NAVAL HEALTH RESEARCH CENTER

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C. G. Blood

J. M. Zouris

D. Rotblatt

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NAVAL HEALTH RESEARCH CENTER
P. O. BOX 85122
SAN DIEGO, CALIFORNIA 92186-5122

BUREAU OF MEDICINE AND SURGERY
WASHINGTON, DC

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Christopher G. Blood

James M. Zouris*

Dan Rotblatt*

Medical Information Systems and Operations Research Department

Naval Health Research Center

P.O. Box 85122

San Diego, CA 92186-5122

*GEO-CENTERS, Inc.

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SUMMARY

Problem

Medical resource planning for combat operations requires projections of the number of casualties that may be incurred by ground forces. Casualty projections are required input to models that forecast the beds, evacuation assets, and personnel requirements needed to support an operation.

Objective

The present report details the use of the FORECAS ground casualty forecasting system and describes the statistical underpinnings of the model.

Approach

FORECAS projections use the rates and patterns of casualty incidence observed during four previous ground combat operations as forecasting baselines. These battle intensity-specific baselines are then adjusted to reflect changes in weapons parity, troop motivation, environmental factors, and battlefield awareness between the past operations and the hypothesized future scenarios.

Results

The FORECAS system projects the wounded-in-action, killed-in-action, and disease/nonbattle injury incidence for U.S. forces opposing various potential adversaries under varying environmental conditions. The simulated casualty data reflects the salient characteristics of the empirical data.

Conclusions

Much variability exists in the potential casualty sustainment among U.S. forces depending upon the adversary and the specific scenario. The FORECAS projection system simulates the numbers of casualties that are likely to be sustained during various ground combat operations and provides medical planners with a tool to help determine the medical resource requirements of combat deployments.

USING THE GROUND FORCES CASUALTY FORECASTING SYSTEM (FORECAS) TO PROJECT CASUALTY SUSTAINMENT

Projecting the injury and illness incidence likely to be incurred during a military operation is a critical component of the medical resource planning process. To assist in medical requirements determination, a system to forecast ground casualties, called FORECAS, has been developed which provides medical planners with estimates of the average daily casualties, the maximum and minimum daily casualty load, the total number of casualties across the operation, and the overall casualty rate for a specified ground combat scenario. Development of the FORECAS planning tool was accomplished in two phases: 1) design and construction of a casualty forecasting model based on empirical data from previous combat operations, and 2) incorporation of casualty rate adjustments to reflect the expected differences in casualty sustainment associated with specific potential adversaries.

The first phase involved examining the rates of casualty occurrence and the distribution patterns underlying the casualty incidence of previous combat engagements. Determination of the mean casualty rates for varying battle intensities is needed as the basis for casualty stream simulations, and these intensity-specific rates were derived from the historical data of previous ground operations: Okinawa, Korea, Vietnam, and the Falklands.[1-4] Further, incorporation of the appropriate underlying distribution patterns for the various casualty types allows the FORECAS system to simulate the 'pulses and pauses' in medical admission incidence that have been observed in past ground operations. Analyses of the historical data (see Appendix A) indicated that the disease and non-battle injury (DNBI) incidence for both combat and support troops may be approximated by generating random deviates using lognormal distributions. Further, patient admission patterns for wounded-in-action (WIA) incidence were represented by an exponential distribution for combat troops in a high intensity conflict, and by a lognormal distribution for troops engaged in a moderate battle intensity scenario (Appendix A). Killed-in-action (KIA) incidence similarly could best be approximated by an exponential distribution for troops in high intensity battles and by a lognormal distribution for lesser intensities.

In addition to these distribution patterns, there was a strong degree of autocorrelation[5] observed within the combat troop WIA and KIA incidence and a lesser degree within the casualty incidence of support troops. This autocorrelation represents another reality of combat – that the magnitude of any one day's casualties is often related to the numbers of casualties sustained in the immediately preceding days. Also, further analyses[5-7] indicated that a significant cross-correlation existed between DNBI incidence and the WIA incidence on the same and preceding days. Both the autocorrelation and cross-correlation functions have been incorporated in the FORECAS model.

The second major phase of FORECAS development entailed incorporating the appropriate casualty rate adjustment for each adversary that U.S. ground forces might oppose. Each adversary-specific adjustment represents an amalgamation of factors which pertain to that particular nation. The factors which comprise the adjustments include terrain, climate, weapons capabilities, and a socio-cultural rating of armed forces' motivation.

Previous modeling efforts have determined that the terrain and climate of an operational theater have the potential to impact the numbers of casualties sustained.[8] Various topographical and climatological conditions (e.g., dense jungle, heavy rain or snow) can inhibit a weapon system's line of fire, as well as impede the movement of weapons and troops. Constraints on the fields of fire or weapons mobility, in turn, are likely to have dampening effects on the casualties sustained.

The weapons capability of an opposing force is also expected to have an impact on the casualties incurred among U.S. ground forces. For U.S. and potential opposition forces, 'state of the art' and numerical strength ratings were computed for artillery, armor, infantry weapons, and airborne attack and flight detection measures. These scores were weighted and an overall weapons parity score was computed for each potential adversary and incorporated into the FORECAS casualty projections.[9]

Societal factors likely to impact the motivation of an armed force were also examined,[10-14] quantified by a subject matter expert (SME) panel, and contrasted for the U.S. and potential adversaries. The societal factors judged to potentially influence armed forces-wide combat motivation included ethnic homogeneity, religious homogeneity, length of conscription, recent engagements, technological sophistication, military tradition, previous military success, and defense spending priority.[9] Similar to the weapons parity score, a motivational parity score was computed to represent the ratio between the societal factors scores of the U.S. and each potential opposing force, and then incorporated into the FORECAS projections.

The consensus of the SME panel was that primary unit (company; battalion) motivation would impact battlefield performance, and consequently, the casualties that an enemy force might inflict upon U.S. ground forces. The unit characteristics expected to affect battlefield dynamics included leadership, vertical (superior-subordinate) bonding, horizontal bonding, and training.[10,14] While reliable data of these types are generally unavailable for the armed forces of potential adversaries, FORECAS allows unit motivation scores to be incorporated if they become available.

The preceding overview provides a general description of the FORECAS model. The following sections of this report provide 1) user documentation for the FORECAS ground casualty projection system, and 2) a detailed accounting of the casualty projection algorithms.

PART I -- USE OF THE FORECAS PROJECTION SYSTEM

INPUT SCREENS

Following start-up, FORECAS prompts the user for parameters that define the potential combat scenario. The first input screen employs a graphical user interface which prompts the user to select the casualty categories to be projected. The five casualty type options are DNBI, WIA, KIA, DNBI & WIA, or WIA & KIA. This input screen is shown in Figure 1.

Users select one of the casualty types by clicking on the corresponding button. To change an entry, the user simply makes another selection and the second selection will override the user's first choice. To proceed to the next screen the user must select a casualty type and then press the ENTER key. If the user fails to choose any casualty type(s) before attempting to proceed to the next screen, a warning screen prompts the user to make a selection.

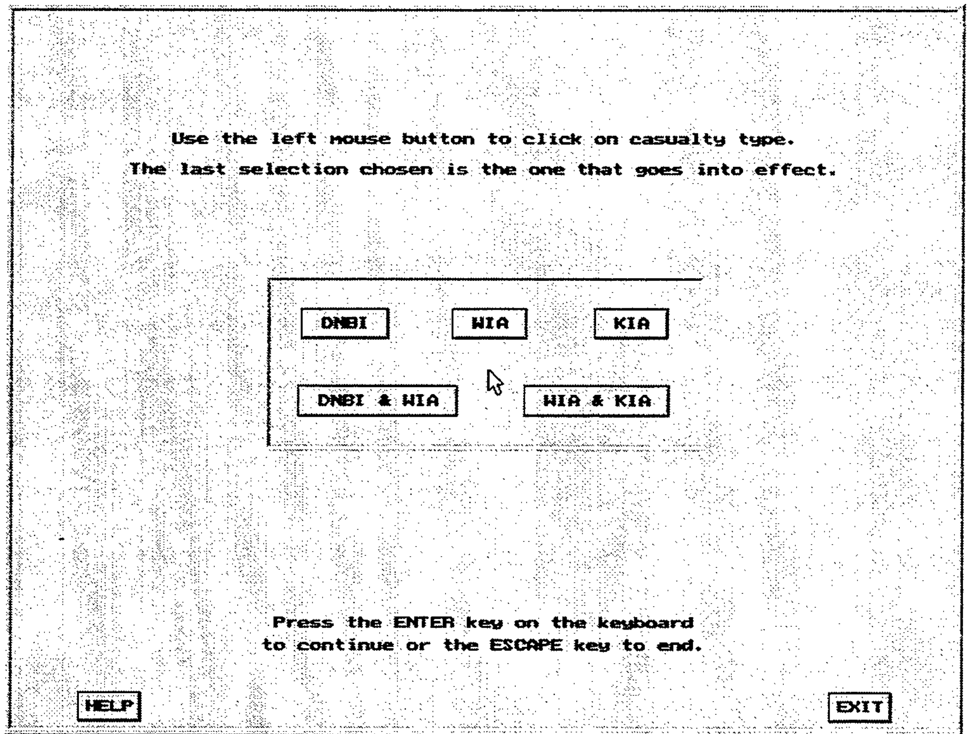

Figure 1. Input screen for selection of admission types.

