net result is that MSG g must be assigned to detachment *det*.
- If the user forbids MSG g from being assigned to detachment *det*, then $f_{g,b} = 0$ for all $b \in B(det)$.

Note that the force/forbid matrix gives the user a great deal of control; in fact, an inexperienced user may inadvertently render the problem infeasible. Therefore, MSGAT executes infeasibility corrections prior to solving if the user performs one of the following actions:

- Forces more MSGs to a particular detachment than the number of available billets at that detachment, or
- Forces and forbids an MSG to the same detachment.

In addition to these feasibility checks, a post-processing step also verifies solution quality and notifies the user of any potential problem with MSGAT's output.

We now describe BALMOD's mathematical formulation. For simplicity, the formulation described in this article assumes that the number of MSGs rotating is equal to the number of billets available. In reality, the number of rotating

MSGs and available billets are not necessarily equal in every assignment cycle. Thus, MSGAT executes a preprocessing step to handle unequal numbers of MSGs and billets.

Indices and sets:

$g \in G$	MSG
$b \in B$	Billet
$k \in K$	MSG or billet attribute
$det \in D$	Detachment
$e \in \{1,2,3\}$	Experience level
$c \in \{1,2,3\}$	Flow commodity
$B_{det} \subseteq B$	Set of billets located in detachment det

Input data:

$det(b)$	Parent detachment of billet b
$v^k_{g,b}$	Penalty incurred by MSG g and billet b for attribute k
w_k	Weight given to attribute k
w_{bal}	Weight given to the experience balance attribute
pen^c_e	Penalty for assigning an MSG with experience c to a slot requiring experience level e
$f_{g,b}$	Binary input for manually specifying assignment of MSG g to billet b.
exp^c_g	1 if guard g has experience level c, 0 otherwise

Calculated data:

$cost_{g,b} = \sum_k w_k v^k_{g,b}$	Cost of assigning MSG g to billet b, excluding the experience penalty
cap^e_{det}	Slots available for MSGs with experience level e at detachment det

Decision variables:

$ASSIGN^c_{g,b}$	Decision to assign MSG g with experience level c to billet b [binary]
$BILLET^c_{b,det(b)}$	Decision to assign billet b in detachment $det(b)$ to a guard with experience c [binary]
$EXSLOT^c_{det,e}$	Number of MSGs with experience level c assigned to detachment det and assigned to slots requiring experience e

Formulation: BALMOD

$$\min_{\substack{ASSIGN\\EXSLOT\\ASSIGN}} \sum_{g,b}\left(cost_{g,b}\cdot\sum_c ASSIGN^c_{g,b}\right) + w_{bal}\cdot\sum_{\text{det}}\sum_{c,e} pen^c_e\cdot\frac{EXSLOT^c_{det,e}}{\max_{c,e}\left(pen^c_e\right)\cdot|B_{det}|}$$

$$s.t.\ \sum_b ASSIGN^c_{g,b} = exp^c_g \quad \forall g,c \tag{1}$$

$$\sum_{g,c} ASSIGN^c_{g,b} = 1 \quad \forall b \tag{2}$$

$$\sum_g ASSIGN^c_{g,b} = BILLET^c_{b,det(b)} \quad \forall b,c \tag{3}$$

$$\sum_{b\in B_{\text{det}}} BILLET^c_{b,det} = \sum_e EXSLOT^c_{det,e} \quad \forall det,c \tag{4}$$

$$\sum_c EXSLOT^c_{det,e} \le cap^e_{det} \quad \forall det,e \tag{5}$$

$$\sum_c ASSIGN^c_{g,b} \le f_{g,b} \quad \forall g,b \tag{6}$$

$$ASSIGN^c_{g,b} \in \{0,1\} \quad \forall g,b,c \tag{7}$$

$$BILLET^c_{b,det} \in \{0,1\} \quad \forall b,det,c \tag{8}$$

$$EXSLOT^c_{det,e} \ge 0 \quad \forall det,e,c \tag{9}$$

BALMOD's objective function contains two terms. The first term calculates costs associated with attributes unique to MSGs and billets. The parameter $cost_{g,b}$ is a goodness-of-fit measure that is calculated using parameters w_k and $v^k_{g,b}$. The weight parameter w_k is tunable by the user; it is designed to allow the user to emphasize or deemphasize particular attributes in the cost calculation. Weights w_k take on values between 0 and 100. The penalty parameter $v^k_{g,b}$ is incurred by MSG g and billet b for attribute k. Penalties $v^k_{g,b}$ take on values between 0 and 1. A full description of penalties $v^k_{g,b}$ can be found in Enoka's master's thesis (Enoka, 2011).

