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Development of Distributed Interactive Stochastic Combat Simulation (DISCSIM) Model

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Abstract

A number of combat simulation models are scattered and the analytic solution approaches have experienced very difficult computational efforts. Today's computer communication technology let people to do many unrealistic things possible and the use of those technologies is becoming increasingly prevalent throughout the military operation. Both DIS and ADS are welled defined computer aided military simulations.

This study discusses a simulation of stochastic combat network modeling through Internet space. We have developed two separate simulation models, one for clients and another for server, and validated for conducting studies with these models. The object-oriented design was necessary to define the system entities and their relationship, to partition functionality into system entities, and to transform functional metrics into realizations derived from system component behaviors. Heterogeneous forces for each side are assumed at any battle node.

The time trajectories for mean number of survivors and combat history at each node, some important combat measures, and relative difference computations between models were made. We observe and may conclude that the differences exit and some of these are significant based on a limited number of experiments.

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1. Introduction

There are well known theories, comments, conclusions, and recommendations over many years to examine the nature of combat. We have stated that most of the existing combat models are not based on any firmly established theory.[1,2,11] The most widely used in the analysis of combat is the Lanchester model or its stochastic equivalent. We call them as deterministic or exponential model, respectively. These models are tested, reviewed, and evaluated in many applications by researchers and practicians, and finally, they have come up with some cautions of using these models.[2,7,8,9] Ancker and Gafarian including some other authors have worked on this problem for decades, and people believe that a combat is an extremely complicated phenomena and it has a number of uncertain elements during the realization of the process. They also realized that the elements of combat are largely quantitative in nature even though sometimes word models could be thought of as a very general model. On the other hand, a mathematical model has been treated as an abstraction of a real-world situation, that can emulate the nature closely enough to be used for predictive purposes. Simulation is another technique for developing a model that contains unpredictable events and elements in the course of a combat situation.

A number of combat simulation models are scattered since the high speed digital computers are available. The analytic approaches for solving a combat, either exactly or approximately, have experienced very difficult computational efforts. Beginning from one-on-one stochastic duel by Ancker [1], only a few analytical solutions up to three-on-two combats are available, where the numerical methods are applied in implementing the model's fidelity. A preliminary study on many-on-many stochastic combat situation using simulation was done by Gafarian, et al.[9] Comparisons for eight combat measures including winning probability, survivors, duration, etc., are made with that of previously suggested models such as deterministic or exponential model, and the results showed that the evidence of differences exists between models.

We have noticed that there still exists unreasonable assumptions in the theory of

Lanchester square law.[11] One of the assumptions states that all opponents are visible and in range. This may not be the case that we usually face with in real situation. The principal factors of this argument are terrain, weather, and tactics. Terrain features of importance includes rivers, mountains, deserts, forests, roads, and highways, gulches, cliffs, ground cover, brush, urban area, etc. Important weather features include rain, snow, sleet, cold, heat, humidity, light, wind conditions, etc. The human being needs special attention. The human decisions largely set the initial conditions and boundary conditions for the initial and succeeding firefights and finally determine the end of combat. Taking these facts into consideration a simulation study which contains three fire allocation strategies such as random selection, evenly distributed power, and concentrated power, was done in an appropriate manner.[14] The outputs from the experiments were varying significantly between strategies employed.

We have read and heard two very important proposed axioms in the theory of combat. Even though these are not generally accepted as laws we shall call them as axioms. First axiom is that any combat is a hierarchical network of firefights. And second axiom states that a firefight is a terminating stochastic target attrition process on discrete state space with a continuous time parameter.[2] The idea of representing combat as a set of separable mini battles was put forward by Roland[17] in connection with the analysis of trials data on the armor/anti-armor battle. The main purpose of the study was to investigate to see if the combat can be represented as a series of small engagements or nodes, distributed along a time axis, each node perhaps being linked to others in the network, with links representing flows of forces between nodes. The formation of networks at the lower levels of aggregation depends primarily on environmental and weapons system factors, tactical decisions of commanders, and firefight outcomes. These influence the each small battle conditions, variables, and parameters during the course of a combat. Changes in them can terminate firefights, reorganize if needed, and start new ones.

