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Computer Modelling of a Tank vs Tank Battle on a Realistic Terrain

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ABSTRACT

A computer simulation model of a tank *vs* tank battle scenario was earlier developed and programmed on PRIME–750. The model has been refined and improved further in terms of organisation, terrain and tactics. The present paper describes the following features, which have been incorporated into the model : (a) units in formation (b) physical terrain features in the form of sand dunes (c) tactical manoeuvres and (d) real-time graphic display of the whole combat action. In accordance with the scenario, improved criteria for manoeuvres bypassing obstacles, search and fire have been introduced.

1. INTRODUCTION

Since World War II, a large number of war game models have been developed in United States, U.K., Australia and Canada for the following purposes : (a) to train or test commanders and staffs, (b) to investigate weapon systems' effectiveness and tactical alternatives, (c) to develop and test plans for intended operation. These war games differ from the classical as well as deterministic mathematical models as these are probabilistic and dynamic in nature and result in simulation of more realistic real-life situations on digital computers[1]

Simulation methodology when applied through use of a large digital computer can cater to very high levels of complexity. The builder of a model is relatively free to include in his model a large number of events and the factors influencing them. There are, however, good reasons to start with a simple model which can be gradually modified and improved towards realism. Singh[2,3] reports a computer simulation model of a probabilistic and dynamic tank *vs* tank battle scenario in which the defender is provided an armed helicopter unit support against surprise advance of the attacker towards an important place. The number of fighting units, rate of fire, reaction time,

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single and successive shots (fired after correction) hit/kill probability, mobility and line of sight probability are among the main factors integrated in the model. The game has been repeated for some battle parameters and then, their effects on the outcome have been analysed.

The model has been reviewed by various experts who have made valuable suggestions for its further development in terms of organisation, terrain and tactics. Pooling these suggestions the model has been restructured for a scenario where the battlefield contains some physical features in the form of sand dunes. The attacker moves its two squadrons one on each flank towards the defender leaving behind one squadron in reserve. The defender hastily deploys its two squadrons to intercept and frustrate the attackers mission.

In accordance with the scenario, improved criteria for manoeuvre bypassing obstacles, search and fire have been introduced. The whole combat action along with the terrain features is displayed on a graphic terminal. Option for initial deployment positions, direction of squadrons' move, troops manoeuvres before contact and sequential reserve deployment, if required, are some of the interactive features of the software. As an illustration, effects on the casualties of both attacker and defender due to different manoeuvres are domonstrated.

2. SCENARIO

Goline is an important terrain feature along the border of two countries and has its tactical importance. The area under consideration is covered with a densely scattered sand dunes of various sizes. The enemy sacrifices its artillery support to achieve surprise armour offensive to capture it. The defender have had no time but to deploy its armour (with a stand by armed helicopter unit) to intercept and destroy the enemy before reaching the objective. In this context the model assumes the following combat operations.

On the battlefield the attacker (Blue) start moving its armour towards the defender (Red), leaving reserve in the rear. The move takes place by bounds on assigned flanks. In the formation, each unit moves around the obstacles cutting–off the line of sight and searches for the enemy in its sector of fire, under the covering fire of other tanks of its troop. In the meanwhile, the defender occupies hull–down positions ahead of the objective and watches the enemy's advance. After ascertaining opposing force before contact, each side decides whether or not to call the reserve, and if called through which gridpoint to join the battle.

If and when a unit has sighted a target within the effective gun range, it acquires the target and fires up to a maximum of three rounds and immediately moves to change its position, provided it survives by the return fire. If one or more rounds hit the target and if it is a casualty, all other units will cancel their activities with respect to this unit. Otherwise the target moves from its current position and searches for an enemy unit. In this way each unit moves, manoeuvres, searches for the target, acquires the target and fires.

The battle continue till either side has reached the objective or reduced to a non-fighting strength, whichever state is reached earlier.

The state and outcome of the battle will thus depend upon the relative merit of the battle factors (or variables) relating to weapons system of both sides, terrain and tactics and their mutual interactions.