The second input screen (see Figure 2) prompts the user to select the battle intensity of the proposed scenario. The combat intensity options are as follows: NONE, LOW, MODERATE, HEAVY, INTENSE. The "NONE" battle intensity category represents no combat activity -- tensions may exist but no combat is taking place (e.g., an occupying force). Disease and nonbattle injury incidence (DNBI) will still occur under "none" but battle casualties (WIA or KIA) are not expected. If the user selects WIA or KIA incidence in conjunction with "NONE" battle intensity, an error message will appear indicating "There are no wounded or killed soldiers when there is no military confrontation." The other battle intensity options reflect the magnitude of injury and illness incidence evidenced in previous combat operations of similar intensities.[15] The "LOW" intensity represents U.S. casualty rates from a light intensity period during the Okinawa operation combined with the average rates observed during the Vietnam and Falklands operations. "MODERATE" intensity uses a baseline of casualty rates from a period of moderate intensity combat during the Okinawa operation combined with average rates from the Korea, Vietnam, and Falklands operations. The "HEAVY" intensity tempo is represented by casualty rates from a moderate period of conflict during the Okinawa operation, combined with the average across the whole of the operation, which includes the intense periods of combat taking place on the island. Lastly, the "INTENSE" battle tempo uses a baseline rate that is a composite of casualty incidence from a period of heavy intensity combat during the Okinawa operation, the average incidence across the entire Okinawa operation, and the casualties sustained during the Battle for Hue in Vietnam. These definitions are available while on this screen by clicking on the "help" button.

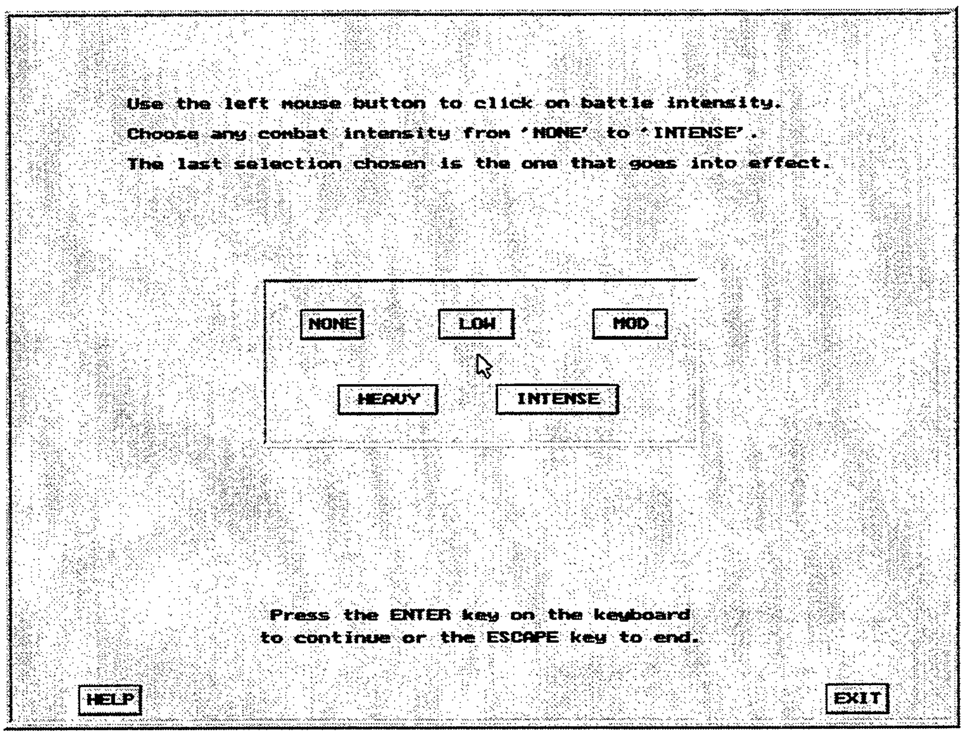

Figure 2. Input screen for selection of battle intensity.

The next input screen (see Figure 3) prompts the user for the numbers and types of troops as well as the length of the operation. There are three categories of troops from which the user may select: INFANTRY, SUPPORT, and SERVICE SUPPORT. The "infantry" troops category represents the ground (dismounted) combat troops participating in the operation. The "support" troops category includes intra-divisional support such as tank, artillery, light-armored infantry, and combat engineer units. The third troop category, "service support" represents extra-divisional support personnel which include the Force Service Support Group (FSSG) and the Surveillance, Reconnaissance, Intelligence Group (SRIG). Upon selecting a troop type, the user is then prompted to enter the numerical strength for this troop category, after which the ENTER key is pressed to register this information. The user may select one, two, or three troop categories, and may alter their strength input by re-clicking on that troop category. After all troop categories have been selected, the user presses the ENTER key and is prompted for the length of the operation in days.

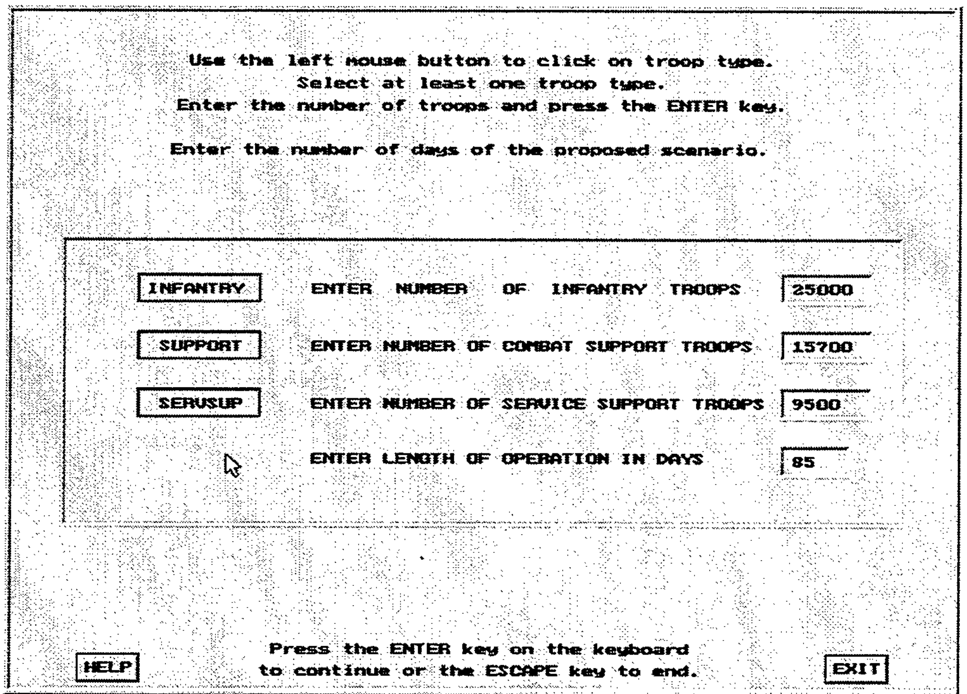

Figure 3. Input screen for selection of troop strength and length of operation.

The next input screen (see Figure 4) prompts the user to select the adversary of the U.S. forces in the casualty simulation. The user selects an adversary by clicking on an opposition force displayed on the screen; if more than one adversary is selected, the last selection overrides the previous selection. After an adversary has been selected, pressing the ENTER key incorporates the underlying weapons parity and motivational parity factors of this opposition force into the FORECAS casualty projections.

