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DISTRIBUTION CHARACTERISTICS OF MARINE CORPS CASUALTY AND ILLNESS RATES

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Distribution Characteristics of Marine Corps Casualty and Illness Rates

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SUMMARY

Problem

Modelling of medical resource requirements during military operations requires projections of disease and non-battle injury (DNBI) rates as well as wounded-in-action (WIA) and killed in action (KIA) rates.

Objective

The current analysis examines the underlying statistical distributions of WIA, KIA and DNBI incidence rates among combat and combat support troops deployed to Okinawa and Korea.

Approach

DNBI, WIA and KIA data were extracted from Marine Corps unit diaries for a 150-day period of the Korean War and from a 90 day period of the Okinawa operation during World War II. The statistical distributions of DNBI, WIA and KIA incidence for both combat and combat support troops were analyzed separately.

Results

Lognormal and normal distributions were used to roughly approximate Poisson processes of the DNBI rates of the combat and combat support troops from both military operations. The WIA and KIA rates from each campaign were modelled with the use of compound Poisson processes and exponentially distributed interarrival times.

Conclusions

Assessment of the discrete statistical distributions of the daily disease and casualty incidence rates allows more accurate modelling of theater medical requirements. The use of a point estimate in predicting any of the rates other than DNBI combat support troops is inappropriate due to the dispersion and nature of the data.

Distribution Characteristics of Marine Corps Casualty and Illness Rates

Forecasts of casualties and illness incidence is requisite to the medical resource planning of military operations. By fitting a theoretical distribution to the historical data, information may be inferred from the actual underlying nature of the distribution which can then provide a basis for modelling future casualty and disease and non-battle injury (DNBI) rates.

One basic difference distinguishes DNBI from casualty incidence in a theater of operations. Personnel will become ill and receive non-battle injuries no matter the tempo of the military operation. Recent studies[1] found DNBI rates to range from 0.867 to 2.936 per 1,000 Marines per day for different monthly periods during peacetime. These data indicate a positive inflow of DNBI occurrences among military personnel independent of combat operations. Further, the incidence of these illness rates are Poisson distributed and can therefore be roughly approximated by a normal distribution. With a normal distribution, 68 percent of the patients will fall within one standard deviation of the mean rate, 95 percent of the patients will fall within two standard deviations of the mean and nearly all will fall within three standard deviations.

The pulse and pause nature of military conflicts, however, must be taken into account when analyzing WIA and KIA rates. An investigation[2] examining casualty incidence during Western Pacific ground operations indicated that rates varied significantly among individual operations. This study also documented that the rates varied by the operations' length as well as the point in the overall conflict in which the operations were mounted. Consequently, these rates cannot be approximated by a normal distribution.

The intent of the current investigation is to enhance the understanding of the statistical properties of DNBI, WIA and KIA rates. Depending upon the underlying distribution, additional information beyond a "mean rate" may be needed to properly model future rates. By examining the dispersion, the range and other statistical properties of the data from which the rates are computed, vital information can be assessed for use in rate forecasting.

METHOD

Data were extracted from the unit diaries of Marine Corps battalions stationed in Korea between February and June of 1951. The unit diaries included information on individuals wounded, killed and sick, as well as the daily strength of the unit. These unit diaries are stored at the Marine Corps Historical Center in Washington, D.C. Similar data from the Okinawa operation, housed at the National Archives, were extracted from muster rolls of Marine Corps battalions engaged in the three-month operation from 1 April through 30 June 1945.

Separate rates were computed representing the daily incidence of DNBI, WIA and KIA casualties among both combat and combat support personnel per 1000 troop strength. Rates are used rather than the actual incidence so that a uniform perspective among the different sized battalions may be obtained. These discrete event processes were aggregated into daily totals which can then be analyzed as Poisson occurrences. The aggregated daily totals yield a time series that can then explain the characteristics of the random event process. The operations and time periods were chosen to reflect the temporal nature of military operations.

Initial analyses of the rate distributions include graphical depictions in the form of histograms and line charts. Although these charts can be used to display a data set, mathematical procedures are also used to determine their underlying statistical properties. Formal goodness-of-fit testing examines the null hypothesis (H_o) that a given random variable x follows a stated probability function $F(x)$ and the goodness-of-fit test measures the conformity of the variable to the hypothesized distribution. The null hypothesis states that "the variables do come from some specific distribution" and the alternate hypothesis states that "the rates do not conform to the hypothesized distribution." The preliminary objective of the analysis is to test the null hypothesis:

H_o: $X \sim F(\theta)$ where F is the hypothesized distribution,
and θ is a vector of estimated parameters.

The goodness-of-fit analysis was the Lilliefors[3] test, which examines the maximum absolute difference between the empirical distribution function (EDF) and the fitted cumulative distribution function (CDF). The EDF then is $F_n(x)$, which is a right-continuous step function with $F_n(x_i) = i/n$ for each $i = 1, 2, ..., n$. $F_n(x)$ was plotted against the X_i's. The X_i's are ordered into ascending order (hence the term order statistics), thereby resulting in a plot of two monotonically increasing variables.

The CDF (for the case of the exponential distribution) is then the hypothesized distribution where:

$F(x) = 1 - \exp(-X_i/B)$ and B is the estimated mean.

The CDF is then plotted alongside the EDF. The index of goodness-of-fit is a measure of closeness (D_n) between the functions F_n (EDF) and F (CDF). D_n is the largest vertical distance between $F_n(x)$ and $F(x)$ for all of the values of x.