The second term in the objective function calculates penalties related to the balance of experience levels across detachments. Each arc connecting a node in D to a node in E has a cost that depends on the level of mismatch between MSG experience level (flow commodity) and experience level represented by the target node in E. Note that a normalization factor is included in the objective function term relating to the balance penalty. This is done to ensure that the resulting balance penalty is between 0 and 1, as the penalties for the other attributes are also between 0 and 1.

BALMOD's constraints function as follows. Constraint set 1 ensures that each guard g is assigned to exactly one billet b while assuring that the flow originating from node g is of the correct commodity. (Note that for each guard g, exp_g^c is equal to 1 for exactly one experience level c.) Constraint set 2 ensures that each billet b is assigned one MSG g. Constraint set 3 enforces flow conservation at each billet node $b \in B$. Constraint set 4 enforces flow conservation at each detachment node $d \in D$. Constraint set 5 ensures correct calculation of the experience balance penalty, given detachment experience demands. Constraint set 6 enforces conditions expressed by the force/forbid matrix. Constraint sets 7–9 impose binary and nonnegativity restrictions on the decision variables, as appropriate.

Note that BALMOD is an integer linear program rather than a linear program (LP), as would be required in a classical assignment model. Constraints 6 and 7 are required because multicommodity network flow problems do not always have integer optimal solutions. However, empirical observations suggest that the LP relaxation of BALMOD very often has an integer optimal solution.

Assignment Modification

In addition to making good initial assignments, MCESG assignment personnel need to have the ability to make small changes to existing assignments. It is not uncommon for published assignments to undergo several modifications throughout an assignment cycle due to changes in MSG or billet input data. Typically, modifications impact several MSG-billet pairs. Because modifications often occur after an assignment has been published, it is important to limit the number of MSG-billet pairs impacted. To this end, MSGAT uses the Assignment Modification formulation ASMOD to generate modified assignments. ASMOD has the same functionality as BALMOD and uses all of the data, decision variables, and constraints that BALMOD uses. However, ASMOD also introduces several new pieces of data, decision variables, and constraints. Key among these is the parameter $d_{\max}$, which allows the user to select the maximum number of MSG-billet pairs that can be modified, thus enabling MCESG to define the degree of persistence required between assignments. We now describe the remaining data, decision variables, and constraints introduced by ASMOD (in addition to the data, decision variables, and constraints used in BALMOD).

Input data:

$d_{\max}$	Maximum number of changes between the existing assignment and the new assignment
$assign_{g,b}^{old}$	MSG-billet assignment in the assignment being modified

Constraints:

$$\sum_{(g,b):assign_{g,b}^{old}=0} \sum_{c} ASSIGN_{g,b}^{c} + \sum_{(g,b):assign_{g,b}^{old}=1} \left(1 - \sum_{c} ASSIGN_{g,b}^{c}\right) \leq 2 \cdot d_{\max} \quad (10)$$

The objective function in formulation ASMOD is the same as that in BALMOD. Likewise, ASMOD also contains constraint sets 1–9, as well as one additional constraint set. The left-hand side of constraint set 10 calculates the number of MSG-billet pairs that differ in assignment status between the incumbent assignment and the new assignment. The first term counts the number of MSG-billet pairs for which an assignment was not made in the incumbent assignment and is made in the new assignment, whereas the second term counts the number of MSG-billet pairs for which an assignment was made in the incumbent assignment and is not made in the new assignment. The total number of changes between the incumbent assignment and the new assignment is restricted to be at most $2 \cdot d_{\max}$. Note that if guard g was previously assigned to billet b and is now assigned to billet b', then two MSG-billet pairs ((g,b) and (g,b')) have changed.

