CARMONETTE

VOLUME I

GENERAL DESCRIPTION

NOVEMBER 1974

PREPARED BY

GENERAL RESEARCH CORPORATION
OPERATIONS ANALYSIS DIVISION
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MCLEAN, VIRGINIA 22101

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An overview of the CARMONETTE ground combat simulation. A brief discussion of model organization, application, and outputs. The mathematical models and history of the model are contained in annexes to this volume.

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FOREWORD

There are three levels of description in the documentation of CARMONETTE. These levels correspond to the assumed level of interest of readers in the details of the material. For the general reader Part I of Volume I provides a general overview. For a more detailed study of the components; Part II of Volume I covers the mathematical models of the battle model, special sensor detection computations are discussed in Appendix A and the background of the model is reviewed in Appendix B.

The complete coverage of the input requirements is found in Volume II. Full understanding of the contents of Volume I is assumed of the reader of Volume II. An illustrative problem, including sample inputs and a discussion of preprocessor, battle model, and post processor output is contained in the main body of Volume II. The appendices contain a complete input listing, a discussion of the variability of the model, and a glossary of CARMONETTE terms.

Volume III is primarily intended for the programmer and consists of a technical description of the model with appropriate flow charts. Each subroutine and function is described and the calling sequence is given.

A complete CARMONETTE treatment to include a listing of gamer inputs, and the outputs of the preprocessors, battle model and post processors is contained in Volume IV. Persons desiring copies of this volume should address their requests for the Control Data version to the Operations Analysis Division, General Research Corporation, and for the UNIVAC version to the US Army Concepts Analysis Agency.

The basic structure of CARMONETTE will change slowly, but the detailed program is continuously evolving. The data is exact as of 14 November 1974. The user, however, should expect to find modifications to the listing provided by GRC, whose extent will increase with time after the cutoff date of the present publication.

ACKNOWLEDGMENTS

The original version of CARMONETTE was designed by Mr. Richard E. Zimmerman under the supervision of Dr. W. E. Cushen. Mr. Hebron E. Adams, Mr. Richard E. Forrester, Mrs. Joan F. Kraft, and Mrs. Barbara B. Oosterhout published the first comprehensive technical memorandum on the simulation.

Dr. Joseph A. Bruner, Dr. William C. Pettijohn, Mr. Robert G. Hendrickson, and Mr. Dick M. Lester are former supervisors who contributed to the development and extension of the basic concept. Dr. Bruner, Mr. Lester, Mr. Adams, and Mr. Forrester developed the aviation models for CARMONETTE III, an especially important contribution.

The application of CARMONETTE III to the US Army Combat Developments Command Small Arms Weapons System study provided the impetus to further define the simulation of infantry activities.

The programming staff at RAC during the development of CARMONETTE III included Mr. Gary Bolling, Mr. Dennis Rollins, Mrs. Sandra Viet, and Miss Patti Gleason, who labored diligently. Much of the programming was done by Mr. Arvin Cook, and Mr. Eugene Lentz of Computer Usage Company. Mr. John Kenworthy, although he joined the effort late in the program, was singularly responsible for the final success of the programming, and his design of an output processor was outstanding.

Formal model documentation on CARMONETTE III was prepared by Charles A. Bruce, Jr., Daniel E. Cowgill, Walter Eckhardt, Richard H. Gramann, Steven L. Jordan, John Kenworthy, Donald W. Mader, and Irwin Miller.

CARMONETTE IV, V, and VI were developed by Mr. Norman W. Parsons, with the assistance of Mr. Gary W. Bolling, Mr. Charles A. Bruce Jr., Mr. Russell Criste, and Mr. Richard G. Williams.

The 1974 redocumentation titled CARMONETTE, Volumes I through IV, was prepared by Mr. Gary S. Colonna and Mr. Richard G. Williams and draws upon previous documentation as well as the authors' experience in running the model in a "production mode."

Documentation on special sensors was prepared by Mr. Norman W. Parsons.

CONTENTS

Figures

Tables

Part I
GENERAL DESCRIPTION

INTRODUCTION

CARMONETTE is a Monte Carlo, critical event sequenced, fully computerized simulation of ground combat. The design of the simulation is such that it can create a realistic representation of close combat during the brief intense engagement phase lasting for approximately 1 hour or so. Continuation of the simulated combat beyond 1 hour becomes unrealistic because a decision fundamental to the execution of the maneuver would undoubtedly be made at that point. CARMONETTE has no capability to reproduce a military commander's mind, and thus the simulation must be terminated and the results reviewed. The simulation may then continue with an appropriate order from a commander if desired.

The activities that are simulated are movement, target acquisition, firing, and communication. These basic military activities are fundamental during the brief intense combat phase referred to above. The combined-arms team concept that has been included in CARMONETTE requires models to describe the movement, target acquisition, firing, and, to a limited extent, communications activities of infantry, armor, artillery, and helicopter units. The structure of CARMONETTE can simulate a fighting unit of an individual man or vehicle up to approximately a platoon-sized unit. When the unit size is a platoon, a battalion action can be simulated.

Areas of application of the model are:

Comparison of alternative weapon systems and tactics— real or hypothetical.

Comparison of alternative sensor/target acquisition systems.

Evaluation of combat potential of low echelon forces.

Generation of data for higher level studies.

Extention of situations or variables of a field experiment.

INPUTS

Terrain

The simulated battle is played on a topographic map of the area of interest, see Fig. 1. A reference grid is then placed on the simulated battlefield as shown in Fig. 2. The size of this grid is optional, however it must be constant throughout a game. Although there is no definite way of estimating the proper grid size for a given simulated game, some guidelines can be presented and the user advised as to the restrictions that are placed on a free choice of grid size. As a guide the grid size should be as small as practicable. However, the grid size must be large enough to contain the battle being simulated. The design of the simulation permits a battlefield size that is a maximum of 60 by 63 grid squares. The simulation does not restrict the number of units that may be in a grid square at one time, however it is unusual for more than two or three units to be in a square at the same time. Following the above reasoning, Table 1 shows the relationship between grid size, unit size, force size, and zone of action. This table is only a rough guide and does not preclude the use of other grid, unit, or force sizes if they satisfy the needs of the problem. Since 1970, the forces portrayed have generally been a company team versus a battalion task force, and a 100-meter grid has proved very satisfactory.

Having subdivided the battlefield by use of the reference grid, each of the 3780 (60 × 63) grid squares is described explicitly in terms of:

(a) Elevation
(b) Height of vegetation
(c) Trafficability of roads
(d) Cross-country trafficability
(e) Cover
(f) Concealment

The average elevation is used in determining slopes and lines of sight between grid squares. The average height of vegetation is added to the elevation of the intervening terrain to determine intervisibility.

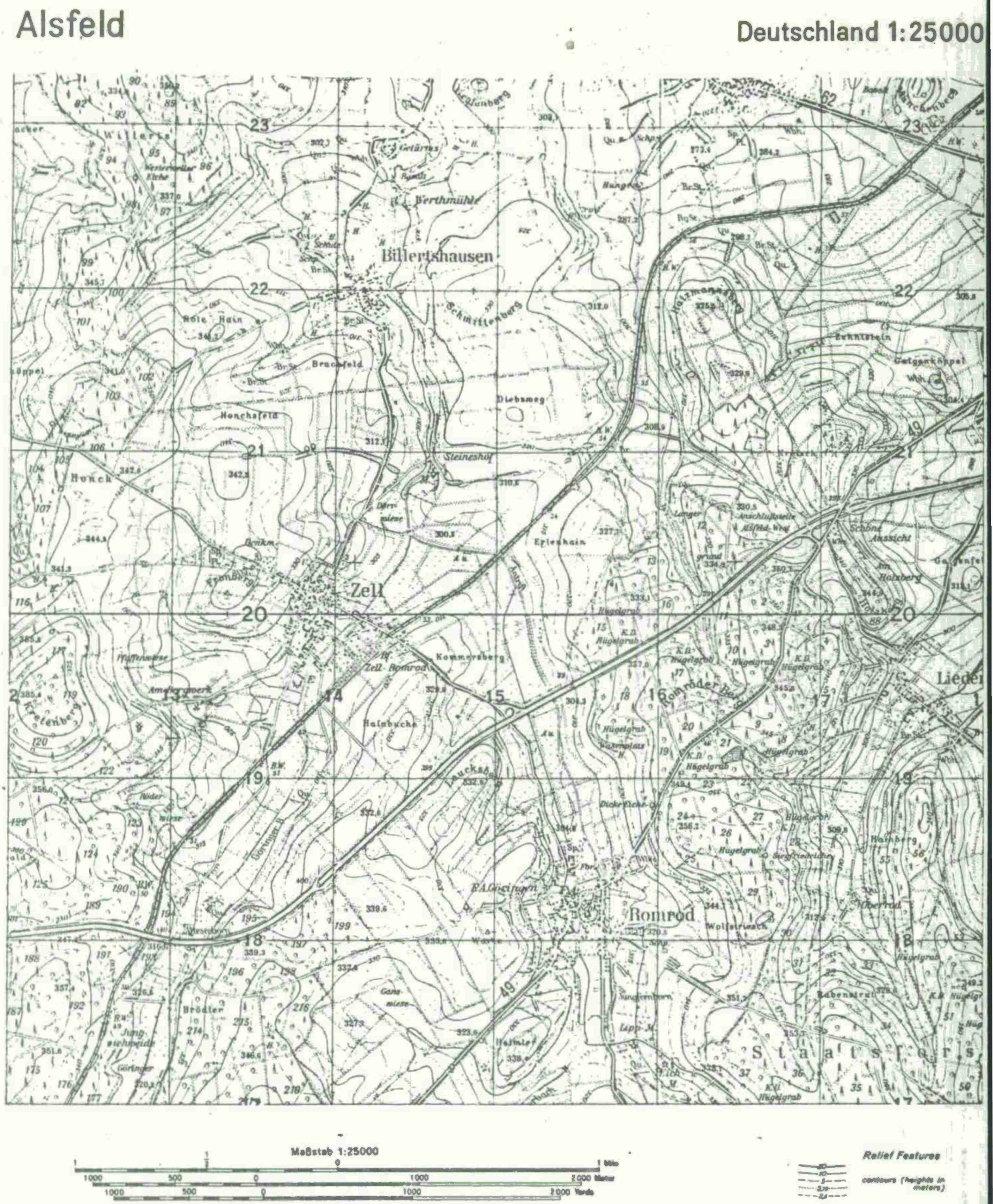

Fig. 1 - Geographic Map of Game Area

Fig. 2 - Map of Game Area with Reference Grid in Place

Table 1

RELATION BETWEEN GRID SIZE, UNIT SIZE, FORCE SIZE, AND ZONE OF ACTION

Grid size (m)	Approximate unit size				Maximum force size		Maximum zone of action	
	Infantry	Mechanized infantry	Artillery	Aviation, aircraft	Infantry	Mechanized infantry	Width (m)	Depth (m)
10	1 Man	n/a	1 tube	n/a	2 Plts	n/a	600	630
25	2 Men	1 Veh	2 tubes	1	1 Co	1 Co	1500	1575
50	½ Sqd	2 Vehs	4 tubes	1	1 Bn	1 Bn	3000	3150
100	1 Sqd	3 Vehs	6 tubes	2	2 Bns	2 Bns	6000	6300
250	1 Plt	7 Vehs	12 tubes	4	4 Bns	4 Bns	15000	15750

Trafficability is combined with the slope to give the maximum movement rate for units. Trafficability of roads depends on the quality of the road. Cross-country trafficability depends on the condition of the soil and any trees or brush that might hinder movement.

Cover and concealment are used to indicate the exposed area of an element. Tables are used to convert target size to exposed area for the varying degrees of cover or concealment.

CARMONETTE defines net cover as the capability of dismounted troops to find protection against fragments from exploding rounds. Net cover is differentiated from cover by the fact that cover gives protection from flat trajectory non-fragmenting ammunition, whereas net cover gives protection from overhead artillery bursts and flat trajectory fragmentating ammunition. The probability of killing dismounted troops, given a hit in the unit's area by a fragmenting rounds, depends on the weapon type, ammunition type, the response to fire of the troops (if any), and the net cover.

Weapons

A total of 56 weapon types may be played in CARMONETTE. These weapons are classified into three general groups: 12 may be artillery and mortars; 22 direct fire, fragmentation; and 22 direct fire, non-fragmentation. Each weapon may have two ammunition types.

For each type of weapon to be simulated, the following data are required:

(a) The minimum and maximum effective range (in meters),

(b) The minimum number of men required to serve the weapon,

(c) The mean and standard deviation (in minutes) of the time to aim the weapon initially,

(d) The mean and standard deviation (in minutes) of the time required to reaim the weapon at the same target after the weapon has been fired,

(e) The mean and standard deviation (in minutes) of the time required to reload the weapon after firing,

(f) The velocity of a round in meters per second. This should not be the muzzle velocity but the average velocity of a round over its anticipated range of employment during the game.

A measure of the impact area is required for the artillery and mortars. This area is the average area covered by a volley of one round from each piece in the firing unit.

The number of rounds that are fired each time one of the weapon types is fired is referred to as "rounds per trigger pull." In most cases this number is one. In the event that the normal mode of fire for a weapon is burst fire, the number of rounds per trigger pull is indicated. The neutralization weight of each round fired, which is used to determine the suppression state of target units, may also be indicated. For example, one tank round may be considered more devastating or demoralizing than one rifle round. This neutralization weight must be an integral multiple of that weapon which has a neutralization weight of one.

In order to simulate the accuracy of each weapon, CARMONETTE considers the total tactical standard deviation (SD) as a function of range and the following factors: weapon type, first or subsequent round at same target, previous round hit or miss, firer moving or stationary, target moving or stationary, whether or not the firer is partially suppressed by hostile fire, and ammunition type.

Kill probabilities given a hit, target priorities, and firing signatures are also input for each weapon.

Sensors

A total of 36 sensors may be used by the simulated forces. The sensors are subdivided into six classes of six types each. Three special classes represent unaided eyes and binoculars (Class 1), passive night vision devices (Class 2), and radars (Class 4). Special subroutines were developed for these devices to support a limited visibility study. These subroutines are not generally used at present since data on these devices is now available in a form that can be input directly into one of the three general sensor classes. The model represents information about non-firing targets as being in one of four states:

(1) Target's location unknown,

(2) Target known to be located in a certain area,

(3) Target erroneously pinpointed within an area,

(4) Target correctly pinpointed.

Inputs required for each sensor to be used are:

(a) Range,

(b) Probability of completely losing target information, given that line of sight is lost,

(c) Probabilities of improving information state,

(d) Probabilities of losing information state.

