NAVAL HEALTH RESEARCH CENTER

USING THE SHIPBOARD CASUALTY PROJECTION SYSTEM (SHIPCAS) TO FORECAST SHIP HITS AND CASUALTY SUSTAINMENT

C. G. Blood

J. S. Marks

L. P. Le

Technical Document 97-3C

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

NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
BETHESDA, MARYLAND

USING THE SHIPBOARD CASUALTY PROJECTION SYSTEM (SHIPCAS) TO FORECAST SHIP HITS AND CASUALTY SUSTAINMENT

Christopher G. Blood

Jeffrey S. Marks*

Lieu P. Le*

Medical Information Systems and Operations Research Department

Naval Health Research Center

P.O. Box 85122

San Diego, CA 92186-5122

*GEO-CENTERS, Inc.

Technical Document No. 97-3C, supported by the Naval Medical Research and Development Command, Bethesda, MD, Department of the Navy, under Work Unit No. 63706N M0095.005-6704. The views expressed in this article are those of the authors and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government. Approved for public release, distribution unlimited.

SUMMARY

Problem

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

Objective

The present report describes the SHIPCAS Shipboard Casualty Projection system in terms of a guide to its usage and a description of its statistical underpinnings.

Approach

SHIPCAS casualty projections are based on empirical data from previous naval combat operations that have been adjusted to reflect advances in weaponry and changes to ship structures that have occurred since the historical operations.

Results

The SHIPCAS system simulates ship hits and casualty sustainment under user-defined combat scenarios. Simulated casualty data reflects the salient characteristics of the empirical data.

Conclusions

The shipboard casualty projection system simulates casualties likely to be sustained during various naval combat operations. The SHIPCAS system provides output for single operations which incorporates the variability in casualty sustainment observed across previous operations as well as output reflecting the casualty averages across multiple operations.

USING THE SHIPBOARD CASUALTY PROJECTION SYSTEM (SHIPCAS) TO FORECAST SHIP HITS AND CASUALTY SUSTAINMENT

Medical resource planning for naval combat operations requires projections of the numbers of casualties that may be incurred by shipboard forces. These casualty projections are required inputs to models that forecast the beds, medical equipment, evacuation assets, and health care personnel needed to support an operation. Because the logistics of shipboard casualty evacuation can be problematic, reliable estimates of the medical resources needed aboard ships are critical to the timely treatment of any battle wounds sustained. At the same time, because shipboard space is a scarce commodity, it is important that allocation of supplies is kept to a minimum. A planning tool called the shipboard casualty projection system (SHIPCAS) has been developed to forecast shipboard casualty incidence. SHIPCAS projections have recently been adjusted to incorporate contemporary threats; the present report outlines use of the SHIPCAS tool and explains the statistical underpinnings upon which the projections are based.

Projections of casualties among forces afloat require two separate sets of forecasts. First, estimates must be made of the likely number of ships that will sustain hits by enemy forces, and second, the incidence of casualties aboard the individual ships must be projected. SHIPCAS projections are based upon empirical data[1,2] of eighty naval operations during World War II which have then been adjusted to reflect changes in hit probability[3] and casualty sustainment[4] resulting from advances in weapons and changes to ship structures. The SHIPCAS system allows the planner to define a specific scenario in terms of U.S. task force composition, adversary's weapons systems, expected battle intensity, length of the operation, and whether it is a littoral or open ocean operation. The model then generates graphical and tabular output detailing the total number of casualties for the operation, the average daily number of casualties, the maximum daily number of casualties, and the casualty rates per 1000 strength per day. In addition to projecting the numbers of ships hit and resulting casualties, SHIPCAS also provides estimates of the temporal points in the operation during which shipboard strikes are most likely.

The present report describes the SHIPCAS shipboard casualty projection system in two sections. Part I is a user's guide that outlines operation of the shipboard casualty simulation software. Part II then addresses the statistical underpinnings upon which the casualty projections are based.

PART I -- USE OF THE SHIPCAS CASUALTY PROJECTION SYSTEM

SHIPCAS System Minimum Requirements

- an IBM or IBM-compatible PC
- Microsoft Windows version 3.1 or higher
- an EGA, VGA, or SVGA monitor
- a hard drive with 2.5 MB free disk space
- DOS version 4.01 or higher
- serial mouse
- 640k memory

Menu Description

The SHIPCAS menu, shown as follows, is oriented in a logical manner that allows the user to design a naval combat scenario, run the scenario, and view the projected casualties. The main menu consists of the following choices: EXIT, EDIT, RUN, and VIEW. An overview of each of the main menu and sub-menu selections is provided.

