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14. ABSTRACT: Deploying Army units continuously through operational requirements creates a potential burden on readiness and operational availability. Forces currently committed to Operation Iraqi Freedom limit America's ability to respond to other contingencies around the world. One way to study this problem is through modeling and analysis of deployment tempo. Accurate predictions of deployment tempo rely on careful comparison of forecast cases of demand for available force structure over the period of interest. The US Army Center for Army Analysis uses several methods of modeling unit participation in operations to determine the best alternatives for the many possible policy and force structure options. These variables include use of the Reserve Component forces, rotation rule policy, potential substitutions, and operation size, duration, and frequency. The Study of Total Army Rotation Initiatives (STARI) uses a custom built discrete event simulation model to study this problem. The FULCRUM model simulates unit rotations for various alternatives of regional posture of engagement and unit manning. STARI presents an analysis of alternatives using the FULCRUM model to compare readiness and deployment tempo measures of effectiveness.

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deployment tempo, DEPTEMPO, rotation rule, unit manning, army force structure, scheduling, total army analysis

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DEPLOYMENT TEMPO ANALYSIS IN THE US ARMY

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Deploying Army units continuously through operational requirements creates a potential burden on readiness and operational availability. Forces currently committed to Operation Iraqi Freedom limit America's ability to respond to other contingencies around the world. One way to study this problem is through modeling and analysis of deployment tempo. Accurate predictions of deployment tempo rely on careful comparison of forecast cases of demand for available force structure over the period of interest. The US Army Center for Army Analysis uses several methods of modeling unit participation in operations to determine the best alternatives for the many possible policy and force structure options. These variables include use of the Reserve Component forces, rotation rule policy, potential substitutions, and operation size, duration, and frequency. The Study of Total Army Rotation Initiatives (STARI) uses a custom built discrete event simulation model to study this problem. The FULCRUM model simulates unit rotations for various alternatives of regional posture of engagement and unit manning. STARI presents an analysis of alternatives using the FULCRUM model to compare readiness and deployment tempo measures of effectiveness.

KEYWORDS: DEPTEMPO deployment tempo, rotation rule, unit manning, army force structure, scheduling

PURPOSE OF THE STUDY

Total Army Analysis (TAA) generates Army wartime force structure requirements through combat modeling of selected scenarios. Priority for specific requirements goes to wartime force apportionment. However, the Army must also conduct day-to-day operations in support of National Command Authority (NCA) engagement and Combatant Commander (COCOM) responsibilities. Forward presence posture of engagement (POE) requirements for rotational forces may exceed these wartime requirements for certain unit types. The Study of Total Army Rotation Initiatives (STARI) supports TAA through determination of peacetime requirements for the Army to meet a set of projected operational POE requirements. Army Deputy Chief of Staff for Operations-G3 (G3) developed two cases of rotational POE forward presence for initial TAA feasibility analysis (figure 1) in the 2010 timeframe. The purpose of the study is to balance Army force structure against these peacetime rotational requirements. This allows senior Army officials to make an informed decision on risk to wartime and peacetime force structure allocation.

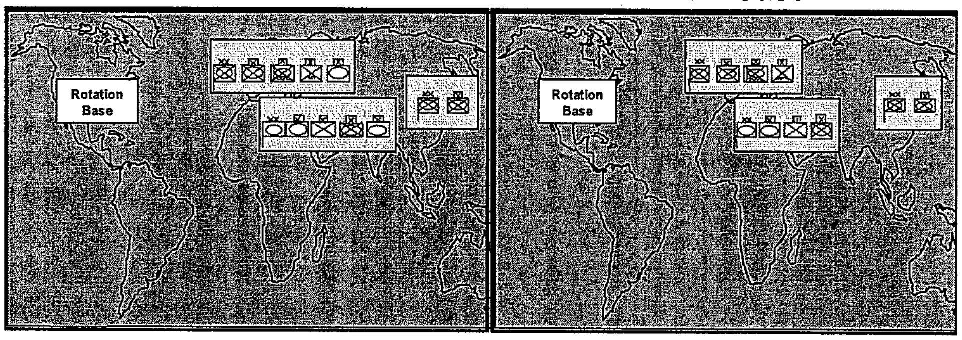
STARI consists of two related studies. Both efforts examine Army force structure from 2009-2011 for the most recent analysis, TAA-11. The results of STARI define requirements and illustrate the effects of policy on different forward presence rotational POE cases. The first portion of STARI analyzes the feasibility of high and low cases of Army forward presence in concert with Unit Manning (UM). The second portion of the study develops rotational requirements for use in sourcing Army units for TAA. Only the first portion of STARI will be discussed in this paper.

G3 establishes the future rotational forward presence force structure using a variety of methods. Some requirements are capabilities-based Mission Task Organized Forces (MTOF) developed by subject matter experts. Others are derived from current operations expected to continue for at least eight more years. The two cases in figure 1 encompass a theoretical high and low bound of future rotational POE. This provides maximum and minimum rotational feasibility constraints for further examination.

The 6 BCT case in figure 1 anticipates four mechanized or armored Brigade Combat Teams (BCT), one Stryker BCT, one airborne BCT, and one infantry battalion forward deployed for regional engagement and smaller-scale contingency (SSC) operations in the future. The 9 BCT case analyzes robust regional engagement involving 6 heavy BCTs, one Stryker BCT, and 6 light / airborne infantry battalions. All forces in both cases deploy from fixed Continental United States (CONUS) bases. There are no forward stationed forces in Korea, Germany, or elsewhere. Both cases involve the rotation of Active Component (AC) forces only.

ROTATIONAL DEPTEMPO STUDIES

The U.S. Army's current demand for unit deployments results from non–traditional missions including foreign humanitarian assistance and peacekeeping. Current operations in the Global War on Terrorism (GWOT) illustrate this point. While direct conflict lasted only a few months in Afghanistan and Iraq, no one can accurately anticipate how long it will take to stabilize these two countries. Currently (September of 2003), 16 of the 33 AC Army brigades were deployed to Afghanistan and Iraq. More than nine U.S. brigades are scheduled to replace these units. This rotation scheme places significant demand on the Army and its soldiers.



- Analysis of Active Component (AC) brigades only
- Cases are illustrative of possible scenarios based on future strategy
- All forces rotate from CONUS base
- No combat brigades permanently stationed overseas
- Some support units may continue overseas basing

Figure 1. 2 Cases of 2010 Rotational POE Forward Presence

The main goal of force structure planning is to achieve the correct quantities of unit types in the active and reserve components based on anticipated capabilities requirements. Realization of this goal often conflicts with minimizing variation in deployment time among units of the same type. Deployment tempo (DEPTEMPO) is defined as the number of days the unit trained or deployed overnight in a month. If DEPTEMPO is higher than policy allows, readiness, morale, family, and retention problems might arise. Also, high deployment rates inhibit unit training and availability for wartime requirements.

Historically, the measure of effectiveness (MOE) of DEPTEMPO is used to track unit deployments. DEPTEMPO is reported monthly on the Unit Status Report (USR). This MOE can be forecast for a set of requirements based on unit availability and assumptions. Senior Army leaders often request analysis of policy changes on operational requirements and availability. DEPTEMPO and other metrics provide an analytical basis for senior decision makers to quantitatively evaluate options in a policy Analysis of Alternatives (AoA).