3. MATHEMATICAL MODELLING

Generally, the progress of a battle is assumed dependent on the battle parameters such as, fire power, protection, mobility, terrain and tactics. Each of these factors in turn depends upon a number of other factors. For example, fire power is a function of accuracy, rate of fire and lethality of a shell. As such it is quite difficult to correlate all these factors mathematically in the form of equations. Hence resort is made to simulation methods for studying such problems. Some factors, which have been expressed mathematically are given below for their explicit use in the work :

3.1 Hit Probability

The probability of hit is given by the relation

$$P_h = \iint_A f(x, y)dxdy \tag{1}$$

where A is the projected area of the target and

$$f(x, y) = (1/2\pi\, s_x s_y) \operatorname{Exp}[-\{(x/s_x)^2 + (y/s_y)^2\}/2]$$

Here s_x and s_y denote standard deviation of the line and range errors about the aim point. For given values[2] of s_x and s_y, head-on and side-on SSHP (P_h) of centurion *vs* M–47/48 have been calculated from Eqn. (1) in the input file. (Table.1)

Probability of kill (P_k) due to a hit depends upon the type of round and the actual point of impact on the target. Let P_h be the probability that a round will hit on a given area with lethal penetration probability P_d then

$$P_k = P_h \times P_d \tag{2}$$

In practice probability of hit/kill decreases on a moving target and increases substantially with each successive round fired after correction of range and line errors. These probabilities have been approximated by lower and upper zone values[2,3].

3.2 Terrain Modelling

Consider obstacles of average size s, uniformly scattered with average number m per unit area, to cut off the vision at height h_0. Then the probability of getting n obstacle in a range R is governed by the differential equation

$$P_n(R + dR) = P_n(R)\,[1 - \theta.dR + o(dR)] + P_{n-1}.(R)\,[\theta.dR + o(dR)]$$

$$P_n'(R) = -\theta.P_n(R) + \theta.P_{n-1}(R). \tag{3}$$

Whence the probability of getting no obstacles or getting line of sight in a range less than or equal to R is given by

$$P_0(R) = \exp(-\theta R) \tag{4}$$

where $\theta = m \times s$.

If the observer is at a height h and that the vision is obscured by an obstacle of height H ($h > H$), then the probability of getting line of sight is given[4] by

$$P_o = \exp(-\theta RH/h)$$

In practice the actual terrain between the observer and the target may contain obscurers of various types and sizes like shrubs, trees, sand dunes, hills etc. In that case, we may approximate θ by

$$\theta = m_1 s_1 + m_2 s_2 + \ldots\ldots \tag{5}$$

where m_1, m_2, ... refer to the number densities of obscures of size s_1, s_2, ... respectively. Thus $P_0(R)$ which ineffect is the probability of the detection of a target at a distance R, is modified accordingly.

Alternatively, the line of sight between the observer and the target may also be obtained geometrically, by considering each obscurer separately. Consider observer at a point (X_1, Y_1), the target at (X_2, Y_2) and an obscurer at (X_o, Y_o) with radius r.

Then the equation of imaginary line of sight between the observer and the target is

$$Y - Y_1 = (Y_2 - Y_1) \times (X - X_1) / (X_2 - X_1) = G(X - X_1) \tag{6}$$

The length of perpendicular on this line from the point (X_o, Y_o) is given by

$$L = [G(X_o - X_1) + (Y_1 - Y_o)] / \sqrt{(G \times G + 1)} \tag{7}$$

If

$$L > r, \text{ the obstacle does not obstruct the vision} \tag{8}$$

$$L \leq r, \text{ the obstacle obstructs the vision}$$

In order to compare results for LOS from the Eqns (8) and (4),a simulation experiment[5,6] has been conducted over a terrain containing sand dunes of varying sizes as shown in Fig. 1. 20000 pairs of positions on this battlefield are randomely