Information concerning firing targets does not include State 2 and does not require probabilities of losing a information state.

Mobility

In addition to dismounted infantry, CARMONETTE plays four types of ground vehicles and three types of helicopters. Input data includes:

(a) Doctrines that describe how a unit will act under varying conditions of cover and target availability,

(b) Rates at which ground and air units move,

(c) The time required for infantry units to dismount and remount from ground and air personnel carriers,

(d) Altitudes at which aircraft operate.

Units

The forces to be gamed are organized into a maximum of 48 units per side; each of these units may have a maximum of 63 killable elements. These units are not necessarily the squads, platoons, and companies with which the military gamer is familiar. CARMONETTE units are individual weapon systems such as a tank or an antitank guided missile, or they are groupings of elements that have the same degree of mobility and vulnerability, the same sensors, and are located within the same reference grid square. When a unit is fired upon, all of its elements are equally vulnerable, although the probability of a hit or a kill given a hit is determined for each element individually. When a single element of any unit is detected, the entire unit is considered to be detected. Also, when one element of a unit detects an enemy unit, all other elements are considered to have detected this enemy.

A unit may be assigned up to four groups of weapons. For example, a tank may have a main gun, an air defense machine gun, and a coaxial machine gun; a rifle squad may have two light antitank weapons, one machine gun, one grenade launcher, and five rifles.

Two units are required to describe the characteristics of troops mounted in carriers. The carrier is one unit, and the infantry squad is a second unit. The carrier unit retains the number of men designated as drivers and its main weapon when the troop unit dismounts.

Such characteristics as the area occupied may depend on whether the troop unit is mounted in the carrier unit. The horizontal area that a unit occupies when it is deployed is used to compute hit probabilities for fragmenting munitions.

The visible area of the largest element of the unit is used for detection calculations. The height of the unit's sensors above the ground is used for line-of-sight calculations.

Certain units may be ordered to hold fire until they are quite close to the enemy or until fired on. If a unit is given such orders, once it opens fire it will continue to search for and fire at targets, even though all targets withdraw beyond the hold-fire range.

Class Indexes. Each unit is described by indexes for target class, vulnerability class, element-size class, mobility class, fire-response class, and sensor class. These indexes are some of the data that are required by the simulation to provide for the bookkeeping and for representing the combat in a realistic manner; they have no analogue in actual combat. Although the number of indexes available in the simulation for each of the above classes is fixed, it is not necessary that all be used.

Target Class. Each unit in the battle presents a target of certain value to opposing forces. The target-class index is used in the target list as the basis of selection of units as targets for different weapon types and in the danger-state table to be discussed in the section on vulnerability class.

The two factors associated with the assignment of a unit to a target class are the unit's vulnerability to the various weapons and the firepower possessed by the unit. For example, an armored personnel carrier mounting an antitank guided missile would be a more desirable target than a similar carrier without the missile. Both carriers have the same vulnerability to the tank gun, but the one with the missile is a greater threat to the tank; therefore the carriers should be assigned to different target classes. There are sixteen target classes in CARMONETTE.

Vulnerability Class. The probability of kill given a hit on a target is a function of the vulnerability of the target and of the firer's ammunition and weapon type. Because several units have identical or similar vulnerabilities, they are grouped into classes, and the vulnerability class index is used to determine the probability of kill by each weapon and ammunition. The vulnerability class index is also used to indicate the preferred ammunition type for each weapon type against each unit. Hence, if two units are composed of tanks with different armor, they would be placed in different vulnerability classes as are armored personnel carriers and tanks. There are twelve vulnerability classes.

Element-Size Class. Each unit is classified according to the size of its principle element(s). The element-size class is used to determine the probability of detection and the probability of hitting the element. The element-size class of a unit is determined by two criteria: (a) the largest area that any element presents to a sensor, and (b) the greatest area that any element presents to a direct-fire weapon.

The element-size class is used with the concealment available to determine the exposed visible area of an element of a target unit for determining the probability of detection and is also used with the cover available to determine the exposed vulnerable area of an element of a target unit for determining the probability of hit by a direct-fire weapon. Ten element-size indices are available.

Mobility Class. The mobility class index is used to describe a unit's rate of movement over terrain of various trafficability and road conditions for ground units or climb and dive angles for air units. Two units with similar mobility characteristics should be assigned to the same mobility class.

In addition to dismounted infantry, there are four ground and three air mobility classes.

Fire Response Class. The fire response class is used to describe a unit's reaction to hostile fire. Thresholds are used to indicate the response of each of these classes to fire. All classes may be partially suppressed by direct or by indirect fire; dismounted infantry and unarmored vehicles may be pinned down by either direct or indirect fire or both. Helicopters respond only to direct fire and take evasive action by dropping to treetop level. If the helicopter is guiding a missile to a target, it will not drop to treetop level until after the missile impacts.

The fire response classes represented in CARMONETTE are: dismounted infantry, open vehicles, light armor, heavy armor, and helicopters.

Sensor Class. Sensor-class indexes are assigned to differentiate the unit's ability to detect targets under similar conditions. The sensor class index is used together with the size of the target, the unit's response to fire (if any), the unit's current level of information about the target, and the target motion (if any), to determine the probability of gain or loss of target information. As previously stated, there are six sensor classes in the model.

Orders. In order to provide a mechanism to cause the units being simulated to act in a realistic manner, each must be given detailed orders that will control its actions throughout the simulated battle. If a unit is killed, it simply stops following its orders. The basic set of orders is listed in Table 2. A sequence of these orders is given to each unit.

Table 2

CARMONETTE COMMANDS

Narrative order[a]	Order	Qual 1[b]	No 1	Qual 2	No 2	Qual 3	No 3	Qual 4	No 4	Qual 5	No 5
move NoSToPping at RATE r to SQuaRE xx yy with KIND of fire k PRiORity p[c]	NSTP	RATE	r	SQRE	xxyy	KIND	k	PROR	p	ALT	a
MOVE under DOCTrine m at RATE r to SQuaRE xx yy with KIND of fire k PRiORity p	MOVE	DOCT	m	RATE	r	SQRE	xxyy	KIND	k	PROR	p
STAY and FIRE s shots at SQuaRE xx yy with KIND of fire k PRiORity p	STAY	FIRE	s	SQRE	xxyy	KIND	k	PROR	p		
STAY until TIME tt.tt or FIRE s shots with KIND of fire k PRiORity p	STAY	TIME	tt.tt	FIRE	s	KIND	k	PROR	p		
STAY for INTervaL tt.tt or FIRE s shots with KIND of fire k PRiORity p	STAY	INTL	tt.tt	FIRE	s	KIND	k	PROR	p		
DISMount in present location	DISM										
REMOunt in present location	REMO										
CHange ALtitude to get LOS	CHAL	LOS									
CHange ALtitude to TReeToP	CHAL	TRTP									
CHange ALtitude to LAND	CHAL	LAND									
SKIP FORWard nn orders UNConDitionally	SKIP	FORW	nn	UNCD							
SKIP BACKward nn orders UNConDitionally		BACK	nn	UNCD							
if current TIME ≤ tt.tt				TIME	tt.tt						
if dead FRiendly UNits ≥ uu				FRUN	uu						
if dead ENemy UNits ≥ uu				ENUN	uu						
UNTiL friendly unit uu is in SQuaRE xx yy, if uu dies STAY 63.99				UNTL	uu	SQRE	xxyy	STAY			
UNTiL friendly unit uu is in SQuaRE xx yy, if uu dies SKiP 1 order				UNTL	uu	SQRE	xxyy	SKP1			
UNTiL friendly unit uu is in SQuaRE xx yy if uu dies go to EXIT pt				UNTL	uu	SQRE	xxyy	EXIT			
if FRiendly CAsualties ≥ nnnn				FRCA	nnnn						
if ENemy CAsualties ≥ nnnn				ENCA	nnnn						
if ENemy UNits ≥ uu are closer then RaNGE nnnn meters				ENUN	uu	RNGE	nnnn				
if FRiendly UNIT CAsualties ≥ uu for vul class TYPE vv				FRCA	uu	TYPE	vv				

[a] r:1-7 a:1-7 xx:1-60 vv:1-12
k:0-7 m:1-4 yy:1-63 nnn:1-4095
p:1-7 s:1-7 nn:1-63 tt.tt:1-63.99
uu:1-48

[b] Qual is left justified

[c] ... at ALTitude a (if unit is helicopter)

When the conditions of the current command are satisfied, the next command will be executed.

Two kinds of moving commands are provided. One is to move without stopping to a given square. This designated square may be adjacent to the unit's present location or any other square on the battlefield. The advance of units is coordinated by having them move several squares and then await the arrival of their flank units. In addition to moving without stopping, another move command indicates a doctrine permitting the unit to stop occasionally to fire as it moves along. Commands that can be given to a stationary unit are: remain in position for a time interval or until a particular time, or fire at a particular grid square. Superimposed on the time criterion for changing commands is the criterion to fire a number of shots and then change commands. The dismount command provides for dismounting infantry from a carrier, which may be a helicopter or ground vehicle. The remount command permits the troops to remount the carrier and move to a new location. No provision is made for causing groups of units to take up any particular formation on the battlefield. Commands must be provided to each separate unit to cause the intended formation to be created.

Each command may contain a firing order. Firing commands describe the kind of fire to be undertaken and also the priority of target selection for the weapons of the unit. The kind of fire may be either at pinpointed targets or suppressive fire at a grid square and may also indicate the capability of firing while moving. The skip order permits modification of the sequence of commands depending on current status or location of friendly or enemy units.

THE SIMULATION OF TIME AND SPACE

It is through the simulation of time and space that the interaction of the forces and their environment can be accounted for. Actual combat activities occur simultaneously over several areas of the battlefield. That is, when several platoons attack across a front, the shots fired by the enemy and by the men in each platoon will often occur simultaneously.

In addition the activities of units and individuals in actual combat are continuous. Of course the terrain of an actual battlefield, although it may vary, is continuous without abrupt changes in elevation. A point must be made of this simultaneous and continuous feature of actual combat because a computer simulation of combat requires sequential handling of the events and discrete representation of terrain. Thus there is an important distinction between actual combat and the simulation of combat.

The space or terrain simulated must be described so that the elevation of a unit and also the height of vegetation between itself and the enemy is always known. It is important to recognize that the elevations within a terrain square in the real world may be such that from certain parts of the square certain other terrain squares can be seen. The averaging process reduces these higher points and raises the lower points of a square. Elements of units that would be distributed throughout a square are handled as if they all existed at the average elevation of the square. The height of intervening vegetation must also be carefully averaged to preclude a very high tree from completely destroying intervisibility, whereas in real life elements of the unit could be positioned to avoid the masking effect of one very high tree in their area.

No two events can take place simultaneously in a computer. However, they indeed will be taking place simultaneously on a real battlefield. In addition all significant phenomena must be simulated by discrete events. An example of one insignificant event is the flight of a projectile from the weapon to the target. This is, of course, a continuous process in real life; however, the computer does not trace out the projectile path but rather notes the time of impact as a future event and simulates other battle activities in the interim.

Another event that is not traced out in its entirety is the movement of a unit from one grid square to the next grid square. In this case the time that the unit will cross the boundary between grid squares is established as the next event for the unit. Having crossed the boundary, the time of arrival at the center of the new square is determined and this is established as the next event for the unit. Thus by discontinuous handling of the firing and moving events for each unit, time is available for handling the largely simultaneous activities of many units.

Another step in the sequential handling of events is the use of periodic assessment for target acquisition and neutralization. The probability of detecting a target is determined for the most part by dwell time of the sensor on the target, range from the sensor to the target, and the target characteristics in relation to the environment. Periodically the targets available to the unit are assessed and increased or decreased accordingly. Another periodic phenomenon is neutralization assessment. The number of rounds impacting in the vicinity of a unit during a neutralization interval is calculated. Rounds received some time ago will not be important to the unit as far as its neutralization is concerned. Thus during every neutralization period the rounds fired at the unit several intervals ago are erased from its memory, and the unit will only respond to the rounds fired at it in the more recent intervals.

ACTIVITIES SIMULATED

Activities Common to More Than One Arm

The activities simulated that are common to more than one arm are target acquisition, target selection, firing and impact, neutralization, move selection, and communications.

The target acquisition calculations take place on a periodic basis, as was mentioned previously. Four states of target information are utilized for each enemy unit: (a) location unknown, (b) location known merely within a grid square (nearest square), (c) an erroneously pinpointed state, and (d) an accurately pinpointed state. If intervisibility exists, the validity of a unit's information about an enemy unit may change depending on the range, the exposed portion of the target unit, whether the target unit is moving, and the current activities of the observing unit. A unit that has lost line of sight to an enemy unit loses one level of information each target acquisition period until merely "nearest square" information is available to the unit. On the next and each succeeding target acquisition period there is a probability that target information will be totally lost.

Targets are selected for the main weapon type of a unit; or if it is busy, targets are investigated for the other weapon types. Targets are selected from enemy units that are valuable (described by three Target Lists) and/or dangerous (described by the Danger State Table). The targets must be pinpointed either accurately or erroneously to be selected. Each weapon is given a target list, ranking the enemy unit types on which it is to fire. For example, the main weapon of an infantry unit might be a machine gun, and the operators might be told by the priority list to first seek enemy infantry units and then enemy mortar units. Friendly units are described by their degree of vulnerability to enemy fire. This degree of vulnerability can be either serious, moderate, or invulnerable and can depend on the range between the units. A unit can be told to fire from either the Danger State Table or one of the Target Lists. Firing from the Danger State Table causes the unit to look for possible targets among those enemy units to which it is most vulnerable and then to select the target that appears highest on the Target List for the weapon. On the other hand, firing from a Target List causes the unit to look for targets that are highest on the list and then to select from these the one to which it is most vulnerable. If a firer knows which enemy units are engaging him or his side, he will automatically select according to the Danger State Table priorities. This concept of range-dependent danger states and a priority list for target selection permits simulation of the complex thought process of a tank commander deciding whether to fire at an infantry antitank weapon at short range or a machine gun at long range.

One of the features of the target selection simulation is the crew allotments to the weapons assigned to the unit. The assumption is made that the assignment of weapons within a unit is in the order of importance, and thus the men available in the unit are assigned to the main weapons and then to second or third or fourth weapons as far as they will go. This procedure permits simulation of casualties on a machine gun squad. The machine gun would be designated as the main weapon and as squad members are killed the riflemen will stop firing their rifles and operate the machine gun.