The next input screen (see Figure 5) allows the planner to indicate the type of terrain of the proposed combat scenario. The user selects from 17 types of terrain and may select as many as are appropriate. For each selected terrain type, an associated percentage of the overall battlefield terrain must also be entered. After each percentage is entered, the user presses the ENTER key and proceeds to enter another terrain type if appropriate. The sum of the percentages must equal 100%

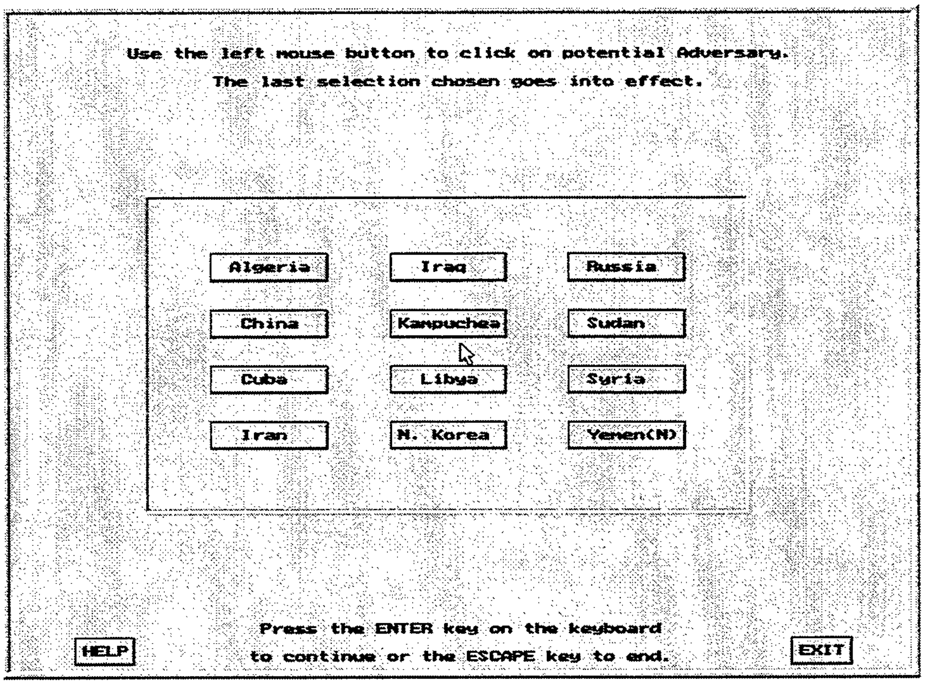

Figure 4. Input screen for selection of opposition forces.

or an error message is displayed. The user may edit the percent of a previously entered terrain type by pressing on that terrain button; this action requires that previously entered terrain category percentages be re-entered. Also included is an "UNKNOWN" terrain button to be used when the planner is uncertain of the terrain of a specific adversary; in this case the calculations associated with the terrain's impact will be based on the topography of the overall country. If "UNKNOWN" is selected, no other terrains may be chosen. All calculations presume that U.S. forces are deployed to the territory of the adversary. The next input screen, climate factors, operates in the exact manner as the terrain screen. There are 12 climate types from which to choose (see Figure 6), and a percentage of the overall anticipated climatological conditions is entered for each selection.

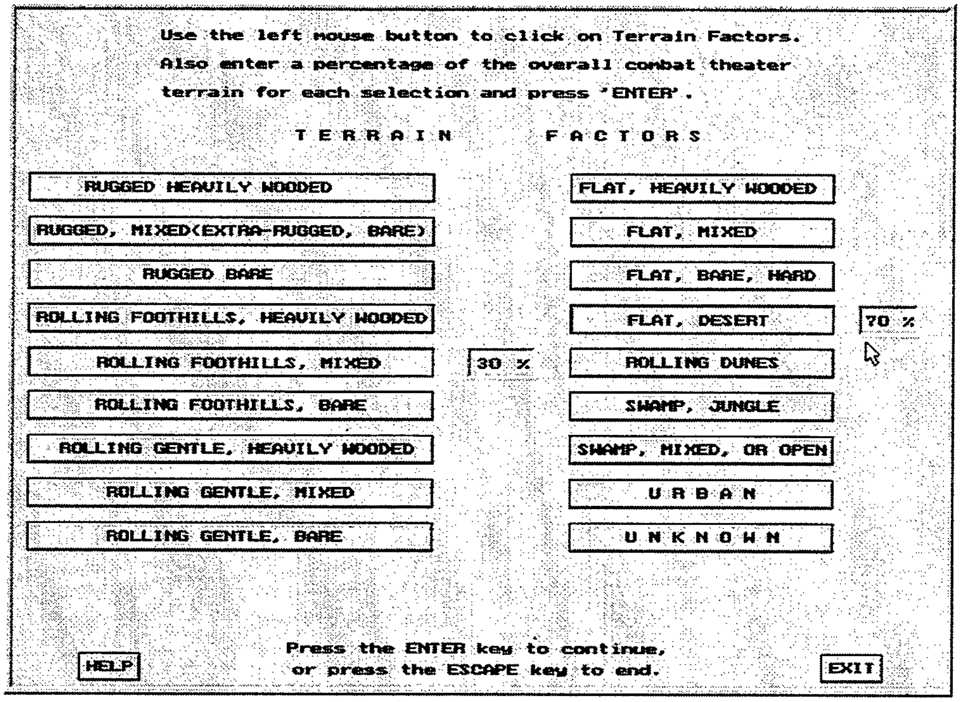

Figure 5. Input screen for selection of terrain factors.

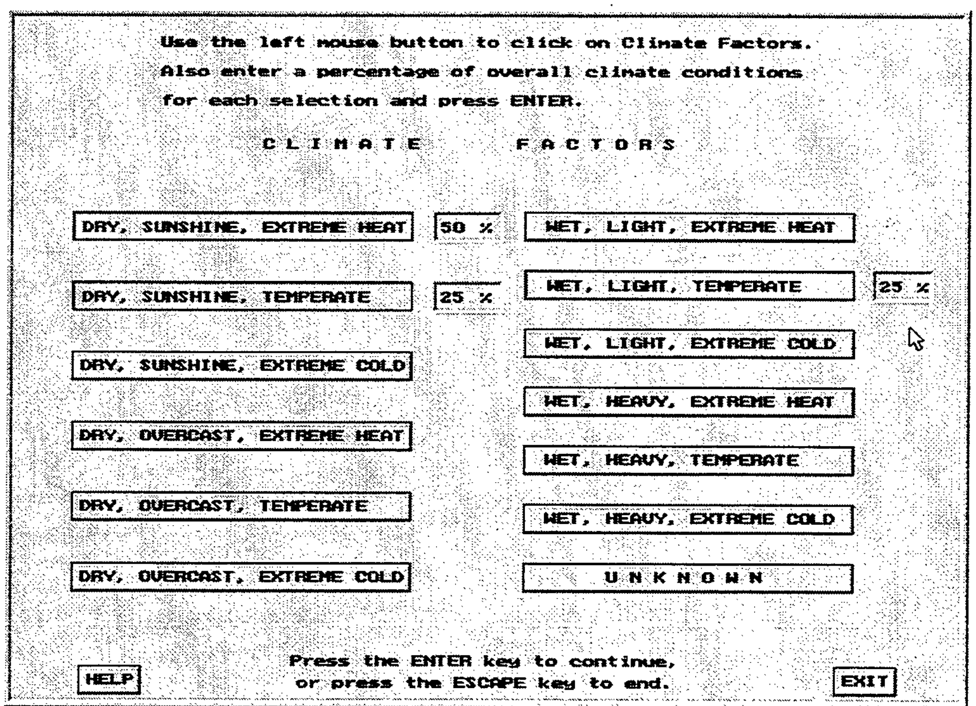

Figure 6. Input screen for selection of climate factors.

The final input screen within the FORECAS planning tool is for Unit Morale/Cohesion scores. While it is expected to be rare that the user would have information on the cohesiveness of both U.S. and opposition force primary units (companies/battalions), should this data be available it can be incorporated into the casualty sustainment projections. If the "NOT AVAILABLE" button is selected, FORECAS simply proceeds to the next screen. If the "U.S." button is pressed, however, the user is prompted for a score for U.S. forces, presses the ENTER key, and then enters a score for the opposition forces. Inputs must be made for both the U.S. and the adversary if either is selected. Inputs may be edited by pressing on the "U.S." or "ADVERSARY" buttons. Figure 7 is a display of this screen.