So:

$$D_n = \text{Sup}\{|F_n(x) - F(x)|\}$$

Where:

$F_n(x) = 0,\quad x < X(1)$

$F_n(x) = i/n,\quad X_{(i)} \leq x < X_{(i+1)},\ i = 1, ..., n-1$

$F_n(x) = 1.\quad X_{(n)} \leq x$

and:

$F(x)$ is the CDF.

The Lilliefors test focuses on the interarrival times of the occurrence of each of the DNBI, WIA and KIA events. A typical Poisson process will have interarrival times following an exponential distribution. This hypothesis requires that the actual incidence of DNBI, WIA and KIA from the battalions be examined. A fixed interval of time [0, T], was studied for each military operation (T = 90 for Okinawa and T = 150 for Korea). The actual number and time of events are then observed in that time interval. This occurrence of each incidence within that fixed time interval will follow a uniform distribution. The actual time of occurrence of each event is designated as t_i within the time period and the t_i's are put into ascending order where $0 \leq t_1 \leq t_2 \leq ....t_n \leq T$. These n events then conform to a uniform distribution or U(0,T). This can be tested with a non-parametric analysis such as Lilliefors[4].

Several of the event processes studied do not conform to a simple Poisson process. A significant violation is one of batch arrivals. A stochastic process is a simple Poisson process if arrivals come one at a time. This is clearly not the case in military scenarios; especially regarding WIA and KIA incidence. This type of stochastic process is termed a compound Poisson process.

Another necessary condition for a simple Poisson process is one of constant variance throughout the time interval[5]. This requirement assumes that for any random sub-sample of the entire time interval, there is a constant variance among the pulses and pauses of the studied event.

Besides solely examining the data as different Poisson processes, supplementary analyses are indicated. The nature of any military conflict suggests that the occurrence of each of these events may possess some inherent degree of time series attributes. The rates are aggregated events taken over a fixed time interval and so the idea of a time series analysis warrants consideration. This type of analysis presumes that the phenomena has been produced by a stochastic process that possesses a design that can be modelled. The description will be represented in terms of how the rate's randomness is embodied in it's own process.

A time series structure is appropriate for the combat troop rates and may be analyzed with an *A*uto*R*egressive *I*ntegrated *M*oving *A*verage model[6]. The classic Box-Jenkins ARIMA(p,d,q) model will be used to evaluate the temporal nature of the rates, (Y_t). This type of model incorporates an autoregressive term (p), a differencing term (d), and a moving average term (q). A well defined ARIMA model will parsimoniously describe the behaviour of a time series. The autoregressive term (p) will predict Y_t from previous values of the specified aggregated rate. This is set up as:

$$Y_t = \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \ldots \Phi_p Y_{t-p} + a_t$$

a_t is an independently distributed random variable with zero mean or,

$a_t \sim NID(0,\sigma^2)$. This is also known as white noise.

The differencing term (d) is used when a series is not invariant with respect with time.

Non-stationary processes have a variance that changes with respect to time. ARIMA models cannot be analyzed unless the variance is stable over the course of the fixed interval. The presence of drift or trend in a series requires that the series be differenced. A time series process that does not need to be differenced is said to be stationary in the homogeneous sense.

The moving average term (q) represents a random shock with finite persistence. A moving average process generates each observation of Y_t by a weighted average of random disturbances that go back (q) periods in time. These random disturbances are also assumed to be independently distributed across time; i.e., a white noise process.

Parameters for p, d and q must then be specified for the ARIMA model. The use of autocorrelation (ACF) and partial autocorrelation (PACF) plots and line charts can help in determining the appropriate values for the parameters. The ACF plot shows the lagged correlations within confidence intervals while the PACF shows the correlations between days with any intervening lags partialed out.

RESULTS

DNBI

Figures 1 and 2 are graphical presentations of the aggregated DNBI rates among combat and combat support troops from Okinawa and Korea. The processes making up the two different DNBI rates differ significantly. The combat troops, which by definition are subjected to heavier battle exposure, are more likely to experience irregular health care, and in general, are more likely to sustain non-battle injuries and incidence of illness. The aggregated DNBI flows demonstrate the volatile and erratic nature of this process. The estimated sample mean of the Okinawa combat troops DNBI rates is 4.81, the standard deviation is 3.15 and the range is from 1.3 to 14.53. Among the aggregated combat troop rates there is a tendency for the rates to possess some degree of time series behaviour. There are visible patterns within the flows that suggest a trend amongst the data. The use of an ARIMA model is then indicated. Initial analysis for the Okinawa combat troop DNBI rates requires the use of autocorrelation and partial autocorrelation plot functions (ACF and PACF).

PLOT 1. AUTOCORRELATIONS OF OKINAWA COMBAT DNBI RATES

```
          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
LAG   CORR. +----+----+----+----+----+----+----+----+----+----+
                                     I
  1  -0.252                    X+XXXXI    +
  2  -0.230                    X+XXXXI    +
  3   0.126                    +     IXXX  +
  4   0.094                    +     IXX   +
  5  -0.089                    +   XXI     +
  6  -0.006                    +     I     +
  7   0.044                    +     IX    +
  8  -0.119                    +  XXXI     +
  9   0.121                    +     IXXX  +
 10  -0.099                    +   XXI     +
 11   0.149                    +     IXXXX +
 12   0.023                    +     IX    +
 13  -0.157                    + XXXXI     +
 14  -0.017                    +     I     +
 15   0.102                    +     IXXX  +
```

