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Battle Group Combat Simulation Model('BAGSIM') as an Experimental Tool

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Abstract

This paper describes a Battle Group Combat Simulation Model(called 'BAGSIM'). BAGSIM is developed to be used as an experimental tool for studies about combat modelling at battle group level. Thus it takes many of the parameters and situations into consideration at this level, and it is designed to be easily adapted to represent equivalent situations to the other more aggregated models.

Further the main processes occurring in its simulation procedure such as target detection process, target selection process, firing and killing processes are verified by comparison with the existing stochastic duel models.

1. INTRODUCTION

There are a large number of combat modelling methodologies currently in use : deterministic Lanchester equation, exponential Lanchester equation, stochastic duel (general renewal) theory, the volley fire methodology of Helmbold, Monte-Carlo simulation and the firepower score methodology [3].

These methodologies have been implemented to give representation of the combat situation, but most of the models based on these methodologies suffer weeknesses in

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verification. This is because of difficulties of obtaining the field exercise or real battle data necessary for the verification. For this reason, alternatively the simulated battle data is used (6). This data is provided by the simulation model incorporating the identical battle situation to that considered in the model.

Further, the combat simulation model has the potential to represent a combat situation in as much detail as the military modeller chooses, although it would slow the model execution. When a large amount of detail is involved, the simulation model provides a suitable experimental tool.

Hence, for this purpose, a Battle Group Combat Simulation Model (called 'BAGSIM') has been developed. The BAGSIM model is constructed to represent land combat at the battle group level, and takes many of the available parameters and situations into consideration at this level so that it provide an experimental tool necessary for studies about combat modelling.

2. Development of BAGSIM

2.1 Assumptions

The battle is between two sides, traditionally known as Blue and Red, using direct-fire weapon system. Both the temporal and spatial aspects of the combat are represented.

The units of each side can be grouped together, and each group may contain a number of different weapon types. The groups are initially deployed around the perimeter of the battle area, with the initial position of each unit in a group being the same. A group could consist of just one unit.

Either side or both sides may advance or neither moves. When they advance, groups move in a straight line, parallel to each other. The movement rate of a group is constant throughout the battle.

In the process of an engagement, a line of sight opens between groups, and an engagement starts if detection occurs. The exposure will continue for a limited time, and detection occurs either through movement or as the result of an opponent's firing signature. Detection occurs between individual units rather than between groups.

If a unit detects more than one target, the target selection rules are used to decide which of the enemy units is engaged. Either the first target detected or the one with the highest priority will be engaged.

When a unit's target is killed by another firer, two possibilities are considered. Either the unit switches to another target after completing its current shot or the unit switches immediately after its target is killed. The former situation is refered to as 'overkilling' whilst the latter is 'non-overkilling'. However, note that the unit which has been killed is no longer selected as a target.

A firer will disengage from his target and switch to a new target when the target exposure ends or if the target takes 'jockeying' action. 'Jockeying' is a move between fire positions during which the unit is assumed to be out of line of sight. The amount of ammunition is limited for both sides, and if a weapon runs out of ammunition during a battle, it can still be detected and killed, but can not fire.

A battle is deemed to be over on the basis of the following criteria :

1. When one side has been annihilated or reduced to a certain preset percentage of its initial size.

2. When the shortest distance between two groups on either side has reached a certain preset value.

3. When all the combatants have withdrawn after firing a preset number of rounds.

2.2 Model Parameters

In modelling the situation described in the previous section, various parameters are required and are described below.

The following times or distributions of times are required : exposure time, detection time by movement, time of jockeying manoeuvre and inter-firing times. The inter-firing times are sometimes considered as consisting of several parts; time of adjustment, time prior to firing and time of flight for the first shot; time prior to firing and time of flight for subsequent shots. The distributions of the times are then selected as either negative exponential, Erlang, Lognormal or constant, with appropriate parameters being specified.

The following probabilities are required: probability of a line of sight, probability of detection by firing signature and single shot kill probability. All of these probabilities can be considered as constant or range dependent.

Finally, inputs are required to specify movement rate, number of shots before jockeying, number of rounds available, whether or not 'overkilling' is to be included, target selection rules, target selection priorities and the battle stopping condition.