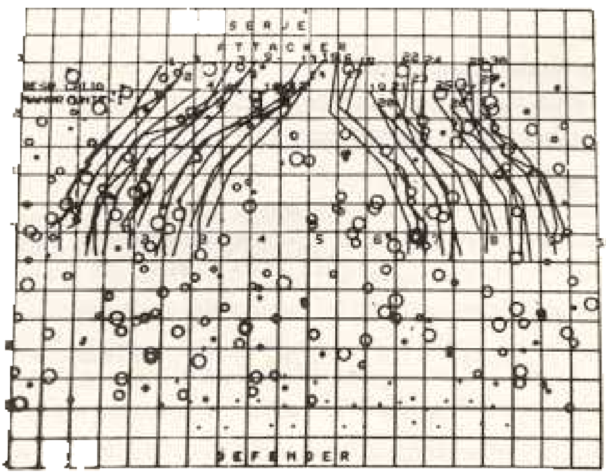

Figure 1. Scatter of sand dunes on the battlefield and initial movement of the attacker force.

selected and the line of sight for all pairs tested by the computer with the help of Eqn. (8) for various dunes densities m=2,4,6 and 8. The simulated probabilities for LOS at various ranges are shown graphically in Fig. 2. The LOS calculated from Eqn (4) for s=0.1 km. (average size of the obstacles) and m=2,4,6,8 are also shown in Fig. 2. The results from both the approaches are found in close agreement.

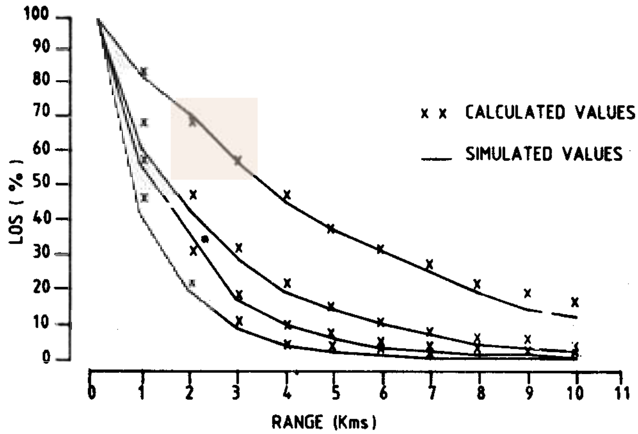

Figure 2. LOS versus range for average number of dunes – (2,4,6 and 8 per square km).

Since both the approaches are equivalent, we have used Eqn. (8) for sand dunes on a specified area, and Eqn. (4) for other types of obscurers in the detection process.

4. SIMULATION OF COMBAT

The essential features of the combat that must be simulated appear to be comprised of the following battle factors(variable)

(i) Hit/Kill probability per round of a particular weapon *vs* opposing weapons.

(ii) Combat rate of fire.

(iii) Probability of seeing enemy.

(iv) Mobility.

(v) Communication system to share combat information.

(vi) Human factors to influence performance of weapons.

(vii) Physical terrain features of battlefield.

(viii) Mission of units.

(ix) The technique or doctrine of fighting to be applied.

The first six factors are pure performance characteristics of a weapons system with respect to the seventh (terrain features). Each of these factors may be determined from proving–ground experiments, field exercises and/or theoretical studies. The eighth factor is a quantitative statement of the missiop of each of the opposing units.

The last factor represents the intent of a set of rules, or expression of doctrine, that permit a sensible combination of the first six battle factors (force) with the mission and the terrain factors. Monte Carlo simulation enables the influence of such integration of battle factors to be a natural part of battle.

A basic assumption is that, to simulate battle successfully, the battle factors used must refer directly to individual participants in a combat action. This appears attractive for the reason that the physical characteristics of weapons are (usually) best determined on an individual basis and are (usually) the most accurate information available. The results of calculation starting from such data are apt to be more believable than calculations starting from less known data, averaged in some way before insertion into the model. So, as a first step in refining the model of battle, the combat action is broken down into its essential elements of manoeuvre, search and fire. Thus precise statements of calculations the computer must perform in order to simulate the actions of each combat unit are formulated.