SHIPCAS Menu Options

EXIT	**EDIT**		**RUN**	**VIEW**	
Exit	Ship Selection>	Major Combatants Auxiliaries	Run	Hit Distribution>	Major Combatants Auxiliaries
	Scenario Selection		Iterate	Casualty Distribution>	Major Combatants Auxiliaries
	Weapon Selection>	Weapon Selection Weapon Selection % Bomb Options Missile Options Gun Options Torpedo Options		DNBI Distribution Summary	

EXIT

The first main menu option encountered is EXIT. Selecting EXIT reveals the sub-menu heading of the same name, and when selected, allows the user to leave the program.

EDIT

The EDIT option allows the user to access the SHIP SELECTION, SCENARIO SELECTION, and WEAPON SELECTION sub-menu headings. The composition of the U.S. task force, length of the operation, battle intensity, type of operations (littoral/open ocean) and the adversary's weapons systems are input using the preceding sub-menu options.

Ship Selection Sub-Menu

Choosing SHIP SELECTION allows the user to determine the number and type of U.S. naval vessels in the proposed task force. From this sub-menu, selection of MAJOR COMBATANTS brings up a dialog box for selection of the warships to be included in the task force. The user can choose from Conventional Aircraft Carriers, Nuclear Powered Aircraft Carriers, Guided Missile Cruisers, Nuclear Powered Guided Missile Cruisers, Destroyers, Burke Class Guided Missile Destroyers, Kidd Class Guided Missile Destroyers, and Guided Missile Fast Frigates (Figure 1).

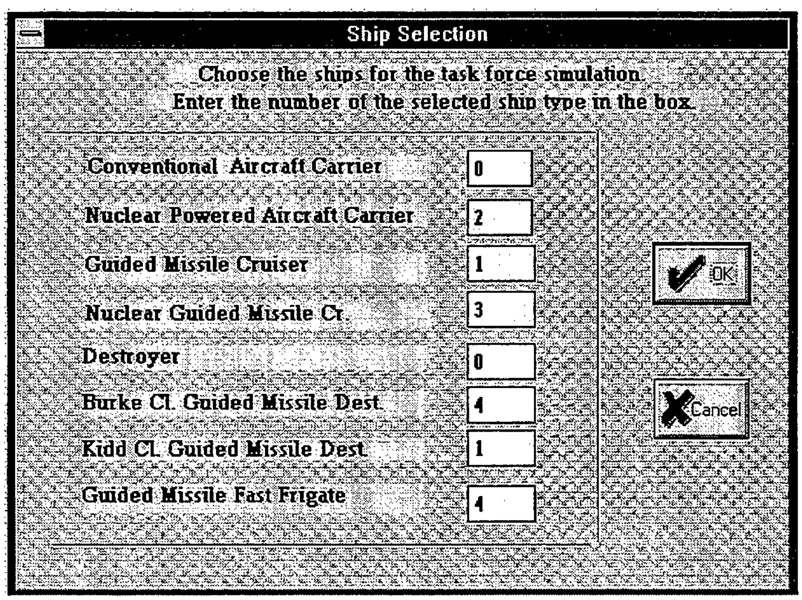


Figure 1. Major Combatant Ship Selection screen.

To enter the desired number of each ship type the user clicks on the input box next to the ship name or toggles down to the correct box by using the *TAB* key and types in the number. If an error is made while entering data, the user may return to the input box and type in the correct number or use the *CANCEL* button to start over with all selections at their previous values. Pressing the *OK* button or hitting the *RETURN* key after selecting the number of each desired type of ship encodes the inputs and returns the user to the main menu.

The other sub-menu option under SHIP SELECTION is AUXILIARIES. Selecting this option allows the user to enter the number and type of support vessels in the task force. The dialog box offers a choice of Cargo, Transports, Minesweepers, Motor Torpedo Boats, and Tank Landing Craft as seen in Figure 2. The numbers of auxiliary ships are entered in the same manner as combatant ships. The task force may consist of warships only, auxiliary ships only, or a combination of both.

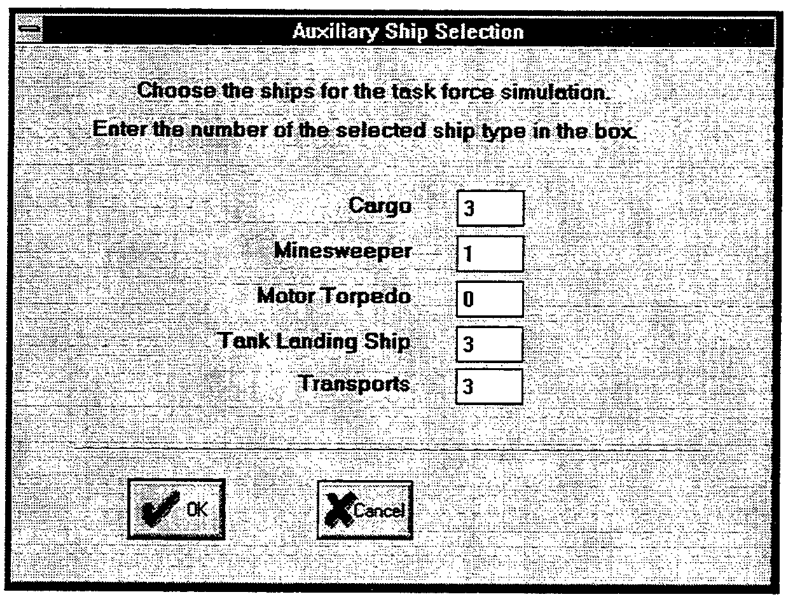


Figure 2. Auxiliary Ship Selection screen.