The firing and impact simulation includes position disclosure resulting from firing, ammunition expenditure, and casualty assessment. In position disclosure each weapon has a firing signature, such as flash or dust, so that when it is fired it is possible for the enemy to observe the signature and ultimately locate the unit. Position disclosure is in addition to the target acquisition simulation but works in the same fashion in that the farther away the observing unit is from the firing, the lower the probability of discovery of the firer's exact location. Every time a unit fires one of its weapons the ammunition expended is removed from the unit's supply. Ammunition expenditure may be on a basis of more than one round per trigger pull to simulate bursts from machine guns and other weapons. The probability of hit is determined by the range, the exposed portion of the target, the total tactical dispersion of the weapon at that range, and whether this is the first or subsequent shot at this target. Having determined the number of hits, the probability of kill is used to determine how many elements of the target are killed. In the event that a troop carrier is killed the survivors on board will dismount.

When a target is killed it ordinarily exhibits its death in some fashion. An infantryman or helicopter will fall to the ground, and vehicles often burn on being killed. Each friendly unit that is in line of sight of the dead unit has a chance of learning of the death of the target. If a unit does not know a particular enemy target is dead, it can fire additional rounds at the dead target. After the calculation of casualties for each firing, the firing unit is given an opportunity to reselect a target. This may be the same target or another target, depending on the situation at the time of the selection.

Neutralization or suppression, the reaction to incoming fire demonstrated by a unit in the impact area, is a well recognized weapons effect. In addition to several factors that cannot be quantified, neutralization is a function of the number and caliber of rounds impacting in a given area over a given period of time, and the model considers these four factors in the following manner. The size of indirect fire, artillery and mortar, impact areas are required inputs; the model sets the impact area for direct fire weapons equal to the area of one grid square. The given period of time is also an input and is called the neutralization interval. The number of rounds impacting in a given area during the neutralization interval are recorded by the model. The only factor unaccounted for is the caliber of the rounds, and it is represented by assigning a neutralization weight to each weapon. The neutralization weight shows the relation between the amount of suppression a round will cause when compared to the suppression caused by a single round from a rifle, which has a neutralization weight of 1. For example, if in the opinion of the gamer the suppression caused by a round from a medium howitzer is 15 times greater than that caused by a single rifle round, the medium howitzer should be assigned a neutralization weight of 15. CARMONETTE provides two levels of suppression: partially suppressed and pinned down. Partial suppression may be caused by either direct or indirect fire; the sum of both is considered to determine if a unit is pinned down. A partially suppressed ground unit conducts surveillance and fires its weapons at reduced accuracy, requires twice the usual time to aim its weapons, and moves at a reduced rate. The reaction of a partially suppressed helicopter depends on whether or not it is guiding a missile to a target. If the helicopter is not guiding a missile, it will immediately drop to treetop level and move to another location. If it is guiding a missile, it will wait until the missile impacts before dropping to treetop level. A pinned down unit does not fire, move, or conduct surveillance, and it retains only nearest-square intelligence. Dismounted infantry and open vehicles may be pinned down or partially suppressed. Armored vehicles and helicopters may only be partially suppressed. By inputting thresholds for each level of suppression for infantry, open vehicles, light armor, heavy armor, and helicopters, the gamer can cause a unit to react to fire when the combined neutralization weight of rounds landing in the vicinity of the unit exceeds the threshold.

The move selection simulation is straightforward. As was pointed out earlier, units are given commands to move to a particular grid coordinate, and they will do so by the most direct route. It should be pointed out that move selection is made only to the adjacent grid square that is in the direction of the coordinates to which the unit is moving, and a new move selection must be made for each move from one grid to the next.

Communications between CARMONETTE units is primarily for the purpose of exchanging target information. When a weapon unit acquires information on an enemy unit, it informs its immediate headquarters of the grid square in which the target is located. Weapons units also report enemy units that they know to be dead. Target information and enemy units known dead are subsequently passed to higher headquarters and subordinate weapons units by the headquarters that initially received the information.

Infantry Activities

Infantry in CARMONETTE may be dismounted or it may be mounted in armored personnel carriers (APC) or in transport helicopters. Direct fire weapons may inflict casualties on dismounted infantry either by hitting individuals with a non-fragmenting round or by hitting them with fragments from a round that has exploded. In the first instance, the number of individuals who are hit by incoming rounds is determined by comparing the probability of hitting an infantryman with a random number drawn for each member of the unit; the probability of a kill given a hit is then compared with a random number drawn for each individual who was hit. A fragmenting round always impacts in the area occupied by the dismounted unit it engaged, and then the probability of killing infantry is compared to a random number drawn for each member of the unit. The individuals in the unit who are killed are chosen at random so that more than one shot can be credited as having hit a single man. A dismounted infantry unit can be pinned down in real life and in the CARMONETTE simulation. Infantrymen riding in an APC can be killed when it is hit. The probability of survival of troops inside troop carriers when the carrier is destroyed is an input to the model. When the carrier is hit, a random number is drawn for each passenger to determine his status. Helicopter passengers are treated in a like manner; however, the probability of their surviving when the helicopter is destroyed is considerably lower.

Mechanized Activities

Most of the mechanized units' activities are in the area of common activities. However, mechanized units do react to hostile fire in three distinct ways. Heavily armored units cannot be pinned down and only a state that may be described as "buttoned up" is provided. This state can be caused to occur when a sufficient volume of either direct or indirect fire falls in the vicinity of such a unit. Lightly armored units, such as APCs and scout cars, may also be caused to "button up" under either direct or indirect fire. Troops riding in APCs can be ordered to dismount and remount during the simulated battle. Surviving passengers in APCs also dismount and continue the mission on foot when the carrier is destroyed. Unarmored vehicles act in a way that is consistent with their lack of armor and can be pinned down.

Artillery Activities

The simulation of artillery units that has been incorporated in CARMONETTE includes mortars. Because of the range capability of most artillery units, they are positioned on the edge of the CARMONETTE battlefield, and their apparent range in the simulation is reduced to account for their closer location. The two types of fire missions that artillery and mortar units can be given are scheduled fires and on-call fires. In scheduled fires a unit is ordered to fire on a particular grid coordinate for a period of time. The on-call fire mission causes the artillery to await calls from the units that are given the capability of calling artillery. In this case the calling unit provides the artillery with the necessary target information. The adjustment phase of artillery fire is not simulated. Casualties are assessed against dismounted infantry in all cases and against armored vehicles and their passengers when appropriate muntions are fired. All units that are in the area under artillery attack have the rounds included when their neutralization calculation is made.

Helicopter Activities

The two distinct features of helicopters are their flight profile and their response to fire. CARMONETTE can simulate the actions of attack, scout/observation, and troop transport helicopters. The attack helicopter moves about the battlefield in a terrain following mode and "pops up" to engage targets. Troop transport helicopters move to the landing zone in the terrain following mode. The scouts can employ the same tactics as the attack helicopters, or they can fly in a straight and level search pattern. With the exception of an attack helicopter that is guiding a missile toward a target, all helicopters will drop to treetop altitude and continue the mission if a sufficient amount of direct fire is received. An attack helicopter that has launched a guided missile at a target will continue to guide the missile to impact and will then drop to treetop level under the above conditions.

ACTIVITIES NOT TREATED

The CARMONETTE simulation does not treat certain activities primarily because they are not deemed important during the brief intense combat that the simulation is designed to represent. Others have been left out in order to make the simulation possible and to concentrate on the activities of moving, shooting, and communicating. The activities not treated are resupply, evacuation and maintenance.

COMMAND, CONTROL AND COMMUNICATIONS

Another important point is the method used to simulate command, control, and communications. This aspect of the simulation is important because an assumption that these factors are accounted for in the same detail as the more straightforward combat activities often leads to erroneous impressions concerning the simulation. The simulation of command, control, and communications (C^3) functions in CARMONETTE is very complex. Complex, that is, from the standpoint of the true situation being simulated. For units and task forces of the size considered, the mission-type order is the appropriate way to cause the actions desired.

Other elements of C^3 are identification of friend or foe, transfer of information among units, and formations of the elements of a unit. In CARMONETTE the identification of friendly units is complete. Firing cannot take place against units on the same side. Likewise, once a target is pinpointed, it is not questioned whether it is an enemy. The transfer of information among units on the same side takes place through the Communications Routine. During its communication cycle, each weapon unit reports to its immediate commander the "nearest square" location of enemy units known to it. During the commanders' communication cycles, commanders relay the information to their superior, subordinate, and adjacent headquarters.

Any headquarters can be given the capability of calling for attack helicopter and/or artillery support. The capability to call artillery can also be given to a weapon unit under certain conditions. When the situation demands support, the support will be provided if the support unit is not already committed to other missions.

The combat formation of the elements of a unit in CARMONETTE is not simulated. This is one of the simplifications that have been made in the course of creating the simulation. The result of this simplification is that when a unit has acquired a target by the acquisition of one element, it will have full knowledge of all elements in the target unit. There are area weapons whose effects depend on the formation of the target unit; however, this distinction is not made in CARMONETTE.

OUTPUT

The philosophy that has guided the design of the output program is that only the minimum required output would be provided without the user specifically requesting more detail. In the sections that follow the source of information, the messages transmitted, and the output formats will be explained in non-technical terms. The details of how to obtain the output options and the system configuration are explained in Vol III.

Sources of Output Information

During the processing of each event that is deemed to have significance an output message is placed on magnetic tape. The primary record of events is referred to as the history tape. The history tape records all move selections, target selections, boundary crossings, firings, impacts, and status information such as out-of-ammunition, response to fire, line of sight, intelligence level, and recognition of target death for each live unit.

Non-events are not recorded. For example, if a unit does not select a target, a message is not transmitted. The consequence of this approach is that a very careful study of the input is required to determine if a unit that does not appear to be taking part in the battle is in fact present.

Event History Message

The event history message contains two parts. The first part is the same for messages from all sources within the battle model. The second part contains information of interest concerning the specific event from which it is transmitted. Part one of every message contains the side, unit, time of the event, location of the unit, and the nature of the event. Part two of the messages varies depending on the event taking place. The messages are described in detail in Part III of Vol II.

Output Reports

CARMONETTE produces six non-optional reports. Figure 3 is an example of the Chronological Cumulative Casualties Report. An example of the Target-Kill Report is shown in Fig. 4. The Operational-Statistical Report is shown in Fig. 5, and the Ammunition Expenditure Report in Fig. 6. Whenever a treatment is replicated, the average results of all replications are summarized in the Treatment Summary Target Kill Report, an example of which is in Fig. 7. An example of the Average Ammunition Expenditure by Weapon Type Report is in Fig. 8.

A very useful optional report is the chronological history report. This report is shown in Fig. 9. By requesting this option, most of the event messages placed on the event history tape will be printed. The primary purpose of this option is to ensure that the battle scenario is being followed. If a selective history, which records only the events pertaining to selected units is desired, this option may be selected in place of the chronological history. An example of this report is in Fig. 10. The information contained in the Average Ammunition Expenditure by Weapon Type can be reported by time interval; an example of this optional report is shown in Fig. 11. The Variance of Ammunition Expenditure by Weapon Type is also available and is shown in Fig. 12.

The Range Interval Post Processor

This program lists the number of engagements (firings), number of rounds fired, troop and vehicle casualties for each weapon on both sides, for all target classes that were engaged, in range intervals of a specified number of meters. Total accumulated casualties are then listed by range interval from the longest to the nearest range. The averages for all replications of the treatment follow. The listing is for each replication of each treatment.

TREATMENT9901 SUMMARY OF REPLICATION 1 07/19/74

CHRONOLOGICAL CUMULATIVE CASUALTIES

RED	27	2.8835	32,58,	0	CASUALTY WPN NO.	36	FIRER NO.	34	VEH BEFORE	1	AFTER	0	MEN BEFORE	3	AFTER	0	CUMULATIVE	3
RED	1	5.3386	26,55,	0	CASUALTY WPN NO.	13	FIRER NO.	31	VEH BEFORE	4	AFTER	3	MEN BEFORE	40	AFTER	38	CUMULATIVE	5
RED	1	5.6284	26,55,	0	CASUALTY WPN NO.	13	FIRER NO.	31	VEH BEFORE	3	AFTER	2	MEN BEFORE	38	AFTER	36	CUMULATIVE	7
RED	1	5.7839	26,55,	0	CASUALTY WPN NO.	35	FIRER NO.	25	VEH BEFORE	2	AFTER	1	MEN BEFORE	4	AFTER	2	CUMULATIVE	9
RED	7	6.1694	29,49,	0	CASUALTY WPN NO.	36	FIRER NO.	35	VEH BEFORE	4	AFTER	3	MEN BEFORE	40	AFTER	36	CUMULATIVE	13
RED	2	6.8074	25,55,	0	CASUALTY WPN NO.	6	FIRER NO.	37	VEH BEFORE	0	AFTER	0	MEN BEFORE	32	AFTER	31	CUMULATIVE	14
RED	1	7.2383	26,55,	0	CASUALTY WPN NO.	13	FIRER NO.	30	VEH BEFORE	1	AFTER	0	MEN BEFORE	2	AFTER	0	CUMULATIVE	16
BLUE	35	7.9602	6,56,	0	CASUALTY WPN NO.	16	FIRER NO.	28	VEH BEFORE	1	AFTER	0	MEN BEFORE	3	AFTER	0	CUMULATIVE	3
RED	11	8.5542	27,45,	0	CASUALTY WPN NO.	13	FIRER NO.	31	VEH BEFORE	3	AFTER	2	MEN BEFORE	30	AFTER	28	CUMULATIVE	18
RED	2	8.6892	24,54,	0	CASUALTY WPN NO.	6	FIRER NO.	37	VEH BEFORE	0	AFTER	0	MEN BEFORE	31	AFTER	29	CUMULATIVE	20
BLUE	31	8.7944	15,39,	0	CASUALTY WPN NO.	14	FIRER NO.	24	VEH BEFORE	1	AFTER	0	MEN BEFORE	3	AFTER	0	CUMULATIVE	6
RED	30	9.0974	26,49,	0	CASUALTY WPN NO.	35	FIRER NO.	26	VEH BEFORE	1	AFTER	0	MEN BEFORE	3	AFTER	0	CUMULATIVE	23
RED	11	9.2800	27,45,	0	CASUALTY WPN NO.	45	FIRER NO.	30	VEH BEFORE	2	AFTER	1	MEN BEFORE	28	AFTER	26	CUMULATIVE	25
RED	11	9.9643	27,45,	0	CASUALTY WPN NO.	44	FIRER NO.	17	VEH BEFORE	1	AFTER	0	MEN BEFORE	2	AFTER	0	CUMULATIVE	27
RED	19	9.9858	20,54,	0	CASUALTY WPN NO.	41	FIRER NO.	8	VEH BEFORE	3	AFTER	2	MEN BEFORE	9	AFTER	6	CUMULATIVE	30
RED	22	10.0276	26,52,	0	CASUALTY WPN NO.	35	FIRER NO.	26	VEH BEFORE	1	AFTER	0	MEN BEFORE	3	AFTER	0	CUMULATIVE	33
RED	8	10.7114	24,44,	0	CASUALTY WPN NO.	6	FIRER NO.	37	VEH BEFORE	0	AFTER	0	MEN BEFORE	30	AFTER	29	CUMULATIVE	34
BLUE	30	11.5342	15,40,	0	CASUALTY WPN NO.	14	FIRER NO.	21	VEH BEFORE	1	AFTER	0	MEN BEFORE	3	AFTER	0	CUMULATIVE	9
RED	10	11.6448	24,43,	0	CASUALTY WPN NO.	1	FIRER NO.	40	VEH BEFORE	0	AFTER	0	MEN BEFORE	24	AFTER	23	CUMULATIVE	35
BLUE	34	12.7109	6,56,	0	CASUALTY WPN NO.	16	FIRER NO.	28	VEH BEFORE	1	AFTER	0	MEN BEFORE	3	AFTER	0	CUMULATIVE	12
BLUE	1	14.5132	10,46,	0	CASUALTY WPN NO.	46	FIRER NO.	5	VEH BEFORE	1	AFTER	0	MEN BEFORE	1	AFTER	0	CUMULATIVE	13