PLOT 2. PARTIAL AUTOCORRELATIONS OF OKINAWA COMBAT DNBI RATES

```
          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
LAG   CORR. +----+----+----+----+----+----+----+----+----+----+
                                     I
  1  -0.252                    X+XXXXI    +
  2  -0.313                  XXX+XXXXI    +
  3  -0.034                     +   XI    +
  4   0.064                     +    IXX  +
  5  -0.007                     +    I    +
  6   0.008                     +    I    +
  7   0.011                     +    I    +
  8  -0.128                     + XXXI    +
  9   0.078                     +    IXX  +
 10  -0.115                     + XXXI    +
 11   0.182                     +    IXXXXX
 12   0.095                     +    IXX  +
 13  -0.077                     +  XXI    +
 14  -0.082                     +  XXI    +
 15  -0.033                     +   XI    +
```

The DNBI combat series, as indicated by Figure 1, has obvious nonstationary attributes. The variance as well as the mean varies over the course of the time interval. To account for this the series is logged and then differenced once. The autocorrelations (plots 1 and 2) are shown for 15 days. The military operation in Okinawa is historically seen as a heavy-intense operation and so there is the expectation for varying levels of combat activity. This explains the nonstationary aspects of the DNBI series. The series needs to be differenced once thereby setting the term (d) to one. The autocorrelation at any lag shows the Pearson correlation between the specified days. The partial shows the correlation with any intervening lags partialed out. The ACF plot spikes once and the PACF spikes at the first and second lag and then becomes insignificant. Using this information and the previously mentioned differencing term, an ARIMA(0,1,1) model is indicated. The coefficient on the moving average term is 0.408 and has a T-ratio of 4.23 which is significant.

The Okinawa combat support troops aggregated DNBI rates show a constant variance throughout the entire time period. Examinations of individual support battalions show that the events are distributed uniformly throughout the time period and the amount of time between occurrences is best explained by an exponential distribution. The variance is also constant in any subsample of the time period. The normal distribution can then be used as a rough approximation to a Poisson process.

Figure 3 is a histogram depicting the frequency of occurrence of different rate ranges for the Korean combat troop DNBI data. The estimated sample mean is 3.35, the standard deviation is 2.29 and the range is 0 to 13.41. A lognormal *distribution is used to approximate* the Poisson process.

The Korean combat support troop DNBI data appear to fit a normal distribution (See Figure 4). The estimated sample mean is 0.774, the standard deviation is 0.352, and the range is from 0.1169 to 2.46. Performing a Lilliefors test for goodness-of-fit resulted in a positive confirmation of normalcy. The largest absolute vertical difference (D_n) came out to be 0.09617, which is less then the critical test statistic. The two-tailed P value came out as 0.1247, which indicates the rates can use a normal distribution as an approximation to a Poisson process, or:

H_o: $X \sim N(\mu, \sigma^2)$ with the parameters estimated from the data.

The analysis on the Okinawa support troop rates proved to be similar to the Korean data. Probability plots were computed for the DNBI rates. The normal distribution is also used as a rough approximation to a Poisson process, where:

H_o: $X \sim N(\mu, \sigma^2)$ with the parameters estimated from the data.

The estimated sample mean of the combat support troops is 2.31, the standard deviation is 1.12, and the range is 0.0 to 5.97.

WIA

Figures 5 and 6 are displays of daily wounded-in-action rates among combat and combat support troops during the Korean War and Okinawa. The WIA rates did not fit the normal model so an alternate analysis was necessary. The most common daily occurrence of WIAs among combat troops was zero. Further, the combat support troops were less prone to being involved in combat, and so they sustained even fewer battle injuries. The pattern in Figure 6 suggest that the process generating the casualty flows could be a compound Poisson process. A negative binomial distribution could also be a possibility. For discrete distributions, the ratio τ can be used to distinguish between different possibilities. The ratio is computed as the variance divided by the mean or, $Var(x)/E(x)$. For a Poisson process the sample variance is equal to the sample mean and so the ratio τ is equal to 1. For the case of a negative binomial distribution the ratio is greater then 1 and this is the case with the Korean combat troops WIA rates. The aggregated rates have an estimated sample mean of 2.853, standard deviation of 8.691 and a range from 0 to 74.2. The combat support troop rates have an estimated sample mean of 0.139, standard deviation of 0.257 and a range from 0 to 1.23.

Time series methodology was set up for the aggregated Okinawa combat WIA rates. The estimated sample mean is 6.86, the standard deviation is 6.65 and the range is 0.0 to 31.76. ACF and PACF plots were set up to determine the appropriate ARIMA model.

PLOT 3. AUTOCORRELATIONS OF OKINAWA COMBAT WIA RATES

```
               -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
LAG    CORR.  +----+----+----+----+----+----+----+----+----+----+
                                         I
 1   -0.137                         +XXXXI    +
 2   -0.029                         +   XI    +
 3   -0.155                         +XXXXI    +
 4    0.018                         +    I    +
 5   -0.100                         +  XXI    +
 6    0.082                         +    IXX  +
 7   -0.155                         +XXXXI    +
 8    0.131                        +     IXXX  +
 9   -0.045                        +    XI     +
10    0.047                        +     IX    +
11   -0.160                        + XXXXI     +
12    0.126                        +     IXXX  +
13   -0.037                        +    XI     +
14   -0.023                        +    XI     +
15   -0.136                        +  XXXI     +
```

PLOT 4.PARTIAL AUTOCORRELATIONS OF OKINAWA COMBAT WIA RATES

```
               -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
LAG    CORR.  +----+----+----+----+----+----+----+----+----+----+
                                         I
 1   -0.137                        X+XXXXI    +
 2   -0.049                         +XXXXI    +
 3   -0.169                         +XXXXI    +
 4   -0.032                         +   XI    +
 5   -0.124                         + XXXI    +
 6    0.023                         +    IX   +
 7   -0.168                         +XXXXI    +
 8    0.060                         +    IXX  +
 9   -0.034                         +   XI    +
10   -0.006                         +    I    +
11   -0.141                         +XXXXI    +
12    0.056                         +    IX   +
13   -0.006                         +    I    +
14   -0.102                         + XXXI    +
15   -0.123                         + XXXI    +
```

Figure 5 shows that the series has a non-constant variance throughout the course of the time interval. The series was logged and differenced once to account for the varying mean and variance. Plots 3 and 4 show a rough decay in the PACF and a single spike in the ACF. This information leads to a ARIMA(0,1,1) for the log transformed series. The coefficient on the moving average term is 0.1635 and the t-statistic is 1.56. Plot 5 indicates that there is no significant correlation among the residuals and that they are a white noise process.