Rotational DEPTEMPO studies examine the balance of force structure to minimize unit deployment time and equitably distribute deployments among available units.[i] Figure 2 defines the major variables and MOE used to study rotational problems. "Rotation rules" are applied as theoretical constructs to compare cases and policy. Rotation rules prohibit units from participating in operational deployments, such as Bosnia or Kosovo, until a minimum time has passed since the last deployment. In these studies, AC forces typically follow unit utilization under rotation rules of 3, 4, or 5. The "rule of 3," for example, states that for every month a unit is deployed, it cannot deploy again for two months. Under the rule of 3, if a battalion is deployed to Bosnia for 6 months, then it is ineligible to

- R = # of Units by SRC in the rotational POE requirement *
- X = # Units by UIC available in supply* = pool
- L= Rotation length (months) = how long the deployment lasts
- r = Rotation Rule = Constraint against units deploying too often; used to compare available units against requirements
- t = Length of time period (months)
- DEPTEMPO = Percentage of deployed days out of available days for the pool during the time period
- Readiness = Percentage of units in the pool available during the time period
- c = # CTCs per year for pool = How often a unit goes to a Combat Training Center such as NTC or JRTC
- c_{INT} = CTC interval (months) = Constraint against units attending a CTC too often
- AOTR = Additional Overnight Training Rate (days) = Local deployment for training days per month a unit experiences.

***STARI types include (1) Mechanized / Armor BCT, (2) Light Infantry BN, or (3) Stryker BCT**

Figure 2. DEPTEMPO Study Variable Definitions

redeploy anywhere in the world for 12 months upon its return. There must be at least three units capable of meeting the Bosnia requirement in the inventory. Similarly, under the "rule of 5," 5 separate units would deploy to meet a single 6-month operational rotation requirement over a 30-month period.

G3 guidance for TAA 11 included using a rotation rule of 5 for AC forces and a rule of 10 for Reserve Component (RC) forces.[ii] Units are free to conduct training and other operations when not deployed. G3 develops requirements independently from resources. Army forces necessary for an operation depend on strategy and planning--not the Army's ability to sustain that requirement. Furthermore, examining the two cases of baseline overseas presence serves as a useful force sizing construct alternative to combat modeling. Once requirements are finalized, they are compared against current force structure to determine additional forces necessary and the risk of not creating them. Rudimentary calculations show us that sustaining the 9 BCT case is infeasible under the rule of 5 with current force structure. Ignoring the required type of BCT, the Army needs 45 AC brigades to maintain a rule of 5 for the 9 BCT case. There are currently 33 AC brigades in the inventory (not counting 75th Ranger Regiment). The 6 BCT case is feasible given current force structure.

This simple analysis belies the complicated nature of the study involved. For example, senior decision-makers must know the impact of future force structure decisions on Army Transformation to the Future Force. Execution of day-to-day operations cannot interfere with scheduled fielding of new equipment. Leaders also want to know the effect of rotational POE alternatives on readiness, training, costs, risk, and morale.

Future alternatives and programs impact the availability of forces. Army Transformation, UM, basing, technology, and force sizing issues all affect the practice of employing units to meet national strategy objectives. Rotational POE studies using DEPTEMPO analysis allow the Army to compare alternatives with accepted base cases. For example, national strategy implications including mobility may dictate continuous regional engagement in separate areas of responsibility of 5 active Army brigades at any given time. Under the rotation rule of 3, a "pool" size of 15 brigades (or 5 divisions) will be necessary to meet those requirements. Three different subsets of the 15-brigade pool will deploy for 6-month periods. The impacts of this policy depend on the types of brigades necessary for each requirement and each brigade's availability during the time period of interest.

Using MOE, analysts compare effects on Army forces if different policy options and requirements are implemented. Metrics, including DEPTEMPO and readiness, serve as comparison criteria for different cases of requirements and policy options for the AoA. DEPTEMPO analysis typically does not examine individual personnel tempo (PERSTEMPO) or emergency wartime deployments. Nor is it a measure to adequately account for impacts on equipment readiness (OPTEMPO).

The general approach to rotational DEPTEMPO analysis focuses on comparing supply and demand for unit types over time. Demand is a function of requirements for forward presence. Defense Planning Guidance (DPG) scenarios establish rotational forward presence cases as a series of operations in which the Army can expect to participate. Requirements are lists of units classified by Standard Requirements Codes (SRCs) for each operation in a case. Requirements include combat, support, and command and control forces SRCs necessary to conduct operations. Supply is a list of available units with Unit Identification Codes (UIC). UICs are the existing units of an SRC type. There are currently over 4,600 Army units – each having a unique UIC. Each specific unit is typed by one of over 600 SRCs. All units (UIC) having the same SRC can accomplish the same mission. UIC Supply is matched to SRC demand over the period of interest (typically 10 years) as a schedule of rotations. UIC deployment time and readiness are accounted for against the pool. The rotation rule is applied to ensure each UIC is not used within the specified minimum amount of time prescribed by the rule. Constraints applied during this matching process simulate application of policy to operations. DEPTEMPO studies use statistics to determine MOE differences between POE cases and policy options. In STARI, requirements and supply are aggregated at brigade level to simplify the study. STARI examines three types of brigade requirements; mechanized / armored, light infantry, and Stryker Brigade Combat Teams (SBCT).

UNIT MANNING

Former Secretary of the Army Thomas White implemented UM in the Army. In 2002, Secretary White tasked the Chief of Staff of the Army (CSA) to, "Enhance unit readiness via unit cohesion [and] stabilize individuals and units to the maximum extent feasible." The Secretary of the Army also requested analysis to determine the, "Impact on readiness and availability of forces, duration of rotational deployments, required force structure to support unit rotation policies, and impacts of rotations on UM." The 172nd Separate Infantry Brigade will test UM while it converts to a SBCT from 2003 to 2005. These manning initiatives are scheduled for implementation Army-wide over the next five years.[iii]

UM proponents believe that Army combat units function better when their personnel stay together for longer periods of time. The 1999 Rand study *Stability and Cohesion as Criteria for Personnel*

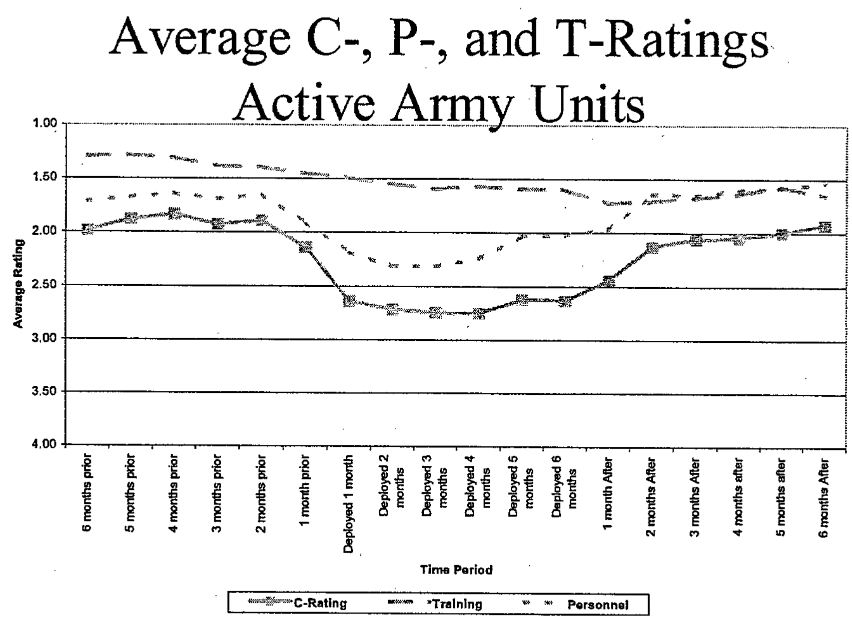


Figure 3. Deployment Impacts on Readiness (La Barbera, 2001)

Assignment and Rotation Policy posited that, "military units whose members collectively possess cohesion…tend to perform better than otherwise similar units lacking such characteristics" (Winkler et al, 1999). Furthermore, Winkler states, "Absence of stability (turbulence) can reduce soldier morale and unit cohesion."

Manning initiatives involve 3 courses of action (COA). The first COA is the Individual Replacement System (IRS). IRS is the basis for all personnel replacements in units today. IRS schedules individual soldiers for programmed and unanticipated losses based on priorities. IRS serves as the base case to establish quantifiable metrics for the AoA in STARI.