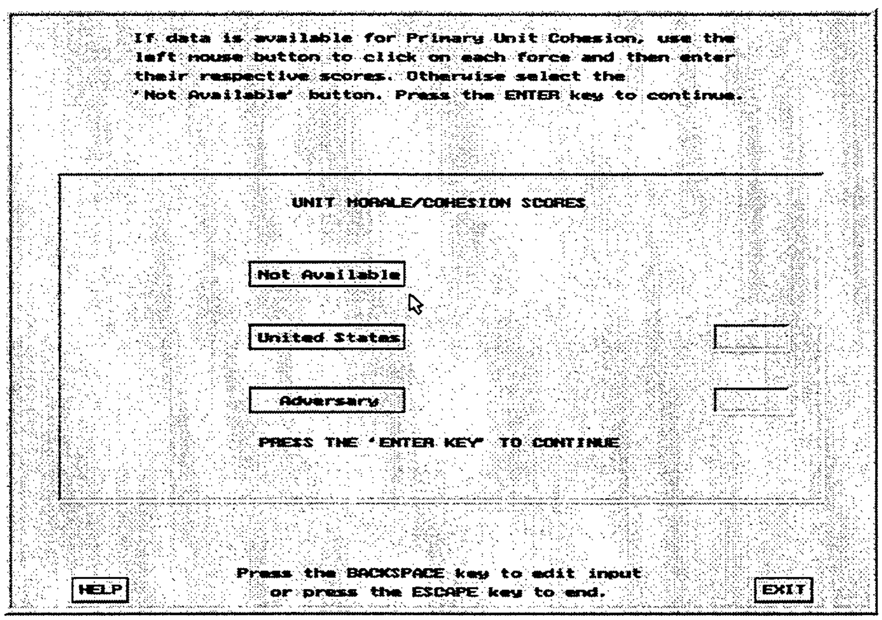

Figure 7. Input screen for selection of unit morale/cohesion score.

OUTPUT SCREENS

After the user has entered all of the the required input, FORECAS automatically generates a series of output screens. The first output screen is a graphical display indicating the magnitude of the likely 'pulses and pauses' in daily casualty incidence during the defined operation. This graph displays the numbers of casualties (WIA, DNBI, KIA) that might be expected on a daily basis across the length of the simulated scenario. The line graphs of WIA and DNBI incidence represent "medical admissions" (the numbers of casualties likely to require at least three days of treatment) and are provided sequentially for infantry troops, support troops, service support troops, and then all troops combined (see Figure 8). It is important to note that the graphs depict a representation of the magnitude of the pulses and pauses that might be expected for a ground scenario with characteristics similar to those defined by the user; however, they are not intended to represent the expected casualties on any specific day of the operation.

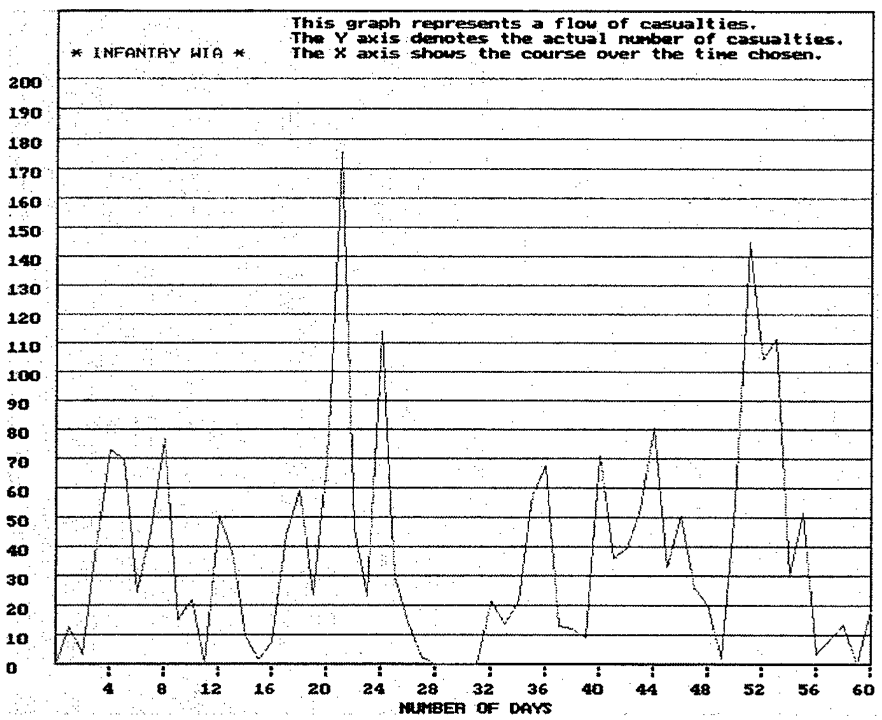

Figure 8. Output screen displaying infantry WIA incidence.

After each graphical display, a tabular presentation of the incidence information is provided for that troop type and casualty category (see Figure 9). The tabled data includes total number of presentations (defined as all patients requiring treatment at an Echelon II facility or higher), total number of admissions, average daily number of presentations, average daily number of admissions, minimum number of admissions on any one day, maximum number of admissions on any one day, and average rate of admissions per 1000 strength per day. Additionally, the DNBI admissions are further compartmentalized into disease, nonbattle injury, and battle fatigue components.

```
                    DNBI RESULTS SCREEN

The casualty flow is DNBI Infantry
The troop strength is 10000 personnel
The length of the operation is 60 days
The battle intensity is Light
The adversary is IRAQ

      DNBI TOTALS                          DNBI AVERAGES

Total Presentations      662     Daily Presentation     11.0
Total Admissions         552     Daily Admissions        9.2
   Total Disease         371        Daily Disease        6.2
   Total NBI              81        Daily NBI            1.4
   Total BF              100        Daily BF             1.7

The minimum DNBI admissions on a single day was 0
The maximum DNBI admissions on a single day was 34

The minimum DNBI admissions per day per 1000 troops was 0.08
The maximum DNBI admissions per day per 1000 troops was 3.39

Rates are based on  0.95 total DNBI admissions per day per 1000 troops

DISEASE           = 0.63 per day per 1000 troops
NON BATTLE INJURY = 0.14 per day per 1000 troops
BATTLE FATIGUE    = 0.18 per day per 1000 troops
```

Figure 9. Output screen displaying infantry summary DNBI information.

FORECAS also creates a summary output file that can be viewed in text format. Each time the program is executed an ouput file is generated that documents the user-defined parameters of the simulated scenario as well as summary casualty data. The text file may then be saved and/or printed for further analyses and scenario comparisons. If the file name is not changed, the data in this output is overwritten each time the program is executed. The name of the output file is ‘result.out’.

PART II -- STATISTICAL UNDERPINNINGS OF FORECAS

The algorithms underlying the FORECAS projections were developed in two phases. First, formulae were developed to simulate the trends in casualty incidence observed during previous combat operations and incorporated into a software environment. After the algorithms for simulating the casualty sustainment of past combat operations were validated, various adjustments to these projections were incorporated into the FORECAS planning tool. These adjustments reflected U.S./adversary weapons parity, parity levels in combat motivation indices, impacts of varying terrain and climate factors, and increases in U.S. battlefield omniscience.

SIMULATION OF HISTORICAL TRENDS

As detailed in the introduction of this report, casualty incidence data from four previous ground combat operations were analyzed to determine average daily rates of casualty incidence, underlying data distributions, and correlations within and between casualty types. Because the simulation of medical admissions is contingent upon underlying rates of casualties (per 1000 strength per day) rather than discrete casualty occurrences, continuous distributions were determined to be appropriate for modeling illness and injury incidence.

WIA Rates

Analyses of WIA data from the infantry troops involved in previous combat operations indicated that the underlying distributions varied with the battle intensity of the ground action. Use of the *BestFit Probability Distribution Fitting* software (utilizing Kolmogorov-Smirnov and Chi Square goodness-of-fit tests) indicated that WIA rates of high and intense battle tempos were best represented by exponential distributions (see Appendix A). However, for moderate and light battle intensities, the empirical WIA data of infantry troops were best represented by lognormal distributions. Support troop WIA rates were best represented by lognormal distributions for all battle intensities.