RESULTS

Having described the optimization models implemented by MSGAT, we now turn our attention to an analysis of MSGAT's performance. To facilitate comparison of MSGAT with manual assignments, MCESG provided all available input data from assignment cycles 4–10, 5–10, 1–11, 2–11, and 3–11, where cycle N–YZ is the Nth assignment cycle in fiscal year 20YZ. Actual assignments made manually during those cycles were also provided. We now compare assignments produced by MSGAT to MCESG's manually-generated assignments using the following MOEs:

1. Percentage of billets that received a requested experience level. Although MSGAT attempts to balance experience levels across detachments, individual detachments are also able to request particular experience levels. MCESG did not document the number of first, second, and third posters at each detachment in any of the assignment cycles, making it impossible to evaluate the degree to which experience levels were balanced among detachments. Thus, this MOE measures the number of billets that received a requested MSG experience level instead.
2. Percentage of billets that receive a requested rank.
3. Percentage of MSGs who are assigned to a new tier (i.e., a tier to which the MSG has not previously been assigned).
4. Percentage of billets requesting an A/ qualified MSG that receive such an MSG.
5. Percentage of billets at 1/5 posts that receive an MSG. Recall that a 1/5 post is a post with one detachment commander and five watchstanders; in other words, a small embassy. Filling a billet in a 1/5 post is preferred over filling a billet in a post with more MSGs.
6. Percentage of MSGs who receive a detachment preference.
7. Percentage of MSGs who receive a region preference.

For each MOE, a high percentage is preferred over a low percentage. Note that this list of MOEs does not utilize all of the attributes listed in Table 1; this is because the input data necessary to consider these attributes was not recorded by MCESG in previous assignment cycles.

Attribute Weights

For each assignment cycle, we used MSGAT to generate three assignments using attribute weights as shown in Table 2. Each set of weights was designed by subject matter experts at MCESG in such a way as to favor the interests of a particular entity within the MCESG organization.

Recall that a higher weight indicates a more important attribute. The *MSG-centric* weights favor MSG interests such as the MSG's region and detachment preferences while maintaining high weights on factors that impact MSG safety, such as A/ status and billets at 1/5 Posts. The *Region-centric* weights emphasize attributes that favor the interests of regional leadership, such as experience and rank. The *Headquarters (HQ)-centric* weights emphasize attributes important at the HQ level of MCESG, such as assigning MSGs to new tiers. These weights most closely reflect the decision process and priorities that MCESG currently uses when creating assignments.

Analysis

We now examine MOE satisfaction in assignments generated using MSGAT as compared to

Table 2. Attribute weights for the three MSGAT-generated assignments.

Attribute	MSG-centric	Region-centric	HQ-centric
A/	90	100	100
1/5	70	70	70
Tier	5	5	40
Experience-Request	15	25	15
Rank	15	30	5
Preferences	50	5	5

Note: Weights for the gender, DC, SSgt select, and experience-balance attributes are set to 0 because the corresponding input data was not documented for any of the historical assignment cycles.

MCESG-generated manual assignments. In addition to assignments generated using the attribute weights given in Table 2, several ''single-MOE'' assignments were generated for each set of assignment cycle data. The single-MOE assignments were created to determine the maximum possible satisfaction of each MOE in each assignment cycle; in other words, to determine an upper bound on performance. In single-MOE assignments, all attribute weights are equal to zero other than the weight for the MOE being optimized; this weight is strictly positive. Figures 2 and 3 summarize the performance of MSGAT as compared to MCESG's manually generated assignments for each assignment cycle. We now discuss each MOE and assignment cycle in turn. Note that not all assignment cycles are shown for each MOE; the assignment cycles presented are those for which historical data was available.

Billets requiring A/-qualified MSGs: Figure 2a shows the percentage of billets requesting an A/ that received an A/-qualified MSG. MSGAT assigns at least 20 percent more A/-qualified MSGs to billets requiring them than the manual assignment in every historical comparison. In the 4–10 cycle, MSGAT successfully fills the