Fig. 3 - Chronological Cumulative Casualties Report

TARGET KILLS BY WEAPON TYPE

RED WEAPON NUMBERS	BLUE TARGET CLASSES											
	CLASS 1		CLASS 2		CLASS 4		CLASS 7		CLASS 8		CLASS 10	
	MEN	VEH	MEN	VEH	MEN	VEH	MEN	VEH	MEN	VEH	MEN	VEH
3	0	0	0	0	0	0	0	0	2	0	0	0
4	0	0	0	0	0	0	1	0	0	0	0	0
14	6	2	0	0	4	1	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	6	2
46	0	0	1	1	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	1	0	0	0
52	0	0	0	0	0	0	0	0	5	0	0	0
TOTALS	6	2	1	1	4	1	1	0	8	0	6	2

RED WEAPON NUMBERS	TOTAL KILLS	
	MEN	VEH
3	2	0
4	1	0
14	10	3
16	6	2
46	1	1
50	1	0
52	5	0
TOTALS	26	6

Fig. 4 - Example of the Target-Kill Report

BLUE UNITS	LOCATION INITIAL		LOCATION FINAL		NUMBER OF MOVES	NUMBER OF ROUNDS FIRED	NUMBER OF ROUNDS RECEIVED	TROOPS INITIAL	TROOPS FINAL	VEHICLES INITIAL	VEHICLES FINAL	UNIT DEATH TIME
1	10,46,	0	10,46,	0	0	6	24	11	0	1	0	14.5132
2	10,46,	0	10,46,	0	0	8	36	0	10	0	0	0.0000
3	10,44,	0	10,44,	0	0	22	18	11	1	1	1	0.0000
4	10,44,	0	10,44,	0	0	8	0	0	10	0	0	0.0000
5	13,48,	0	9,46,	0	4	0	0	11	1	1	1	0.0000
6	13,48,	0	9,46,	0	1	0	81	0	4	0	0	0.0000
7	10,45,	0	10,45,	0	0	5	266	3	2	1	1	0.0000
8	13,48,	0	13,48,	0	0	5	163	3	3	1	1	0.0000
9	7,41,	0	7,41,	0	0	0	0	11	1	1	1	0.0000
10	7,41,	0	7,41,	0	0	0	0	0	10	0	0	0.0000
11	7,41,	0	7,41,	0	0	0	0	11	1	1	1	0.0000
12	7,41,	0	7,41,	0	0	0	0	0	10	0	0	0.0000
13	15,41,	0	15,41,	0	0	34	55	11	1	1	1	0.0000
14	15,41,	0	15,41,	0	0	8	0	0	8	0	0	0.0000
15	7,41,	0	7,41,	0	0	0	0	3	3	1	1	0.0000
16	15,41,	0	15,41,	0	0	5	32	3	3	1	1	0.0000
17	16,34,	0	16,34,	0	0	32	0	11	1	1	1	0.0000
18	16,34,	0	16,34,	0	0	0	0	0	10	0	0	0.0000
19	15,32,	0	15,32,	0	0	0	0	11	1	1	1	0.0000
20	15,32,	0	15,32,	0	0	0	0	0	10	0	0	0.0000
21	15,31,	0	15,31,	0	0	0	0	11	1	1	1	0.0000
22	15,31,	0	15,31,	0	0	0	0	0	10	0	0	0.0000
23	16,33,	0	16,33,	0	0	0	0	3	3	1	1	0.0000
24	14,31,	0	14,31,	0	0	0	0	3	3	1	1	0.0000
25	10,44,	0	10,44,	0	0	20	36	4	0	1	0	17.7961
26	10,45,	0	10,45,	0	0	28	267	4	4	1	1	0.0000
27	15,33,	0	15,33,	0	0	0	0	4	4	1	1	0.0000
28	15,32,	0	15,32,	0	0	0	0	4	4	1	1	0.0000
29	14,41,	0	14,41,	0	0	198	55	3	3	1	1	0.0000
30	15,40,	0	15,40,	0	0	47	27	3	0	1	0	11.5342
31	15,39,	0	15,39,	0	0	21	22	3	0	1	0	8.7944
32	8,41,	0	8,41,	0	0	0	0	3	3	1	1	0.0000
33	7,41,	0	7,41,	0	0	0	0	3	3	1	1	0.0000
34	2,58,	0	6,56,	0	98	4	14	3	0	1	0	12.7109
35	2,58,	0	6,56,	0	51	3	14	3	0	1	0	7.9602
36	1,21,	0	1,21,	0	0	64	0	40	40	5	5	0.0000
37	1,34,	0	1,34,	0	0	96	0	40	40	7	7	0.0000
38	1,10,	0	1,10,	0	0	96	0	40	40	7	7	0.0000
39	2,21,	0	2,21,	0	0	24	0	33	33	5	5	0.0000
40	4,39,	0	4,39,	0	0	36	0	24	24	4	4	0.0000
TOTALS						770	1110	331	305	54	48	

Fig. 5 - Example of the Operational-Statistics Report

BLUE	MAIN WEAPON						WEAPON B					WEAPON C					WEAPON D				
UNIT	WPN	AMMO TYPE 1 BEGIN	END	AMMO TYPE 2 BEGIN	END	WPN	AMMO TYPE 1 BEGIN	END	AMMO TYPE 2 BEGIN	END	WPN	AMMO TYPE 1 BEGIN	END	AMMO TYPE 2 BEGIN	END	WPN	AMMO TYPE 1 BEGIN	END	AMMO TYPE 2 BEGIN	END
1	44	210	204	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	42	8	0	0	0	50	300	300	0	0	52	980	980	0	0	0	0	0	0	0
3	44	210	188	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	42	8	0	0	0	50	300	300	0	0	52	980	980	0	0	0	0	0	0	0
5	44	210	210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	42	8	6	0	0	50	300	300	0	0	52	980	980	0	0	0	0	0	0	0
7	41	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	41	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	44	210	210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	42	8	8	0	0	50	300	300	0	0	52	980	980	0	0	0	0	0	0	0
11	44	210	210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	
12	42	8	8	0	0	50	300	300	0	0	52	980	980	0	[illegible]					
13	44	210	176	0	0	0	0	0	0	0	0	[illegible]								
14	42	8	6	0	0	50	300	300	[illegible]										0	0
15	41	5	5	0	[illegible]										[illegible]	0	0	0	0	0
16	41	[illegible]										[illegible]	450	0	0	0	0	0	0	0
								[illegible]	0	0	48	450	450	0	0	0	0	0	0	0
					[illegible]	[illegible]	25	25	0	0	51	200	200	0	0	0	0	0	0	0
		[illegible]	[illegible]	0	0	19	25	25	0	0	51	200	200	0	0	0	0	0	0	0
36	7	960	928	240	208	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	6	1080	996	720	708	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	6	1080	984	720	720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	2	624	600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	1	465	429	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TOTAL AMMUNITION EXPENDITURE BY WEAPON TYPE

WEAPON TYPE	AMMO 1	AMMO 2
1	36	0
2	24	0
6	180	12
7	32	32
13	24	48
35	20	0
36	7	0
41	15	0
42	24	0
44	122	0
45	110	0
48	84	0

Fig. 6 - Example of the Ammunition-Expenditure Report

SUMMARY OF TREATMENT9901
NUMBER OF REPLICATIONS 3

AVERAGE TARGET KILLS BY WEAPON TYPE

BLUE WEAPON NUMBERS	RED TARGET CLASSES CLASS 1 MEN	VEH	CLASS 2 MEN	VEH	CLASS 4 MEN	VEH	CLASS 5 MEN	VEH	CLASS 9 MEN	VEH	CLASS 11 MEN	VEH	CLASS 12 MEN	VEH
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	.3	.3	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
6	1.0	.3	1.3	.7	0.0	0.0	.3	0.0	6.0	0.0	0.0	0.0	0.0	0.0
7	2.0	.7	.7	.3	0.0	0.0	.3	0.0	1.0	0.0	0.0	0.0	0.0	0.0
13	6.0	2.0	5.3	2.7	3.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	5.0	1.7	1.3	.7	2.0	.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.0	0.0	3.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	2.0
41	4.0	1.3	3.3	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	0.0	0.0	4.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	.3
45	0.0	0.0	1.3	.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS	18.0	6.0	21.0	9.7	5.0	1.7	.7	0.0	9.0	0.0	.3	.3	7.0	2.3

VARIANCE OF TARGET KILLS BY WEAPON TYPE

RED WEAPON NUMBERS	BLUE TARGET CLASSES CLASS 1 MEN	VEH	CLASS 2 MEN	VEH	CLASS 4 MEN	VEH	CLASS 7 MEN	VEH	CLASS 8 MEN	VEH	CLASS 10 MEN	VEH
3	0.0	0.0	0.0	0.0	0.0	0.0	.3	0.0	2.3	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	.3	0.0	2.3	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.3	0.0	0.0	0.0
14	7.0	.3	2.3	2.3	5.3	.3	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	.3
37	12.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	9.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48	0.0	0.0	.3	.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.3	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0
52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	0.0	0.0	0.0

Fig. 7 - Example of the Treatment Summary Target Kill Report

BLUE AVERAGE AMMUNITION EXPENDITURE BY WEAPON TYPE

WEAPON TYPE	AMMO 1	AMMO 2
1	44.0	0.0
2	45.3	0.0
6	196.0	12.0
7	45.3	18.7
13	11.7	25.0
35	20.0	0.0
36	11.3	0.0
41	13.7	0.0
42	21.3	0.0
44	180.0	0.0
45	18.0	0.0

RED AVERAGE AMMUNITION EXPENDITURE BY WEAPON TYPE

WEAPON TYPE	AMMO 1	AMMO 2
3	36.0	0.0
4	96.0	40.0
5	0.0	20.0
14	27.3	28.0
16	48.0	0.0
17	.7	0.0
37	11.7	0.0
38	15.0	0.0
43	24.0	0.0
46	252.0	0.0
47	7.3	0.0
49	168.0	0.0
50	165.0	0.0
52	219.3	0.0
53	3.3	0.0

Fig. 8 - Example of the Average Ammunition Expenditure by Weapon Type Report

```
RED   50    .2461  22,30,  0  INTELLIGENCE ENUN DEAD  0 LOS  0 IN SENRG  0 NKON  0 PR  R 0/A 0 ERRPR R 0/A 0 NS B 0/A 0

                              I2= 0000000000000000  I3= 0000000000000000  I4= 0000000000000000
                              LOS= 0000000000010000  ENUN DEAD= 0000000000000000  SURV= 0000000000000000
BLUE  32   9.6484  41,17,  0  INTELLIGENCE ENUN DEAD  8 LOS 31 IN SENRG  3 NKON  3 RR R13/A15 ERRPR R19/A20 NS B25/A24

                              I2= 0001177340073577  I3= 0000175300063577  I4= 0000074300062157
                              LOS= 0075777310173577  ENUN DEAD= 0001000300012434  SURV= 0000000040000043

RED   42   1.0000  36,34,  0  NEW MISSION, ORDER NUMBER= 332   OCTAL  0000051440070042 4364
RED   42   1.0000  36,34,  0  MOVE SELECT  FROM 36,34,  0  TO 35,34,  0  TIME CEN TO ROUND, .1836    VEL =  4.537
RED   42   1.1836  35,34,  0  MOVE FROM 36,34,  0,TIME TO CEN  .1835,VEL  4.537,EXP-CONC 1.8,COVER  .5,NETCOV 2,LOS 0020020000125034

BLUE  30   1.0000  46,16,  0  NEW MISSION, ORDER NUMBER= 860   OCTAL  0000153420000000000
BLUE  30   1.0000  46,16,  0  DISMOUNTED UNIT 31  VEHICLES  1  MEN  9, DISMOUNT TIME  .5000
BLUE  31   1.5000  46,16,  0  NEW MISSION, ORDER NUMBER= 571   OCTAL  0001073100031620046
BLUE  35   2.3027   5,56,190  CHANGE ALTITUDE TO 2  LOS=0000000000000000

BLUE  52   2.0469  39,15,  0  ARTY CALLED    WPN NO.  1 UNIT NO. 17 TGT AREA 33,38 AIM TIME  .3005 TGT NO. 30 AMMO NO.  1
BLUE  52   2.0898  10,46,  0  HELO CALLED----RESPONDED BY UNIT 35  TGT NO.21  TGT LOC. 45,49  ALT 0

RED   45    .7581  20,60,  0  TARGET SELECT  WPN NO.  3  AREA TGT  TGT LOC 43,19    AIM/REAIM TIME  .2126
RED   32   1.0002  25,35,  0  TARGET SELECT  WPN NO. 37 TGT NO. 10 TGT LOC 38,16,  0 AIM TIME  .1118 AMMO NO. 1

BLUE  19   1.3769  42, 2,  0  FIRING          WPN NO.  4 TGT NO.  0 RANGE  3220. M   TIME OF FLIGHT  .2351 RELOAD TIME  .2725
BLUE  41   1.0315  37,16,  0  FIRING          WPN NO. 52 TGT NO. 13 RANGE  1789. M   TIME OF FLIGHT  .0042 RELOAD TIME  .0020
RED    4   1.3135  26,32,  0  FIRING          WPN NO. 38 TGT NO. 14 RANGE  2125. M   TIME OF FLIGHT  .1814
BLUE  14   1.4946  40,16,  0  POSITION DISCLOSURE, I1 TO I3= 0003140000010000 I3 TO I4= 0010000000102200

BLUE   5   1.4624  38,16,  0  IMPACT(TARGET)  WPN NO.  2 FIRER NO. 43 VEHICLES BEFORE  0 AFTER  0 TROOPS BEFORE  9 AFTER  9

BLUE  10   1.4624  38,16,  0  IMPACT(TARGET)  WPN NO.  2 FIRER NO. 43 VEHICLES BEFORE  1 AFTER  1 TROOPS BEFORE  3 AFTER  3

RED   43   1.4624  22,50,  0  IMPACT(FIRER)   WPN NO.  2 TGT NO.  0 P(H) 0.00 P(K)  .02 NO. OF ROUNDS  6 NO. OF HITS  0

RED    4   1.4949  26,32,  0  IMPACT(FIRER)   WPN NO. 38 TGT NO. 14 P(H) 0.00 P(K) 0.00 NO. OF ROUNDS  1 RELOAD TIME  .4658
RED   32   1.3096  25,34,  0  IMPACT(FIRER)   WPN NO. 37 TGT NO. 10 P(H)  .38 P(K) 0.00 NO. OF ROUNDS  2 RELOAD TIME  .5017
BLUE  13   1.4944  42,16,  0  IMPACT(FIRER)   WPN NO. 13 TGT NO. 13 P(H)  .41 P(K)  .52 NO. OF ROUNDS  1 NO. OF HITS  1

RED   13   1.4944  29,33,  0  IMPACT(TARGET)  WPN NO. 13 FIRER NO. 13 VEHICLES BEFORE  2 AFTER  1 TROOPS BEFORE  8 AFTER  4
```