Scenario Selection Sub-Menu

After selecting the desired number of ships in the task force, the user then sets the length of the operation, battle intensity, and area of operations using the SCENARIO

SELECTION option (Figure 3). There are five different battle intensities (None, Light, Moderate, High, Intense) available from which to choose. The length of the naval operation, up to 180 days, is then entered in the Length of Scenario input box. Lastly, the user designates the percentage of operational time that the ships will be operating in a littoral or open ocean environment. Pressing *RETURN* or clicking on the *OK* button enters the values selected and returns the user to the main menu.

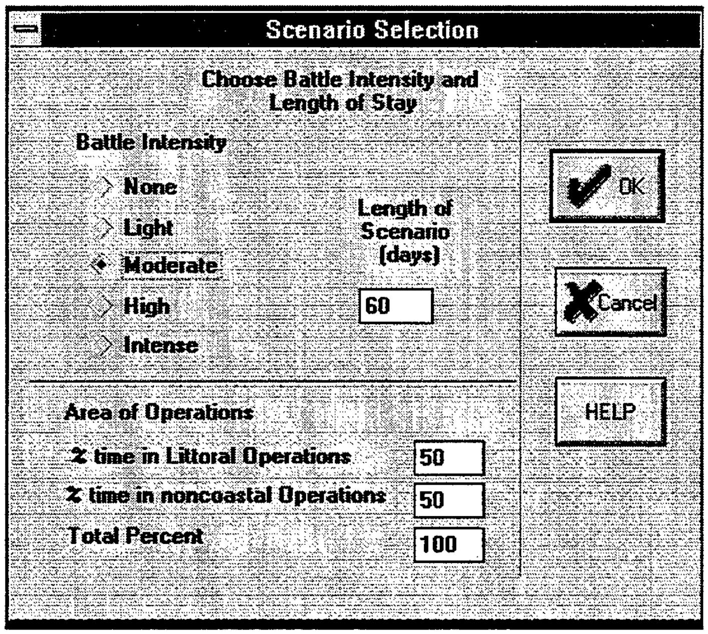


Figure 3. Scenario Selection screen.

Weapon Selection Sub-Menu

The WEAPON SELECTION sub-menu option allows the user to choose the weapon types, weapon delivery mechanisms, and weapon guidance systems possessed by the potential adversary. Figure 4 shows that the user may select different weapon types from five main weapon categories (bombs, missiles, guns, torpedoes, mines). Following weapon selection, the user assigns the percentage of overall expected weapon usage corresponding to each selected weapon type using the WEAPON SELECTION PERCENT option (Figure 5). The total percentages across weapon types must sum to 100% or the user will encounter a warning screen.

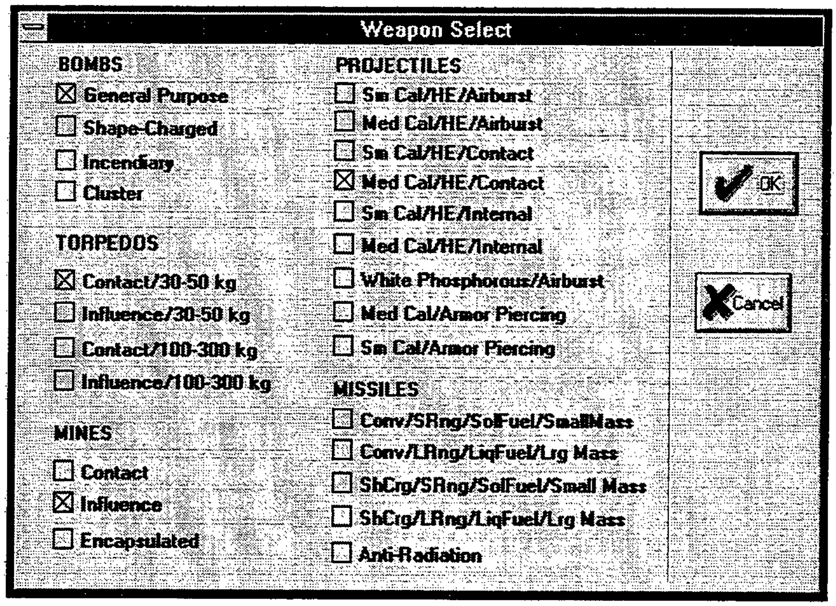


Figure 4. Weapon Select screen.