All units report readiness monthly on the USR. This report specifies a unit's ability to accomplish their assigned mission. Readiness categories are C1 through C5. C1 means the unit can accomplish its wartime mission. Units with readiness of C3 or below are considered unavailable for immediate deployment. Units base their readiness reports on their available personnel and equipment. USR also accounts for whether or not units are properly trained.

Hix' 1998 Rand study suggests IRS causes severe problems with unit readiness. Hix found that units not deployed to operational rotations experience a decrease in unit readiness. These units transfer personnel to deploying units to fill "peacetime nondeployable" spaces.[iv] Hix' work is supported by historical readiness studies at the Center for Army Analysis (CAA). La Barbera (2001) found that units deploying to Bosnia experience a drop in readiness before and during deployment. Figure 3 depicts average personnel, training and overall readiness ratings for all units deployed to Bosnia from 1998 to 2001. Units with the highest readiness are depicted at the top, with 1.0 being the best.

UM proponents suggest that, under IRS, increases in Permanent Change of Station (PCS) moves due primarily to the necessity for overseas basing result in overly repetitive training or unqualified small units and weapons crews. Conversely, soldiers are not allowed to leave UM assignments for schooling or PCS during the unit life cycle. UM may also reduce PERSTEMPO from deployments and provide soldiers with a more predictable family life. Tillson's 1999 study lends credence to these suggestions. Upon analysis of soldiers' attitudes, Tillson discovered that soldiers react negatively to PCS moves combined with DEPTEMPO. Tillson concedes, however, that, "resource and manning shortages in their units and problems with leadership...seemed to loom larger in [soldiers] concerns than problems of tempo" (Tillson, 1998). Army leaders experimented with UM initiatives several times during the past 50 years to alleviate problems with IRS. Elton's 2002 article *A Unit Manning System for the Objective Force* summarizes past attempts and the reasons they failed.

The second UM COA is referred to as Life Cycle (LC) UM. This system proposes to build each unit individually over a Build and Train (BT) period of 9 months. When all personnel arrive at the unit at the same time under UM, small units and weapons crews will have stability. LC units are utilized for the remainder of their life cycle. Then all unit personnel leave by PCS to other assignments or leave the Army. Once the unit's life cycle is complete, it undergoes another BT period of 9 months with all soldiers arriving at the same time.

Cyclic Continuous (CC) UM is the third manning COA. CC UM entails building each unit for 9 months as in LC UM. Then 25-33% of personnel are replaced annually in programmed "packages." This regeneration time, takes from 1-3 months when other, low priority tasks including maintenance, leave, and support are accomplished. After every regeneration interval of 10-15 months, the unit gets another package. Figure 4 illustrates the UM life cycle of COA 2 and 3. This cycle of build, deploy, then build again must be modeled against requirements to determine the steady-state effects of UM.

During the build and train periods and regeneration periods of the unit life cycle, a unit is not ready due to training. Hence, there is a real reduction in readiness with implementation of UM when compared with current practice under IRS. This potential readiness reduction requires a full examination of Unit Manning initiatives and their potential effects on long-term day-to-day operations of field units. Any systematic reduction in readiness has profound impacts on unit operations and national security. This must be analyzed to provide senior leaders with the information for sound decisions on future policy.

MEASURES OF EFFECTIVENESS

While DEPTEMPO is typically the metric of choice for comparison of rotation options, other metrics add to the analysis. *The Army Rotation Rule Project* (TARRP) metrics include additional force structure required and number of reserve soldiers deployed. Heidelbaugh's 2002 *Unit Rotation Analysis – Korea* (URA-K) study included stationing feasibility and equipment / personnel compatibility in rotating units. Generally accepted official Army MOE such as readiness and DEPTEMPO give credibility to the results.

Severe constraints are imposed when adopting rotation rules and UM policy. These constraints necessitate solutions to meet NCA requirements while minimizing unit deployment. These solutions currently take one of three forms: reduced presence, unit or component substitution, or lower rotation rule. This analysis highlights the burden of rotations on AC units. There are rarely sufficient AC units to meet requirements. Therefore, a slack metric is necessary to account for infeasible solutions.

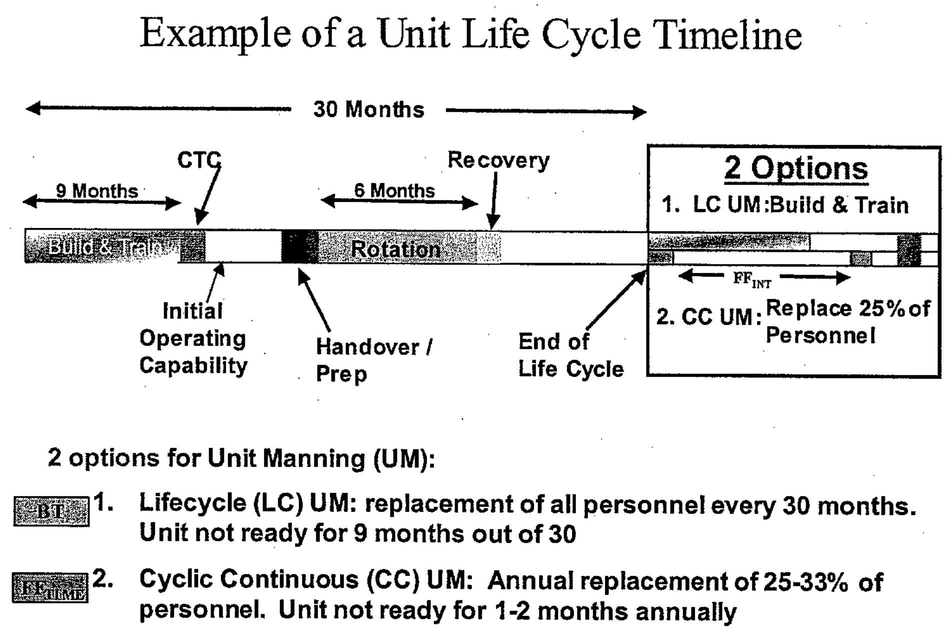


Figure 4. Unit Life Cycle under Unit Manning (UM)

Readiness impacts discussed above necessitate the use of readiness as a MOE in the analysis of alternatives. Readiness is reported monthly by every unit in the active Army and is well understood by decision makers. One limitation of the study is that the current definitions of readiness are used. Wartime readiness is reported on the USR and "peacetime nondeployables" (as sighted by Hix) have no impact on USR readiness.

Given La Barbera's conclusions, it is necessary to consider whether any model readiness decrement should be applied to units under UM COA 1, IRS. A review of AC divisional USR readiness data for June through September of 2003 shows that very few units have readiness problems during deployment.[V] In this time period, an average of 5.2% of the approximately 400 AC divisional units reported overall readiness below C2. Only 3 individual units were unready due to personnel shortages during this period. Of these three units, none are combat units. Of the 13 units reporting C3 due to training, 10 were combat units. Almost half of all units analyzed were deployed during this time. Therefore, no readiness decrement is applied to units in the model under UM COA 1 for current IRS practice.

Potential decreases in personnel turbulence and increases in unit cohesion due to UM are not evaluated as part of this study. The Army does not use cohesion or turbulence as accepted metrics today.[vi] This fact inhibits analytical analysis of these potential UM benefits. STARI analysis uses historically accepted MOE of readiness and DEPTEMPO. The exception to this is the need for development of a slack metric to produce meaningful analysis. It is difficult to predict with any surety which of the 3 manning COAs the Army may choose in future circumstances. Therefore, the slack metric must be general and applicable to all three UM COAs. Fixed requirements allow comparison of all 3 UM COA. Units are isolated resources in the system and are scheduled for rotations. Arrivals (operational rotations) must bypass unavailable resources as in a discrete event simulation but the MOE must compare differences in the AoA. Having a standard queue would serve no purpose because requirements must be met on time. Furthermore, the slack metric cannot apply to UM build periods, as no policy exists for allowing these periods to be of flexible duration. Any flexibility in the UM variables is insufficient to balance rotations against the rule of 5 rotation policy. Slack in UM intervals also makes the MOE less rigorous. Eliminating any flexibility in the UM policy application algorithm reduces variability in the model and makes the algorithm easier to code. Consequently, the model is easier to verify.