Fig. 9 - Example of the Chronological History Report

```
1 9931    1 9931

SELMIS

1 301 342 51* -0* -0* -0* -0* -0* -0* -0* -0* -0* -0* -0* -0* -0* -0* -0* -0* -0


     TREATMENT 9931                                          BATTLE HISTORY                                          07/30/74
                                                             REPLICATION  1

SIDE UNIT   TIME   LOCATION      EVENT

BLUE   34    .6953   2,58,  0  INTELLIGENCE ENUN DEAD  0 LOS  0 IN SENRE  0 NKCN  0 PP E 0/A 0 ERRPF E 0/A 0 NS E 0/A 0

                                I2= 000000000000000002  I3= 0000000000000000  I4= 0000000000000000
                               LOS= 3000000000000000   ENUN DEAD= 0000000000000000   SURV= 0377777777777777
BLUE   34    .8652   2,58,  0  INTELLIGENCE ENUN DEAD  0 LOS  0 IN SENRE  0 NKCN  0 PP E 0/A 0 ERRPP P 0/A 0 NS E 0/A 0

                                I2= 5000000000000000  I3= 0000000000000000  I4= 0000000000000000
                               LOS= 0000000000000000   ENUN DEAD= 0000000000000000   SURV= 0377777777777777


BLUE   30   6.2273  15,40,  0  NEW MISSION, ORDER NUMBER=  59    OCTAL   0000073100031120044
BLUE   30   6.2275  15,40,  0  TARGET SELECT   WPN NO. 13 TGT NO. 19 TGT LOC 25,56,   0 REAIM TIME  .1929 AMMO NO. 1

BLUE   34   6.2334   2,58,  7  NEW MISSION, ORDER NUMBER= 187    OCTAL   0000015330000000000
BLUE   34   6.2334   2,58,  0  CHANGE ALTITUDE TO 0  LOS=0010000000000500
BLUE   34   6.2336   2,58,  0  NEW MISSION, ORDER NUMBER=  93    OCTAL   0000013510000620000


BLUE   30   9.5742  15,40,  0  CASUALTY WPN NO. 14   FIRER NO. 20 VEH BEFORE  1 AFTER  0 MEN BEFORE  3 AFTER  0 CUMULATIVE    3

BLUE   34  1..2235   4,47,  0  CASUALTY WPN NO. 16   FIRER NO. 30 VEH BEFORE  1 AFTER  0 MEN BEFORE  3 AFTER  0 CUMULATIVE    6

                               BATTLE TERMINATED, MAXIMUM TIME   20 EXCEEDED

                               COMPUTER TIME THIS REPLICATION  333.858 SECONDS

                               LAST RANDOM NO. THIS REPLICATION  2635686419
```

Fig. 10 - Example of the Selective History

```
BLUE  AVERAGE AMMUNITION EXPENDITURE BY WEAPON TYPE AND TIME INTERVAL

TIME FROM     0.0000  TO    4.9999
            1            5.0
            2            5.3
            6           36.0
            7            9.0
           13             .3
           35            4.0
           36            3.0

TIME FROM     5.0000  TO    9.9999
            1           17.0
            2           13.3
            6           52.0
            7           22.7
           13           25.3
           35           13.0
           36            4.3
           41             .7
           44           17.3
           45           17.3

TIME FROM    10.0000  TO   14.9999
            1           12.0
            2           13.3
            6           76.0
            7           17.3
           13           10.7
           35            3.0
           36            3.0
           41            4.0
           42           13.3
           44           84.7

TIME FROM    15.0000  TO   19.9999
            1           19.0
            2           13.3
            6           44.0
            7           16.0
           13             .3
           36             .7
           41            9.0
           42            8.0
           44           78.0
           45             .7
```

Fig. 11 - Example of the Average Ammunition Expenditure by Weapon Type Report

BLUE VARIANCE OF AMMUNITION EXPENDITURE BY WEAPON TYPE

WEAPON TYPE	AMMO 1	AMMO 2
1	12.0	0.0
2	341.3	0.0
6	48.0	144.0
7	85.3	85.3
13	8.3	109.0
36	4.3	0.0
41	5.3	0.0
42	21.3	0.0
44	2428.0	0.0
45	84.0	0.0

RED VARIANCE OF AMMUNITION EXPENDITURE BY WEAPON TYPE

WEAPON TYPE	AMMO 1	AMMO 2
3	144.0	0.0
4	576.0	48.0
5	0.0	336.0
14	56.3	133.0
16	768.0	0.0
17	.3	0.0
37	4.3	0.0
38	7.0	0.0
46	1484.0	0.0
47	65.3	0.0
49	2997.0	0.0
50	351.0	0.0
52	2001.3	0.0
53	5.3	0.0

Fig. 12 - Example of the Variance of Ammunition Expenditure by Weapon Type Report

MANAGEMENT ASPECTS

The management aspects (level of effort, time, and computer costs) associated with typical investigations using CARMONETTE are shown in Table 3.

CARMONETTE program specifications are shown in Table 4.

Table 3

MANAGEMENT ASPECTS OF CARMONETTE

Task	Technical Effort	Calendar Time	Computer Cost
Terrain Inputs	0 - 2 TMM	0 - 1 month	0 - $1000
Program Revisions	0 - 4 TMM	0 - 4 months	0 - $4000
Scenario and Inputs	1 - 6 TMM	1 - 3 months	$1000-$2000
Production Runs	2 - 6 TMM	1 - 3 months	$10,000-$20,000 (40-200 replications)
Analysis	2 - 6 TMM	1 - 3 months	$1000-$3000
Report Preparation	2 - 6 TMM	1 - 3 months	-
TOTALS	7 - 20 TMM	4 - 17 months	$12,000-$60,000

Table 4

PROGRAM SPECIFICATIONS

		Control Data 6000 series	Univac 1108
Program Language	FORTRAN	Extended	V
First Preprocessor	24 Routines; 13300 Instructions; Storage:	32,000 words	45,000 words
Second Preprocessor	20 Routines; 3500 Instructions; Storage:	20,470 words	28,000 words
Battle Model	60 Routines; 20980 Instructions; Storage:	49,152 words	55,000 words
Post Processor	18 Routines; 3790 Instructions; Storage:	36,200 words	40,000 words
Range Interval	5 Routines; 1170 Instructions; Storage:	62,500 words	50,000 words

Battle Model Running Time: 9 to 15 seconds of Central Processor time per minute of simulated battle time.

Part II

MATHEMATICAL MODELS

INTRODUCTION

The mathematical models used in the CARMONETTE battle model are discussed in this Part. The mathematical models discussed are detection, hit probabilities, and casualty calculations. In addition the random-number generators for uniform and normal pseudorandom number will be described.

DETECTION

The CARMONETTE detection model is based on a simplification of the theory of detection. The simplifications are made because of lack of detailed field experiments on which to base a more realistic model. The theory of detection indicates that the contrast of the target, the atmosphere attenuation, the angular motion, the angle of incidence of impinging light, the experience of the observer, fatigue, camouflage of the target, and a host of other factors are important in the detection phenomenon. The model uses the existence of line of sight, the response state of the observer, whether the target and/or the observer is moving, the target solid angle subtended at the observer, and the sensor type to look up the probability of detection in a table. The probability therefore must take into account all of the non-explicit factors. The provision of six sensor types allows differentiation among some of the implicit factors. Appendix A describes the special sensor detection computations.

Line of Sight

CARMONETTE defines intervisibility as the physical condition of no intervening terrain or vegetation between an observer and a target. Furthermore, intervisibility is symmetrical in that if a particular observer-target pair is intervisible it does not matter which is considered the observer. Intervisibility does not automatically imply target detection. Intervisibility is assumed, without calculation, between observers and targets in adjacent grid squares. No asymmetries due to observer or target location or activity are considered.

For observer-target pairs whose line of sight is either at 45° or parallel to one of the axes of the terrain grid, the calculation is straightforward. The observing unit's sensor height added to the elevation of its grid square and the target unit's height added to the elevation of the target's grid are used to compute the slope of the line of sight. The slope between the observer's grid and each grid between the observer and target is then compared with the line-of-sight slope. If any intervening slope is greater than the line-of-sight slope, intervisibility does not exist.

A more complex algorithm is needed for the case when the difference in the X coordinates is not equal to the difference in the Y coordinates. For this situation a "staircase" is considered such that grids used in computing the slope between the observer's grid and each grid between the observer and target does not depend on which of the two units is considered the observer. It can be shown that unless this procedure is used, intervisibility computed from one may be different from that computed from the other.

Solid Angle

The solid angle subtended at the observer is defined as the exposed area of the target divided by the square of the range to the target. Setting up the table of detection probabilities as a function of solid angle reduces two of the parameters of the detection phenomenon to one. Sixteen levels of the probability of detecting a non-firing enemy and six levels of the probability of detecting a firing enemy are input as a function of solid angle.

Information Changes, Non-firing Target

The target information model is a Markov chain process. A Markov chain process is defined by specifying the set of states the process can be in and the transition probabilities between states. The process can be in only one state at any one time, and the probability of movement from one state to another depends only on the current state and not on any previous states. CARMONETTE defines four states of information about a target: State 1 indicates that no information is known, State 2 indicates that the location of the enemy is known to the nearest grid square, State 3 indicates that the enemy is erroneously pinpointed, and State 4 indicates that the enemy is accurately pinpointed. States 1 and 4 are self-explanatory. Units possessing at least nearest square information on a target will pass nearest square information to their superior headquarters and may call for indirect fire. The erroneously pinpointed state is an intermediate level of information between merely nearest grid square and accurately pinpointed. A unit that fires on the basis of erroneously pinpointed information has no chance of hitting the target, however.

The transition probabilities between any current state and any subsequent state when line of sight exists between an observer and a target are given in Table 5.

Table 5

TARGET INFORMATION TRANSITION MATRIX;
LINE OF SIGHT EXISTS

Current state	Subsequent state[a]			
	1	2	3	4
1	P(11)	P(12)	P(13)	P(14)
2	P(21)	P(22)	P(23)	P(24)
3	P(31)	P(32)	P(33)	P(34)
4	P(41)	P(42)	P(43)	P(44)

[a]Where P(ij) is the probability of being in a subsequent state j having just been in a state i.

Only six probabilities are required as input. The others are derived algebraically. The user must supply:

- The probability of not gaining any information (P11)
- The probability of gaining nearest-square information and no more (P12)
- The probability of gaining nearest-square information and accurately pinpointing (P14)
- The probability of retaining accurate pinpoint (P44)
- The probability of complete loss of an accurately pinpointed target (P41)
- The probability nearest-square information is lost (P21)

The transition probabilities when line of sight does not exist are given in Table 6.

Table 6

TARGET INFORMATION TRANSITION MATRIX;
NO LINE OF SIGHT

Current state	Subsequent state[a]			
	1	2	3	4
1	1	0	0	0
2	$\overline{P(LOS)}$	$1-\overline{P(LOS)}$	0	0
3	0	1	0	0
4	0	0	1	0

[a]Where $\overline{P(LOS)}$ is the probability that nearest-square information about a target will be lost, given that line of sight does not exist.

Target Information Changes Due to Firing

When line of sight exists to a unit that is firing, an observing unit may receive information concerning the firer according to the probabilities given in Table 7.

Table 7

FIRING TRANSITION MATRIX;
LINE OF SIGHT EXISTS

Current state	Subsequent state			
	1	2	3	4
1	F(11)		F(13)	
2		F(22)	F(23)	
3			F(33)	F(34)
4				F(44)

Only the values of F(13) or F(23), which are equal, and F(34) are input; the rest are derived algebraically.

HIT PROBABILITY

The hit probability of direct fire weapons as a function of range is calculated using the equation

$$P(R) = 1-e^{-\left\{\frac{r^2}{2[s(R)]^2}\right\}}$$

Where s(R) is the total tactical dispersion of the weapon at the range R, and r is the equivalent radius of the target area. For the calculation of the probability of hit of killable elements of multiple element targets the target area is the area of one killable element of the unit.

Values of the total tactical dispersion are stored for each of 12 conditions of volley history, firer activity, and target activity and the two ammunition types permitted each weapon as three coordinates of a parabolic curve. The three values are taken to be at zero range, 0.707 maximum range, and maximum range of the weapon. A parabolic approximation is used to determine the value of total tactical dispersion at any range between the minimum and the maximum. Even though the minimum range of a weapon is greater than zero, the value of total tactical dispersion must be extrapolated back to zero range. Negative values are not allowed.