5. SIMULATION OF MOVEMENT/MANOEUVRES

Consider movement of a unit from its current position (X_1, Y_1) to another position (X_2, Y_2), through obstacles on the battlefield. Then the equation of the line joining the two points is given by Eqn. (6).

Let there be a circular obstacle of radius r with centre (X_0, Y_0). Then, the length of the perpendicular from the centre of the obstacle on the line joining the two points, is given by Eqn. (7).

If $L>r$, the obstacle does not obstruct the path along the two points. If $L< r$, the obstacle falls on the line and so the unit will move through $X_3 = X_0 \pm r$ depending on the position of X_2. Presence of obstacles from (X_3, Y_3) to (X_2, Y_2) is tested by the computer similarly. The choice of next position (X_2, Y_2) to be occupied by a unit, is made such that manoeuvre of the unit formation is maintained in the specified (or modified by enemy action) direction. The specified flank of manoeuvre is controlled by the equation

$(Y-Y_i)^2 = (X-X_i)$, with the given vertex (X_i, Y_i).

Thus if the troop leader takes account of this direction, then the members of this troop can be caused to maintain a specified posture relative to the troop leader, while the entire squardon moves towards the objective.

6. SIMULATION OF LOS

The LOS depends upon atmospheric visibility and physical terrain features. If visibility permits, the line of sight between two points will exist if and only if there is no intervening obstacles to cut off the vision. Consider sand dunes as obstacles of radius r ($0 < r < 100$) meters, scattered on the battlefield. The line of sight between any two points (X_1 , Y_1) and (X_2 , Y_2) will exist if and only if there is no obstacle with $r > L$, see Eqn. (8), and there is visibility. It may be noted that in these calculations sand dunes are approximated by circles with varying radii scattered over the battlefield.

The location (X , Y) and the radius r of these sand dunes can be obtained from map. The atmospheric visibility (due to fog, smoke, etc.) has also been decided with the help of Eqn. (4) by suitable chosen value of θ. Thus detection takes place if and only if there are no obscurer of any kind between the observer and the target.

7. SIMULATION OF FIRING

Consider the problem of simulating the fire of the main gun on a tank, after it has been laid on the target and decision has been taken to fire at that particular time. Given the correct hit probability for the circumstances applying to any particular round, a decision can easily be made through Monte Carlo procedure by the computer to determine whether the given round did hit its target. Thus suppose that the correct hit probability for the round is known to be 0.4. Then if the computer chooses a number at random between 0 and 1, there is a 40 percent chance that the number so chosen will be less than 0.4 and a 60 percent chance that it will be greater than 0.4. Thus the computer will be making proper decision by calling a 'hit' if the randomely selected number is less than 0.4 and a miss if it is greater than 0.4. Similarly, given the correct kill probability for the circumstances applying to any particular hit, a decision can be made by the computer whether the particular 'hit' did 'kill' its target.

8. COMPUTER MODULES

The combat action has been broken into steps, each involving a single basic action by a combat unit. Fortran Programmes have been developed whereby the computer generates the activities of each combat unit on the battlefield. The activities – move and search, target acquisition and fire, and dead units are distinguished by three states, 1, 2 and 0 respectively. Initially, all combat units are assigned state 1 and later this state is updated to 2, 1 and 0 whichever occurs earlier. The computer keeps a track of all combat units and maintains, state and time registers in the common block of its memory.

The war game model contains a main programme and the following subroutines to be used by the main programme as and when required.

(i) Main Programme

(ii) Random Number Generator

(iii) Terrain Generator

(iv) Movement/Manoeuvre–Att.

(v) Enemy Search by Att.

(vi) Movement/Manoeuvre –Def.

(vii) Enemy Search by Def.

(viii) Target Acquisition and Fire – Att.

(ix) Target Acquisition and Fire –Def.

(x) Reserve Unit

(xi) Hit/Kill Generation.