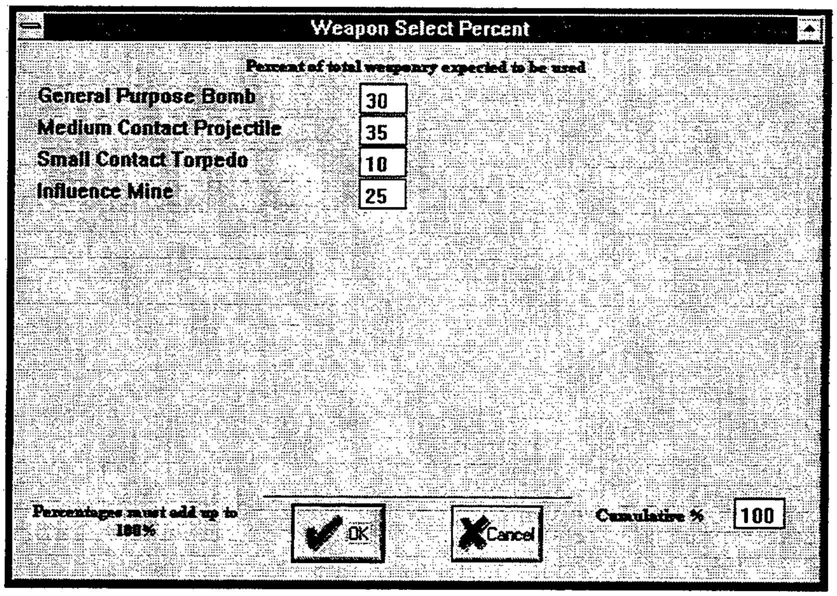


Figure 5. Weapon Select Percentage screen.

Next, the user is prompted for the likely guidance systems and delivery mechanisms associated with each selected weapon type. For example, if "general purpose bomb" type was chosen as the only weapon possessed by an adversary, the BOMB OPTIONS selection screen (shown in Figure 6) would then require input from the user. However, if bombs, torpedoes, guns, and missiles were all chosen as the adversary's weapons, then BOMB OPTIONS, TORPEDO OPTIONS, GUN OPTIONS, and MISSILE OPTIONS would each require input. Each respective OPTION section allows the user to specify the percentage of different guidance systems and delivery platforms for each weapon type. The total percentage for guidance systems and delivery methods must each sum to 100%.

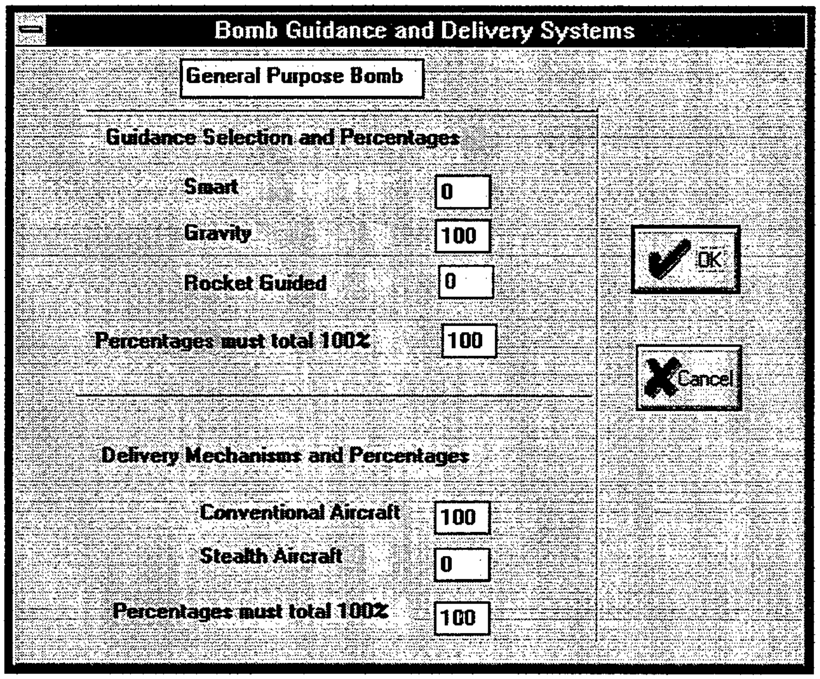


Figure 6. Bomb options screen.

RUN

After the user has entered the required information, the RUN option becomes available with the RUN and ITERATE sub-menu options. Selecting the RUN sub-menu option invokes a single execution of the SHIPCAS simulation. Selecting the ITERATE option allows the user to enter the number of iterations to be executed from which summary casualty statistics are derived.

VIEW

After the simulation has been executed, the results may be viewed by selecting the VIEW option. The user may select from the HIT DISTRIBUTION, CASUALTY DISTRIBUTION, DNBI DISTRIBUTION, and SUMMARY sub-menu options if a single run is executed. If the ITERATE option is selected, then the SUMMARY option is available to view the results.