A short and preliminary study on the problem of combat networking was conducted analytically, where 2-on-2 combat is decomposed into two separate 1-on-1 battles and firefights are begun at different times randomly chosen.[12] That means there exists some random amount of time delay after either one of the two nodes starts the conflict at time zero. Search or joining time to another battlefield after ending a battle is also taken account into this model. From the earlier experiences, we have found that the mathematical formulation of the state probabilities are extremely tedious work and numerically generated solutions are too much time consuming. This is even worse in the case of a large size battle. A simulation may be the alternative to overcome these deficiencies, and therefore many combat experts are willing to employ the simulation techniques as a means for their researches.

Current status on the development of computing facilities are spectacular and the changes are made momentarily. Such a new circumstance leads us to intercommunicate each other through computer network. One at a desk in the office can link with another at next door by LAN system. Now it is further extended and the examples include like city to city, state to state, at last country to country. World wide web(WWW) let people to do many unrealistic things possible electronically with a simple operation. E-mail, voice mail, video mail, and video conferencing are the most popular services in WWW space. Wireless telecommunication technologies enable us to extend the computer network applications in private or public domain. Specially, the use of those advanced technologies is becoming increasingly prevalent throughout the military operations modeling and simulation community. Actually, not many people recognize the fact that the computer network technology was initiated in military society in early 1960s.

Today both distributed interactive simulation(DIS) and advanced distributed simulation(ADS) are well defined computer aided methodologies for the analysis of military operations. DIS is a system of interconnected, time-coherent simulations which uses the specific IEEE 1278 protocol to create a distributed, interactive environment. ADS is the technology area that provides a time-coherent, interactive, synthetic environment through geographically distributed and potentially dissimilar simulation. To fall into the class of ADS, a simulation has to interact with other simulations. Although many technologies will benefit simulation in various ways, the five major technologies which are likely to have the greatest impact on ADS are : increased computational power, high speed wide area networks, distributed exercise management, mobile communications, and software improvement.[6,15]

This article discusses a way of modeling a combat as network of some small battles that are interconnected through Internet. The stochasticity of firefights, of course, is still valid in each small battle environment. We will call this small battlefield as a battle node.

2. Distributed Interactive Stochastic Combat Simulation (DISCSIM)

We have developed two separate simulation models, one for clients(nodes) and another for server. And then they are linked together to perform an experiment via internet.

The object-oriented design is introduced to the model to define the system entities and their relationship, to partition functionality into system entities, and to transform functional metrics into realizations derived from system component behaviors. Heterogeneous forces for each side are assumed at any node.

Suppose we consider an engagement with a_0 combatants on side A and b_0 for side B. This engagement is thought to be decomposed into n different nodes. Each node contains its own battle size for both sides. Let us assume that there are a_k and b_k combatants on both side in the k^{th} node.($k = 1, 2, \cdots$) n This tells us that $a_0 = \sum_{k=1}^{n} a_k$ and $b_0 = \sum_{k=1}^{n} b_k$. We allow here that the Lanchester square law assumptions are made within each node unless any specific predetermined rule is applied.

Input and Output Parameters

a_k , b_k : number of initial combatants on each node for both sides. ($k = 1, 2, \cdots, n$)

p_A , p_B : single shot kill probability on each side.

X_A, X_B : interfiring time random variable on each side

μ_A, μ_B : mean interfiring time for each side.

D_k : delay time random variable for k^{th} node. ($k = 1, 2, \cdots, n$)

S : search or joining time random variable for next available node.

$P[A], P[B]$: winning probability for each side.

$E[T_D]$: expected battle termination time.

$E[T_k]$: expected battle node termination time on k^{th} node.

$E[A_k(t)]$: time trace of estimate for mean number of survivors on k^{th} node at time t for side A.

$E[B_k(t)]$: time trace of estimate for mean number of survivors on k^{th} node at time t for side B.