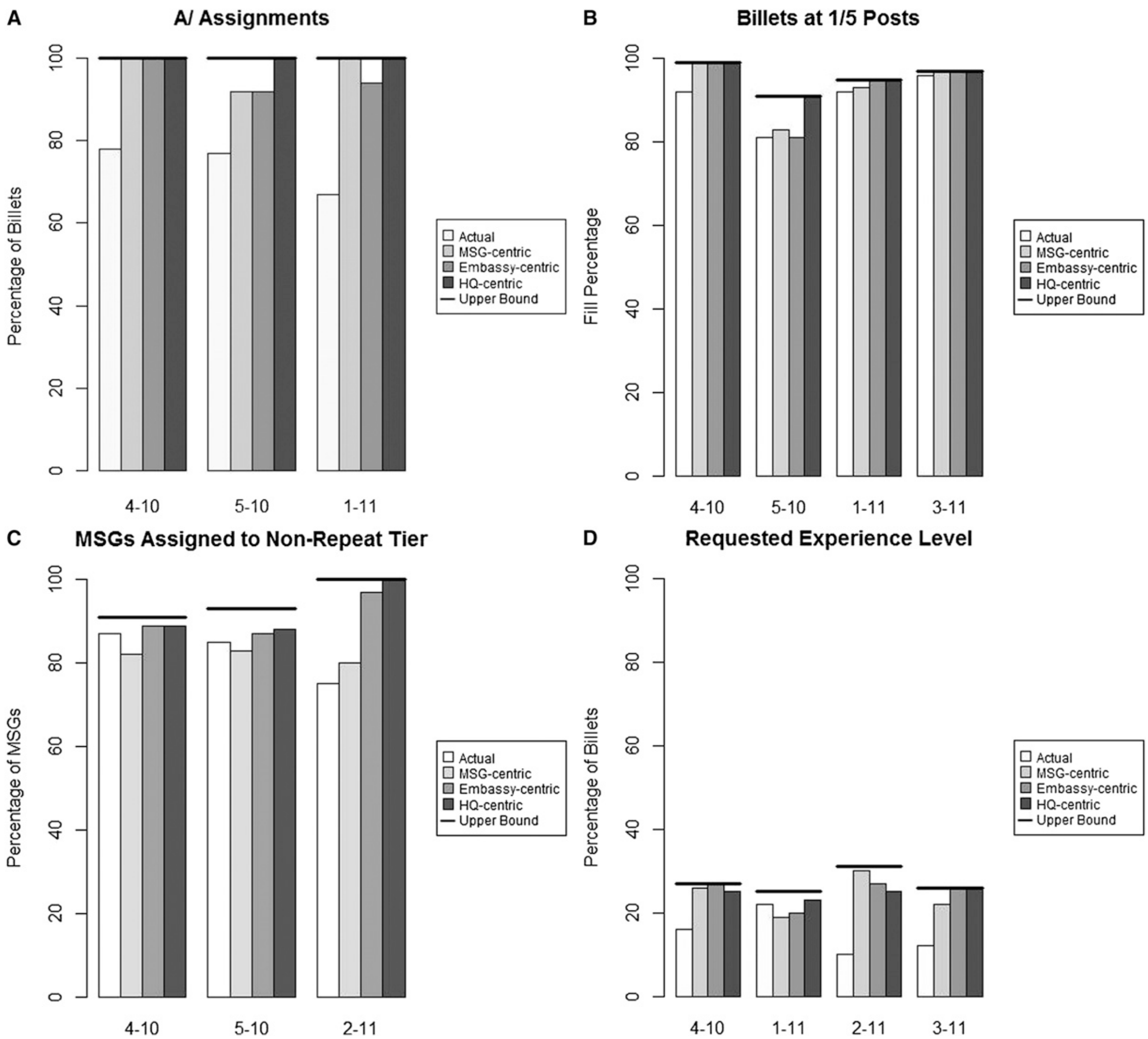

Figure 2. MSGAT assignments compared with actual (manual) assignments for assignment cycles 4–10, 5–10, 1–11, 2–11, and 3–11 with respect to A/ assignments, billets at 1/5 posts, nonrepeat tier assignments, and embassies receiving requested experience levels.

