SIMULATION OF CASUALTY SUSTAINMENT DURING NAVAL COMBAT OPERATIONS

Christopher G. Blood
Michael S. Odowick
Jeffrey S. Marks

Naval Health Research Center
P.O. Box 85122
San Diego, CA 92186-5122, U.S.A.

ABSTRACT

Accurate forecasts of the casualties likely to be sustained during naval warfare allow sufficient resources to be programmed to meet the medical demands of the operation while at the same time minimizing resource overallocation. A simulation tool called the shipboard casualty projection system (SHIPCAS) has recently been developed to assist planners in medical resource programming.

SHIPCAS is a forecasting tool that projects WIA (wounded-in-action), KIA (killed-in-action), and DNBI (disease and non-battle injuries) incidence among naval surface forces. By simulating ship strikes during naval operations, SHIPCAS provides medical planners with the injury and illness estimates required to assist in determining the needed medical resources. The SHIPCAS system models casualties afloat by allowing the user to define a specific scenario in terms of task force composition, expected battle intensity, and length of operation. The model then produces graphical and tabular information detailing the total number of casualties across the operation, the daily average number of casualties, the maximum daily number of casualties, and the casualty rates per 1000 strength per day. In addition to projecting the number of ships hit and the resulting casualties, SHIPCAS also provides estimates of the temporal points in the operation during which ship strikes are most likely.

1 INTRODUCTION

Casualty estimates are provided for two levels of care: presentations and admissions. Presentations represent all injuries and illnesses requiring admission to a medical treatment facility; admissions are the subset of medical presentations that are retained for treatment three days or longer.

Two separate components are essential to projecting shipboard casualty incidence: 1) calculation of the number of ships likely to be struck during an operation, and 2) estimation of the wounded and killed which would result from the ship strikes. In order to provide operationally-relevant projections, historical naval warfare data from eighty operations and 850 ship attacks in the western Pacific during World War II were extracted and analyzed in terms of the hit rates and casualty incidence. (Blood 1990 and 1992). The operations were segregated into five separate battle intensities (no combat, light, moderate, heavy, intense) and ship attack rates, WIA and KIA frequencies, and distributions of weapons and ship types were then examined for each battle tempo. Shipboard DNBI rate projections are based upon ship type; while DNBI rates were found to vary by size of ship (Blood and Griffith 1990), combat status had but a slight impact on illness incidence (Blood et al. 1992), (Blood and Nirona 1990).

2 USE OF THE SIMULATION TOOL

2.1 Designing a Scenario

Simulation of the casualties sustained afloat begins with defining a task force and setting

the operational parameters. To choose the ship types involved in the scenario, TASKFORCE is selected under the EDIT option. From this sub-menu, selection of MAJOR COMBATANTS brings up a screen for selection of the warships to be included in the task force. The options provided include Destroyers, Carriers, Frigates, and Cruisers. In addition to the major combatants, the task force may also include auxiliary ships. The number of auxiliary ships are specified in the same manner as for the major combatants.

Once the composition and size of task force have been set, the user returns to the main menu. Then the operational scenario may be defined by selecting SCENARIO under the EDIT option. The resulting screen permits the user to assign a battle intensity level and to designate the length of the operation. The choices for battle intensity are None, Light, Moderate, Heavy, and Intense. Lastly, the user enters the length of the operation on this screen in terms of the number of days the operation will last.

2.2 Running the Model

After the required user input has been entered into the model, the simulation may be executed under the RUN option in one of two modes: RUN mode yields casualty data based on a single simulation of the user-defined operational scenario; ITERATE mode computes mean casualty statistics across a number of simulated operations. The "single" simulation mode provides 1) tabular information on the ships hit and the weapons involved, 2) a table of casualties sustained by ship type, 3) a graph projecting temporal points in the operation in which the ship hits occur, 4) a graph delineating casualty sustainment over time, and 5) summary statistics across the operation. "ITERATE" option mode requires the user to designate the number of iterations of the simulated scenario across which the casualty statistics will be calculated. The projection program then computes means across the iterations for the number of ship hits, frequencies and rates of WIA, frequencies and rates of KIA, maximum daily casualty load, and total operational casualty load. A tabular

display of projected DNBI (disease and non-battle injury) frequencies and rates, for each ship type in the task force, is available in both RUN and ITERATE mode.

2.3 Viewing the Results

The VIEW option from the main menu allows the user to choose from HIT DISTRIBUTION, CASUALTY DISTRIBUTION, DNBI DISTRIBUTION, and SUMMARY STATISTICS sub-options to view the output of the model. The HIT DISTRIBUTION is available separately for major combatant ships and auxiliary vessels.