CAA developed "missed rotations" as the slack metric. Missed rotations are the scheduled deployments that units cannot complete due to policy limitations such as the rotation rule and UM. The missed rotations metric is the total number of infeasible deployments over the 10-year period. The slack metric reflects any number of policy alternatives available for senior decision-makers. One alternative is to increase units allocated to rotational missions through force structure realignment or RC participation. Or, the Army could allow increased DEPTEMPO in the form of a lower rotation rule.

For ease of comparison in the AoA, DEPTEMPO and readiness are averaged over the 10-year simulation period. Furthermore, these metrics are converted to averages expressed as a percentage for the entire run and pool size. Readiness is the fraction of units available out of the total pool per month. The Future Unit Life Cycle, Rotation, and Unit Manning (FULCRUM) model uses readiness, DEPTEMPO, and missed rotations to compare POE alternatives under UM.

FULCRUM CONCEPT

To determine the potential impacts of UM, a model must schedule the unit life cycle from figure 4 with anticipated requirements for the 6 BCT and 9 BCT POE cases. Past studies of rotation problems vary in level of resolution. At the macro level, studies examine force structure across the Army for sufficiency against a set of rotational requirements. Macro level studies typically involve future forces and requirements that may be somewhat vague. Unit substitutions can complicate macro level studies. CAA's TARRP (Shearer, 2001) used a matching process to virtually schedule demand requirements and collect DEPTEMPO statistics. [vii] While useful for detailed analysis, the methodology in TARRP created enormous pre- and post-processing burdens on analysts. Also, verification of TARRP output was a constant and difficult challenge to overcome. However, the TARRP methodology serves as the basis for rotation problem study. TARRP matched requirements to available forces by SRC with a rotation rule constraint. TARRP used the slack metric of "units short" and created force structure for comparison in the AoA. This metric allowed detailed comparison of AC and RC force structure against rotational requirements and policy alternatives.

The micro level of DEPTEMPO studies involves examining some small sub-element of a rotation problem. For example, Heidelbaugh's unpublished 2002 URA-K study analyzed potential rotations to Korea for light infantry battalions. Analyzing two or three SRC as in URA-K allows for greater accuracy using a linear program. Heidelbaugh's study analyzed near-term rotation options. This allowed a much more refined study including stationing options, training considerations including detailed equipment and personnel comparisons by SRC.

CAA used Microsoft Excel spreadsheet-based schedules of rotations to provide cost and verify DEPTEMPO MOE in Heidelbaugh's URA-K study. Accounting for unit locations by month provides visualization that is easily understood. Visual depiction on a calendar using colored bars serves as a graphic display of the model run for ease of verification. Many division long-range training schedules in the Army use this method. Additionally, Excel's mathematical processing ability allows assignment of values to each cell. Updating these hand-generated schedules proved time-consuming and precluded in-depth AoA. Automating this rotation scheduling in Visual Basic for Applications (VBA) for Excel enabled modeling of the unit life cycle (figure 4).

Modeling of the potential system is essentially a scheduling problem. Units are resources and operations arrive in discrete intervals. The example of a unit lifecycle depicted in figure 4 is discretely modeled in FULCRUM for all UIC in an SRC with the POE case requirements for that SRC. Durations of deployments, aggregated with training and other events, provide the DEPTEMPO metric value. UM build and regeneration time periods then become preparation or maintenance time in the steady-state system. Accounting for the build time decrements readiness for the COA analyzed. Rotation rules limit the time between unit deployments. The myriad UM variables, potential excursions, and difficulty of creating and manipulating schedules by hand drove the creation of the custom, automated FULCRUM model.

Initial senior leader guidance on UM was vague. Many of the concepts inherent in UM impact current policy. Furthermore, implementing significant changes to a personnel system that manages over 480,000 active duty soldiers is a daunting task. Creation of FULCRUM began when the Unit Manning Task Force developed acceptable courses of action shown in figure 4.

FULCRUM requires easily updated inputs through a customized Graphic User Interface (GUI), and customized results specific to the problem and metrics defined. These factors directly influenced creation of a custom model. Microsoft Excel's built in programming capability, VBA, provided the catalyst for building the FULCRUM model.

Model flexibility proved extremely important in order to allow a wide range of policy analysis. The ill-defined nature of the problem and broad range of potential options (figure 1 and figure 4) created a large number of variables in the model.

Requirements are specified in terms of BCT, the basic Army combined arms fighting force. BCT are also the chosen level of analysis for UM. There are five basic types of BCT: Light (which includes Airborne and Air Assault), Mechanized, Armored, Stryker, and Armored Cavalry Regiment (ACR). BCT are used as a surrogate for SRC to limit the problem size. Each BCT type requires individual analysis due to varying numbers of each type in the Army and different quantities of each type as stated in the POE requirements in figure 1. Mechanized BCT are almost always substitutes for armored brigades and vice versa.[viii] This means that only three types of units are accounted for in the analysis: heavy (mechanized and armored), light, and Stryker BCT. Substitutions are included in the pool giving an aggregate number of all units that can fill a specific requirement.

ASSUMPTIONS

As modeled, UM times are deterministic. If the build time intervals are not fixed within the model another degree of freedom limits the accuracy of the analysis. Furthermore, no policy specifies acceptable variation in UM timelines. FULCRUM uses the most likely course of action developed by the Unit Manning Task Force (UMTF). Therefore, for modeling accuracy the regeneration interval is considered a fixed value, separate from the regeneration time. Alternately, if the regeneration interval is allowed to vary by policy change, the slack variable of missed rotations may decrease for a run. Also, instituting UM will have no other adverse effects on readiness and readiness will otherwise (for equipment and training) be the same for all UM COA.

USR DEPTEMPO data does not adequately detail a unit's non-deployment training time. This time factor is known as the Additional Overnight Training Rate (AOTR). AOTR consists of overnight on-post training such as gunnery that is conducted but not at a set interval. AOTR varies widely between types of units and times of the year. Past analysis from TARRP and the Army G3 indicate AOTR averages about 4 days per month that a unit is not deployed. This is the assumed value used in FULCRUM.[ix]

FULCRUM is a steady state model. The STARI methodology assumes that supply and demand do not change over the course of a run. Therefore, while FULCRUM accounts for transformation periods, we must assume that this transformed unit still meets the original requirements. Thus, the model is not an exact solution to a particular set of inputs but a mathematical tool for estimating the steady state consequences of UM policy changes. FULCRUM provides needed insight into a high-level Army issue.

Under LC UM, all personnel PCS from a unit once it enters a build and train period. FULCRUM methodology assumes that the rotation rule doesn't apply after a LC build phase. These build periods must be staggered over the whole pool of units to avoid overwhelming the training base and installation support facilities. The FULCRUM UM scheduling algorithm staggers build times between units by 1 month to represent this actual limitation. UM policy assumes most soldiers leave the Army at the end of a unit life cycle and the rest are carefully managed on an individual basis. The impact of this proposed policy on PERSTEMPO requires further analysis beyond the scope of this study. Scheduling Combat Training Center (CTC) rotations is the last priority in the model's code.[x]

FULCRUM DEVELOPMENT

Variables from figure 1 and figure 4 formed the basic inputs to the model. CAA established ranges for these inputs from common practice, other studies, policy, or feasibility constraints. Additionally, Army Transformation schedules must be included in any analysis of future operational requirements. A GUI allows the analyst to easily adjust many of the model variables (figure 5). Input options allow the inclusion or exclusion of UM in the runs. Furthermore, Excel's input validation feature aids in verification of the model. Analysts cannot enter values outside the feasible ranges of UM and rotation variables. CAA developed algorithms in VBA to schedule operational rotational deployments and CTC rotations using values from the input sheet (figure 8). Another algorithm schedules UM.