Hit Distribution Sub-Menu

The HIT DISTRIBUTION option is available separately for major combatant ships (see Figure 7) and auxiliary vessels, and displays the number of hits that occur for each 'ship type by weapon type' combination. Additional information, in the form of a graphical display, is available by clicking on the GRAPH button. The resulting graph (Figure 8) indicates when the ship hits occurred throughout the simulation by plotting the number of hits by day of operation. Double clicking in the upper left corner of the graph, or clicking on the *OK* button, removes the graphical display and returns the user to the main menu.

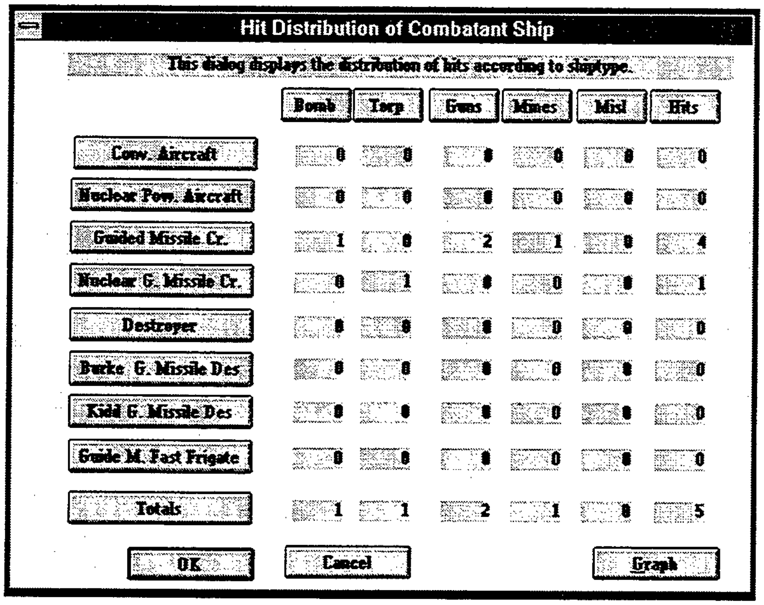


Figure 7. Hit Distribution of Combatant Ship screen.

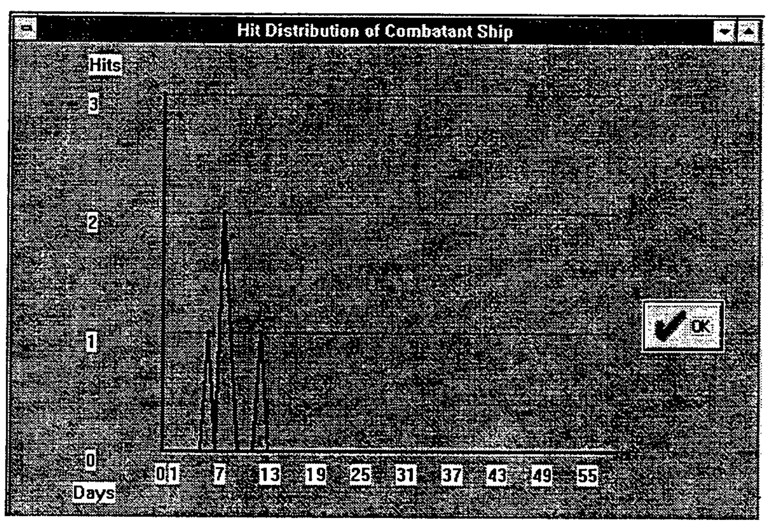
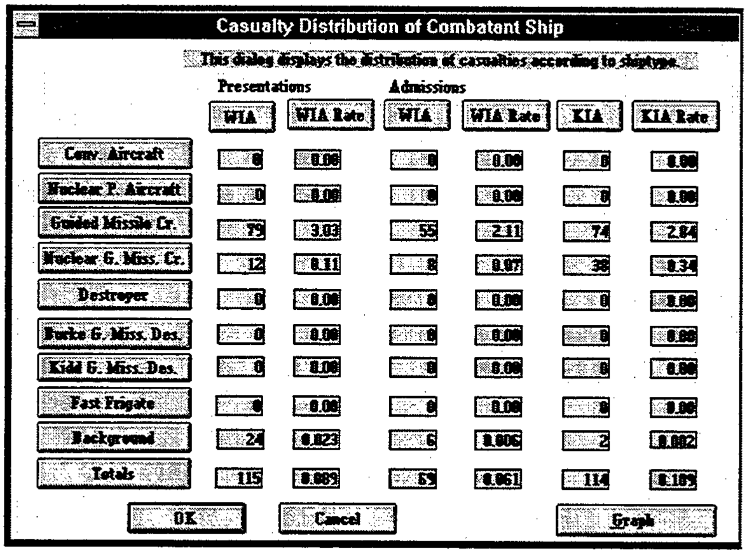


Figure 8. Graphical display of the temporal distribution of hits.