$S[A_k(t)]$: time trace standard deviation estimate for survivors at time t on side A.

$S[B_k(t)]$: time trace standard deviation estimate for survivors at time t on side B.

$E[A]$: mean number of survivors at the end of the battle on side A.

$E[B]$: mean number of survivors at the end of the battle on side B.

Figure 1 shows coarse flow chat for the DISCSIM model. First of all, at each node we select the battle with initial forces, parameters, and set which marksmen are alive and their potential targets. The starting times for all distributed combat are reported to server. An appropriate interfiring time is drawn for each surviving combatant at every node. On each node, the marksman with the minimum interfiring time is determined, and then the minimum time for each node is compared at server. The node possessing the minimum time draws a uniform random number to determine if the shot results in a kill. This is done by comparing the number drawn to the shooting side's probability of kill. If a kill occurs the combatant just killed is removed from consideration and simulation time is advanced by the interfiring time of the successful marksman. The information generated so far is monitored and stored at server machine and the operator of the server can use them for upcoming decision making, for examples, stop the battle and join to other node or continue the engagement until next order is made, etc.

Every time a kill is made at any node, the simulation then determines that if one of the sides is at the end of a combat, that is, a breakpoint, and if so it next checks where the winning survivors should go and join with. This can be done by looking up the scenario that has been set at the beginning of the simulation. Once adding and receiving processes are done at a particular node the server recognizes it and removes the node from the list that just reached its breakpoint. The server also checks if the required number of replications is complete. If it is, the required statistical analyses are done and an output report of the results is generated. If not, another independent replication is carried out..

If we like to explain the role for both server and node more in detail it could be described in anther way. Figure 2 presents both server and node windows where the users can input initial parameters and also monitor the battle status, history, and some final output statistics.

For nodes

1. Once a message is received from server, determine which unit on either side has the minimum interfiring time among the survivors and transmit this to the server.
2. When the message to fire is arrived from server, the corresponding unit fires against target that is preassigned and checks if kill is made. If the kill is occurred, the target is removed and a new interfiring time is assigned to the killing unit. If he or she missed the target, simply generate a new interfiring time and apply it as the next time to fire to the same target.
3. If some surviving units are added to either side after the end of battle at other node, we just accept it and count them as colleagues from the point that event occurs.

For server

1. Collects all information that have occurred at all participating nodes.
2. The server collects the minimum interfiring times for each active node, then again find the minimum of them, and then transmit the order to continue the battle.
3. Make some decisions when a message is transmited from any node, for examples,
   a. prepare to move the surviving units from one to other nodes in the middle of engagement,

b. prepare to move the winning survivors at any node to other nodes at the end,

c. transmit any information to some nodes if necessary or desired.