Output for a representative FULCRUM run is depicted in figure 6. The output shows a 10-year schedule of activities for each brigade in the rotation pool. Each run simulates unit locations by month from left to right for every brigade in the pool. The number and duration of rotations in the POE case are depicted on the schedule. FULCRUM aggregates metric values of unit deployment and readiness for each month.

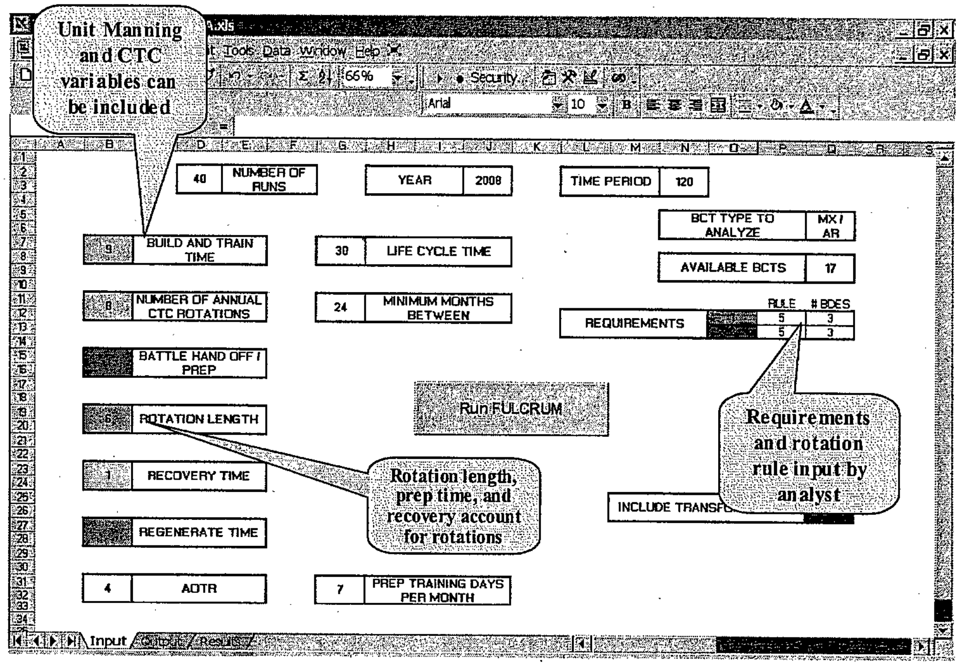


Figure 5. FULCRUM Input Sheet

In FULCRUM, insufficient pool size to meet a given rotation rule for the requirements will cause a missed rotation. The output displays missed rotations in red (figure 6) while the program records summary statistics. In this way, the "price" trade-off of a rotation rule policy is determined and visually displayed for each POE analyzed.

The FULCRUM results sheet in figure 7 depicts all of the inputs and the MOE results for each batch of runs. The results for each run are calculated based on strict accounting of unit deployments and activities. When aggregated, this bookkeeping establishes the numeric values for the MOE. Using Excel's statistical processing capability enables quick analysis of all runs in the batch. Thus, changing factors through an experimental design yields quantifiable results for analysis of the three UM alternatives.

Figure 8 displays the higher logic of the VBA code used in FULCRUM. The logic incorporates three versions of the basic scheduling algorithm also shown in figure 8. FULCRUM uses variations on the scheduling algorithm for generating UM build and regeneration periods, operational rotations, and CTC schedules.

The model can compute the average build time over the period of interest for further examination of UM initiatives. Build time affects readiness and, when added to deployment time, reduces unit availability for contingency operations. Furthermore, the model can compute the number of missed CTC rotations to determine the impact of the POE cases and UM initiatives on unit training opportunities and the training centers usage. To limit the scope of the study, neither of these metrics was used in STARI. Transformation is scheduled by quarter with a duration allocated for unit set fielding and unit training upon introduction of the objective force vehicles. It can also account for unit

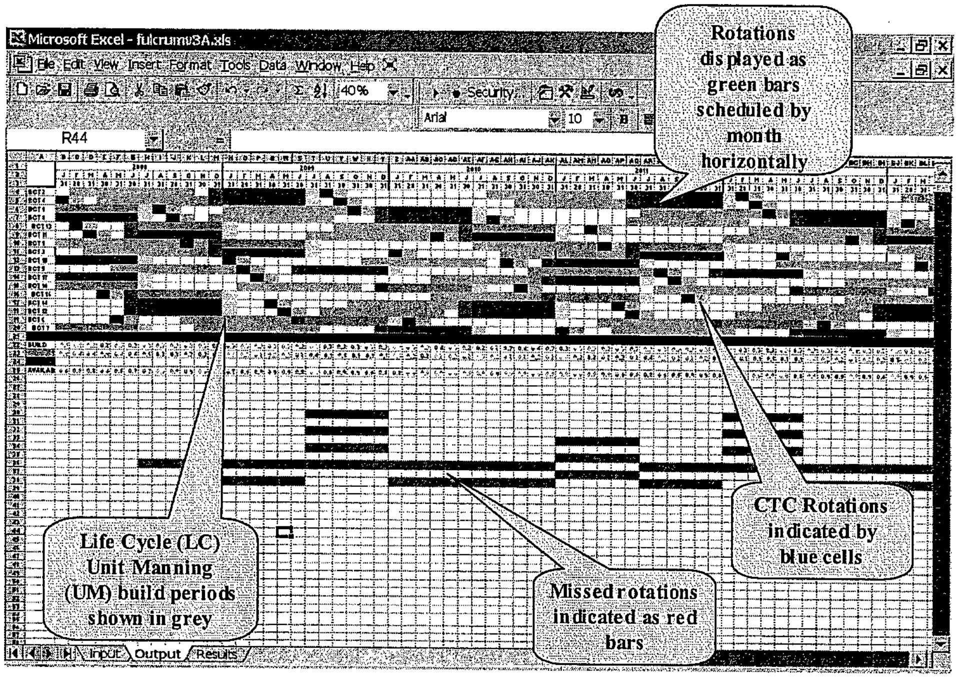


Figure 6. FULCRUM Output Sheet

conversion to SBCT in the near term using the same methodology. STARI incorporates the Army Transformation schedule from May 2003 as developed by the Army Deputy Chief of Staff for Programs-G8 (G8).

FULCRUM's flexibility gives a broad range of uses across the operations research problem spectrum. In the Department of Defense (DoD) community, FULCRUM is applicable to scheduling almost any size military entity resource to requirements. It can be used to schedule personnel to daily shifts with minor modifications. Tailoring MOE for a particular problem is much simpler in FULCRUM than in a standard simulation.

For example, analysts can compare costs between alternatives by dynamically linking formulae to cost data in the model code. Also, FULCRUM can include stochastic events through Excel's built in mathematical functions. This will allow CAA to analyze DEPTEMPO related to unplanned deployments including humanitarian assistance and domestic response SSC operations. Also, the model output needs no interpretation by a trained analyst. The ease of use of the FULCRUM model and the fact that MS Excel is more widely available than off the shelf simulation packages makes the model widely distributable within DoD.