Additional information in the form of a graphical display of the number of hits that occurred each day of the operation can be obtained by selecting the GRAPH button.

The second choice of viewing options is the CASUALTY DISTRIBUTION screen. This window depicts WIA and KIA frequencies, and rates per 1000 strength per day for both combat and auxiliary ships. A graphical display of the projected casualties on a daily basis is available by selection of the GRAPH button

The DNBI DISTRIBUTION screen is similar to the CASUALTY DISTRIBUTION screen except that it provides tabular information on the disease and non-battle injuries projected to occur during the operation. The last option within the VIEW menu is the SUMMARY screen. This option provides a tabular display of summary statistics across the operation. These statistics include mean daily casualty frequencies and mean casualty rates per 1000 strength per day as well as the maximum single day casualty load and total operation casualty load.

3 STATISTICAL BASIS AND MODELING METHODOLOGY

3.1 Hit Rates and Battle Intensity

Ship hit rates were computed for each of the eighty WWII operations analyzed. Because large numbers of ships were involved in many operations and relatively few ships were actually struck, rates were computed as hits per 100 ship days $((Hits/Ships*Days)*100)$. The

data across all operations yielded a range of 0.0 to 50.00 hits per 100 ship days. These rates were partitioned into five groups of near equal observations to represent the varying battle intensities required by medical resource models. The range and mean ship hit rate for each battle intensity level are:

	RANGE	MEAN
NONE	0.0000	0.0000
LIGHT	0.0295 to 0.2579	0.1739
MODERATE	0.2738 to 0.6095	0.4297
HIGH	0.7067 to 3.8462	1.0236
INTENSE	5.8824 to 50.000	11.7798

The first step that the SHIPCAS program performs is the simulation of the number of hits that occur for the user-designed scenario. Variates from a normal distribution are generated around the estimated parameters of the hit rate for the chosen battle intensity to determine the number of hits occurring during the operation. Statistically, this process is represented by equation (1):

$$H = (Y/100)S \qquad (1)$$

where:

H = the number of hits (in the hypothetical operation),

$Y \sim N(m,s)$, variates from a normal distribution,

m = mean number of hits per 100 ship days (from the empirical data),

s = standard deviation of the number of hits per 100 ship days (from the empirical data),

S = the number of days in the operation.

3.2 Timing of Hits

The next process is simulation of the temporal points in the operation when each of the hits occurred. Analysis of the empirical data allowed the computation of a mean inter-arrival time between hits (3.8 days). Random deviates based on this mean and drawn from an exponential distribution then provide projected days in the operation on which each hit occurs. Equation (2) symbolizes this process.

$$T \sim expo(b), \qquad (2)$$

T = inter-arrival time,

b = estimated mean of the exponential distribution.

3.3 Ship Hit Determination

Examination of the distribution of the ship types that were attacked during the historical scenarios, as well as their overall presence, provides the foundation for the ship hit determinations within the SHIPCAS model. The relative risks of each ship type were computed to control for the amount of days of exposure. The distributions of hit percentage, total ship days percentage, and relative risk were:

Combatant	% of hit ships	Ship days %	Relative Risk
Destroyers	55.4	57.3	0.97
Carriers	15.7	12.3	1.28
Frigates	8.2	20.4	0.40
Cruisers	20.6	9.9	2.08

Auxiliaries	% of hit ships	Ship days %	Relative Risk
Cargo	7.1	6.2	1.14
Mine Sweepers	32.0	15.9	2.01
Torpedo Boats	30.6	24.5	1.25
Tank Landing	27.2	43.0	0.63
Transports	3.1	10.4	0.30

To account for the relative risk of ships in the user defined scenario, equation (4) shows how each empirically computed risk was weighted by the number of ships the user chose of that type:

$$r_k = n_k x_k \qquad (4)$$

where:

k = each individual ship category (i.e., destroyers, carriers, etc.),

r_k = the weighted relative risk for ship type k in the user defined task force,

n_k = the number of ships of category k in the task force,

x_k = the relative risk of a ship of category k.

The probability of any individual ship in the task force being hit is then calculated in

equation (5) by dividing the relative risk of a ship of that type by the aggregated weighted risks of all ship types:

$$Y_i = x_i / \sum_k r_k \tag{5}$$

where:

i = the category of the target ship (i.e., destroyer, carrier, etc.),

Y_i = the probability of an individual ship of type i being hit,

x_i = the relative risk of a ship of category i,

k = each individual ship category (i.e., destroyers, carriers, etc.),

r_k = the weighted relative risk for ship type k in the user defined task force.

With the individual ship probabilities normalized to 100 percent, they are then aggregated to form a continuous distribution between 0 and 1. A uniform random variate is then chosen between 0 and 1 to determine which ship is struck for each hit during the operation.