The maximum range should be the greatest range at which it is desired that the weapon be used in the simulation and not necessarily the actual maximum range of the projectile. The total tactical dispersion for a particular range is given by the approximation

$$s(R) = a+[(b-a)/0.5M]R^2 +[(c-2b)/0.5M](R^2/M)(R -0.5M)$$

where
- a = the dispersion at zero range
- b = the dispersion at 0.707 maximum range
- c = the dispersion at maximum range
- M = the square of the maximum range the weapon employs in the simulation
- R = the range to the target

The number of hits scored is found by

$$H = \sum_{i=1}^{z} h(i)$$

where

$$h(i) = \begin{cases} 1 \text{ if } P(R) \geq X(i) \\ 0 \text{ if } P(R) < X(i) \end{cases} \quad i = 1,2,\ldots, z$$

and X(i) is a uniform random number generated for each of the shots at the target, and z is the number of rounds given by

$$z = \min(A,NF)$$

where A is the remaining ammunition, N is the number of rounds per trigger pull, and F is the number of weapons fired. The number of weapons fired is found by

$$F = \min(W,C)$$

where W is the number of weapons assigned and C is the number of crews available to fire the weapons. The number of crews available is found by

$$C = [M(j)/C(j)]$$

where the brackets indicate that only the integer part of the right-hand side is to be used, M(j) is the number of men that are available to fire weapon j and C(j) is the crew size required by weapon j. The number of men available to fire weapon j is given by

$$M(j) = Y - \sum_{\substack{i=1 \\ i \neq j}}^{4} M(i)$$

where M(i) is the number of men currently engaged in firing weapon i and Y is the total number of men assigned to the unit.

CASUALTY CALCULATION

The number of kills may be equal to or less than the number of hits. The casualty calculations employed are different for vehicles and infantry. No more than one vehicle can be destroyed in any single firing (one unit firing one weapon type at one target unit) regardless of the number of hits. The survival of any mounted troops is assessed by a separate probability. Multiple kills on exposed infantry caused by fragmenting ammunition are assessed by a third probability. Lastly, the number of kills on infantry by small arms provides for multiple fatal hits on the same man.

Vehicle Casualties

Precluding the destruction of more than one vehicle when several hits are scored eliminates the perfect distribution of fire and intercommunication among the elements of a firing unit that the alternative implies. The number of vehicles killed is given by

$$K = \begin{cases} 1 \text{ if } P(K/H) \geq X(j) \text{ for all } j \leq H \\ 0 \text{ if } P(K/H) < X(j) \end{cases}$$

where P(K/H) is the probability of kill given a hit for the weapon and ammunition against the target, and H and X(j) are as previously defined.

Casualties to Mounted Troops

If a vehicle is destroyed, the number of casualties to the mounted troops is assessed to determine if there are any survivors. The number of survivors that will dismount from a troop carrier that has been killed is given by

$$S = \sum_{i=1}^{T} s(i)$$

where

$$s(i) = \begin{cases} 1 \text{ if } P(S/K) \geq X(i) \\ 0 \text{ if } P(S/K) < X(i) \end{cases} \quad i = 1,2, \ldots,T$$

and P(S/K) is the probability of survival if a troop carrier is killed, T is the number of troops in the carrier, and X(i) is as previously defined.

Casualties to Exposed Infantry Due to Fragmenting Ammunition

All exposed infantry units in the impact area of indirect-fire weapons are considered for purposes of calculating casualties. The impact area of indirect-fire weapons is at most three times the grid interval in length and width. This restriction permits the calculation to be simplified and is not considered to be a serious restraint. With the above restriction, nine squares at most may contain units to be considered. The number of men killed by a volley is found by

$$K = \sum_{i}^{I} \sum_{j}^{J} k(i,j)$$

where k(i,j) is the number of men killed in unit i and square j, J is either 1, 3, or 9, depending on the actual size of the impact area for a volley from the particular weapon, and I is the number of units in the area. Figure 13 shows how the grid squares are located around the center of impact (CI).

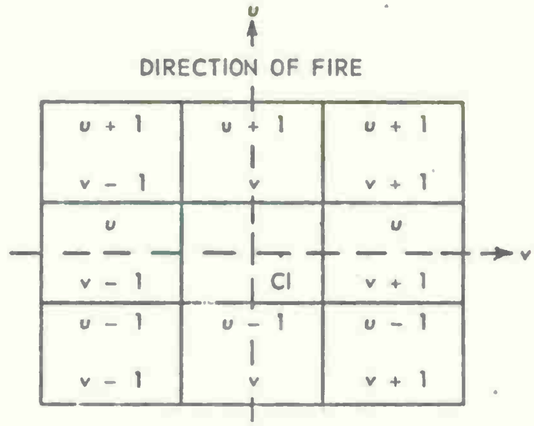

Fig. 13—Arrangement of Grid Squares around CI at v, u

The orientation of the v, u, axes of the impact area with the x, y axes of the battlefield is required to determine the grid squares to be considered. If the impact area is a square, the orientation is assumed inmaterial and the u axis is taken as parallel to the x axis. Rectangular impact areas are either 1 by 3 or 3 by 1 grids, where the first dimension is taken as the width (i.e., in the v direction) and the u axis may be parallel, perpendicular, 45 deg, or 135 deg to the positive x axis. The grids that are considered, in addition to the CI at x, y, are given in Table 8.

Table 8

GRID SQUARES CONSIDERED IN ASSESSING INDIRECT-FIRE CASUALTIES
(In addition to x, y)

Direction of fire, relative to + x axis	Width × length, grids			
	1 × 3		3 × 1	
Parallel	x+1, y	x-1, y	x, y+1	x, y-1
Perpendicular	x, y+1	x, y-1	x+1, y	x-1, y
45 deg (225 deg)	x+1, y+1	x-1, y-1	x-1, y+1	x+1, y-1
135 deg (315 deg)	x-1, y+1	x+1, y-1	x-1, y-1	x+1, y+1

The number of casualties in each unit in each square is found by

$$k(i,j) = \sum_{m=1}^{M} d(m)$$

where M is the current number of men in unit i in square j, and d(m) is found by

$$d(m) = \begin{cases} 1 \text{ if } P(K/H_{inf}) \geq X(m) \\ 0 \text{ if } P(K/H_{inf}) < X(m) \end{cases} \quad m = 1,2, \ldots,M$$

where $P(K/H_{inf})$ is the probability of kill of each man in an infantry unit if the square it occupies is hit by fragmenting rounds, and X(m) is as previously defined.

For calculating infantry casualties due to direct-fire fragmenting rounds, only the grid square of impact is considered, and only the target unit is assessed casualties even though other infantry units may be in the same square. Thus the number of casualties due to direct-fire fragmenting rounds is found by

$$K = \sum_{m=1}^{M*} \sum_{h=1}^{H} d(m,h)$$

where

$$d(m,h) = \begin{cases} 1 \text{ if } P(K/H_{inf}) \geq X(m,h) \\ 0 \text{ if } P(K/H_{inf}) < X(m,h) \end{cases}$$

and

$$M* = \sum_{i=1}^{M} \sum_{j=1}^{h-1} d(i,j) \quad 1 < h \leq H$$

where M is the total men alive in the unit at the beginning of the assessment, M* is the number of men alive after assessment of each hit on the unit, and the other factors are as previously defined.

Non-fragmenting Ammunition Casualties to Infantry

When a burst from a machine gun or a volley from a rifle squad is fired at an infantry unit, more than one projectile may hit the same man. If all these hits on the same man are killing, the number of casualties must not be greater than one. The number of men killed by direct-fire non-fragmenting rounds is found by

$$K = \sum_{m=1}^{M} d(m)$$

where

$$d(m) = \begin{cases} 1 & \text{for all } m = [X(j+1)M/64)] + 1 \\ 0 & \text{otherwise} \end{cases}$$

As before, the brackets indicate the integer part of the calculation, and the constant 64 is one greater than the largest uniform random number that can be generated. The calculation of m is only done for $d(j) = 1$; thus the $(j+1)^{th}$ random number is used to determine which individual is declared a casualty. The determination of a killing hit $d(j)$ is given by

$$d(j) = \begin{cases} 1 \text{ if } P(K/H) \quad X(j) \\ 0 \text{ if } P(K/H) \quad X(j) \end{cases} \qquad j = 1, 2, \ldots, H$$

Vehicle Kills by Artillery

The introduction of dual purpose/improved conventional munitions (DP/ICM) provides the artillery a means of destroying armored vehicles. The CARMONETTE Artillery Routine simulates this capability in a manner very similar to the treatment of infantry kills by fragmenting ammunition.

UNIFORM RANDOM NUMBER GENERATOR

The uniform pseudorandom-number generator used in CARMONETTE is due to Rotenberg.[1] The value of the next random number is found by multiplying

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[1]A. Rotenberg, A New Pseudo-Random Number Generator, J. Assoc. Comp. Mach., 7:75-77(1960).

the current random number by a fixed value and adding a constant. The formula is

$$X(i+1) = (2^a+1)X(i)+C \pmod{2^{35}}$$

where

$$C = (0.5+\sqrt{3}/6)2^{35} \text{ and } a = 7.$$

The method is called the "congruential additive method;" since it does not require multiplication or division, it is faster than methods that do. The indicated multiplication is accomplished by shifting X(i) to the left "a" bits and then adding X(i). The constant C is added and the result stored until the next random number is needed. The method generates a full period of 2^{35} numbers for $a \geq 2$ and C odd. The article by Rotenberg and a companion article by Conveyou[2] indicate that taking "a" large or $C = (0.5 \pm \sqrt{3}/6)\,2^{35}$ reduces the serial correlation coefficient. Based on this advice the values shown above were chosen. Only the high-order six bits of each random number are used becasue the probabilities are packed in only six bits.

NORMAL RANDOM-NUMBER GENERATOR

Standardized normal psuedo-random numbers are generated using the sum of four uniformly distributed random numbers. The formula is:

$$Z = \left|(S-4m)\right|(s\cdot k)$$

where S is the sum of four independent uniform random numbers, m is the population mean of the numbers, s is the population standard deviation of the numbers, and the constant, k, is due to the sum being composed of four numbers.

The uniform psuedo-random numbers are generated using the method previously described. The set of numbers 0 to 63 are equally likely with probability 1/64. The mean of the population is 31.5 and the standard deviation is 18.62. The standardized normal psuedo-random numbers

[2]R. R. Coveyou, Serial Correlation in the Generation of Pseudo-Random Numbers, J. Assoc. Comp. Mach., 7:72-74 (1960).

have mean 0.001 and standard deviation $\pm$ 0.996 and range from -3.4 to +3.4. The mean and standard deviations compare well with the standardized normal distribution function having mean zero and standard deviation $\pm$ 1. The probability that a value beyond either the upper or lower value of the range is 0.0003; thus truncation at $\pm$ 3.4 is justified.

Appendix A

SPECIAL SENSOR DETECTION COMPUTATIONS

VISUAL DETECTION ROUTINE

The unaided eye and binoculars under low-light level conditions are identified as sensor class 1 type 1 and class 1 type 2 respectively.

The input variables for the Visual Detection Routine are listed in Table A1. Table A2 shows the numerical values included in the program as constants. Table A3 shows the program calculations in the preprocessor and battle model programs. The relative sensitivity of the eye, which is included as a data table is shown in Table A4.

Figure A1 is a flow chart of the preprocessor calculations, Fig. A2 is a flow chart of the battle model calculations. Figure A3 shows Blackwell's Curves, which are included as a data table.

IMAGE INTENSIFIER ROUTINE

Passive night vision image intensifier sensors are identified in the program as sensor class 2. Three types have been played: starlight scope, crew-served weapon sight, and night observation device. Up to six types can be played.

The input variables for the Image Intensifier Routine are shown in Table A5. The various values included in the program as constants are shown in Table A6. Table A7 shows the various calculations performed in the preprocessor and battle model programs.

In the execution of the computations, those calculations which are based on the input values (night sky brightness and various constants) are performed in the preprocessor program. Figure A4 is a flow chart of these computations. The probability of detection calculations which use the target and background reflectance values are performed in the battle model program. Figure A5 is a flow chart of these computations.

Table A1

VISUAL DETECTION ROUTINE INPUTS

Symbol	Definition	Input form
σ_s	Scattering cross section	Form 40
σ_s	Absorption cross section	Form 40
$R_{B(\lambda)}$	Background reflectance	Form 38
$R_{T(\lambda)}$	Target reflectance	Form 39
MD	Minimum dimension of target (meters)	Form 39

Table A2

VISUAL DETECTION ROUTINE
VALUES INCLUDED IN PROGRAM AS CONSTANTS

Symbol	Definition	Value
$B(\lambda)$	Night sky spectral radiance	
	Moonlight	$B(\lambda) = 10^{(-.237\lambda - 7.87)} \times 10^{-2}$
	Part moon	$B(\lambda) = 10^{(+.480\lambda - 8.76)} \times 10^{-2}$
	Starlight	$B(\lambda) = 10^{(+1.45\lambda - 9.95)} \times 10^{-2}$
β	Angular size of a minimal visual target	Fig. B4
$K(\lambda)$	Relative sensitivity of the eye	Table B8
MAG	Magnification	1.0 unaided eye 7.0 7 × 50 binoculars
C_G	Constant	0.75
α	Constant	0.5 unaided eye 33.0 7 × 50 binoculars
N_1	Constant	1.5 unaided eye 0.01 7 × 50 binoculars

Table A3

VISUAL DETECTION ROUTINE

PROGRAM CALCULATIONS

Symbol	Definition	Computation
	Computed in Preprocessor Program	
M_3	Visual background reflectance	$M_3 = R_B(\lambda)B(\lambda)K(\lambda)d\lambda$
M_4	Visual target reflectance	$M_4 = R_T(\lambda)B(\lambda)K(\lambda)d\lambda$
P_1	Integral of night sky brightness	$P_1 = B(\lambda)K(\lambda)d\lambda$
LL	Light level	$LL = \pi\alpha(685)(9.3 \times 10^4)P_1$
	Computed in Battle Model Program	
R	Observer-target range	(Normal program calculation)
T	Transmittance	$T = e^{-(\sigma_s + \sigma_s)R}$
K_3	Computational variable	$K_3 = 1 - e^{-\sigma_s R}$
C_o	Intrinsic contrast	$C_o = \frac{\lvert M_4 - M_3 \rvert}{M_3}$
C	Perceived contrast	$C = \frac{C_o}{1 + \frac{K_3 \cdot P_1}{C_G \cdot T \cdot M_3}}$
N_f	Computational variable	$N_f = \frac{MD \cdot MAG}{R}(57)(60)\frac{1}{\beta}$
P_D	Probability of detection	$P_D = 1 - e^{(-N_1 \cdot N_f^2)}$

Table A4

RELATIVE SENSITIVITY OF THE EYE

Wave length (microns)	K_λ
0.4	4.37×10^{-3}
0.5	2.69×10^{-1}
0.6	7.47×10^{-1}
0.7	3.55×10^{-3}
0.8	3.89×10^{-6}
0.9	1.70×10^{-8}

This table is included in the program as a data table.