MODEL VARIABILITY

FULCRUM is a discrete model. Requirements and UM build periods arrive at uniform time intervals. This limits STARI to a comparison of steady-state alternatives. Inter-arrivals and event durations are variable between batches of runs but not within the batch. Given the same inputs the results will be exactly the same for every run. The scheduling algorithm (figure 8) developed for the FULCRUM model is fairly simplistic. It begins with the first time period and schedules requirements and UM variables in

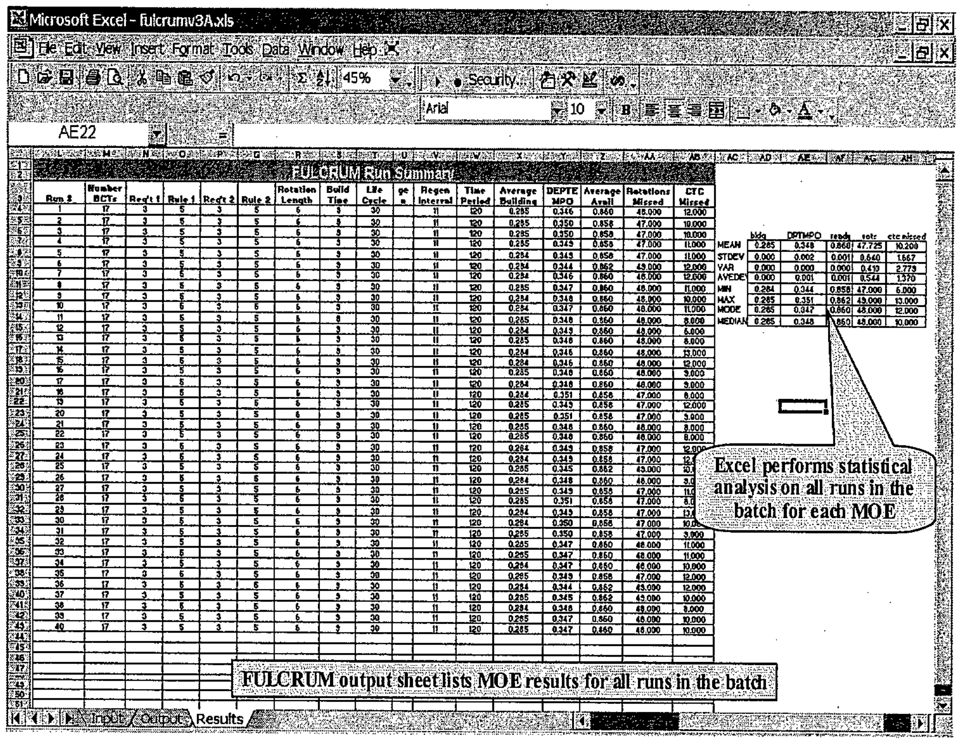


Figure 7. FULCRUM Results Sheet

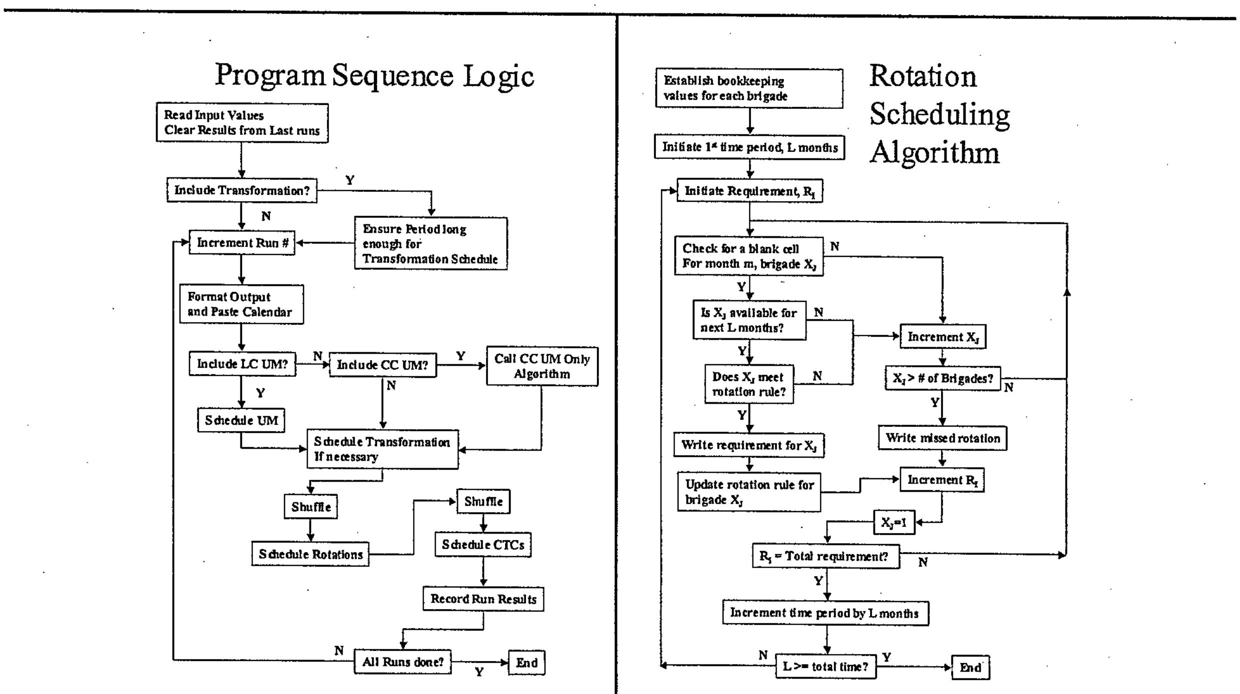


Figure 8. FULCRUM Logic

sequence from top to bottom and left to right. This algorithm is easy to code and verify. The algorithm does not compare one unit's UM schedule with another when scheduling rotations. Therefore, each run has some scheduling inefficiency. This problem manifests itself only in runs involving UM variables.

To remedy this problem CAA introduced variability into the model through a shuffling algorithm. The shuffling algorithm randomly changes the order of all BCT after the UM build phase and the requirements scheduling phase.

Shuffling randomly necessitates statistical analysis of results across runs in a batch. Parametric analysis provides a measure of how often the BCT must be shuffled and of the effect of choosing a different random seed. This analysis also gives insight into the need for more runs per batch. Statistical comparison of the means of the variables demonstrates that there is a difference between running the model 30 times and running it 100 times per batch. There is no statistical difference when the random seed value is changed or when the number of times the brigades are shuffled is changed.[xi]

Batch run times are dependent upon the number of runs and number of times shuffling. Therefore, it is important to examine accuracy in evaluating the need to conduct 100 runs per batch. The difference between means for the metrics of readiness and DEPTEMPO is no more than 0.3% for the parametric analysis runs. Also, the difference across runs for the missed rotations metric is less than 0.5. The standard deviation between the means of all runs is extremely small. This accounts for the statistical difference between sets of runs when changing variability factors in the model. The resolution of each MOE is the nearest whole number. Thus, a fraction of relative error has only negligible bearing on the AoA. Furthermore, there is no propagation of the error as the results are the observed values. Therefore, in the interest of short run times, CAA used 30 runs per batch.

MODEL VERIFICATION

CAA established an acceptable range of inputs for each variable in the model. Excel's "data validation" function allows only that range of values as input. CAA tested the model for the high and low values of each variable with multiple combinations of the nontrivial factors. Of course, it is impractical to check every combination of variables for the established ranges. CAA determined that the FULCRUM output and results are acceptable.

During verification, FULCRUM developers gave careful attention to computation of MOE and ensuring the output generated the right graphical values for each set of inputs. Several variables are trivial and do not affect the output or results. Some variables were fixed throughout the runs to limit the scope of STARI. These variables represent the most likely course of action. For example, examining multiple excursions of BT time may impact personnel policy but not give much insight into readiness. All BT excursions are basically the same UM COA. Figure 9 depicts the study variables used in the model and their treatment. Shaded portions show variables that changed depending on the POE case, type of BCT being examined, or the excursion being evaluated.

Variable	Range	Trivial	Fixed	Excursions
Number of Runs	1-100	No	30	All
Year	2000-2010	Yes	2008	All
Time Period (t)	60-120	No	120	All
POE Requirement (Ri)	0-5	No	Case Dependent	
Rotation Rule (r)	1-5	No	Excursion Dependent	
Build and Train Time (BT)	0-12	No	9	4,5,6,7
Life Cycle (LC)	11-120	No	30	4,5,6,7
Available BCTs (X)	4-33	No	Type BCT Dependent	
Number of CTC Rotations	0-20	No	Type BCT Dependent	
Months between CTC Rotations	18-30	No	24	All
Battle Hand Off / Prep Time	0-3	No	1	All
Rotation Length (L)	6-12	No	Excursion Dependent	
Recovery Time	0-3	No	1	All
Regeneration Time (FF_{time})	0-3	No	2	6,7
Regeneration Interval (FF_{int})	0-15	No	12	6,7
Additional Overnight Training Rate	0-10	Yes	4	All
Prep Training Days Per Month	0-10	Yes	7	All

Figure 9. FULCRUM Variables and their Treatment

	Available	Required		CTC Rotations*
		6 BCT Case	9 BCT Case	
Mechanized/ Armor BCT	17	4	6	8
Light Infantry Battalions♣	29	4	5	15
Stryker BCT	4	1	1	2

*Per Year

♣ A battalion is one-third of a BCT. Units changed for light infantry because requirements are not specified in whole brigades.