PLOT 5. AUTOCORRELATIONS OF RESIDUALS OF OKINAWA COMBAT WIA RATES

```
           -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
LAG    CORR. +----+----+----+----+----+----+----+----+----+----+
                                      I
  1   0.013                     +    I    +
  2  -0.051                     +   XI    +
  3  -0.167                     +XXXXI    +
  4  -0.023                     +   XI    +
  5  -0.093                     +  XXI    +
  6   0.047                     +    IX   +
  7  -0.130                     + XXXI    +
  8   0.107                     +    IXXX +
  9  -0.023                    +     XI     +
 10   0.021                    +      IX    +
 11  -0.140                    + XXXXI      +
 12   0.097                    +      IXX   +
 13  -0.030                    +     XI     +
 14  -0.050                    +     XI     +
 15  -0.136                    +   XXXI     +
```

The estimated sample mean for the Okinawa combat support troops is 0.95, the standard deviation is 1.00 and the range is 0.0 to 4.1. The estimated sample mean of the combat support troops is almost equal to the variance which is indicative of a Poisson process. The interarrival times follow an exponential distribution and the actual time of occurrence over the time interval is distributed uniformly.

KIA

Figures 7 and 8 are graphic depictions of the KIA rates among combat and combat support troops during the Korean War and Okinawa. The KIA distributions for combat and combat support troops each had a mode of zero. This prevalence is more pronounced for the combat support troops, which by definition, were involved in fewer battle encounters. Among the Korea data, the incidence of zero KIAs per day is slightly more than 77 percent for the combat troops and more than 90 percent for the combat support troops. The estimated sample mean of the combat troop rates is 0.209, the standard deviation is 0.731 and the range is 0 to

7.08. The combat support troop rates had an estimated sample mean of 0.013, standard deviation of 0.052 and a range from 0 to 0.4655. The ratio τ is greater then 1.0 for each of these KIA rates so a simple Poisson process is not accepted.

The estimated sample mean for the combat troop KIA rate is 1.42, the standard deviation is 1.51 and the range is 0.0 to 6.4. The estimated sample mean for the combat support troops KIA rate is 0.18, the standard deviation is 0.33 and the range is 0.0 to 1.33.

The KIA rates from each military conflict were highly correlated with the WIA rates from the same time frame. The same processes that generated the WIA rates can be used to partially explain the KIA rates. WIA and KIA rates then are both a function of the level of military activity going on at the time.

CONCLUSIONS

The distribution of WIA, KIA and DNBI rates were examined to gain insight to the underlying mathematical patterns of the data. The combat support troop DNBI rates from the Okinawa operation and the Korean War were normally distributed as an approximation to a Poisson process. Both combat troop DNBI rates however, deviated markedly from a constant daily average. During a military campaign, the combat troops will not be in a stationary location and they will be exposed to sporadic hazards. This can lead to sporadic latrine set-ups, varying degrees of personal hygiene and availability of medical care, and other unpredictable effects that will influence the daily DNBI rate. This partially explains why a lognormal distribution can be used as an approximation to a Poisson process for the Korean combat DNBI rates. The use of an ARIMA model was used for the Okinawa combat troop DNBI rates. While univariate time series models cannot be used for explanatory purposes, they can be used for predictive purposes. Support troops had less of these varying effects impacting daily DNBI incidence resulting in parameters associated with a normal distribution. Therefore, a mean DNBI incidence rate can be used to make accurate projections.

In contrast to DNBI rates for combat support troops, the use of point estimates for WIA and KIA rates can prove misleading. Citing a non-zero estimate as a projection does not account for the heavy prevalence of the zero modality nor the dispersion of the distribution for the casualty rates. A static rate of incoming casualties simply does not occur during a wartime event.[2] The use of mean rates for casualty projections, while providing rough approximations of WIA and KIA incidence, does not adequately represent the dynamic properties of military operations. Models projecting casualty rates must incorporate the descriptive characteristics of the statistical distributions. Further, a multivariate paradigm is required to model the interrelationship between DNBI and WIA rates and to express the underlying trends in the time series.