The randomly-generated WIA variates (W) are derived from an exponential distribution as:

$$\mathbf{W \sim exponential(\mu)}$$

While the lognormal variates are derived by first generating normal random deviates (Y) ...

$$\mathbf{Y \sim normal(\mu,\sigma)}$$

...and then the exponential transformation of each WIA variate (W_i) is derived as ...

$$\mathbf{W_i = e^Y}$$

where,

μ = *the observed WIA mean*

σ= *the observed WIA standard deviation*

In addition, there was also a strong degree of autocorrelation within the infantry units' casualty occurrences, indicating a relationship between casualties sustained on a given day and those incurred on immediately subsequent days. For combat support troops, there was a lesser but significant degree of autocorrelation, while for service support troops there was little or no autocorrelation observed. Therefore, in addition to using the appropriate distribution functions, simulation of WIA incidence should incorporate the autocorrelations seen in the empirical data:

<u>infantry troops</u>

higher battle intensities: $\mathbf{W_t = \alpha_1 + \alpha_2(W_{t-1}-\mu) + \alpha_3(W_{t-2}-\mu) + \alpha_4(W_{t-3}-\mu) + exponential(\mu)}$

lower battle intensities: $\mathbf{W_t = \alpha_1 + \alpha_2(W_{t-1}-\mu) + \alpha_3(W_{t-2}-\mu) + \alpha_4(W_{t-3}-\mu) + lognormal(\mu,\sigma)}$

<u>support troops</u>

all battle intensities: $\mathbf{W_t = \alpha_1 + \alpha_2(W_{t-1}-\mu) + lognormal(\mu,\sigma)}$

<u>service support troops</u>

all battle intensities $\mathbf{W_t = lognormal(\mu,\sigma)}$

where:

W_t = *the WIA rate at time t*

μ = *the WIA rate mean*

α_l = *the autocorrelation constants derived from the historical data*

exponential(μ) = *exponential random variate generated by the computer*

lognormal(μ,σ) = *lognormal random variate generated by the computer.*

KIA Rates

Projections of KIA incidence are modeled in an essentially identical fashion as WIA incidence. As with the wounded-in-action incidence, KIA rates also are simulated using an exponential distribution for combat troops at high and intense battle tempos, and a lognormal distribution for the other battle intensities and troop types. Similarly, an autocorrelation function has been incorporated into KIA rate simulations of combat and combat support troops but not for the KIA projections of service support units.

DNBI Rates

Analyses of the DNBI incidence data of the historical combat operations (using the *BestFit* software) indicated that the underlying data distributions were best represented by lognormal distributions (see Appendix A). This was found to be true across all levels of battle intensity and for all troop types. Simulation of the lognormal distribution was performed using the same algorithms as those used to generate the previously-discussed lognormally distributed WIA incidence. Additionally, there is a strong degree of cross-correlation between DNBI and WIA incidence among combat troops, and a lesser but still significant amount among support troops. However, the low level of WIA incidence among service support troops did not warrant inclusion of a cross-correlation function in modeling their DNBI incidence. Consequently, the service support troop DNBI incidence is represented by a simple lognormal distribution:

$$\mathbf{D_t = LN(\mu,\sigma)}$$

while the cross-correlations functions for combat and support troops are incorporated into this formula as:

$$\mathbf{D_t = B_0 + B_1(W_t - W_\mu) + LN(\mu,\sigma)}$$

where,

D_t = *the DNBI variate at time t*

B_1 = *the cross-correlation constants derived from the historical data*

W_t = *the WIA variate at time t*

W_μ = *the WIA mean*

$LN(\mu, \sigma)$ = *lognormal random DNBI variate generated by the computer*

<u>Analysis of the simulated data</u>

At this stage in the development of FORECAS, analysis of the generated casualty stream data was warranted to ensure that the output accurately reflected the statistical trends evident in the empirical data. Analyses were performed on the time series files created by FORECAS to test for autocorrelations and cross-correlations.

Graphs of the autocorrelation function were used to compare the simulated WIA and KIA time series with the historical data; the plots from the simulations indicated a significant degree of autocorrelation in the daily casualty incidence decreasing with time from the first day. This is consistent with findings from the empirical data. Past research found that service support troop DNBI rates were independently distributed -- consequently, no autocorrelation should exist within these series, and none was found. The combat troop DNBI empirical data, however, possessed a degree of autocorrelation and this was accurately reflected in the plots of the infantry troop simulated series. Further, a test for cross-correlation between the DNBI and WIA series showed a statistically significant finding consistent with the historical studies. These analyses indicate that FORECAS simulations accurately depict the statistical patterns of the empirical data.[4]

ADJUSTMENTS TO HISTORICALLY-BASED PROJECTIONS

While the forecasts derived from the empirical data reflect the battlefield dynamics of past operations, it is doubtful that casualty projections based solely on previous trends will adequately reflect the casualty incidence of a contemporary combat scenario. Differences in capabilities between past and future adversaries, changes over time in U.S. forces' capabilities, environmental differences between past theaters and future areas of operation, and advances in technology would all be expected to impact the level of U.S. casualty sustainment. The potential impacts on casualty incidence of these factors, thus, were assessed and quantified, and then these adjustments were incorporated into the FORECAS planning tool.

As part of the process to develop the needed adjustments, a Subject Matter Expert (SME) panel was convened to rate the potential impacts of various societal/cultural factors on armed forces battlefield performance and likely casualty sustainment.[9] Also, the degree of parity between the weapons inventories of the United States and potential adversaries was contrasted, and adjustments were derived to reflect the expected impact of this factor on the baseline casualty rate projections.[9]

Further, the topography and climate of each potential adversary's operational theater is adjusted using the expected impact on casualty incidence for each terrain and climate condition as set forth by Dupuy[8]. The terrain and climate factor adjustments, as quantified by Dupuy, are seen in Table 1. If, for instance, an adversary had terrain that was 60% "rugged, heavily wooded" and 40% "rolling foothills bare", the overall terrain casualty impact score (.50) is obtained by multiplying the proportions by the adjustments and summing (.60*.30)+.(40*.80).

Table 1. Projected Impact of Terrain and Climate on Ground ForceCasualty

Terrain Factors		Factor Score	Climate Factors		Factor Score
1.	Rugged, heavily wooded	0.30	1.	Dry, sunshine,extreme heat	0.80
2.	Rugged, mixed (extra-rugged, bare)	0.40	2.	Dry, sunshine, temperate	1.00
3.	Rugged, bare	0.50	3.	Dry, sunshine, extreme cold	0.70
4.	Rolling foothils, heavily wooded	0.60	4.	Dry, overcast, extreme heat	0.90
5.	Rolling foothills, mixed	0.70	5.	Dry, overcast, temperate	1.00
6.	Rolling foothills, bare	0.80	6.	Dry, overcast, extreme cold	0.60
7.	Rolling gentle, heavily wooded	0.65	7.	Wet, light, extreme heat	0.70
8.	Rolling gentle, mixed	0.75	8.	Wet, light, temperate	0.70
9.	Rolling gentle, bare	0.85	9.	Wet, light, extreme cold	0.40
10.	Flat, heavily wooded	0.70	10.	Wet, heavy, extreme heat	0.50
11.	Flat, mixed	0.80	11.	Wet, heavy, temperate	0.50
12.	Flat, bare, hard	1.00	12.	Wet, heavy, extreme cold	0.40
13.	Flat, desert	0.90			
14.	Rolling dunes	0.50			
15.	Swamp, jungle	0.30			
16.	Swamp, mixed, or open	0.40			
17.	Urban	0.50			

<u>Adjustment Algorithms</u>

For each factor affecting WIA and KIA incidence (terrain, climate, weapons parity, societal factors parity), weights denoting their relative impact on battlefield casualty sustainment were derived from ratings by the Subject Matter Expert panel. By way of example, if each of the four factors were rated to have equal impacts on casualty incidence, their weights would have each been .25. New casualty rate projections, then, are calculated as the historically-observed casualty rate for a designated battle intensity multiplied by the sum of the products of each of the ratings of the aforementioned factors and that factor's assigned weight. Terrain and climate weights were fixed at .15 and .10 respectively (meaning, that of the four factors expected to vary between historical operations and a future scenario, the SME panelist's ratings indicated that changes in terrain should represent 15% of the adjustment to the baseline casualty rate, and climate's impact should represent 10% of the overall adjustment). While the weights for terrain and climate are constant for all casualty projection scenarios, the weights associated with the weapons parity scores and the societal factors parity scores were rated to vary with the type of terrain. The rationale for "sliding weights" is as follows: under certain topographical conditions (jungle, urban setting, mountainous region) the degree of weapons parity becomes relatively less important because of decreased weapons mobility and restricted 'lines of sight.' Under these terrain conditions the degree of human factors parity would take on more relative importance as a determinant of battlefield dynamics. An example of this phenomenon would be the U.S. experience in Vietnam: while the U.S. had an edge in weapons technology, the jungle environment decreased the importance of weapons parity and increased the importance of troop cohesion and motivation. Table 2 indicates the sliding weights associated with weapons parity, societal factors parity, terrain, climate.