3.4 Weapon Determination

The next step in the shipboard casualty simulation process is designation of the weapon type associated with each hit. Again using the empirical data, distributions of attacks by weapons, ships, and battle intensity levels were analyzed and percentage distributions were computed for 1) each weapon by ship combination, 2) weapons within each battle intensity level, and 3) overall weapon distribution. These percentage distributions were determined from a matrix of weapon probabilities for each weapon hitting each ship type during each battle intensity. For cells where no events have occurred, a value for each weapon type was determined using equation (6) as follows:

$$W_{mjk} = O_m + (I_{mj} - O_m) + (T_{mk} - O_m) \tag{6}$$

where:

m = weapon,

j = battle intensity,

k = ship type,

W_{mjk} = weapon m percent with battle intensity j and ship k,

O_m = overall proportion of weapon m striking any ship,

I_{mj} = proportion of weapon m striking during an operation of j battle intensity,

T_{mk} = proportion of weapon m striking ship type k.

Combining the probabilities of the different weapon and ship type combinations, as with ship type determination alone, yields a distribution between 0 and 1. A uniform random deviate is then chosen to determine the specific weapon that strikes the ship.

3.5 WIA and KIA

Empirical data (Blood 1992) indicating the numbers of WIA and KIA sustained in various attacks were used to calculate the average number of casualties for different "weapon by ship" combinations. Goodness of fit analysis indicated that shipboard WIA and KIA incidence are best represented by a Poisson process symbolized in equation (7). SHIPCAS, therefore, yields its wounded and killed projections by drawing a random number from a Poisson process based on the mean frequency of casualties for each weapon by ship combination.

$$X \sim Poisson(l) \tag{7}$$

where:

X is the projected casualties (WIA or KIA) with estimated parameter l.

In addition to these casualties, analysis of the historical data provided information on casualties that occur during operations that are not dependent upon a ship being hit. These "background" casualties, which may result from events such as the firing of weapons, near misses, or defensive maneuvers, are derived by drawing a random deviate from a normal distribution surrounding the mean background casualties observed for that particular battle intensity. Once the total numbers of casualties

are projected, the WIA and KIA rates per 1000 strength per day are computed based on the crew complements of each ship.

3.6 Disease and Non-battle Injuries

Studies have indicated that ship type is a significant factor in disease and non-battle injury incidence while combat status had little practical effect on DNBI incidence. Rates of DNBI, therefore, are averaged across the different ship types in the task force and provide the basis for the simulation of disease and non-battle injury rates. Mean rates of DNBI incidence are transformed into frequencies, based on the designated length of the operation and the crew complements, and DNBI projections are then generated by drawing a deviate from a normal random distribution. This quantity is then partitioned into a disease component and a non-battle injury component based on distributions observed in the empirical data (Blood et al. 1992).

4 CONCLUSION

The shipboard casualty projection system simulates casualties likely to be sustained during various naval combat scenarios. Run in "single" simulation mode, SHIPCAS accurately depicts the variability in ship hit rates and casualty incidence witnessed in previous naval engagements. Deriving projections from "multiple" iterations of a single scenario successfully approximates the mean ship hit rates and casualty sustainment of the empirical data. These forecasts may, in turn, be used as input to the types of models which determine the specific bed, supply, and health care personnel requirements (Systems Research 1992 and Galarza 1987). It is noted that these projections are based on ship structures and weapon systems which have since undergone significant technological advances. Currently, data from a subject matter expert panel of weapons system and ship structure engineers are being used to modify the SHIPCAS model projections to reflect the technological advances in these areas.

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AUTHOR BIOGRAPHIES

CHRISTOPHER G. BLOOD is head of the Operations Research Division at the Naval Health Research Center (NHRC) in San Diego, California. He has been involved in analyzing ground and ship-based casualty incidence from past operations and is active in the development of medical planning tools to project casualty incidence in future scenarios and the related medical resource requirements. Mr. Blood is a member of the Military Operations Research Society.

MICHAEL S. ODOWICK is a former GEO-Centers, Inc. research analyst who worked at NHRC on shipboard casualty projections for future scenarios. Mr. Odowick was the lead programmer in developing the first version of the SHIPCAS shipboard casualty planning tool.

JEFFREY S. MARKS is an Operations Research Analyst and Group Supervisor working at the Naval Health Research Center for GEO-Centers, Inc. Mr. Marks' work focuses on projections of casualties and examining the factors underlying fluctuations in casualty incidence. Mr. Marks is an adjunct professor in the College of Business at San Diego State University, a member of the American Statistical Association, and a member of the Military Operations Research Society.