Casualty Distribution Sub-Menu

The CASUALTY DISTRIBUTION selection shows WIA and KIA frequencies and rates per 1000 strength per day, for both combat (see Figure 9) and auxiliary ships. The rates and frequencies for WIA are further divided into Presentations and Admissions. Presentations represent all injuries and illnesses requiring treatment at a medical facility, while admissions are the subset of presentations that are retained for treatment three days or longer. Also, a graphical display showing projected WIA by day is available by clicking on the GRAPH button. Figure 10 is a graph of WIA incidence over time.


Casualty Distribution of Combatant Ship

This dialog displays the distribution of casualties according to shiptype.

	Presentations		Admissions			
	WIA	WIA Rate	WIA	WIA Rate	KIA	KIA Rate
Conv. Aircraft	0	0.00	0	0.00	0	0.00
Nuclear P. Aircraft	0	0.00	0	0.00	0	0.00
Guided Missile Cr.	79	3.03	55	2.11	74	2.84
Nuclear G. Miss. Cr.	12	0.11	8	0.07	38	0.34
Destroyer	0	0.00	0	0.00	0	0.00
Burke G. Miss. Des.	0	0.00	0	0.00	0	0.00
Kidd G. Miss. Des.	0	0.00	0	0.00	0	0.00
Fast Frigate	0	0.00	0	0.00	0	0.00
Background	24	0.023	6	0.006	2	0.002
Totals	115	0.089	69	0.061	114	0.189

OK Cancel Graph

Figure 9. Casualty Distribution of Combatant Ships screen.

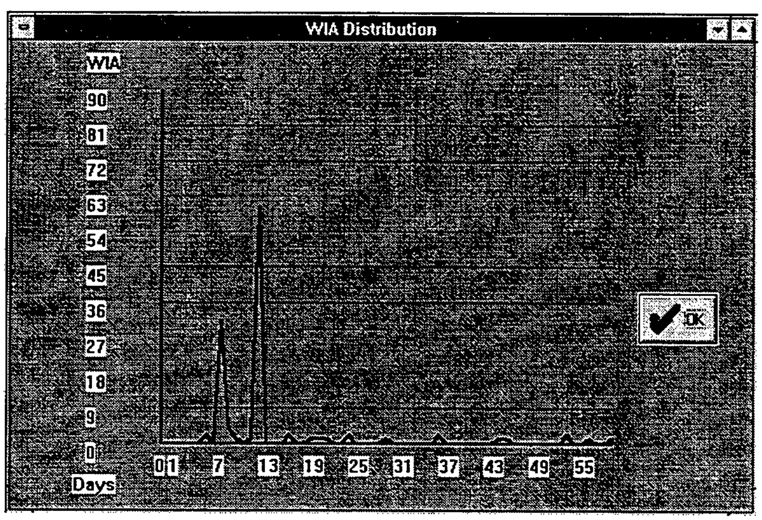


Figure 10. Graphical display of the temporal distribution of WIA.

DNBI Distribution Sub-Menu

The DNBI Distribution selection presents the user with tabular information on the number of disease (DIS) and non-battle injuries (NBI) likely to occur throughout the operation by ship type. Figure 11 is a representation of this screen.

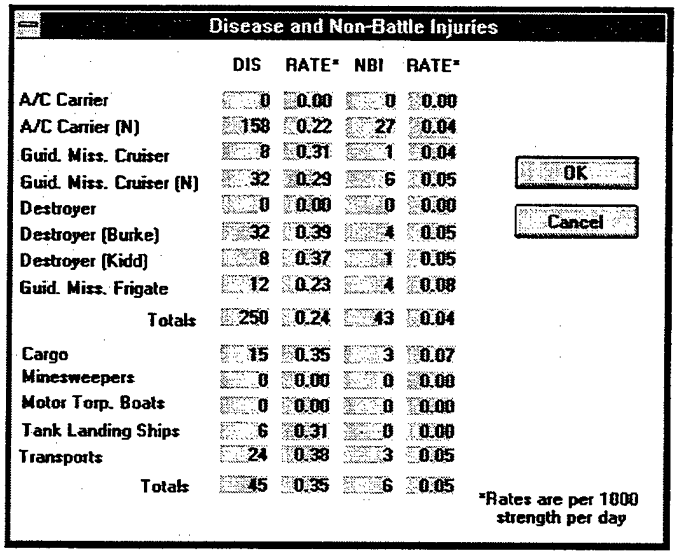


Figure 11. DNBI distribution screen.

Summary Sub-Menu

The SUMMARY option provides a tabular display of the summary statistics across the operation(s). The summary statistics include mean daily casualty frequencies, rates per 1000 strength per day, mean and maximum number of ship hits per day, and the mean and maximum number of hits across the operation(s). Figure 12 is a display of this screen.