Table 2. Weights associated with FORECAS factors by range of terrain scores

Terrain Score	Weapon weight	Societal weight	Terrain weight	Climate weight	Sum of weights
[.76 - 1.00]	.600	.150	.15	.10	1.00
[.60 - .75]	.427	.323	.15	.10	1.00
[.51 - .59]	.396	.354	.15	.10	1.00
[.41 - .50]	.384	.366	.15	.10	1.00
[.30 - .39]	.374	.376	.15	.10	1.00

The SME panel also indicated that, in addition to these factors, the U.S.'s battlefield surveillance capabilities of today would lead to a dampening of casualty sustainment among U.S. troops. Contemporary technology yields a battlefield "omniscience" that was largely nonexistent during the operations upon which the baseline rates were computed. This present-day situational awareness allows U.S. troops to be kept out of harm's way more often than in the past, and consequently will lead to reductions in casualty levels when compared with previous operations. Quantification of the SME panelist's responses yielded a 20% reduction in the casualty incidence expected, due to this factor alone. The algorithm for computing the new casualty rates is as follows:

$$newrate = R_i*(W_i+S_i+T_i+C_i+(-.20))$$

where,

R_i	=	*the historical casualty rate observed for a specific battle intensity*
W_i	=	*weapons parity factor multiplied by the weapons adjustment weight*
S_i	=	*societal factor parity multiplied by the societal factor adjustment weight*
T_i	=	*terrain casualty impact factor multiplied by the terrain factor weight*
C_i	=	*climate casualty impact factor multiplied by the climate factor weight*
-0.20	=	*reduction in casualty sustainment due to contemporary battlefield omniscience*

Similarly if primary unit cohesion scores are available, the weights (Table 3) and algorithm would be:

Table 3. Weights associated with FORECAS factors (with unit morale/cohesion scores) by terrain ranges

Terrain Score	Weapon weight	Societal weight	Unit weight	Terrain weight	Climate weight	Sum of weights
[.76 - 1.00]	.450	.150	.150	.15	.10	1.00
[.60 - .75]	.320	.215	.215	.15	.10	1.00
[.51 - .59]	.278	.236	.236	.15	.10	1.00
[.41 - .50]	.262	.244	.244	.15	.10	1.00
[.30 - .39]	.248	.251	.251	.15	.10	1.00

$$newrate = R_i*(W_i+S_i+U_i+T_i+C_i+(-.20))$$

where,

R_i	=	*the historical casualty rate observed for a specific battle intensity*
W_i	=	*weapons parity factor multiplied by the weapons adjustment weight*
S_i	=	*societal factor parity multiplied by the societal factor adjustment weight*
U_i	=	*unit morale/cohesion parity multiplied by the unit/morale adjustment weight*
T_i	=	*terrain casualty impact factor multiplied by the terrain factor weight*
C_i	=	*climate casualty impact factor multiplied by the climate factor weight*
-0.20	=	*reduction in casualty sustainment due to contemporary battlefield omniscience*

To run through an example, consider that Adversary X has a weapons parity value of .58, a societal factors parity value of .76, unit cohesion scores do not exist, the climate is 'dry, overcast, extreme heat' (casualty impact of .90), and the combat takes place on a terrain of 'rolling foothills, heavily wooded' (casualty impact value of .60). From Table 2 it can be seen that the weights for climate and terrain are fixed at .10 and .15 respectively, and that the weapons parity weight and societal factors weight for this terrain score range (.60 to .75) are .427 and .323, respectively. Therefore, if the historically-based WIA rate for this battle intensity was 2.7 (per 1000 strength daily), then the above factors and weights coupled with the casualty reduction due to present-day battlefield omnsicience would lead to the following computations:

$$\begin{aligned} \textit{wia rate} &= 2.7 \times ((.90 \times .10) + (.60 \times .15) + (.58 \times .427) + (.76 \times .323) - .2) \\ &= 2.7 \times ((.09) + (.09) + (.248) + (.246) + (-.2)) \\ &= 2.7 \times (.474) \\ &= 1.28 \end{aligned}$$

This, then, is the set of calculations that FORECAS performs to derive casualty estimates for varying opposition forces under varying environmental conditions. It should be noted that tied to each historically-based, intensity-specific casualty rate are the underlying environmental factors and adversary-specific parity values of the combat operations from which that historical rate was derived.[9,15] Using the terrain/climate/parity factors associated with the historical rates allows the FORECAS projections for a future operation to be adjusted against the same factors of the previous operations. In the above example, if the historical rate for this specific battle intensity was based on a .85 terrain value (Dupuy's casualty impact scale) then the terrain component of the new projection would be calculated as $.90/.85 \times .10$ rather than $.90 \times .10$.

DNBI

FORECAS projections of disease and nonbattle injury incidence use the battle intensity-specific baseline rates from previous East Asia combat operations (Okinawa, Korea, Vietnam), which are then adjusted for the general declines in hospitalization incidence observed in the more recent conflicts, as well as for the lower rates observed at the beginning of a sustained operation. The observed DNBI rates were first partitioned into three components: disease, nonbattle injuries, and battle fatigue. Determination of a battle fatigue proportion of the DNBI rate is based on Israeli research[16] indicating that rates of battle fatigue approximate one-fourth of the WIA rate. The nonbattle injury incidence is based on previous research[17] by the Naval Health Research Center that determined that 17% of the DNBI rate during an East Asia military operation was attributable to nonbattle injuries. The final component, disease incidence, is computed as the remainder of the DNBI incidence when battle fatigue and nonbattle injuries have been removed: DIS = DNBI - ((WIA*0.25)+(DNBI*0.17)).

After this baseline was established, the disease component was adjusted for observed declines across conflicts due to advances in preventative measures and improvements in medical care. A study performed by the National Research Council[18] indicated that medical advances led to disease rate decreases of 48% and 23% respectively between WWII and Korea rates and those observed in Vietnam. Consequently, the weighted portions of the FORECAS projections derived from the empirical data from Okinawa and Korea were adjusted accordingly.

Additionally, analyses of the Vietnam inpatient data indicated that the first full year's DNBI rates were 80% of the average rate incurred across the six years of the operation (1965-71), with a generally increasing trend evidenced across the years of the conflict. Finally, disease rate projections are reduced 20% to represent the first year of any simulated operation because the baseline rates are derived from empirical data of time periods midway through sustained operations (World War II, Korea, Vietnam), and projections are most needed for emerging military conflicts.

After deriving the expected DNBI rates for an East Asia theater of operations, these rates were then adjusted to reflect the differences in DNBI incidence expected in other geographical regions. Peacetime disease incidence was examined for U.S. shore facilities within Europe, Southwest Asia, and East Asia.[17] Projected combat illness incidence rates for potential adversaries within Europe and Southwest Asia theaters were calculated by adjusting the East Asia disease incidence to reflect the degree of differences in peacetime disease incidence between East Asia and the other theaters. Similarly, projections of nonbattle injury incidence are computed as the empirical baseline adjusted for the differences in nonbattle injury incidence reported in various operational theaters of the past.[19] As with the East Asia theater, the battle fatigue incidence for other theaters is calculated at a rate of one-fourth the rate of the projected wounded-in-action incidence.