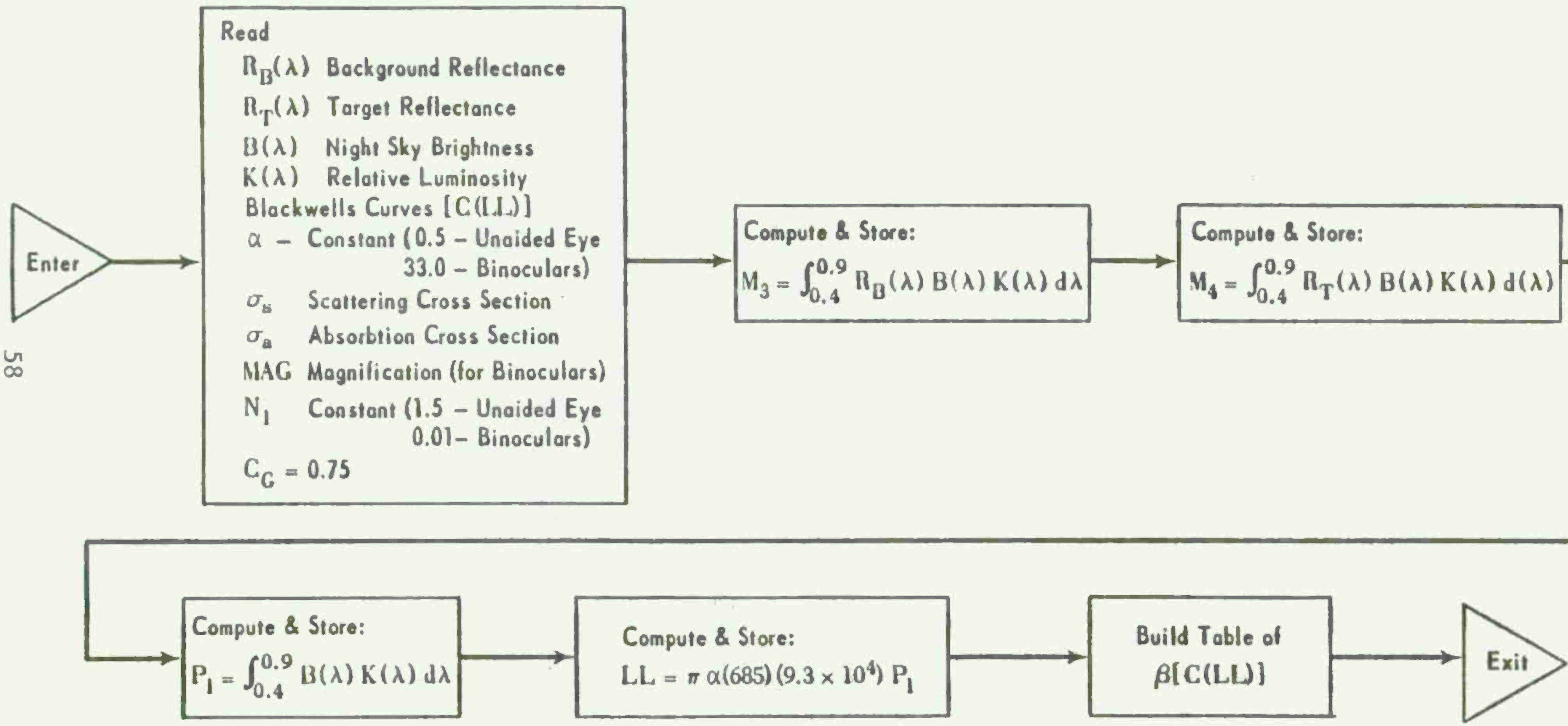

Fig. A1 - Flow Chart — Preprocessor Calculations—Visual Detection Model

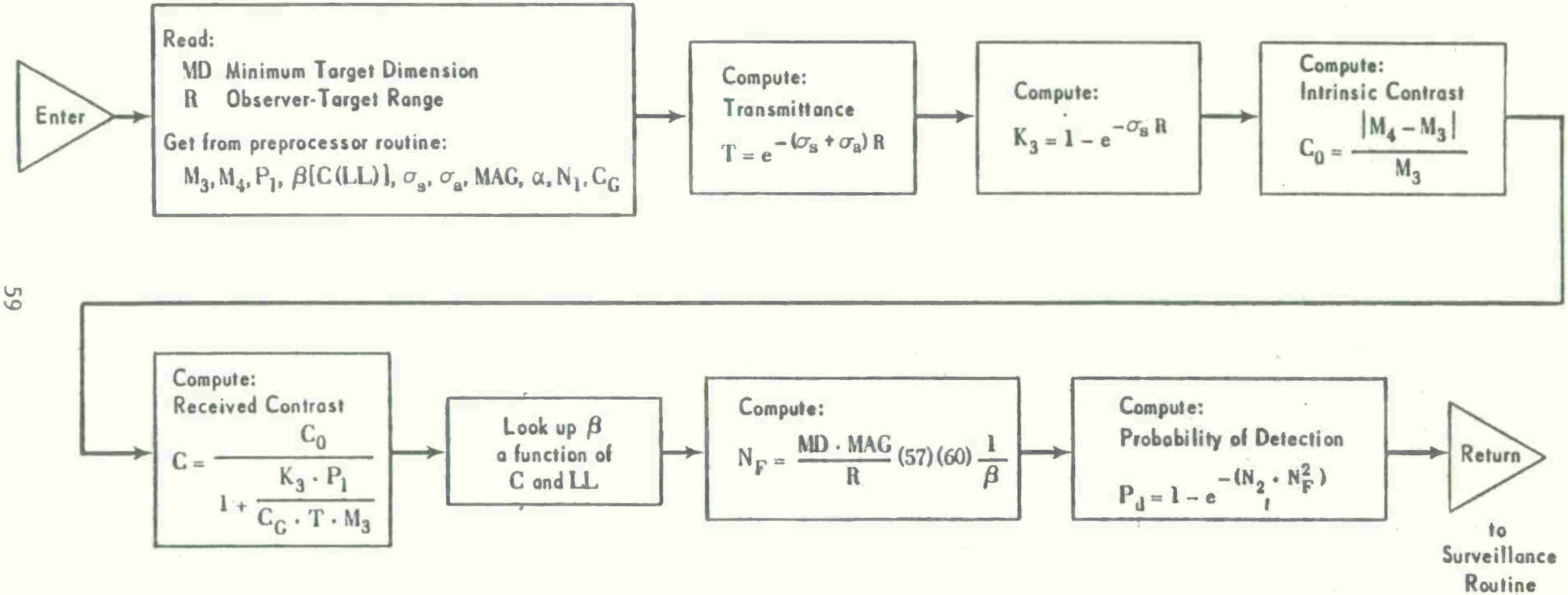

Fig. A2 — Flow Chart — Probability of Detection—Battle Model

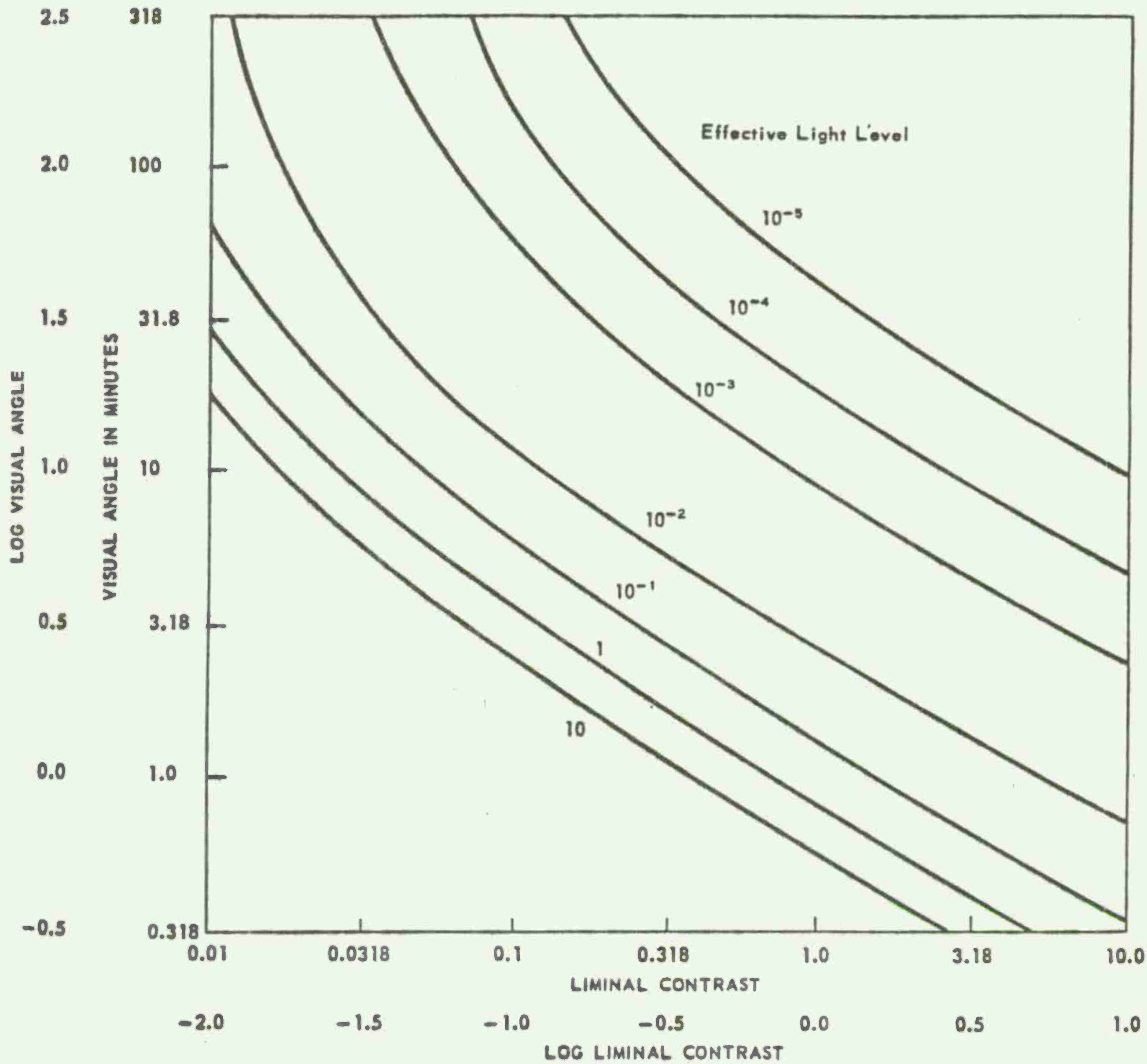

Fig. A3 — Blackwell's Curves

Note: These curves show the angle subtended by a barely detectable target in relation to the target-background contrast and light level, and are included in the program as a data table.

Table A5

IMAGE INTENSIFIER ROUTINE INPUTS

Symbol	Definition	Input form
f	System "f" number	Form 37A
F_o	Objective lens focal length, mm	Form 37A
$T(\gamma)$	Transfer function	Form 37A
$Q(\lambda)$	Photocathode sensitivity	Form 37B
$R_B(\lambda)$	Background reflectance	Form 38
$R_T(\lambda)$	Target reflectance	Form 39
σ_s	Scattering cross section	Form 40
σ_s	Absorption cross section	Form 40

Table A6

IMAGE INTENSIFIER ROUTINE
VALUES INCLUDED IN PROGRAM AS CONSTANTS

Symbol	Definition	Computation
$B(\lambda)$	Night sky spectral radiance	
	Moonlight	$B(\lambda) = 10^{(-.237 \; - 7.87)} \times 10^{-2}$
	Part moon	$B(\lambda) = 10^{(+.480 \; - 8.76)} \times 10^{-2}$
	Starlight	$B(\lambda) = 10^{(+.145 \; - 9.95)} \times 10^{-2}$
C_G	Constant	0.75
N_2	Constant	0.256
t	Time constant, seconds	0.1
τ	Device transmission	0.92
e_c	Electron charge, coulombs	1.6×10^{-19}

Table A7

IMAGE INTENSIFIER ROUTINE
PROGRAM CALCULATIONS

Symbol	Definition	Calculation
	Computed in Preprocessor Program	
MTF	Modulation transfer function	$MTF = T(\gamma)d$
MTC	Modulation transfer constant	$MTC = \frac{1000 \cdot MTF}{F_o}$
σ_r	Resolution length	$\sigma_r = \frac{1}{2\sqrt{2\pi}\ MTF}$
P_2	Computational variable	$P_2 = \frac{1}{e_c} B(\lambda)Q(\lambda)d\lambda$
K_1	Computational variable	$K_1 = \frac{t\tau\pi}{4f^2}$
K_2	Computational variable	$K_2 = 4\pi\sigma_r{}^2$
M_1	Image intensifier background reflectance	$M_1 = \frac{1}{e_c} R_B(\lambda)B(\lambda)Q(\lambda)d\lambda$
M_2	Image intensifier target reflectance	$M_2 = \frac{1}{e_c} R_T(\lambda)B(\lambda)Q(\lambda)d\lambda$
	Computed in Battle Model Program	
R	Observer - target range (m)	Normal program calculation
T	Transmittance	$T = e^{-(\sigma_s + \sigma_a)R}$
K_3	Computational	$K_3 = 1-e^{-\sigma_s R}$
C_o	Intrinsic contrast	$C_o = \frac{\lvert M_1 - M_2 \rvert}{M_1}$

Table A7 cont'd

Symbol	Definition	Calculation
C	Received contrast	$C = \dfrac{C_o}{1 + \dfrac{K_3 \cdot P_2}{C_G \cdot T \cdot M_1}}$
N_B	Computational variable	$N_B = K_1 (M_1 \cdot T \cdot C_G + K_3 \cdot P_2)$
N	Noise strength	$N = \dfrac{N_B^{1/2}}{K_2}$
S	Signal strength	$S = C \cdot N_B$
SN	Signal to noise ratio	$\dfrac{S}{N}$
N_{eff}	Computational variable	
	for $SN < 5.0$	$N_{eff} = SN \dfrac{2}{5} MTF$
	for $SN > 5.0$	$N_{eff} = 2MTF$
N_f	Computational variable	$N_f = 1000 \dfrac{MD}{R} N_{eff}$
P_D	Probability of detection	$P_D = 1-e^{-(N_2 \cdot N_f{}^2)}$