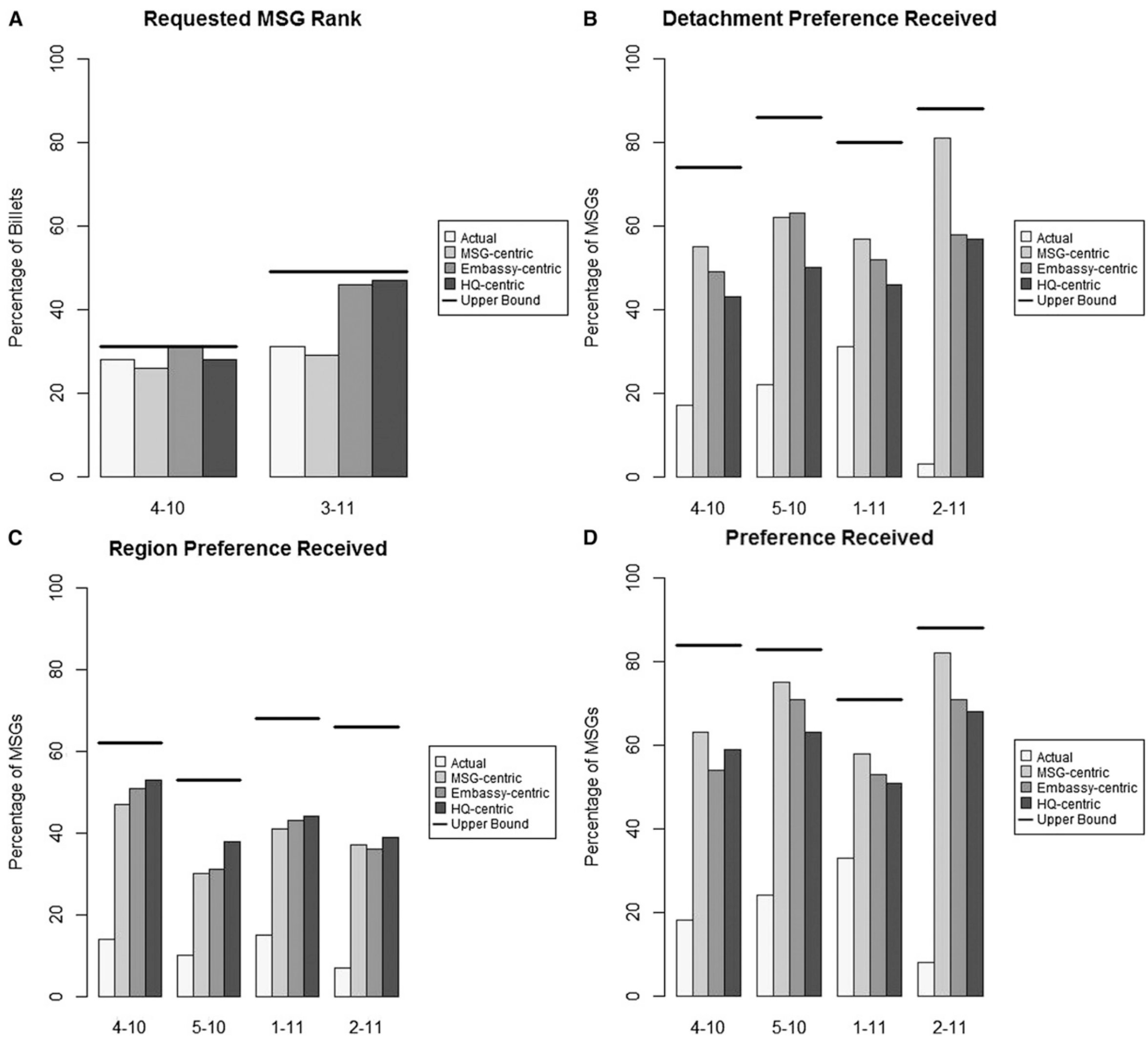

Figure 3. MSGAT assignments compared with actual (manual) assignments for assignment cycles 4–10, 5–10, 1–11, 2–11, and 3–11 with respect to embassies receiving requested ranks and MSG preference satisfaction.

maximum percentage of billets requesting an A/ for every MSGAT assignment; the manual assignment satisfies only 78 percent of billets requesting an A/. In the 5–10 cycle, MSGAT fills the maximum possible percentage of billets with the HQ-centric weights, whereas the MSG-centric and embassy-centric weights fill 92 percent of the billets and the manual assignment fills only 77 percent. In the 1–11 cycle, the manual assignment satisfies only 67 percent of billets requesting an A/, whereas the MSG-centric and embassy-centric assignments each satisfy the maximum percentage of the A/-requesting billets.

Billets at 1/5 posts: Figure 2b illustrates the fill percentage of billets at 1/5 posts. Although the manual assignment performs relatively well according to this MOE, MSGAT assignments fill more billets at 1/5 posts for nearly every assignment cycle comparison. In the 4–10 cycle, every MSGAT assignment results in the maximum percentage of 1/5 billets being filled, whereas the manual assignment assigns only 92 percent. In the 5–10 cycle, the HQ-centric assignment satisfies the maximum percentage of 1/5 billets, whereas the MSG-centric and embassy-centric assignments result in 83 and 81 percent of billets at 1/5 posts being assigned, respectively. The manual assignment for 5–10 results in 81 percent of 1/5 billets being filled. The 1–11 manual assignment fills 93 percent of 1/5 billets, whereas the embassy-centric and HQ-centric assignments fill the maximum percentage of 1/5 billets. The manual assignment performs the best in cycle 3–11, assigning 98 percent of the possible 1/5 billets. However, all 3–11 MSGAT assignments outperform the manual assignment by filling the maximum possible percentage of 1/5 billets.