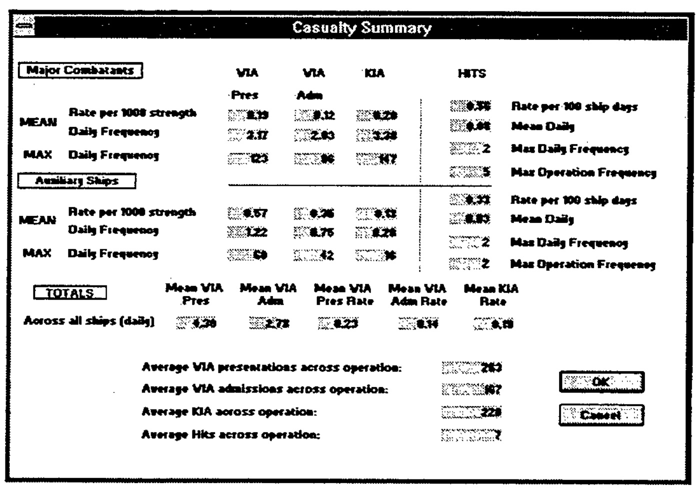


Figure 12. Casualty Summary screen.

PART II -- THE SHIPCAS MODEL

Hit Rates and Battle Intensity

Ship hit rates were computed for eighty WWII naval operations on which the number of ships hit and the number of ships at risk were available. Because large numbers of ships were involved in many operations and relatively few ships were actually struck, rates were computed as hits per one hundred ship days ((Hits/Ships*Days)*100). The data from the eighty operations yielded a range of 0.0 to 50.00 hits per 100 ship days. The operations were partitioned 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 intensity. 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	1.0190
INTENSE	5.8824 to 50.000	11.613

The ship hit rate corresponding to the user-specified battle intensity is first adjusted to reflect the expected difference from the WWII baseline due to the weapons possessed by a present-day adversary. These adjustments are made via the hit shifts in hit probabilities associated with contemporary weapons and advances in U.S. naval defenses, as determined by a panel of Subject Matter Experts.[3] The Subject Matter Expert (SME) panel also provided the expected shifts in hit rates for contemporary operations that are littoral in nature (+61.8%) or associated with an open ocean environment (-47.8%). These adjustments are represented by the following formula:

$$R_{ijk} = r_i + (E_j S_j + \Sigma(W_k P_k))$$

where:

R_{ijk} = Adjusted hit rate,
r_i = Ship hit rate during WWII operations for battle intensity i,
E_j = Hit rate adjustment for the j_{th} environment (littoral vs. open ocean operations),
S_j = Estimated percentage of time operations will be in the jth environment,
W_k = Hit rate adjustment for the k_{th} weapon type (bomb, torpedo, etc.),
P_k = The percentage of time the k_{th} weapon will be used.

Kolmogorov-Smirnov goodness of fit tests[5] indicated that the empirical values within each battle intensity range were normally distributed. Therefore, variates from a normal distribution are generated around the estimated parameters of the adjusted hit rate to determine the number of hits occurring during the operation. Statistically, this process is represented by the following:

$$H = (Y/100)D$$

where:

H = the number of hits (in the hypothetical operation),
$Y \sim N(\mu,\sigma)$, variates from a normal distribution,
μ = mean number of hits per 100 ship days (adjusted),
σ = standard deviation of the number of hits per 100 ship days,
D = the number of ship days in the operation.

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 indicated that the arrivals (hits) were best represented by an exponential distribution and that the mean inter-arrival time between hits was 3.8 days. Random deviates based on this mean and drawn from an exponential distribution were used to approximate the temporal distribution of the hits.

$$T \sim \exp(\beta)$$

T = inter-arrival time,
β = estimated mean of the exponential distribution.

Ship Hit Determination

Examination of the distribution of the ship types 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 (the percentage of hit ships divided by the ship days percentage) 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 Ships	% 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
Minesweepers	32.0	15.9	2.01
Motor Torpedo Boats	30.6	24.5	1.25
Tank Landing Ships	27.2	43.0	0.63
Transports	3.1	10.4	0.30

The probability of any individual ship in the task force being hit is calculated by dividing the relative risk of a ship of that type by the aggregated weighted risks of all ship types:

$$Y_i = x_i / \sum_k n_k x_k$$

where:

i = the index for 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.),
n_k = the number of ships of category k in the task force,
x_k = the relative risk of a ship of category k.

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.

Weapon Determination

The next step is to assign specific weapon strikes to the individual hits that have been generated by SHIPCAS. This is accomplished by using the hit rate adjustment assigned to each weapon, the adversary's expected "use" percentage corresponding to each weapon in their arsenal, and the overall number of weapons expected to be used by that adversary. This is represented by the following formula:

$$N_i = P_i \,/\, \sum_{k=1}^{T} P_k$$

where:

N_i = Number of hits associated with weapon i,
P_i = $(PC_i /(1/T))\,(1+W_i)$,
PC_i = Percent weapon usage represented by weapon i,
T = Total number of weapons used by adversary,
W_i = Hit rate adjustment for weapon i,
K = Each weapon type.

