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A SYSTEM TO PROJECT INJURY AND ILLNESS INCIDENCE DURING MILITARY OPERATIONS

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ABSTRACT

Modeling of medical resource requirements during military operations requires projections of disease and non-battle injury (DNBI) and wounded-in-action (WIA) rates. Historical data were extracted from unit diaries of infantry and support troop deployed during four previous combat engagements. A planning tool (FORECAS) was developed that uses the statistical distributions of DNBI and WIA incidence from previous operations to simulate injury and illness arrival rates for future scenarios. Output of the simulated data reflects the nuances of the empirical data.

1 INTRODUCTION

Forecasts of the expected injury and illness incidence in a combat theater is requisite to the medical resource planning of a military operation (Systems Research 1992 and Galarza 1987). Distribution characteristics of casualty incidence patterns may be derived by fitting theoretical distributions to illness and injury data of previous operations. These distributions can then provide a basis for modeling future disease and non-battle injury (DNBI) rates and WIA (wounded-in-action) incidence.

A medical casualty forecasting system (FORECAS) has recently been developed. The purpose of the FORECAS software is threefold: 1) to provide medical planners with estimates of the average daily rates of medical admissions that may be sustained in a given scenario, 2) to indicate the maximum daily patient loads that may be incurred and for which planning is necessary, and 3) to enhance understanding of the statistical properties of injury and illness rates for use in future modeling efforts. The utility of FORECAS as a planning tool goes beyond supplying the average daily admission rates for operations; FORECAS also reflects the 'pulse and pause' nature of combat operations in the inter-arrival times and the magnitudes of projected medical admission frequencies. By displaying the dispersion, the range, and other statistical properties, FORECAS graphically depicts the potential patient flow within a theater of operations--information that is critical to proper medical resource allocation.

Development of a casualty simulation model required the analysis of historical data to determine the appropriate probability distributions. Data were extracted from the unit diaries of Marine Corps battalions deployed (1) to Okinawa in 1945 (April 1 through June 30), (2) to Korea between February and June of 1951, and (3) to Vietnam between May and June, 1968. Additionally, medical incidence data from the 1983 Falklands conflict was extracted and analyzed. These time periods were selected because they were thought to be representative of potential future operations. All told, the data (Blood 1995 and Blood 1994) upon which this medical projection system bases its forecasts exceeds 3.5 million person-days.

Studies performed at the Naval Health Research Center (O'Donnell 1993 and O'Donnell 1994) found that DNBI rates among combat support troops follow a simple Poisson process that can be approximated by a normal distribution. Among infantry troops, however, greater fluctuations in DNBI rates were evidenced and this process is best represented by a lognormal distribution. Rates of WIA are characterized by a non-stationary Poisson process combined with the appropriate time series attributes (inter-arrival patterns). Further, there was found to be a significant amount of autocorrelation within both the DNBI time series data and the WIA data. Another significant aspect of the empirical rate analysis was the degree of correlation between the WIA rates and DNBI incidence among infantry troops (Blood 1993). Support troops DNBI data, in contrast, is a simple random variable that is independently and identically distributed.

2 USE OF THE FORECAS PROJECTION SYSTEM FORECAS

System minimum requirements: an IBM or IBM-compatible PC, an EGA to SVGA monitor, 640k of base memory, 500k disk space.

The first input screen employs a graphical user interface to prompt the user for the information needed in the simulations. The screen displays the following options regarding illness or injury incidence to be projected: DNBI, WIA, DNBI and WIA.

The second input screen prompts the user for information pertaining to battle tempo. Again, the user makes inputs with the use of the left-side mouse button. This screen requests the degree of battle intensity of the proposed battle scenario. The combat intensity options are: NONE, LIGHT, MODERATE, HEAVY, and INTENSE. The "NONE" category represents a 'no combat' situation; though tensions may exist, no combat is taking place (an occupying force, for example). While DNBI arrivals will still occur in this situation, there will be no WIA. The other battle tempo options reflect the magnitude of injury/illness incidence evidenced in previous combat operations of varying intensities (Blood 1995).

The third input screen allows the user to specify the numbers and types of troops for the projected scenario. There are three categories of troops: INFANTRY TROOPS, SUPPORT TROOPS, SERVICE SUPPORT TROOPS. Combat troops refer to infantry personnel; Support troops represent intra-divisional support such as tank, artillery, light-armored infantry, and combat engineer units; Service Support personnel includes the Force Service Support Group (FSSG) and the Surveillance, Reconnaissance, Intelligence Group (SRIG). Below each of the three troop categories are buttons for specifying the number of that troop type deployed.

The fourth input screen prompts the user for two parameters regarding the operational theater and length of the proposed scenario. The user chooses between EUROPE, EAST ASIA, and SOUTHWEST ASIA as the region and then specifies expected duration of the engagement.

Upon clicking the right-side mouse button, the first of the graphical displays is presented. The graphical presentations consist of DNBI and/or WIA incidence line charts plotted across the temporal course of the simulated scenario. Initially, each graph depicts a single troop type. If the user has selected more than one troop type, there will be a graph for each troop category followed by a composite line chart across all troops categories.

Each arrival stream (DNBI, WIA) is depicted in different colors to enhance user viewing. Along the y (vertical) axis the scale shows the magnitude of the arrivals, while the x (horizontal) axis represents the temporal course of the operation (See Figure 1).