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FIGURE 1. DAILY DNBI RATES AMONG COMBAT AND COMBAT SUPPORT TROOPS

SERVING IN OKINAWA; APRIL-JUNE 1945

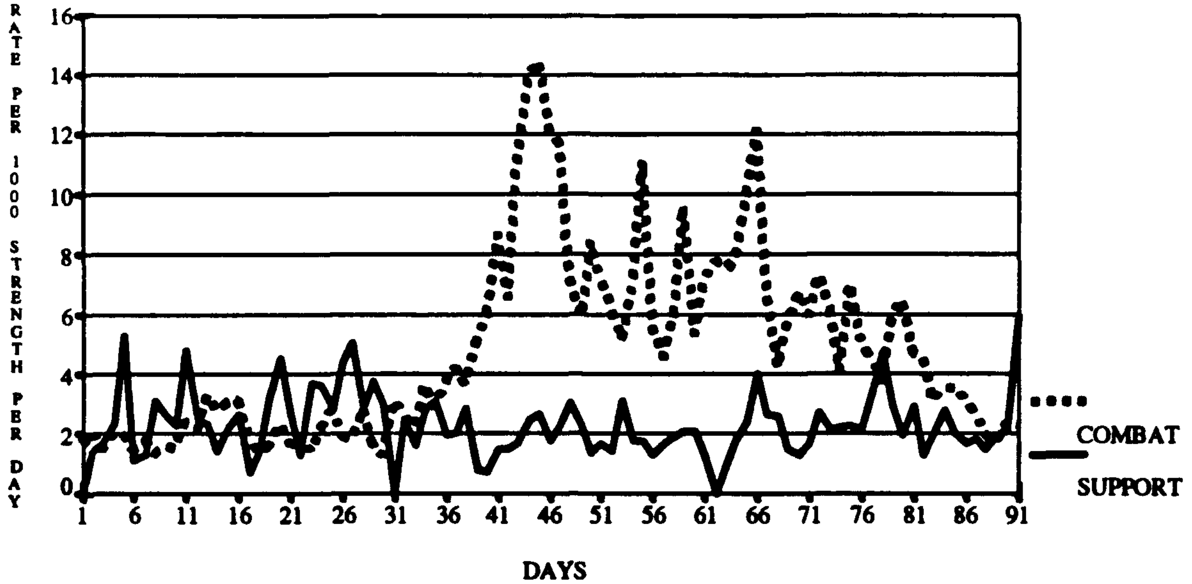
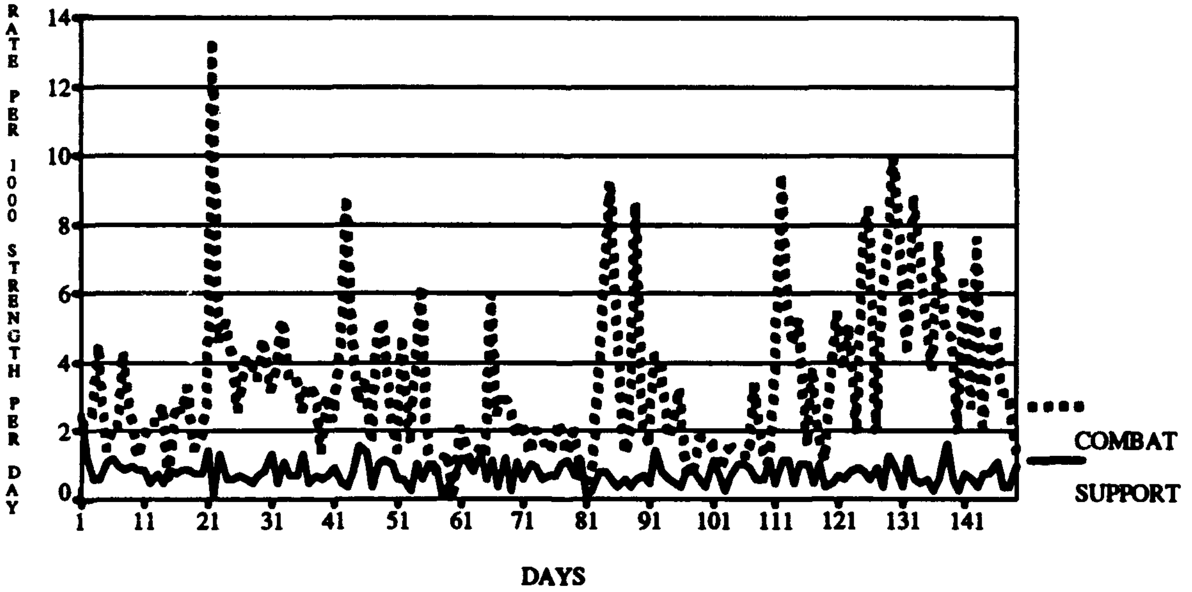