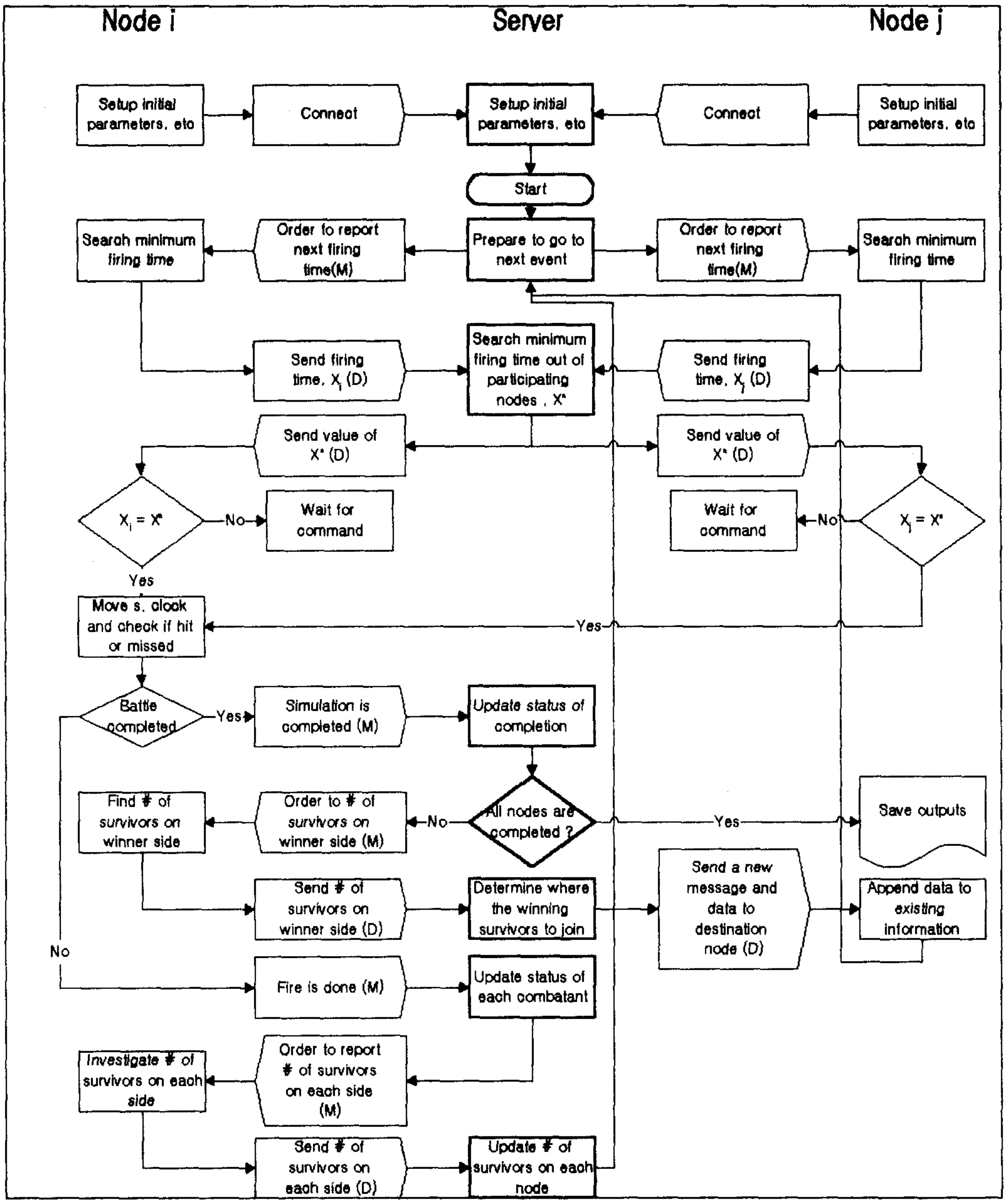
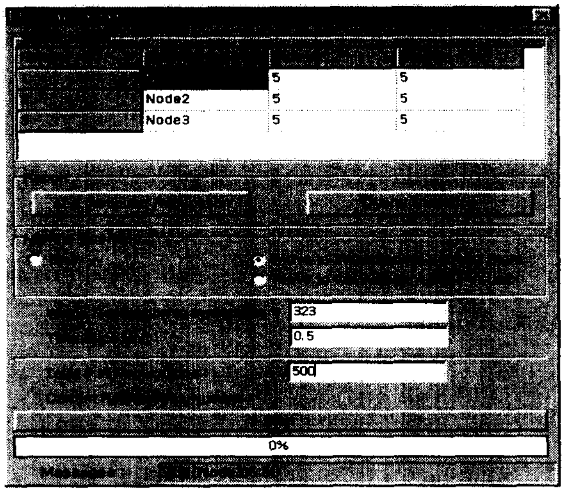