<u>FULCRUM base case:</u>

- No UM
- 1 / 6 / 1 months Prep / Rotation / Recovery
- Rule of 5
- No Transformation
- AC only
- Cavalry regiments not included in analysis

Figure 10. Requirements for Forward Presence cases

BASE CASE AND EXCURSIONS

STARI seeks to communicate a representative understanding of the costs and benefits of different forward presence cases and UM COA. The results must compare the desired policy (rotation rule of 5 with 6 month deployment duration) to determine the feasible region of alternatives for UM. Figure 10 illustrates the number of BCT required for each rotational forward presence POE case. Figure 11 lists the excursions for both forward presence cases. Establishing the rule of 3 has generally been considered the Army goal before the Army G3 established the TAA policy of rule of 5. However, allocating four units to every rotation requirement (rule of 4) may be an achievable compromise between increased DEPTEMPO and missed rotations.

STARI examined the most likely UM values. The UMTF envisions a 9-month build period (BT) to create a combat ready brigade. Under LC UM the unit begins another 9-month build period at the end of its 30-month life cycle. Cyclic continuous UM mandates 1-month periods of regeneration after every 11 months of utilization. Excursion 5 and excursion 7 examine mitigation of the UM readiness reduction. Increasing the rotation length, L allows more efficient use of a unit within its life cycle. This is particularly true in LC UM because the unit disbands after 30 months and the rotation rule no longer applies. Of course, there are many other effects of lengthening rotation times including less movement costs and more PERSTEMPO. These other effects are not included in the analysis. Reducing the rotation rule in CC UM (excursion 7) allows for trade-off analysis for a decision-maker.

The UMTF initially ruled out both UM mitigation options (excursions 5 and 7 in figure 11) as alternatives. However, both excursions must be considered because they are current practice in actual Army operations today. Mechanized/armor, SBCT, and light infantry requirements are all compared separately for each forward presence COA. A total of 7 batches of runs were conducted for each unit type (figure 11). Results for the 9 BCT case and 6 BCT case are shown in figures 12 and 13, respectively. There is one chart for each unit type. Each chart shows the three MOE for each unit type across the base case and six excursions. Blue indicates the average readiness, green indicates DEPTEMPO, and red displays the number of missed rotations. Each chart depicts two scales. DEPTEMPO and readiness are displayed as a percentage across the pool for the 10-year time period. The missed rotations metric shows a total number for the entire 10-year time period.

ANALYSIS AND CONCLUSIONS

The results of the AoA in figure 12 clearly demonstrate the Army is incapable of meeting the requirements of the 9 BCT base case with current AC forces. The charts of figure 12 also demonstrate much more. Readiness decreases across the pool of units upon implementation of UM. For mechanized and armor forces, the requirements cannot be met under the base case or any excursions. Furthermore, reducing the rotation rule also reduces the number of missed rotations but increases deployments on units in the form of DEPTEMPO. The SBCT and light infantry base cases are feasible if the Army allows slight policy flexibility. The Army is capable of fulfilling requirements under LC UM in the 9 BCT case if reduced readiness is accepted, rotations are 9 months long, and some rotations are filled by RC units.

If UM is implemented, certain efficiency benefits result from LC UM because units are no longer bound by the rotation rule. PERSTEMPO management is important in that case. The Army must ensure that individual soldiers are not taken

COA 1 NO UM IRS	**1. Base Case (Rule of 5)** **2. Rotation Rule of 4** **3. Rotation Rule of 3**
COA 2 LC UM	**4. Life Cycle UM** ➢ **Rule of 5, Build Time (BT) = 9 months** ➢ **Life Cycle (LC) = 30 months** **5. Excursion 4 with Rotation Length (L) = 9**
COA 3 CC UM	**6. Cyclic Continuous UM** ➢ **Rule of 5, BT = 9, LC = 30,** ➢ **Regeneration Time FF_{TIME} = 1 month** ➢ **Regeneration Interval (FF_{INT}) = 11 months** **7. Excursion 6 with Rule of 4**

Figure 11. STARI Excursions

from a unit that just deployed and placed into another unit in its build and train phase preparing for a rotation.

Inefficiency results in the model from the inclusion of CC UM due to the assumed inflexibility of the regeneration interval. In CC UM, the build periods are much more frequent. This causes major scheduling problems. Therefore, the regeneration interval must be a flexible amount of time. For example, an acceptable regeneration interval may be 12 months plus or minus 2 months. Then, a unit's higher headquarters must carefully manage the regeneration interval depending on deployments. However, this policy necessity may be at odds with other constraints for UM including professional schooling and training opportunities. These second order impacts are not included in STARI.

Results in figure 13 demonstrate it is easier for AC forces to implement the 6 BCT case. However, mechanized and armored force rotations under this POE will still be problematic. This presents challenges for the Army in establishing a rotation rule of 5 and a UM policy. These challenges can be met in several different ways. The first option is to reduce presence in certain geographic regions or to have gaps in presence. For example, the Army may consider a policy of three 6-month rotations to a certain area every two years. Then, presence in that region would be less than full—thereby increasing operational risk. Another option is for reserve forces to ease the burden by supplementing rotations. Another potential option is for the Army to balance force structure by creating more brigades available to meet future rotational POE requirements.

CAA ran dozens of other FULCRUM excursions as part of the STARI study. These results show that transformation has minimal impact on UM and rotation initiatives. Furthermore, there becomes a DEPTEMPO discrepancy between units in the same pool as L, the rotation length, increases. Discrepancies may be as much as 20% in deployment time for units of the same type over the 10-year period. Other findings indicate that CTC opportunities may be reduced by up to 2 per year for AC brigades based on the 9 BCT case. Also, strategic reserve requirements have little impact on the results.

Availability for contingency operations decreases with implementation of the new manning concepts. This may result in the average availability of only 5 heavy brigades at any given time depending on the requirements and UM policy. So, if a major contingency operation occurs during the 10 year time period, there may be insufficient forces to execute the war plan on time. UMTF proponents argue that forces deployed as part of the future rotational POE will be better situated (geographically) to react to the most likely threats.

FULCRUM allows quick analysis of other excursions as required by the Army staff. It can be easily updated to generate custom MOE without the need for an expensive software package. Also, FULCRUM is exportable to any computer with MS excel.

The broader implications of STARI results must be considered with the proposed manning initiatives. The crux of the problem begins with an inability to quantify the value of UM over the current method of IRS. A readiness decrement may be worth improved unit cohesion and reduced personnel turbulence in Army units. However, these MOE must be defined in a quantifiable manner and accepted by senior decision-makers. The results of STARI indicate that there are trade-offs to any course of action involving future POE rotations. Successful mitigation of the UM readiness reduction is possible with longer rotation times under LC UM and lower rotation rule under CC UM.