2.3 Structure

The BAGSIM program has been written in Fortran to a structured design. Whilst complicated, it is clearly commented to allow the sequence of events to be followed easily. In particular, BAGSIM is designed to be flexible and easily adapted to represnt equivalent situations to other more aggregated models such as Deterministic Lanchester or Exponential Lanchester Model.

The outline structure of BAGSIM is as follows:

- start
- set up a set of assumptions and input data
- initialize for an experiment (engagement)
- start of experiment
- initialization for a single replication
- start of replication
- EVENT-SEQUENCED process
- report and updating
- end of a single replication
- repeat for a required number of replications
- end of experiment

• production of output

A set of assumptions is established through the choice of 'modes' in the BAGSIM program.

Afterwards, BAGSIM requires the input data relevant to the model structure specified by the choice of 'modes.' Then upon initialization the EVENT-SEQUENCED process is initiated.

The EVENT-SEQUENCED process is structured to allow the sequence of events (i. e. exposure, detection and firing) to be followed easilly. The EVENT-SEQUENCED structure is itemised using pseudo-Fortran77 in Annex A.

Many of the functions in BAGSIM are used repeatedly and hence have been implemented as subprograms.

2.4 Outputs

Once the inputs have been provided, BAGSIM simulates an engagement and produces outputs as below.

- event history
- probability of win, lose and draw
- expected number of survivors at the end of the battle
- average combat time at the end of the battle
- expected number of combatants at time t
- cumulative distribution of combat time at the end of the battle
- joint probability distribution of number of survivors at time t

3. Verification of BAGSIM

BAGSIM can represent battle situations identical to those of the Deterministic Lanchester Model, Exponential Lanchester Model, Stochastic Duel Model. These representations basically consist of such processes as target detection process, target selection process, firing and killing processes.

Thus, it is necessary to verify the BAGSIM basic processes.
This is achieved by comparison with other existing equivalent models. The models to be considered are the One-on-One Stochastic Duel Model[1], the Two-on-One Stochastic Duel Model[5] and the MATADOR Model[6].

Comparison with the One-on-One Stochastic Duel Model can help verify the firing and killing processes, whilst comparison with the Two-on-One Stochastic Duel Model can help verify the target selection process. Comparison with the MATADOR Model can help verify the target detection process.

These comparisons are likely to be enough for the verification of BAGSIM processes, even though the full verification can be conducted, for example, by the sensitivity analysis for all the cases appeared in BAGSIM, or by checking BAGSIM process line by line.

3.1 BAGSIM and the One-one-One Stochastic Duel Model

Ancker[1] developed a general solution of the One-on-One Stochastic Duel. The situation in this model is that two combatants, Blue and Red, fire at each other until one is killed with constant single shot kill probitablity (SSKP) and inter-firing times (IFT) being random variates, and there is no limit on the number of rounds.

When the inter-firing times of both sides follow a negative exponential distribution, the probability of a Blue win is given by

$$\Pr(\text{Blue win}) = \frac{p\delta}{p\delta + \tilde{p}\sigma} \qquad \cdots\cdots\cdots\cdots (1)$$

where, $p(\tilde{p})$ is SSKP of Blue (Red) Side

$\delta(\sigma)$ is firing rate of Blue (Red)

By the choice of appropriate modes, BAGSIM can represent the identical situation to that considered in the One-on-One Stochastic Duel Model. In the comparison of these two models, they have produced equivalent results. Some examples are shown in Table 2, which contains win probabilities and the relevant statistics for the 'Significance Test for One Unknown Proportion,' for the four cases shown in Table 1.

Table 1 : Data-Set for the Comparison of BAGSIM and the One-on-One Stochastic Duel Model

Data

Case	Single Shot Kill Probability		Mean Inter-Firing Time(*)	
	Blue	Red	Blue	Red
1	.2	.2	5	20
2	.2	.4	10	10
3	.4	.6	15	10
4	.4	.6	15	20

* The inter-firing times of both sides follow a negative exponential distribution

Table 2 : Comparison of BAGSIM and the One-on-One Stochastic Duel Model

Results

Case	One-on-One Duel Results (Analytic Results)		BAGSIM Results (Simulated Results)		◇ d	◆ p
	Pr (Blue win)	Pr (Red win)	Pr (Blue win)	Pr (Red win)		
1	.8000	.2000	.8036	.1964	.64	.52
2	.3333	.6667	.3294	.6706	.59	.56
3	.3077	.6923	.3080	.6920	.05	.96
4	.4706	.5294	.4764	.5236	.82	.41

d◇=the standardised quantity
p◆=the probability of obtaining a value as large as or larger than the standardised quantity d.