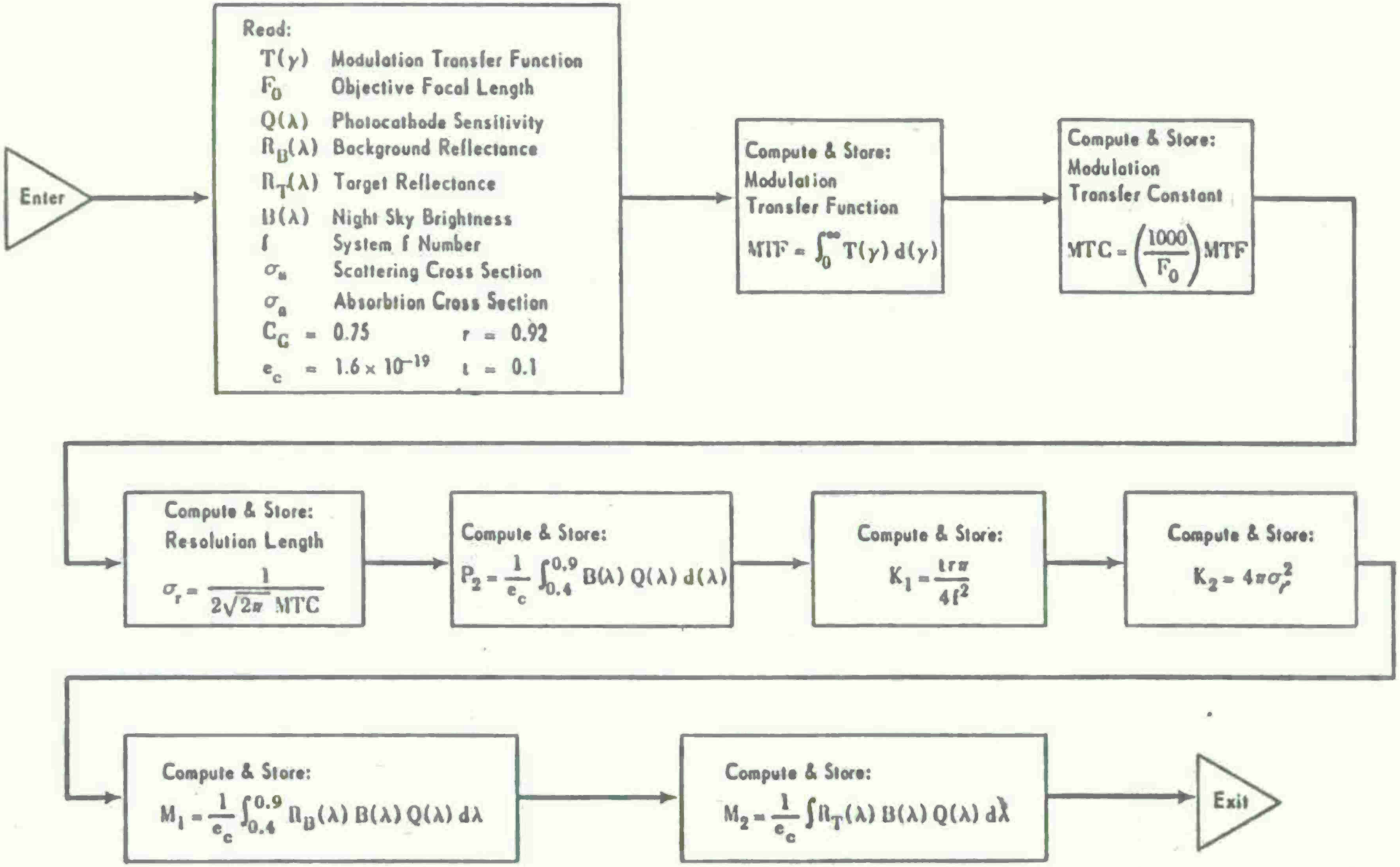

Fig. A4 - Flow Chart— Preprocessor Computations— Image Intensifier Detection Model

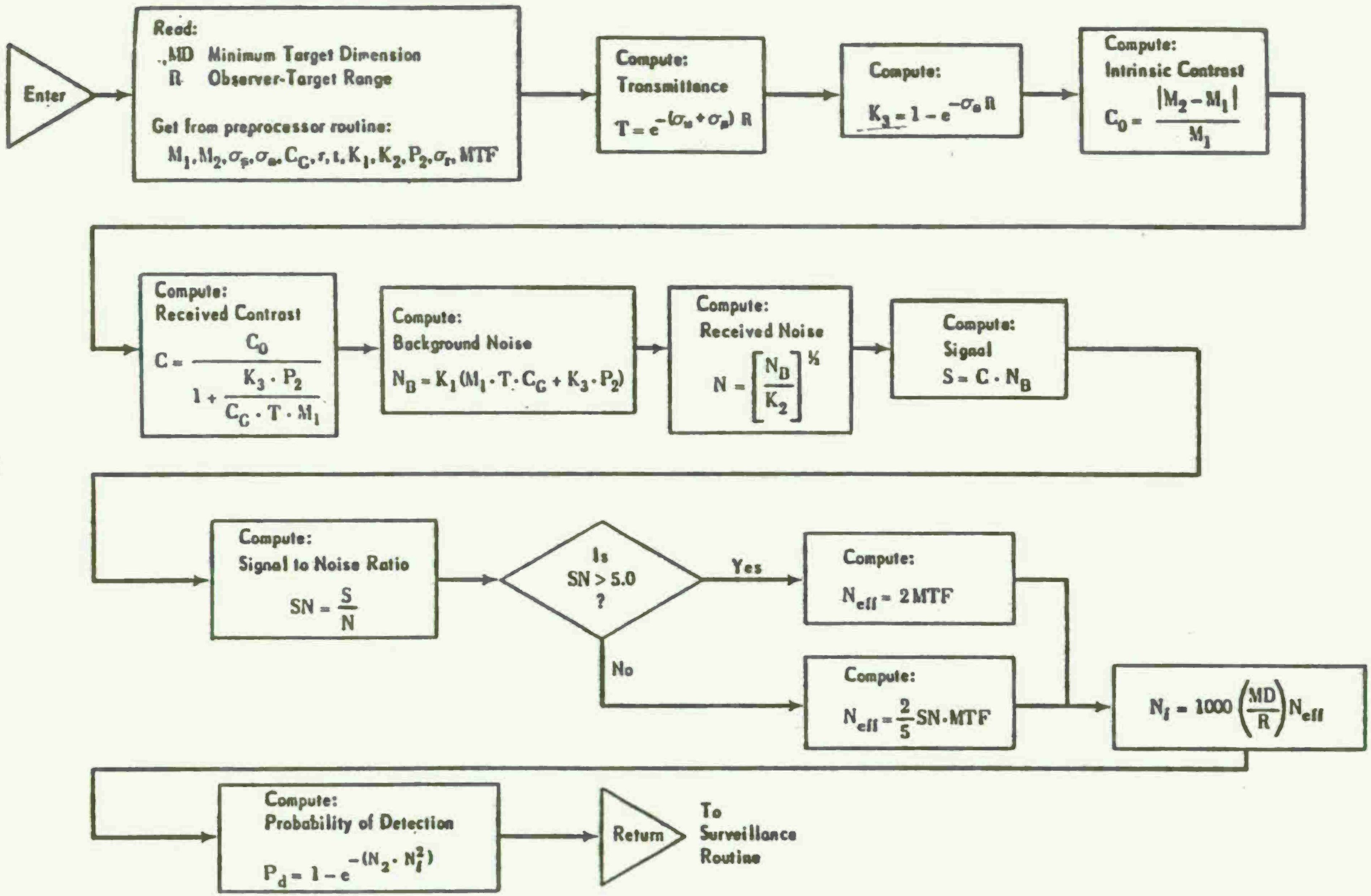

Fig. A5 - Flow Chart—Probability of Detection—Image Intensifier

RADAR DETECTION ROUTINE

Radars are identified in the program as sensor class 4. Two types of radars have been played, the PPS4 and the PPS5. Up to six types can be played. The radar routine as now written does not consider a threshold target speed or the direction of movement but only whether or not the target is classed as moving.

The input variables and computation technique are shown in Table A8.

Table A8

RADAR MODEL CALCULATIONS

Symbol	Definition	Typical values or computation
DGF	Radar degradation factor	1.23
R_{max}	Maximum effective range	
	PPS 5	Pers 3500 m Veh 10000 m
	PPS 4	Pers 1700 m Veh 2500 m
R	Observer-target range (m)	(Normal calculation)
RR_{adj}	Adjusted range ratio	$RR_{adj} = \frac{R}{DGF \cdot R_{max}}$
P_D	Probability of detection	
	if $RR_{adj} < 0.8$	$P_D = 0.9 - \frac{RR_{adj}}{8}$
	if $0.8 \leq RR_{adj} < 1.0$	$P_D = 2.0 - 1.5 \cdot RR_{adj}$

Appendix B

BACKGROUND OF CARMONETTE

CARMONETTE can trace its lineage to the simulations conducted at the Los Alamos Scientific Laboratory (LASL) during WWII. These simulations were used to study the scattering and absorption of neutrons during the fundamental research that led to the making of the first atomic bomb. After WWII, many military operations research scientists were convinced that a method of simulating ground combat as an experimental methodology was an essential missing tool for the study of future military operations.

The first work on the concept that has become CARMONETTE was begun at the Johns Hopkins University Operations Research Office (ORO) in late 1952.[1] [2] [3] Dr. George Gamow, a physicist who at that time was on the ORO staff, put together a hand-played chess-like version of small-unit battle.

The first full scale computerized simulation of ground combat was prepared under the direction of Richard Zimmerman. This was a successful test of the feasibility of a computerized combat simulation and was published in several places.*

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*Most noteworthy was its publication as Chap 21 of Vol II of Operations Research for Management.[4] This paper won Zimmerman the Lanchester Prize as the best paper on operations research published in 1956.

[1]R. E. Zimmerman, Monte Carlo Computer War Gaming, ORO-T-325, Operations Research Office (now GRC), March 1956.

[2]_____, CARMONETTE: A Concept of Tactical War Gaming, ORO-SP-33, Operations Research Office (now GRC), November 1957.

[3]Hebron E. Adams, et al, CARMONETTE: A Computer-Played Combat Simulation, ORO-T-389, Operations Research Office (now GRC), February 1961.

[4]R. E. Zimmerman, A Monte Carlo Model for Military Analysis, in McCloskey and Coppinger (eds) Operations Research for Management, Vol II, the Johns Hopkins Press, Baltimore, 1956.

By 1959 the computer programs for the first version of CARMONETTE had been written for the UNIVAC 1103A and had been debugged. A few situations were run, using as their starting point the final locations of participants in a Combat Developments Experimentation Command (CDEC) experiment. In the CDEC experiment the final assault phase was not carried through. CARMONETTE was used in order to simulate this intense firefight phase. Reprogramming of CARMONETTE to take advantage of the speed and flexibility of the IBM 7040 computer took approximately 50 man months of effort during 1964 and early 1965.

The CARMONETTE simulation was then compared with the hand-played war game of the British Royal Armament Research and Development Establishment (RARDE) and the computerized armored fighting vehicle (AFV) model of the Canadian Directorate of Land Operational Research (DLOR). This comparison was part of the Quadripartite Ad Hoc Working Group on War Gaming (AHWG/WG). (Australia is the fourth member of this working group but did not have a candidate battle model to include in the comparisons.)

Throughout the development, CARMONETTE has undergone a continuous process of modification which has resulted in identifiable stages. CARMONETTE III was developed during the small-arms weapons system (SAWS) program of the US Army Combat Developments Command (CDC) in the mid-1960s. The model was converted for use on the Control Data Corporation 6400 computer in 1968 and 1969. The previous Target Acquisition Routine was separated into a Surveillance Routine and a Target Acquisition Routine, and a Communication Routine was developed for CARMONETTE IV.[5] This version was used in 1969 to assist the US Army Electronics Command in assessing the effectiveness of small units equipped with night vision devices. CARMONETTE V resulted from model expansion and revision to support three

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[5]USAECOM, The Use of CARMONETTE IV in Assessing the Effectiveness of Small Units Equipped with Night Vision Devices, Draft, November 1969, AD 514519L.

studies in 1970 and 1971: NATO Combat Capabilities I,[6] Equal Cost Firepower I and II,[7] [8] and Land Combat Systems I.[9] Changes made included: expansion of playing area from 36 by 63 grids to 60 by 63 grids, increasing the number of weapon units on each side from 36 to 48, introduction of a Remount Routine and an Attack Helicopter Routine, and modification of the Artillery Routine to permit assessment of vehicle kills by DP/ICM rounds. CARMONETTE VI was developed in 1972-1973 for use in the Family of Observation, Scout and Attack Helicopters (SCAT II)[10] and NATO Combat Capabilities II Studies.[11]

The present version of CARMONETTE has improved the Artillery Routine of previous versions and has added an option that permits the gamer to limit the area of search of sensors under certain conditions.

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[6]Norman Farrell, et al, NATO Combat Capabilities Study, RAC-CR-56, Research Analysis Corporation, June 1972.

[7]Equal Cost Firepower Study (ECF-I), Draft Client Report, September 1971.

[8]R. E. Zimmerman, et al, Equal Cost Firepower Study II (ECF II), RAC R-145, Research Analysis Corporation, September 1972.

[9]L. J. Dondero, et al, Land Combat Systems Study (LCS-I), RAC-CR-53, Research Analysis Corporation, May 1972.

[10]James B. Campbell, et al, Family of Observation, Scout, and Attack Helicopters (SCAT II), Phase II, General Research Corporation, CR-27, December 1973.

[11]Gary W. Bolling, et al, NATO Combat Capabilities Analysis II (COMCAP II), OAD CR-8, General Research Corporation, August 1973.

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6. Norman Farrell, et al, "NATO Combat Capabilities Study," RAC-CR-56, Research Analysis Corporation, June 1972.

7. "Equal Cost Firepower Study (ECF-I)," Draft Client Report, September 1971.

8. Richard E. Zimmerman, et al, "Equal Cost Firepower Study II (ECF II)," RAC R-145, Research Analysis Corporation, September 1972.

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12. A. Rotenberg, "A New Pseudo-Random Number Generator," J. Assoc. Comp. Mach., 7:75-77(1960).

13. R. R. Coveyou, "Serial Correlation in the Generation of Pseudo-Random Numbers," J. Assoc. Comp. Mach., 7:72-74(1960).