Conclusion

The FORECAS planning tool was designed to assist medical planners and logisticians in determining the resource needs of specific ground combat operations. FORECAS was constructed in two phases: development of a simulation tool that reflects the statistical trends observed in previous combat scenarios, and assessment and quantification of the adjustments necessary to enable FORECAS projections to most accurately reflect contemporary scenarios. The FORECAS simulations were found to accurately represent the trends observed in the historical data. Further, adversary-specific simulations run using input similar to the U.S. Marine ground forces experience in the Gulf War yields casualty output approximating the actual casualty incidence incurred in that operation.

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APPENDIX A

The empirical data was analyzed using *BestFit Probability Distribution Fitting For Windows®* software. The *BestFit* software derives goodness-of-fit statistics contrasting the distribution of an existing data set with data sets generated with twenty-six different distribution functions. These distribution functions include all the standard distribution functions, including the beta, binomial, exponential, gamma, logistic, lognormal, normal, poisson, uniform, and weibull distributions. Goodness-of-fit analyses indicates how probable it is that each given distribution function underlies a particular data set. These analyses utilize a Chi Square test and a Kolmogorov-Smirnov test for determining the similarity between distribution types. As probabilities increase over .01 the likelihood rises that the empirical data set and the data set generated with a given distribution function are similarly distributed.

Each empirical WIA, KIA, and DNBI data set (Okinawa, Korea, Vietnam, Falklands), for both combat and support troops, was tested against all distribution functions in *BestFit*. Tables A.1 through A.10 display the results of the goodness-of-fit testing where one or more tests supported use of a specific distribution type for the FORECAS simulations. The first six tables indicate that lognormal distributions were found to underlie the disease and nonbattle injury (DNBI) incidence data of combat and support troops for all four historical combat operations (Okinawa, Korea, Vietnam, Falklands). No other distribution pattern was found to be significant for more than a single operation or troop type.

Tables A.7 and A.8 indicate that patient admission patterns for wounded-in-action (WIA) incidence were best represented by an exponential distribution for combat troops in a high intensity conflict and by a lognormal distribution for troops engaged in a moderate battle intensity scenario; all other distribution patterns within *BestFit* yielded nonsignificant probabilities of coming from the same distribution type as the historical data sets.

Killed-in-action (KIA) incidence was similar to WIA incidence in that it could best be approximated by an exponential distribution for combat troops engaged in high intensity battles and a lognormal distribution for lower intensity operations (see Tables A. 9 and A.10). As with WIA incidence, no other distributions trends were found to be significantly similar to the patterns observed in the KIA incidence data of the other historical operations and troop types.

Lastly, statistical comparisons were made between the empirical data and simulated data generated by the FORECAS projection tool. Table A.11 shows that the autocorrelation and cross-correlation coefficients of the simulated data was determined as highly statistically significant as were the correlations of the empirical data. Similarly, the distribution patterns underlying the FORECAS generated output were compared with the distribution patterns of the empirical data sets. Mann-Whitney tests for homogeneity of distribution indicated a probability of .641 that the FORECAS generated WIA data for a heavy battle intensity scenario was similarly distributed to the empirical data from a heavy intensity combat operation. Further, the Mann-Whitney test comparing simulated data for a light intensity scenario with data from a historical operation of light intensity failed to reject the hypothesis that the data sets were not from similarly distributed populations (p.=.304). The Mann-Whitney tests of the DNBI output generated from FORECAS failed to reject the hypothesis that the heavy intensity data was differently distributed than empirical data of a similar intensity level ($p = .524$), and that the data generated for a low intensity operation was dissimilar to the empirical data of a low intensity operation ($p = .575$).

Table A.1 Goodness of fit tests comparing Okinawa combat troop DNBI rates with lognormally-approximated distribution

Statistical Parameters	Historical Data	Approximated Distribution
Formula		**Lognorm(4.82,3.43)**
Mean	4.81	4.82
Median	3.8	3.93
Standard Deviation	3.15	3.43
Variance	9.90	11.74
Minimum	1.3	1.3
Maximum	14.53	14.53

Goodness of Fit Tests	Results
Chi-Square	
Test Value	17.64
Confidence	**>0.06**
Critical Value @ .1	15.99
Critical Value @ .05	18.31
Kolmogorov-Smirnov	
Test Value	0.09
Confidence	**>0.15**
Adjusted Value	0.83
Critical Value @ .15	1.14
Critical Value @ .1	1.22
Anderson-Darling	
Test Value	0.96
Confidence	**>0.15**
Critical Value @ .15	1.61
Critical Value @ .1	1.93

Table A.2 Goodness of fit tests comparing Okinawa support troop DNBI rates with lognormally-approximated distribution

Statistical Parameters	Historical Data	Approximated Distribution
Formula		**Lognorm(0.94,0.56)**
Mean	0.93	0.94
Median	0.86	0.81
Standard Deviation	0.51	0.56
Variance	0.26	0.31
Minimum	0.15	0.15
Maximum	2.87	2.87

Chi-Square	
Test Value	7.76
Confidence	**>0.65**
Critical Value @ .75	6.74
Critical Value @ .5	9.34
Kolmogorov-Smirnov	
Test Value	0.09
Confidence	**>0.15**
Adjusted Value	0.83
Critical Value @ .15	1.14
Critical Value @ .1	1.22
Anderson-Darling	
Test Value	0.515
Confidence	**>0.15**
Critical Value @ .15	1.61
Critical Value @ .1	1.93

Table A.3 Goodness of fit tests comparing Korea combat troop DNBI rates with lognormally-approximated distribution

Statistical Parameters	Historical Data	Approximated Distribution
Formula		**Lognorm(3.60,3.27)**
Mean	3.36	3.58
Median	2.63	2.65
Standard Deviation	2.29	3.27
Variance	5.24	10.72
Minimum	0	0
Maximum	13.41	13.41

Goodness of Fit Tests	Results
Chi-Square	
Test Value	12.85
Confidence	**>0.37**
Critical Value @ .5	11.34
Critical Value @ .25	14.85
Kolmogorov-Smirnov	
Test Value	0.1
Confidence	**>0.10**
Adjusted Value	1.18
Critical Value @ .15	1.14
Critical Value @ .1	1.22
Anderson-Darling	
Test Value	1.19
Confidence	**>0.15**
Critical Value @ .15	1.61
Critical Value @ .1	1.93

Table A.4 Goodness of fit tests comparing Korea support troop DNBI rates with lognormally-approximated distribution

Statistical Parameters	Historical Data	Approximated Distribution
Formula		**Lognorm(0.79,0.44)**
Mean	0.77	0.79
Median	0.72	0.69
Standard Deviation	0.35	0.44
Variance	0.12	0.19
Minimum	0.12	0.12
Maximum	2.46	2.46

Chi-Square	
Test Value	24.13
Confidence	**>0.01**
Critical Value @ .05	21.03
Critical Value @ .025	23.34
Kolmogorov-Smirnov	
Test Value	0.12
Confidence	**>0.01**
Adjusted Value	1.51
Critical Value @ .1	1.22
Critical Value @ .05	1.36
Anderson-Darling	
Test Value	1.99
Confidence	**>0.05**
Critical Value @ .1	1.93
Critical Value @ .05	2.49

Table A.5 Goodness of fit tests comparing Vietnam combat troop DNBI rates with lognormally-approximated distribution

Statistical Paramaters	Historical Data	Approximated Distribution
Formula		**Lognorm(2.04,1.89)**
Mean	1.95	2.03
Mode	0.79	0.79
Median	1.65	1.48
Standard Deviation	1.95	1.89
Variance	3.79	3.56
Minimum	0	0
Maximum	19.02	19.02

Goodness of Fit Tests	Results
Kolmogorov-Smirnov	
Test Value	0.12
Confidence	**>0.05**
Adjusted Value	1.28
Critical Value @ .1	1.22
Critical Value @ .05	1.36
Anderson-Darling	
Test Value	2.31
Confidence	**>0.05**
Critical Value @ .1	1.93
Critical Value @ .05	2.49

Table A.6 Goodness of fit tests comparing Falklands combat troop DNBI rates with lognormally-approximated distribution

Statistical Parameters	Historical Data	Approximated Distribution
Formula		**Lognorm(1.43,1.52)**
Mean	1.32	1.43
Median	1.35	0.98
Standard Deviation	0.89	1.52
Variance	0.79	2.31
Minimum	0.12	0.12
Maximum	3.29	3.29