A statistical summary screen follows each graphical depiction of injury/illness incidence. The user-defined parameters are shown at the top of the screen. Below these parameters are descriptive statistics representing the casualty flow over the operation. For DNBI* and WIA incidence, the output shows:

-TOTAL NUMBER OF PRESENTATIONS
-TOTAL NUMBER OF ADMISSIONS
-Total number of diseases*
-Total number of nonbattle injuries*
-Total number of battle fatigue cases*
-DAILY ADMISSION AVERAGES
-MAXIMUM ADMISSIONS ON A SINGLE DAY
-AVERAGE RATE PER 1000 STRENGTH PER DAY
-MAXIMUM DAILY RATE PER 1000 STRENGTH
-MINIMUM DAILY RATE PER 1000 STRENGTH

Presentations represent the total number of patients expected to be admitted to a treatment facility. Admissions represent only those patients whose treatment is expected to last three days or longer.

Upon hitting the "enter" key, the system then proceeds to the next graphical presentation (line chart for the next troop category). This process repeats itself until all troop categories have been viewed or the user quits. After all the graphs and statistical summary screens have been viewed,

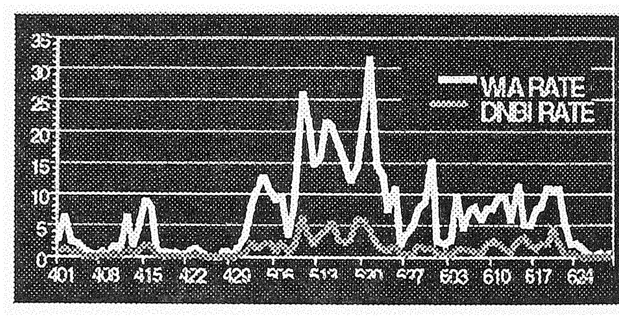

Figure 1: FORECAS depiction of daily patient load

the user is returned to the initial input screen to create another scenario or to quit the program.

3 STATISTICAL UNDERPINNINGS OF FORECAS

The historical data that was studied to form the basis for the simulation comes from Marine company and battalion unit diaries. These battalions were of varying strengths. Numbers of illnesses and injuries were computed per 1000 troop strength per day. This standardization of the data gives the output a uniform perspective which can be easily adjusted across various troop strength levels. The actual simulations are accomplished with the aid of uniform random number generators to start each of the rates.

3.1 DNBI Rates

The simulation of support troop DNBI rates makes use of variates drawn from a normal distribution. These variates historical data. The variates Y, are distributed as:

$$Y \sim N(\mu,\sigma^2)$$

Generation of the infantry troop DNBI can be derived from a lognormal approximation to a Poisson process. The variates from a lognormal distribution are distributed as:

$$X \sim LN(\mu,\sigma^2)$$

Generation of this variate is similar to the normal distribution. After deriving Y, the normal variate, the lognormal variate, X, is then generated:

$$X = e^Y$$

This results in an IID lognormal variate. This is than put into the equation:

$$X_t = \beta_0 + \beta_1 X_{t-1} + \beta_2 W_t + LN(\mu,\sigma^2)$$

where:

X_t = the infantry DNBI variate with the necessary auto and cross correlations.

β_i = constants used to obtain the necessary auto and cross correlations.

W_t = the WIA variate.

$LN(\mu,\sigma^2)$ = the IID lognormal variate

3.2 WIA Rates

Examination of individual battalions shows the historical data of the combat troop WIA rates are represented by single and batch arrivals in a non-homogeneous Poisson process. Representation of the 1000 troop strength per day can be simulated with the use of a continuous distribution. These variates are exponentially distributed.

$$W \sim \text{expo}(\beta)$$

where:

β is the estimated mean.

There is also a strong degree of autocorrelation within each of the combat troop series. Specifying that any of the combat troops series data as being independent is inappropriate. Generation of the series than involves producing a stream of variates that possess the needed serial correlation. Generating the series with autocorrelation then is:

$$W_t = \alpha_1 + \alpha_2 W_{t-1} + \alpha_3 W_{t-2} + \alpha_3 W_{t-2} + \text{expo}(\beta)$$

approximate the Poisson process which best represents the

where:

W_t = the WIA rate at time t.

α_t = constants used to develop the autocorrelation.

$\text{expo}(\beta)$ = the random number drawn from the computer.

The support troops and the extra-divisional troops both have less or no autocorrelation within each series so a simple exponential distribution is used to generate the interarrival times of each casualty event.

3.3 Validation of the Model

Analysis of the casualty stream data generated by FORECAS is warranted to ensure that the projection system accurately reflects the statistical trends evident in the empirical data. FORECAS also has a feature that creates an ASCII data set which can be imported into any common statistical software program to perform validation tests. Analyses were performed on the time series data in the form of serial and cross correlation tests. Past research found that support troop rates are identically and independently distributed -- consequently no autocorrelation should exist within each of these series and none was found. The combat troop DNBI empirical data however possessed a degree of autocorrelation which were accurately reflected in plots of the infantry troop DNBI simulated series.

Autocorrelation function graphs were also used to compare the simulated combat troop time series with the actual data and the plots indicated a significant degree of autocorrelation at the first day which decreases thereafter. This is consistent with the findings from analyses of the historical data. A test for cross-correlation between the DNBI and WIA series demonstrated a statistically significant finding similar to the empirical data. These analyses indicate that the simulations accurately depicted the statistical patterns evidenced in the empirical data.

4 CONCLUSIONS

Because the FORECAS projection system accurately simulates the medical admissions seen in previous military operations and because a great deal of consistency in admission patterns has been witnessed across operations in the past, this tool may prove useful in forecasting the medical requirements of future operations. Such a planning tool may likewise have similar utility in the civilian sector, to the extent that sufficient empirical data exists upon which to base projections.

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