Figure 1. A coarse flow chart of the DISCSIM



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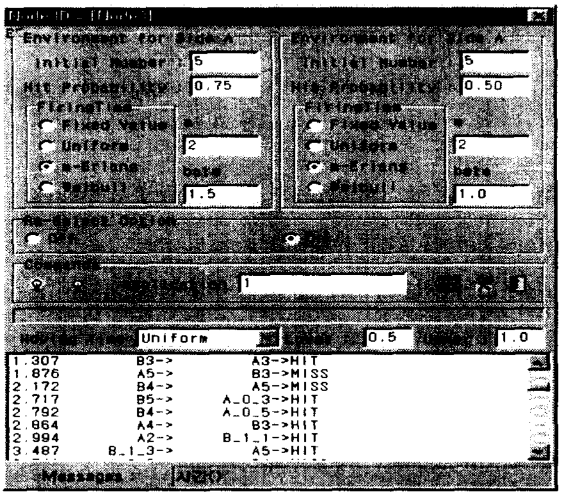


(b)

Figure 2. (a) Server Window : input parameters, battle status, and output statistics, (b) Node Window : input parameters, battle history.

About programming

We have used the Delphi s/w from Borland as a development tool. It provides a way of object oriented programming through VCL component method. This component allows to use TCP/IP protocol for internal message transmission. The server and nodes communicate or transmit the data by utilizing its own encoding/decoding standard format.

A node contains some combatant objects and each of them has its own functions to work properly. For instance, once a node is connected to server, then it informs both IP address and its unique node ID. This procedure is executed by *register* function in it

Sample Outputs

Table 1 and 2 show examples of the above inputs and outputs for a combat with the following characteristics:

1. Side A : Erlang-2 interfiring time with μ_A=1.5, p_A=.75, a_0= 20, and a_k=5 for k=1,2,3,4.
2. Side B : Erlang-2 interfiring time with μ_B=1.0, p_B=.50, b_0= 20, and b_k=5 for k=1,2,3,4.
3. Search time or joining time is uniformly distributed between .50 and 1.0.
4. Breakpoints for both sides at any node are assumed to be zero.
5. Reselect option is on (in case of off, a new interfiring time only for the successful marksman is generated. Those others who also had the killed element as a target are assigned new targets but continue to use the remainder of their previously assigned interfiring time.)

Model Verification

The Model was checked manually to ensure its proper functioning. The appropriate action was taken and the manual simulation continued. The numbers used for five replications were recorded and compared. The model was then run for the same number of replications on the computer.

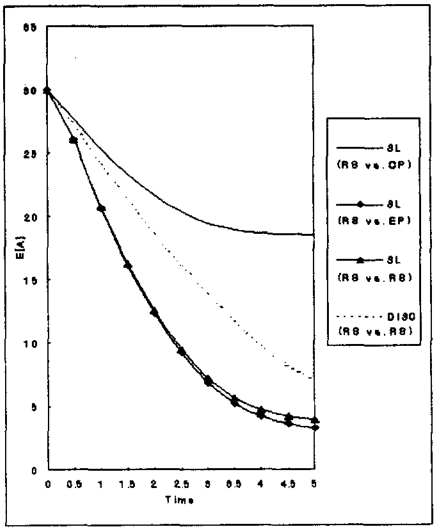
Table 2. Description of time varying characteristics for survivors in a specific replication at each node and overall combat. Erlang-2 Interfiring Time Distribution for both sides, $a_o=20$ $a_f=0$ $\mu_A=1.5$ $P_A=.75$, $b_o=20$ $b_f=0$ $\mu_B=1.0$ $P_B=.50$ Reselect Option for Both Sides : ON , Number of replications = 10,000.