(xii) Analysis

(xiii) Graphic Subroutines

The software operates for three groups (squadrons) each containing tanks in multiple of three and also for 3 × 4+ 2 tanks in a group.

9. INPUT DATA

The war game has been programmed in modular form and accepts inputs both in non-interactive and interactive modes. The data on parameters relating to battlefield, tactical decisions, tanks and their performance characteristics, are provided through a data file. Interactive data, such as, initial deployment, general direction for squadrons move, troop manoeuvre and reserve deployment, may be given by the player on the terminal, if so needed. As such, numerical values in the data file can be changed to the judgement of experienced officers or those determined from field experiments, without disturbing the software. Therefore, with no loss to generality, an input configuration has been assumed to make it operational as dictated by the scenario. The tank characteristics data (Table 1) are taken close to those of Centurion and a M–47/48, from the open literature.

Table 1. Input file

Battle field and terrain		
Depth		8.00 km
Width		10.00 km
No. of dunes		400
Average diameter of dunes		0.1 km
VIS parameter before contact	D	0.4 km
	A	0.5 km
after contact	D	0.4 km
	A	0.4 km

Tactical decision rules	
Av. dist. between bounds bef cont	0.5 km
aft cont	0.1 km
Chord of fire	0.5 km
Fire opening range	1.5 km
No. of rds fired from a position	3
Return fire range	2.0 km
Casualty level for def. move	40 per cent
Casualty level for game termn	60 per cent

Weapons and characteristics

Number of tanks	30	30
Reserve sqn	12	
Rate of fire (rds/min)	4	4
Speed (km/hr) before contact	10	10
after contact	6	6
Speed reserve sqn (km/hr)	12	
Gun laying acquisition time (min)	0.5	0.35
Prob. of a hit killing the target	0.5	0.5

Range	Head–on Hit probability		Side–on Hit probability	
(km)	Red	Blue	Red	Blue
.5	0.94	0.89	0.96	0.93
1.0	0.75	0.68	0.81	0.77
1.5	0.53	0.47	0.59	0.57
2.0	0.34	0.28	0.39	0.36
2.5	0.23	0.17	0.27	0.22
3.0	0.12	0.05	0.14	0.07

Helicopter Unit

Base (X,Y)	(–10,1)
Speed	80 km/hr
VIS (model parameter)	0.2
Kill probability	0.8
Endurance	1 hour
No. of missiles	4
Depth of penetration	4 km

10. RESULTS

In addition to the input file, while conducting the war game, the operator has option to provide through the terminal, initial deployment positions and direction of manoeuvre for attacker groups, and later, grid references for troops manoeuvre and reserve force, if and when required before contact with the enemy. The entire combat action is displayed on a graphic terminal. Progress of one trial run along with interactive command instructions code are given in Fig. 3.

When interpreting the results produced by simulation, it is to be realised that they are not produced by a process of optimisation. Simulation may be considered valid if it faithfully replicates activities as they would infact be implemented in practice. However, once probabilities are injected into a calculation the outcome of that calculation can not be certain. Thus if a model of batlle that assigns probabilities to describe the performance of a weapon is constructed, then a single simulation of any given battle could have any one of a large number of outcomes, according to the play

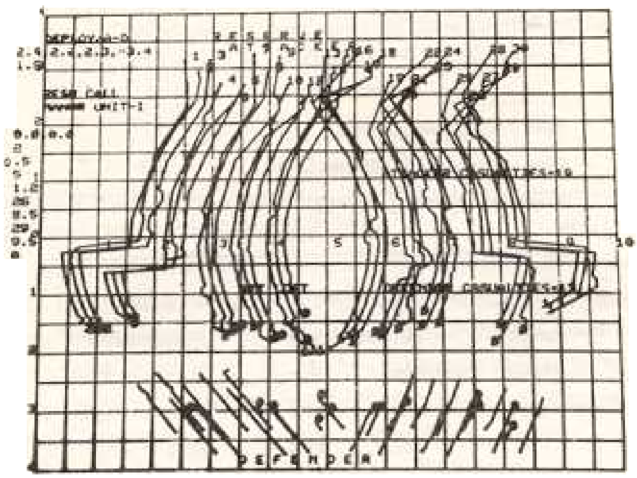

Figure 3. Position at the termination of a game

of chance. The difference in the effectiveness of the competing forces can therefore be measured only by means of the difference in the average outcome of the battle or by similar factors.