FIGURE 2. DAILY DNBI RATES AMONG COMBAT AND COMBAT SUPPORT TROOPS

SERVING IN KOREA; FEB-JUNE 1951



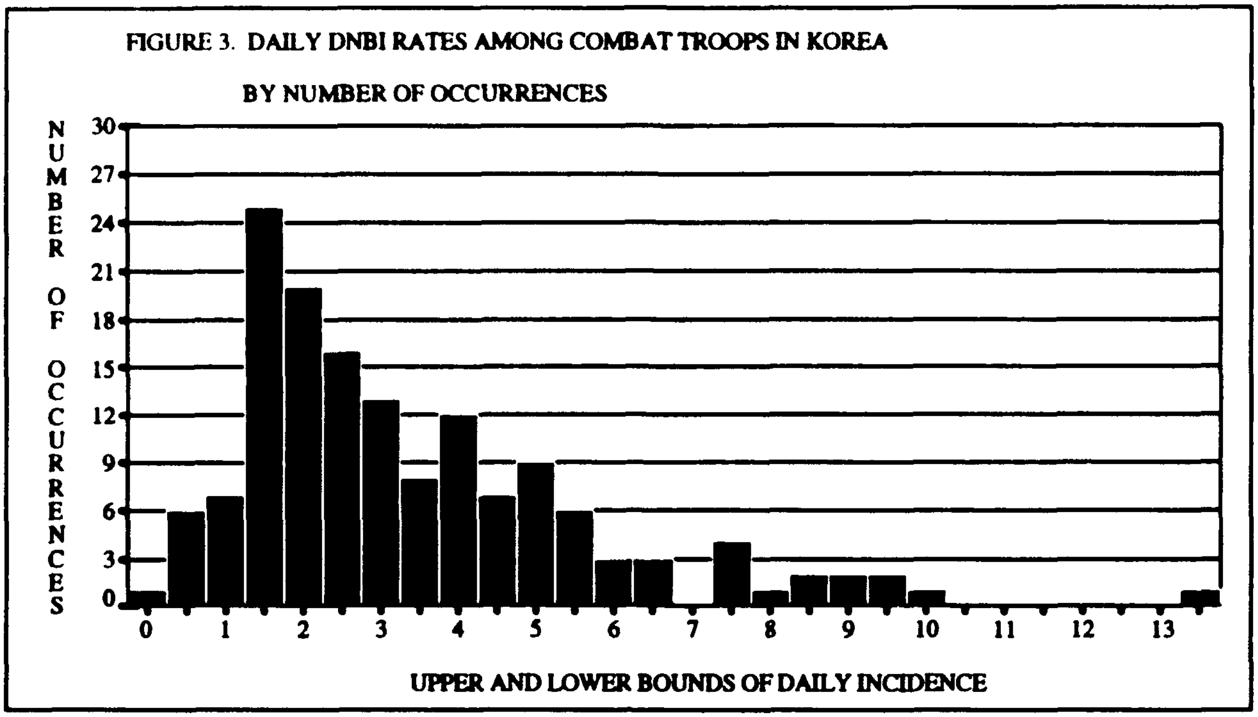


FIGURE 3. DAILY DNBI RATES AMONG COMBAT TROOPS IN KOREA
BY NUMBER OF OCCURRENCES
NUMBER OF OCCURRENCES
30
27
24
21
18
15
12
9
6
3
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13
UPPER AND LOWER BOUNDS OF DAILY INCIDENCE

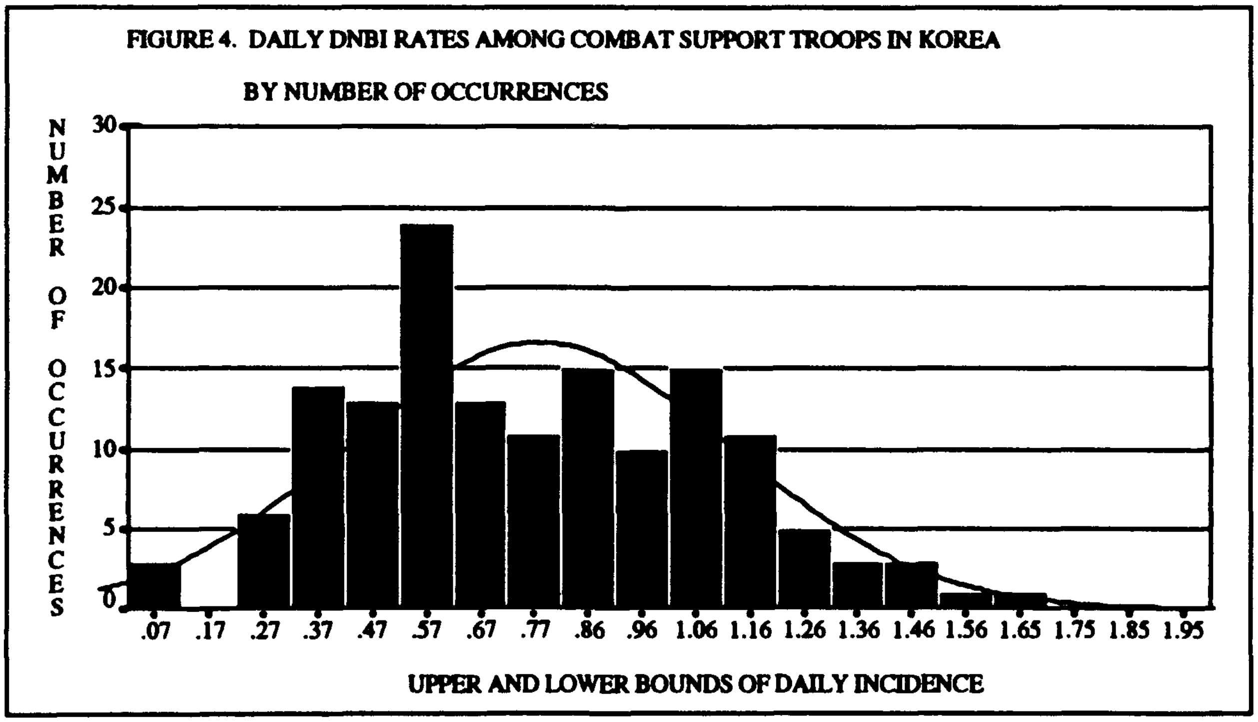


FIGURE 4. DAILY DNBI RATES AMONG COMBAT SUPPORT TROOPS IN KOREA
BY NUMBER OF OCCURRENCES
NUMBER OF OCCURRENCES
30
25
20
15
10
5
0
.07 .17 .27 .37 .47 .57 .67 .77 .86 .96 1.06 1.16 1.26 1.36 1.46 1.56 1.65 1.75 1.85 1.95
UPPER AND LOWER BOUNDS OF DAILY INCIDENCE