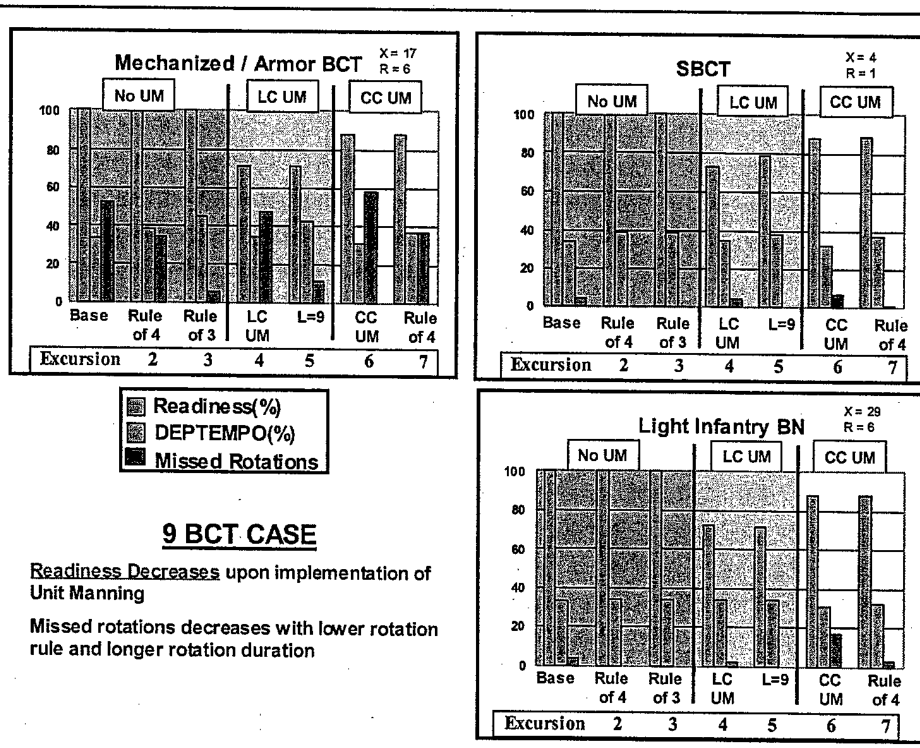


Figure 12. 9 BCT Case Results

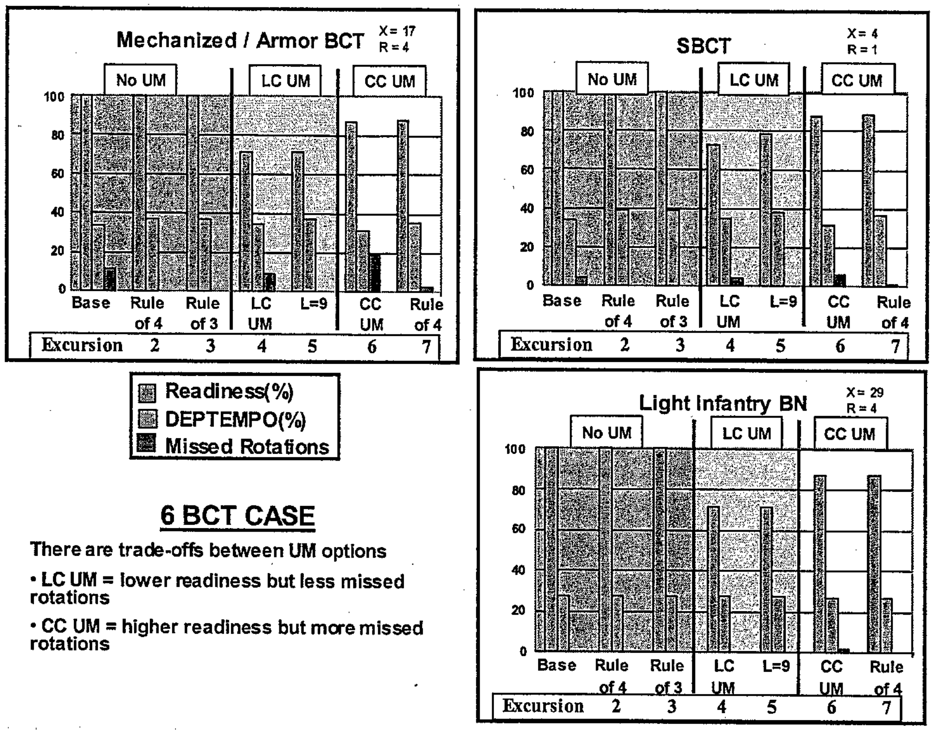


Figure 13. 6 BCT Case Results

Acronyms

AC – Active Component
ACR – Armored Cavalry Regiment
AoA – Analysis of Alternatives
AOTR – Additional Overnight Training Rate
BCT – Brigade Combat Team
BT – Build Time
CAA – Center for Army Analysis
CC – Continuous Cyclic
COCOM – Combatant Commander
CONUS – Continental United States
CSA – Chief of Staff of the Army
CTC – Combat Training Center
DEPTEMPO – Deployment Tempo
DoD – Department of Defense
FULCRUM – Future Unit Life Cycle, Rotation, and Unit Manning model
G3 – Army Deputy Chief of Staff for Operations
G8 – Army Deputy Chief of Staff for Programs
GUI – Graphic User Interface
GWOT – Global War on Terrorism
HQDA – Headquarters, Department of the Army
HRC – Human Resources Command
IRS – Individual Replacement System
LC – Life Cycle
MOE – Measure(s) of Effectiveness
MTOF – Mission Task Organized Forces
NCA – National Command Authority
OIF – Operation Iraqi Freedom
OPTEMPO – Operations Tempo
PCS – Permanent Change of Station
PERSTEMPO – Personnel Tempo
POE – Posture of Engagement
RC – Reserve Component
SBCT – Stryker Brigade Combat Team
SRC – Standard Requirements Code
SSC – Smaller-Scale Contingency operations
STARI – Study of Total Army Rotation Initiatives
TAA – Total Army Analysis
TARRP – The Army Rotation Rule Project
UM – Unit Manning
UMTF – Unit Manning Task Force
USR - Unit Status Report
UIC – Unit Identification Code
URA-K – Unit Rotation Analysis – Korea
VBA – Visual Basic for Applications

Notes

[i] CAA rotational DEPTEMPO studies supported the Quadrennial Defense Review, Total Army Analysis, as well as the G3 Rotation and Manning Task Force.

[ii] The policy also specified rotation length of 6 months and analysis of unit rotations to Korea.

[iii] In accordance with the unpublished UMTF schedule draft dated September 30, 2003.

[iv] Hix found that as many as 50% of soldiers are unavailable for peacetime deployments. This high rate of peacetime nondeployable soldiers is mainly due to policy restricting soldiers from deploying if they have been on an unaccompanied hardship tour, such as Korea, within the last year.

[v] This is in direct contrast to La Barbera's 2001 findings (figure 3) and Hix' conclusions. General Eric Shinseki, CSA, implemented 100% fill of divisional units for FY 2001. CAA attributes the readiness differences to this policy change. Table D-1, Army Regulation 220-1, *Unit Status Reporting*, dated June 10, 2003, stipulates reasons for not counting assigned personnel as available.

[vi] Several articles referenced at https://www.unitmanning.army.mil/Research_items/research.htm address cohesion and turbulence.

[vii] TARRP creates force structure by SRC when policy results in a missed rotation. The created unit is then available for deployment during the run. This allows detailed analysis of force structure by component and branch across the Army when comparing courses of action.

[viii] This is because mechanized and armored units task organize into tank and infantry fighting vehicle (IFV) platoons at company level and mixed companies at battalion level. ACRs are used as substitutes by exception. The 2nd and 3rd Armored Cavalry Regiments are not included in the analysis, as they are typically not used as substitutes for peacetime operations. Additionally, light units are analyzed at battalion level as the supply consists of an odd number and the requirements in the 6 BCT case are not a whole number of brigades.

[ix] 4 days per month is approximately 13% AOTR. Also, units typically spend about 7 days (23%) as AOTR during prep for deployment. This is the value used in FULCRUM. AOTR is applied to all combat units in FULCRUM. URA-K used 19% training days for light infantry battalions in Korea. TARRP applied a 16% AOTR to all units in the Army.

[x] The model schedules 10 CTC rotations every year. This mirrors actual CTC schedules. The Joint Readiness Training Center (JRTC) and National Training Center (NTC) have 10 rotations scheduled per year.

[xi] For up to 18 BCT in the pool. This is the maximum number used in all FULCRUM runs for STARI.

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