Let c_1, c_2……., c_n be the differences in the casualties suffered by the two sides, and m be the mean difference of n repetitions, then for large n

$$z = \sqrt{n}\, m \,/\, \sqrt{\Sigma (C_i - m)^2 / n} \rightarrow N(0,1)$$

If there is no difference between the performance of two sides, the value of z has to be less than some critical value (say, 1.96 at 5 percent level of significance).

To establish the correctness of computer programmes, thirty engagements have been conducted first over a hypothetical situation where both sides assume the same battle parameters. Battle statistics, such as percentage survivals, average number of casualties, average number of rounds fired and hits achieved, and the probabilities of hit, have been calculated. As expected, the differences in the number of rounds fired and the casualties inflicted by the two sides, was found statistically insignificant.

Then, the input parameters in Table 1, have been altered one by one to various force strengths as given in Table 2 (col 2) where centurion defend against M–47/48 tanks. The war game has been repeated thirty times, for each of the following cases :

(i) Attacker manoeuvring its two squadrons one on each flank towards the defender force (2 sqns in hull down position)

 (a) Without reserve

 (b) With sequential deployment of reserve squadron

(ii) Head–on attack

  (a) Without reserve

  (b) With sequential deployment of reserve on a flank

(iii) Reserve helicopter support with the defender

  (a) Attacker without reserve on flanks

  (b) Attacker with reserve on flanks

Average number of casualties, average number of rounds fired and hit achieved, and the probabilities of hit have been calculated and are given in Table 2. Attacker

Table 2. Battle statistics for different manoeuvring and development tactics of the attacker

(Analysis based on 30 games for each case)

Case No.	Force		Casualty/ game	Test of difference Z	Rounds fired	Hit scored	SSHP
1 (a)	28 : 28						
		A	17		80	37	0.46
		D	14	–4.2	84	46	0.55
	30 : 30						
		A	18		80	36	0.46
		D	14	–4.9	93	49	0.53
i (b)	30 : 30+R						
		A	18		107	47	0.44
		D	19	1.2	91	46	0.51
	30 : 30						
		A	19		73	34	0.47
		D	13	–6.9	94	48	0.51
ii (b)	30 : 30+R						
		A	22		94	44	0.47
		D	17	–3.3	108	56	0.52
(iii)	30+H : 30+R						
		A	23		96	43	0.46
		D	17	–5.4	93	49	0.52

gain advantage in terms of casualties by manoeuvring its squandron, one on each extreme flank. This gain further increases by deploying the reserve on positions between these two squadrons. Specifically, with the same force ratio, the attacker gains advantage in reducing own casualties from 19 to 18 and increasing enemy casualties from 13 to 16, through flank manoeuvres. The loss of the defender further increases from 16 to 19 when attacker deploys its reserve squadron sequentially. A gain of 3 casualties to the attacker is also observed due to sequential deployment as against simultaneous deployment of the regiment as a whole.

11. CONCLUSIONS

Simulation methodology has been refined/extended on some battle parameters of a regiment level war game. Consistent with the scenario, units in formation, tactical manoeuvres, and terrain with sand dunes' features have been introduced into model. Appropriate criteria for tactical manoeuvres bypassing obstacles, sighting and fire are developed. The model has been programmed on PRIME–750, with some interactive and display features. Effects on the casualties of both attacker and defender, due to different tactical manoeuvres, have been demonstrated. Although the accuracy of the results is limited by the input data, the software provides a systematic base to approach mixed arms combat situations.

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