FIGURE 5. DAILY WIA RATES AMONG COMBAT AND COMBAT SUPPORT TROOPS SERVING IN OKINAWA; APRIL-JUNE 1945

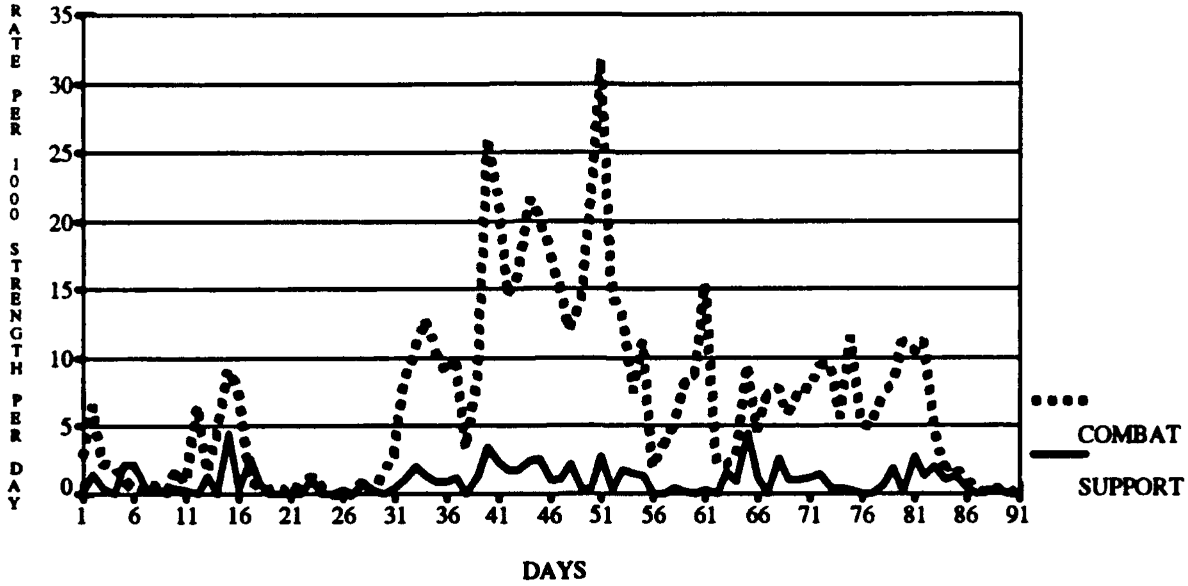
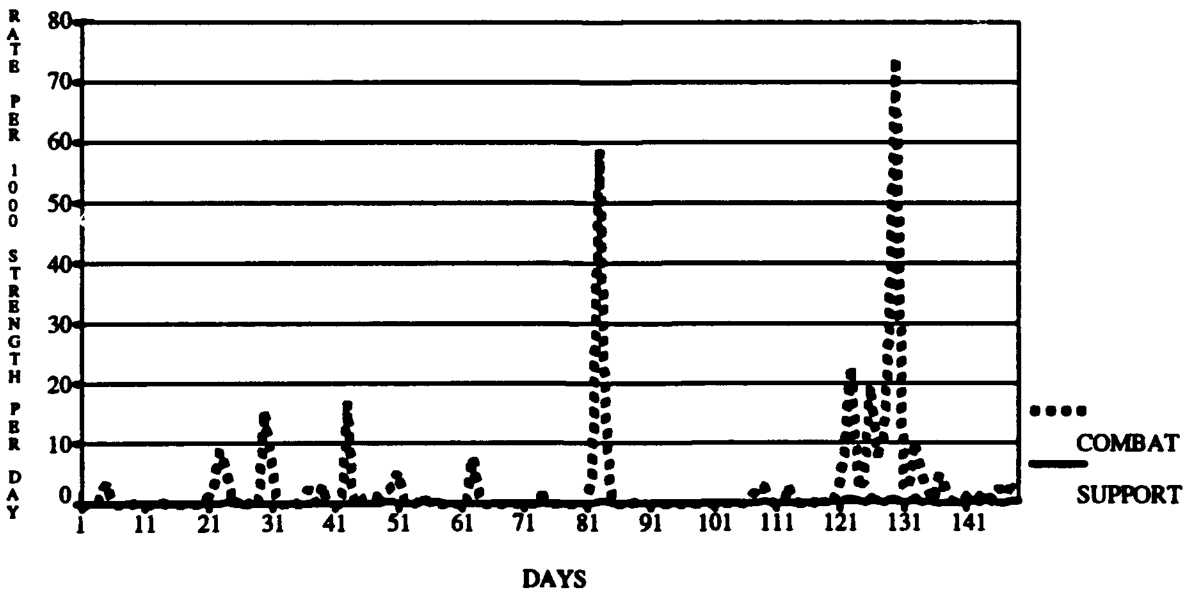