Time	A(t)B(t)	$A_k(t)$ & $B_k(t)$ Node1		Node2		Node3		Node4	
0.0000	(20, 20)	5	5	5	5	5	5	5	5
0.1750	(19, 20)	4	5						
0.2860	(18, 20)			4	5				
0.2900	(18, 20)							5	5
0.3680	(18, 20)							5	5
0.3880	(18, 20)					5	5		
0.4000	(18, 20)					5	5		
0.5410	(18, 20)			4	5				
0.5700	(17, 20)					4	5		
0.6390	(17, 20)							5	5
0.6730	(17, 19)					4	4		
0.7510	(17, 19)					4	4		
0.8700	(17, 19)							5	5
0.8760	(17, 19)	4	5						
0.8910	(17, 18)							5	4
0.9290	(17, 18)			4	5				
0.9450	(17, 18)	4	5						
0.9550	(16, 18)							4	4
0.9840	(15, 18)			3	5				
1.0150	(14, 18)	3	5						
1.0590	(13, 18)			2	5				
1.1340	(13, 18)			2	5				
1.1690	(12, 18)					3	4		
1.2640	(12, 18)			2	5				
1.2830	(12, 18)	3	5						
1.3000	(12, 17)					3	3		
1.3340	(11, 17)			1	5				
1.3510	(11, 17)							4	4
1.4140	(11, 16)							4	3
1.4380	(10, 16)			0	5				
survivors on Node 2 move to Node 1									
1.4380	(10, 16)	3	10						
1.5580	(9, 16)	2	10						
1.5890	(9, 15)					3	2		
1.6000	(8, 15)	1	10						
1.6420	(8, 15)	1	10						
1.6510	(7, 15)							3	3
1.6820	(7, 14)							3	2
1.9780	(7, 13)					3	1		
2.0010	(6, 13)					2	1		
2.1630	(6, 13)	1	10						
2.3620	(6, 13)	1	10						
2.3720	(6, 12)							3	1
2.4960	(5, 12)					1	1		
2.6700	(5, 12)	1	10						
2.7560	(5, 12)					1	1		
3.0630	(5, 12)	1	10						
3.1930	(5, 12)					1	1		
3.2000	(5, 11)							3	0
survivors on Node4 move to Node 3									
3.2000	(5, 11)					4	1		
3.4560	(4, 11)	0	10						
survivors on Node1 move to Node 2									
3.4560	(4, 11)					4	11		
5.7630	(4, 11)					4	11		
6.4060	(4, 11)					4	11		
6.5880	(4, 11)					4	11		
6.8660	(4, 11)					4	11		
7.0490	(4, 11)					4	11		
7.0630	(3, 11)					3	11		
7.1940	(2, 11)					2	11		
7.3250	(1, 11)					1	11		
7.4560	(0, 11)					0	11		
.....	.....	.....		.....		.....		.....	

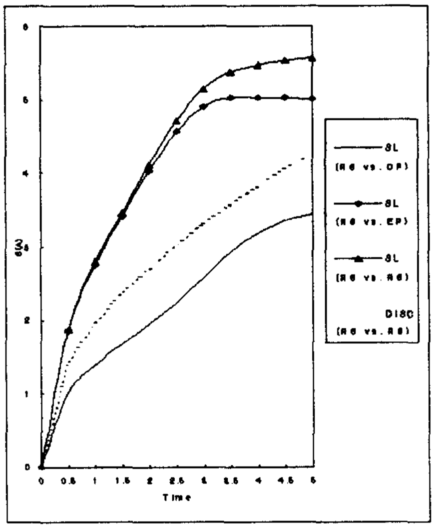
etc.

3. Comparisons with Existing Models

In this section we present a very limited set of examples of the comparisons between DISCSIM and other existing models. Neither deterministic model (DL) nor exponential Lanchester model (EL) will not be considered here, since we already have showed the problems of those models when the stochastic versions of them are participated in the competition of the model's fidelity.



(a)



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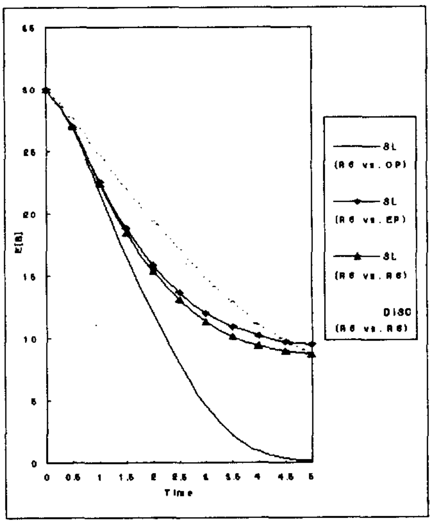