Random deviates are then selected from a uniform distribution of the expected strike percentages associated with each weapon type.

WIA and KIA

The mean frequencies of WIA and KIA were computed for the various 'weapon by ship' combinations which occurred in the Pacific operations attacks. Then the casualty means were adjusted to reflect the impacts of weapon systems advances and ship structural changes on likely casualty sustainment.[4] The first step in making this adjustment was having a Subject Matter Expert panel designate a WWII 'ship x weapon' combination as being the best reference point for each present-day combination of U.S ship and adversary weapon. The SME panel then reached consensus on the directional shift in casualty sustainment (more or fewer casualties) when contrasting contemporary 'weapon x ship' combinations with the reference point combinations; lastly, the mean shift in casualty sustainment was computed from the individual responses of the SME panelists. Goodness of fit testing using Empirical Distribution Function (EDF) statistics[5] indicated that shipboard WIA and KIA incidence are best represented by a exponential distribution. SHIPCAS, therefore, yields its wounded and killed projections by drawing a random deviate based on the adjusted mean frequency of casualties for each weapon by ship combination.

$$X \sim \exp(\lambda)$$

where:

X= the projected casualties (WIA or KIA) with estimated parameter λ,
λ = the estimated mean of the exponential distribution.

In addition to these casualties, analysis of the historical data provided information on casualties that occur during combat operations that are not a direct result of 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.

Disease and Non-battle Injuries

The shipboard DNBI rate projections are based solely upon ship type, because while DNBI rates were found to vary by size of ship,[6] combat status had but a slight impact on illness incidence.[7,8] 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[7].

TESTING OF MODEL RESULTS

Analysis of the casualty stream data generated by SHIPCAS is warranted to ensure that the projection system accurately reflects the statistical trends evident in the empirical data. Empirical distribution function (EDF) statistics, confirms that the projected casualty incidence of SHIPCAS conforms to an exponential distribution, as did the empirical casualty data; these EDF statistics indicate that the shipboard casualty projection system accurately reflected the variability observed across the historical operations. Further, the weapons-adjusted SHIPCAS projections were contrasted with the casualties incurred during naval incidents in recent years (Stark, Roberts, Princeton). While extreme caution should be exercised in asserting validity based on such a limited number of observations, the actual casualties sustained in these incidents were well within the range of outputs provided by the SHIPCAS system.

CONCLUSION

Accurate projections of the number of casualties that may be sustained are critical to programming the needed medical requirements of a combat engagement. Other Department of Defense models[9,10] that calculate the required hospital beds, medical equipment, and health care personnel rely on casualty incidence estimates to generate their output. The shipboard casualty projection system (SHIPCAS) simulates casualties likely to be sustained during various naval combat scenarios. Updated with adjustments for recent advances in weapons and ship structures, SHIPCAS provides a much-needed simulation tool that will allow medical and manpower planners to gauge their resource requirements.

REPORT DOCUMENTATION PAGE	Form Approval OMD No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE 2 April 1997	3. REPORT TYPE AND DATE COVERED Final Oct 94-Mar 97

4. TITLE AND SUBTITLE
USING THE SHIPBOARD CASUALTY PROJECTION SYSTEM (SHIPCAS) TO FORECAST SHIP HITS AND CASUALTY SUSTAINMENT

5. FUNDING NUMBERS
63706N M0095.005-6704

6. AUTHOR(S)
Christopher G. Blood, Jeffrey S. Marks, Lieu P.Le

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Health Research Center
P.O. Box 85122
San Diego, CA 92186-5122

8. PERFORMING ORGANIZATION
NHRC Report No. 97-7

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Medical Research and Development Command
National Naval Medical Center
Building 1, Tower 2
Bethesda, MD 20889-5044

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Medical resource planning for naval combat operations requires projections of the numbers of casualties that may be incurred by shipboard forces. Casualty projections are required input to models that forecast the beds, evacuation assets, and health care personnel requirements needed to support an operation. The present report describes the Shipboard Casualty Projection (SHIPCAS) system in terms of a guide to its usage and a description of its statistical underpinnings. The SHIPCAS casualty projections are based on empirical data from naval combat operations during Pacific operations in World War II and have been adjusted to reflect advances in weaponry and changes to ship structures that have occurred since those engagements. The simulated casualty data reflects the salient characteristics of the empirical data and the projections are consistent with the actual casualties incurred during recent naval incidents.

14. SUBJECT TERMS
casualties, shipboard, Navy, casualty projections, naval combat, hit probabilities

15. NUMBER OF PAGES
18

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI std. Z-39-18

298-102