Chi-Square	
Test Value	6.13
Confidence	**>0.4**
Critical Value @ .5	5.35
Critical Value @ .25	7.84
Kolmogorov-Smirnov	
Test Value	0.16
Confidence	**>0.15**
Adjusted Value	0.85
Critical Value @ .15	1.14
Critical Value @ .1	1.22
Anderson-Darling	
Test Value	0.62
Confidence	**>0.15**
Critical Value @ .15	1.61
Critical Value @ .1	1.93

Table A.7 Goodness of fit tests comparing Okinawa combat troop WIA rates with exponentially-approximated distribution

Statistical Parameters	Historical Data	Approximated Distribution
Formula		**Expon(6.86)**
Mean	6.86	6.86
Median	5.2	4.75
Standard Deviation	6.65	6.86
Variance	44.24	47.01
Minimum	0	0
Maximum	31.76	31.76

Goodess of Fit Tests	Results
Chi-Square	
Test Value	16.66
Confidence	**>0.08**
Critical Value @ .1	15.99
Critical Value @ .05	18.31
Kolmogorov-Smirnov	
Test Value	0.11
Confidence	**>0.05**
Adjusted Value	1.06
Critical Value @ .1	0.99
Critical Value @ .05	1.094

Table A.8 Goodness of fit tests comparing Falklands combat troop WIA rates with lognormally-approximated distribution

Statistical Parameters	Historical Data	Approximated Distribution
Formula		**Lognorm(1.77,3.56)**
Mean	1.78	1.77
Median	0.12	0.79
Standard Deviation	3.55	3.56
Variance	12.63	12.67
Minimum	0	0
Maximum	14.69	14.69

Kolmogorov-Smirnov	
Test Value	0.2
Confidence	**>0.15**
Adjusted Value	1.04
Critical Value @ .15	1.14
Critical Value @ .1	1.22
Anderson-Darling	
Test Value	1.02
Confidence	**>0.15**
Critical Value @ .15	1.61
Critical Value @ .1	1.93

Table A.9 Goodness of fit tests comparing Okinawa combat troop KIA rates with exponentially-approximated distribution

Statistical Parameters	Historical Data	Approximated Distribution
Formula		**Expon(1.63)**
Mean	1.63	1.63
Median	1.12	1.13
Standard Deviation	1.73	1.63
Variance	2.98	2.66
Minimum	0	0
Maximum	7.51	7.51

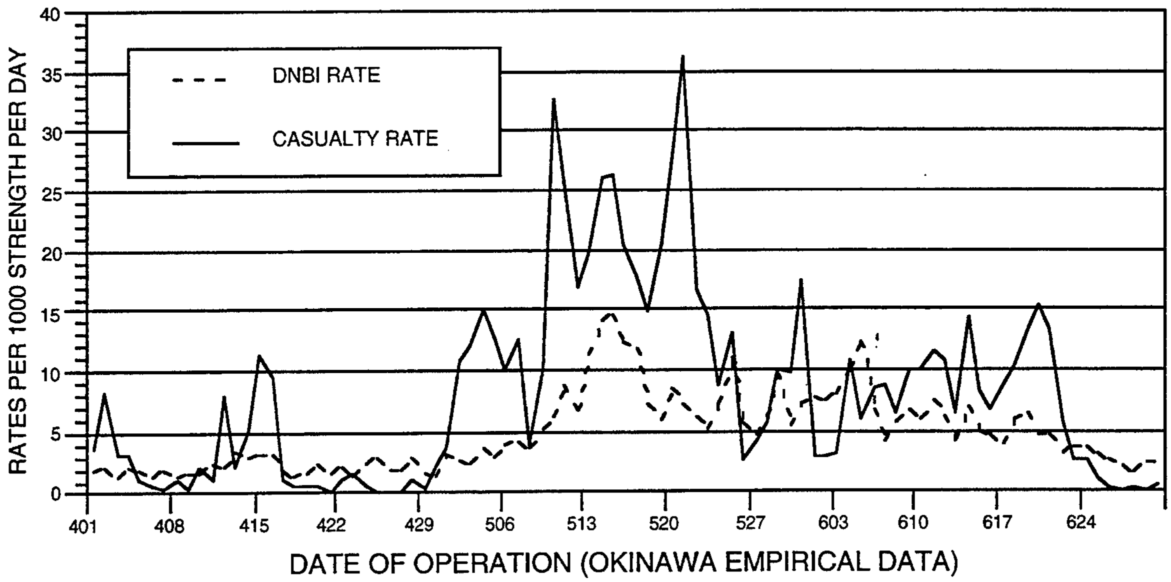
Goodness of Fit Tests	Results
Chi-Square	
Test Value	16.16
Confidence	**>0.09**
Critical Value @ .1	15.99
Critical Value @ .05	18.31

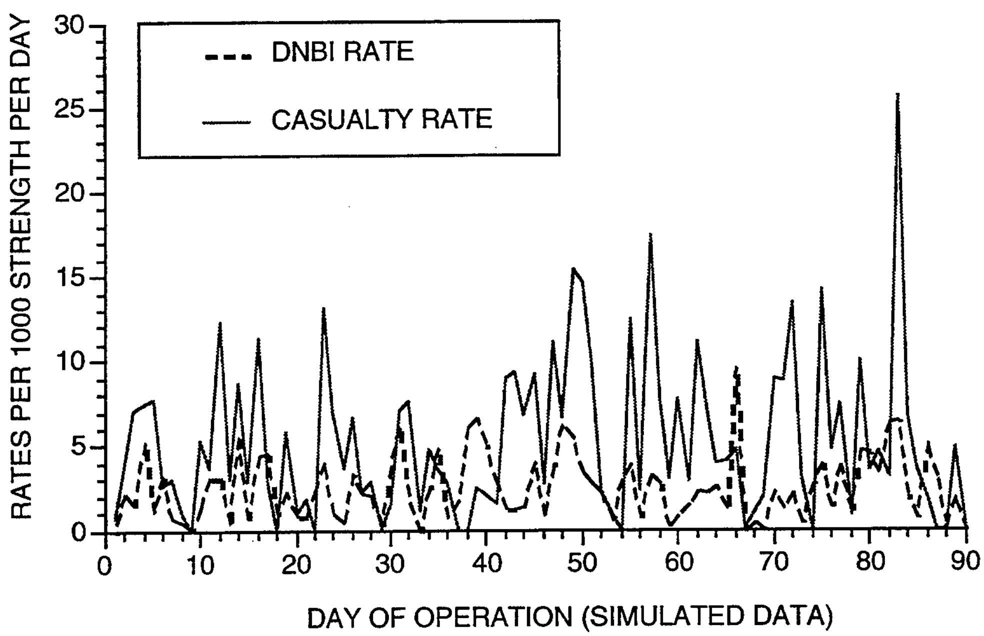
Table A.10 Goodness of fit tests comparing Falklands combat troop KIA rates with lognormally-approximated distribution

Statistical Parameters	Historical Data	Approximated Distribution
Formula		**Lognorm(0.68,1.39)**
Mean	0.68	0.68
Median	0	0.3
Standard Deviation	1.39	1.39
Variance	1.93	1.93
Minimum	0	0
Maximum	5.68	5.68

Chi-Square	
Test Value	14.01
Confidence	**>0.02**
Critical Value @ .05	12.59
Critical Value @ .025	14.45
Anderson-Darling	
Test Value	2.95
Confidence	**>0.025**
Critical Value @ .05	2.49
Critical Value @ .025	3.07

A.11 CORRELATIONAL TRENDS OF EMPIRICAL DATA AND FORECAS SIMULATED DATA





	EMPIRICAL DATA	SIMULATED DATA
AUTOCORRELATION	r = .75	r = .35
DNBI/WIA CROSS-CORRELATION	r = .67	r = .60

all correlation coefficients significant (p < .001)

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13. ABSTRACT ***(Maximum 200 words)***

The FORECAS planning tool was designed to assist medical requirements specialists in determining the resource needs of specific ground combat operations. The FORECAS tool provides projections of wounded-in-action, killed-in-action, and disease/nonbattle injury incidence for infantry, support, and service support troops under various combat conditions. FORECAS was constructed in two phases: development of a simulation tool that reflects the statistical trends observed in previous combat scenario, and assessment and quantification of the adjustments necessary to enable FORECAS projections to reflect contemporary scenarios. The FORECAS simulations were found to represent the trends observed in the historical data.

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