FIGURE 6. DAILY WIA RATES AMONG COMBAT AND COMBAT SUPPORT TROOPS SERVING IN KOREA; FEB-JUNE 1951



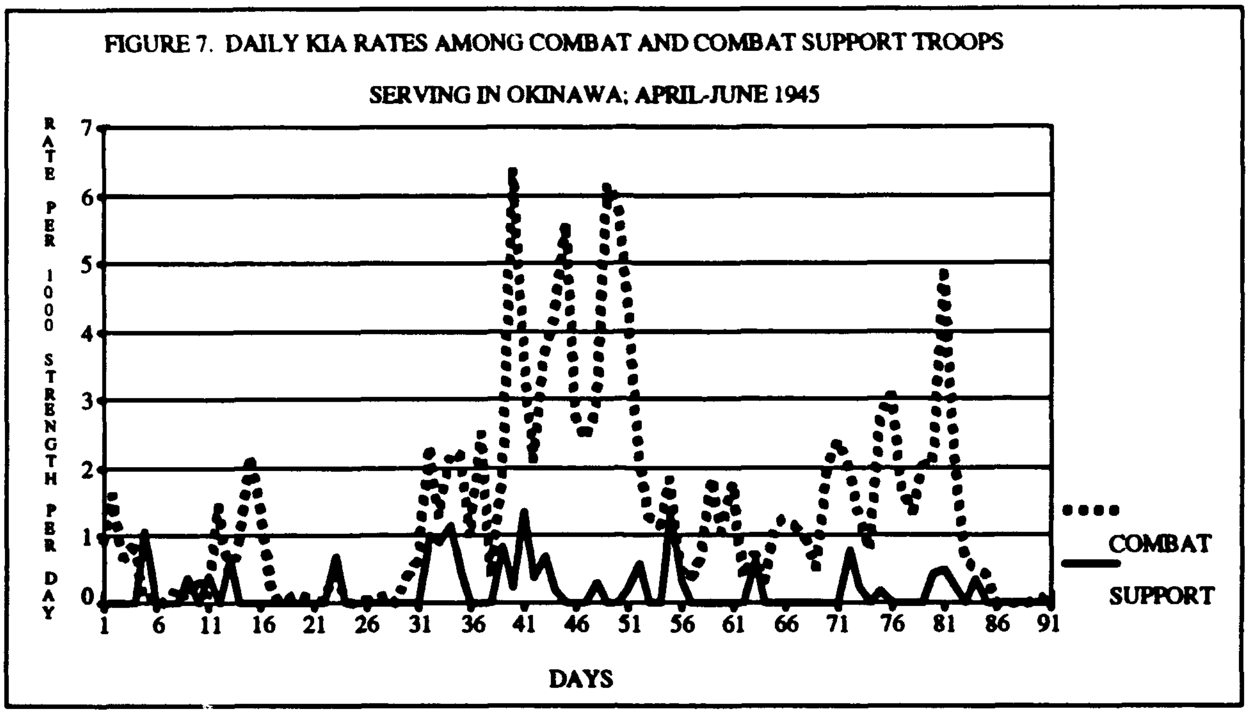


FIGURE 7. DAILY KIA RATES AMONG COMBAT AND COMBAT SUPPORT TROOPS
SERVING IN OKINAWA; APRIL-JUNE 1945
RATE PER 1000 STRENGTH PER DAY
0 1 2 3 4 5 6 7
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91
DAYS
COMBAT
SUPPORT

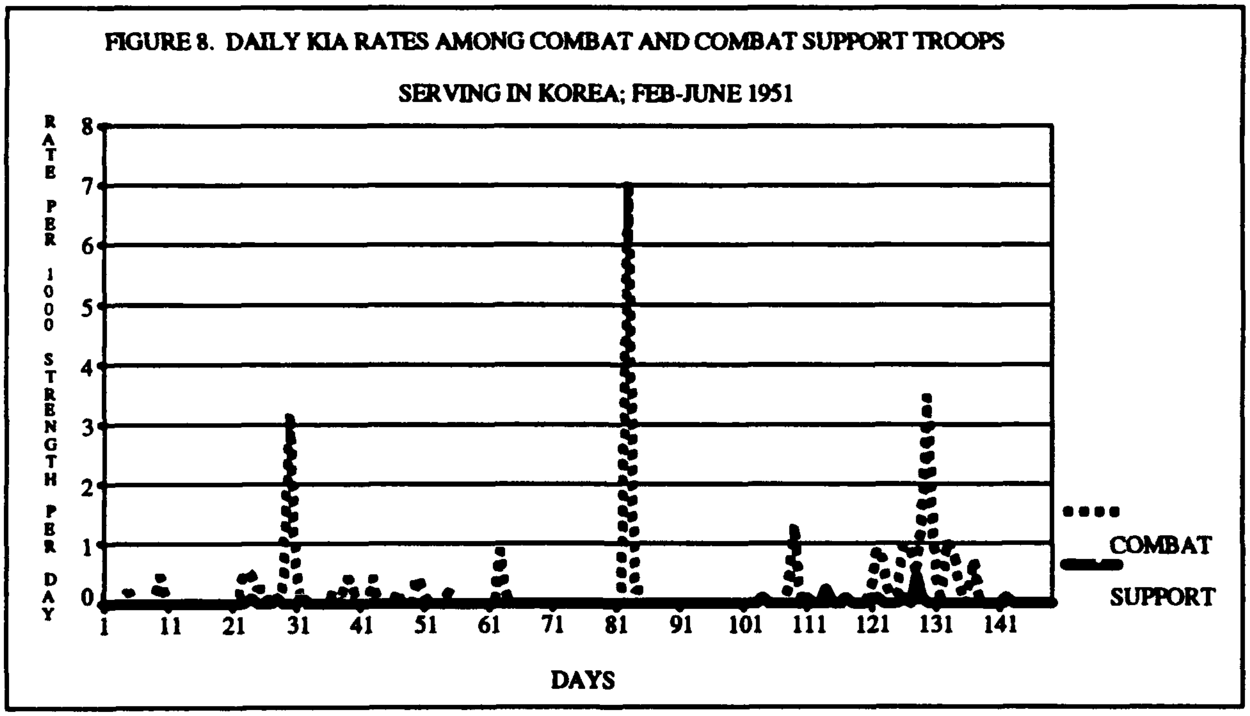


FIGURE 8. DAILY KIA RATES AMONG COMBAT AND COMBAT SUPPORT TROOPS
SERVING IN KOREA; FEB-JUNE 1951
RATE PER 1000 STRENGTH PER DAY
0 1 2 3 4 5 6 7 8
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141
DAYS
COMBAT
SUPPORT

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Disease and Non-Battle Injury (DNBI), Wounded in Action (WIA), and Killed in Action (KIA) rates were examined from Marine Corps unit diaries for a 150-day period of the Korean War. Statistical analyses were performed to ascertain the statistical distribution best representative of each of the rates. DNBI rates fell into a lognormal and normal distribution for combat and combat support troops, respectively. The rates for the WIA incidence best approximated an exponential distribution. The KIA rates were the most difficult to fit to a distribution due to the prevalence of zero daily incidence.

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