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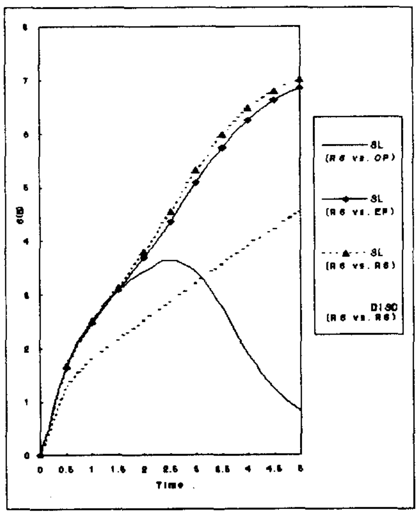

(d)

Figure 3. The time trajectories for the mean number of survivors on both sides and standard deviations.

Basically, the results from four separate models are compared for both mean number of survivors and its standard deviation. The competing stochastic Lanchester models are random selection (RS), concentrated power (CP), evenly distributed power (EP), and DISCSIM which is currently suggested in this study.

Figure 3 presents the time trajectories for the mean number of survivors on both sides and standard deviations. We observe that the differences exist between models.

Table 3 presents the relative differences when the DISCSIM model is compared with the SL model where RS vs RS fire strategy options are considered for both sides. From 10,000 replications the table shows six overall combat parameters simultaneously at the 95 percent confidence level. Column seven shows the absolute precision for each of the relative differences. We see that the average absolute relative difference is 11.99% and the maximum of six relative differences is 25.60%, in fact, there also exist some significant amounts of difference between estimates of the parameters.

4. Summary and Conclusions

A number of combat simulation models are scattered and the analytic solution approaches have experienced very difficult computational efforts. To overcome some of the unrealistic assumptions in the theory of combat a few attempts have been made and tested in an appropriate manner. Both fire allocation strategies and combat networking problems are typical examples. Today's computer communication technology let people to do many unrealistic things possible and the use of those technologies is becoming increasingly prevalent throughout the military operation. Both DIS and ADS are welled defined computer aided military simulations.

This study discusses a simulation of stochastic combat network modeling through Internet space. We have developed two separate simulation models, one for clients and another for server, and validated for conducting studies with these two models. They are linked together to perform an experiment via Internet. The object-oriented design was necessary to define the system entities and their relationship, to partition functionality into system entities, and to transform functional metrics into realizations

Table 3. Relative difference estimates (%)

Stochastic Lanchester (Random Selection) vs DISCSIM (Random Selection)
Interfiring Distribution : Erlang-2 (A) vs Erlang-2 (B)

$P_A = 0.75$ $\mu_A = 1.5 A_o = 20,$ $A_f = 0$

$P_B = 0.50$ $\mu_B = 1.0 B_o = 20$ $B_f = 0$

Bonferroni K : 6 Number of Replications : 10000
$\alpha = 0.05$

	Models		Relative Difference Confidence Interval(%)		MidPoint	Half Length	Average abs (MAX abs)
	SL (RS vs RS)	DISCSIM (RS vs RS)	Left	Right			
$E[A]$	2.8975	2.8810	(-4.96	5.79)	0.41	5.3753	
$S[A]$	4.3391	4.0130	(5.03	9.90)	7.47	2.4345	
$E[B]$	5.7169	4.2510	(22.81	28.38)	25.60	2.7825	
$S[B]$	5.2973	4.5560	(12.70	15.27)	13.98	1.2869	
$P[A]$	0.3723	0.4293	(-20.74	-10.15)	-15.45	5.2913	11.99
$P[B]$	0.6277	0.5707	(6.26	11.83)	9.04	2.7850	(25.60)

derived from system component behaviors. Heterogeneous forces for each side are assumed at any node.

The time trajectories for mean number of survivors and combat history at each node, some important combat measures, and relative difference computations between models were made. We observe and may conclude that the differences exit and some of these are significant based on a limited number of experiments.

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