Nonrepeat tier: Figure 2c shows the percentage of Marines assigned to a nonrepeat tier. MSGAT performs comparably to the manual MCESG assignment in cycles 4–10 and 5–10, while outperforming it significantly in cycle 2–11. With respect to the MSGAT assignments, the MSG-centric weights produce solutions that assign the lowest percentage of MSGs to a nonrepeat tier level in all cycles. This occurs because MSGs often request to be assigned to a repeat tier, even if this tier is undesirable, and in this case their requests are honored. Excluding the MSG-centric assignment, the manual assignment results in the lowest percentage of MSGs being assigned to a nonrepeat tier for every cycle. In assignment cycle 4–10, the embassy-centric and HQ-centric assignments outperform the manual assignment and assign nearly the maximum possible percentage of MSGs to a nonrepeat tier level. The MSGAT assignments slightly outperform the manual assignment in cycle 5–10; however, all assignments assign nearly the maximum possible number of MSGs to nonrepeat tiers. In assignment cycle 2–11, the manual assignment results in only 75 percent of MSGs being assigned to a nonrepeat tier level, whereas the HQ-centric assignment results in the maximum percentage of MSGs being assigned to a nonrepeat tier level.

Requested experience level: This MOE examines the percentage of billets that received a requested MSG experience level and is illustrated in Figure 2d. As the figure indicates, MSGAT assignments significantly outperform the manual assignment for all assignment cycles except the 1–11 cycle, in which all assignments perform comparably. Note that in general, experience requests are difficult to satisfy, as indicated by the upper bounds. This is because detachments tend to prefer second posters over first posters and third posters, and there are generally not enough second posters to satisfy all detachment requests.

Requested rank: Figure 3a depicts the percentage of billets that received a requested MSG rank for cycles 4–10 and 2–11; MSGAT performs comparably to the manual assignment in cycle 4–10 and outperforms it in cycle 2–11 when using the embassy-centric and HQ-centric weights. Each of these 2–11 MSGAT assignments nearly satisfies the maximum percentage of rank requests.

MSG preferences: MSGAT assigns two to three times more MSGs to their requested posts than the manual MCESG assignment. The percentage of MSGs who received a detachment preference appears in Figure 3b. As expected, the MSG-centric assignment generates the highest percentage of MSGs whose detachment preferences are satisfied, although other MSGAT assignments also assign a high percentage of MSGs a preferred detachment. The 4–10, 5–10, 1–11, and 2–11 manual assignments assign only 18, 23, 33, and 1 percent of MSGs to a preferred detachment. With the exception of the 1–11 cycle, the manual assignments are significantly outperformed by MSGAT assignments. The MSG-centric assignment from cycle 2–11 results in the highest percentage of MSGs receiving a detachment preference; it is interesting to note that this outstanding level of detachment preference satisfaction occurs in the assignment cycle with the lowest level of satisfaction in the manual assignment implemented.

Figure 3c depicts the percentage of MSGs who receive a region command preference. In contrast to Figure 3b, the MSG-centric assignments do not always result in the highest number of MSGs receiving a region preference. This happens because in the MSG-centric weight set, the preference attribute is given the highest weight with respect to the other weight sets. The preference penalties are organized such that MSGAT assigns an MSG to a detachment preference before a region preference; further details can be found in Enoka's master's thesis (Enoka, 2011). Thus, the MSG-centric weight set has a higher number of MSGs going to a detachment preference than a region preference. The manual assignments result in the lowest percentage of MSGs receiving a region preference for every historical comparison.

A summary of overall preference satisfaction appears in Figure 3d. This figure indicates the percentage of MSGs who are assigned to at least one of their preferences (detachment or region). The manual assignment is significantly outperformed by the MSGAT assignments in every historical comparison. Although satisfying MSG preferences is not necessarily a top priority for MCESG, these results demonstrate that it is possible to satisfy many MSGs' preferences without sacrificing solution quality with regard to the other MOEs.

Table 3 summarizes the aggregate performance of MSGAT and the manual assignments across all assignment cycles. We denote the total percentage of billets filled satisfactorily with respect to attribute k by method m as P_k^m, where method m represents either MSGAT with a particular set of attribute weights, or the actual (manual) assignment. Let $M_{k,t}$ denote the maximum number of billets that could be filled satisfactorily with respect to attribute k in assignment cycle t, as indicated by appropriate the single-MOE assignment. Furthermore, let $F_{k,t}^m$ denote the number of billets filled satisfactorily with respect to attribute k in assignment cycle t by method m. Then, we calculate P_k^m as

$$P_k^m = \frac{100 \cdot \sum_t F_{k,t}^m}{\sum_t M_{k,t}}.$$

Discussion

MSGAT assignments provide solutions that result in a higher overall satisfaction level than manually generated assignments. In nearly all historical comparisons, the manual assignment is significantly outperformed by every MSGAT assignment with respect to every MOE. Performance is most similar for those MOEs for which the manually generated assignment performs well.

In addition to solution quality, it is also important to consider the time required to produce an assignment. The time taken to enter the required input data for an assignment cycle into the decision support tool was approximately 12 hours of work, by one individual. Once the data was entered and the problem formulated, the computational time was approximately 30 seconds on a personal computer. This can be compared with the 1,200 hours it takes for three Marines within the assignments section at MCESG to enter the data and reach a viable solution. Additionally, the time taken to generate a second solution with MSGAT is very low; usually on the order of 60–120 seconds on a personal computer. This can be compared with the 1–2 weeks required for assignment personnel to generate a second solution.

The main finding of this analysis is that MSGAT is able to provide solutions that satisfy the MOEs more favorably than the manual assignment process at MCESG for data from most historical assignment cycles. The decision support tool provides ''better-fitting'' assignments using fewer resources, and in a shorter time period than the current manual assignment process.

SUMMARY AND CONCLUSIONS

This article describes a personnel assignment tool called the MSGAT. MSGAT implements two integer linear programs to optimally assign (or reassign) MSGs to billets while balancing MSG experience across embassies.

MSGAT offers the user a great deal of control over the assignment process. In particular, MSGAT solves the integer linear programs BALMOD and ASMOD to generate assignments.

Table 3. Summary of MSGAT performance and manual assignments. Total percentage of possible billets filled satisfactorily by manual MCESG assignments and by MSGAT across all assignment cycles (P_k^m).

Attribute	Actual MCESG	MSG-centric	Embassy-centric	HQ-centric
A/	74.7	96.7	95.6	100
1/5	90.7	94.0	94.7	100
Tier	89.3	86.3	95.6	97.2
Experience-Request	57.3	88.0	92.4	91.1
Rank	79.3	71.3	96.0	92.7
Preferences	27.9	84.7	76.2	73.3

These models solve a minimum-cost network flow problem on a two-layer multicommodity network in which MSG experience level serves as the commodity. BALMOD is used to make initial assignments, whereas ASMOD is used to modify existing assignments.

To validate MSGAT and illustrate its usefulness in facilitating the assignment process, we have compared MSGAT's assignments to historical manual assignments from assignment cycles 4–10, 5–10, 1–11, 2–11, and 3–11. Assignments produced by MSGAT are superior to the manual assignments on nearly all MOEs for every historical comparison.

The most significant benefit that MSGAT offers is a substantial improvement in quality of MSG security at each detachment. On average, when compared with historical assignments, MSGAT assignments result in more embassies receiving A/-qualified MSGs, a higher rate of billets at 1/5 posts being filled, a smaller percentage of MSGs being assigned to repeat tiers, a higher percentage of embassies receiving requested MSG experience levels, a higher percentage of embassies receiving required MSG ranks, and a higher percentage of MSGs being assigned to one of their preferences. These factors combine to make a more satisfactory assignment picture at all levels. Not only does MSGAT outperform the manual assignments with respect to overall MOE satisfaction, but it also significantly reduces the amount of time spent by MCESG creating assignments and allows MCESG to focus on other important responsibilities.

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AUTHOR STATEMENT

The authors' views expressed in this article are made available for the purpose of peer review and discussion and do not necessarily reflect the views of the United States Marine Corps, the Department of the Navy, the Department of Defense, or the United States government.

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