The analytic results in Table 2 were obtained using Equation(1), and the simulated results were based on 5000 replications of the same engagement.

The p values in the above cases are all larger than 0.05(i.e. 5% significance level). Hence, the null hypothesis that there is no significant difference between BAGSIM and the One-on-One Stochastic Duel Model is accepted at the 5% level.

3.2 BAGSIM and the Two-on-One Stochastic Duel Model

Gafarian and Ancker [5] extended the One-on-One Duel Model to a Two-on-One Duel Model. As a special example, when Blue's inter-firing times follow an Erlang $(2, \theta)$ distribution, i.e. $\theta^2 t e^{-\theta t}$, and Red's inter-firing times follow a negative exponential distribution with rate σ, the probability of a Blue win is given by

$$\Pr(\text{Blue win}) = \frac{4\alpha_1\alpha_2(\alpha_1+\alpha_2) - 2(\alpha_1^2+\alpha_2^2)\tilde{p}\sigma - (\alpha_1+\alpha_2)(\tilde{p}\sigma)^2}{(2\alpha_1+\tilde{p}\sigma)(2\alpha_2+\tilde{p}\sigma)(\alpha_1+\alpha_2+\tilde{p}\sigma)} + \frac{(\alpha_1+\alpha_2)\tilde{p}\sigma}{(\alpha_1+\tilde{p}\sigma)(\alpha_2+\tilde{p}\sigma)} \quad \cdots\cdots (2)$$

where, $\alpha_1 = 2\theta(1-\sqrt{q})$

$\alpha_2 = 2\theta(1+\sqrt{q}), \quad q = 1-p$

$p(\tilde{p})$ = SSKP of Blue (Red) Side

Once again this Two-on-One Stochastic Duel Model and BAGSIM representing the same situation have produced equivalent results.

The results are shown in Table 4, for the four cases shown in Table 3.

The analytic results in Table 4 were obtained using Equation (2), and the simulated results were based on 5000 replications of the same engagement.

Table 3 : Data-Set for the Comparison of BAGSIM and the Two-on-One Stochastic Duel Model

Input Data

Case	Single Shot Kill Probability		Mean Inter-Firing Time (*)	
	Blue	Red	Blue	Red
1	.3	.2	7	16
2	.7	.4	24	19
3	.4	.6	15	10
4	.2	.4	10	5

* The inter-firing times of Blue side follow an Erlang distribution with shape parameter 2 and those of the Red side follow a negative exponential distribution

Table 4 : Comparison of BAGSIM and the Two-on-One Stochastic Duel Model Results

Case	One-on-One Duel Results (Analytic Results)		BAGSIM Results (Simulated Results)		◇ d	◆ p
	Pr (Blue win)	Pr (Red win)	Pr (Blue win)	Pr (Red win)		
1	.9693	.0307	.9706	.0294	.49	.62
2	.8757	.1243	.8746	.1254	.24	.81
3	.5898	.4102	.5894	.4106	.06	.95
4	.4270	.5730	.4292	.5708	.31	.76

d◇=the standardised quantity
p◆=the probability of obtaining a value as large as or larger than the standardised quantity d.

The p values in the above cases are all larger than 0.05(i.e. 5% significance level). Hence, the null hypothesis that there is no significant difference between BAGSIM and the Two-on-One Stochastic Duel model is accepted at the 5% level.

3.3 BAGSIM and MATADOR

MATADOR[6] is an extension of the One-on-One Stochastic Duel Model, and it considers more parameters, detection by movement or firing, and limited ammunition. BAGSIM was again adapted to represent the identical situation to that considered in the MATADOR model. In this comparison, these two models have also produced equivalent results. The results are shown in Table 6, for the four cases shown in Table 5.

The analytic results were obtained from p.4 of reference [6] and the simulated results were based on 50,000 replications in order to get higher accuracy because the number of input parameters considered in this simulation is more than that considered in previous simulations.

The χ^2_{total} values in Table 6 are all less than the critical value $\chi^2_{0.05(2)}$, 5.99. Hence, the null hypothesis that there is no significant difference between BAGSIM and MATADOR is accepted at the 5% level.

Table 5 : Data-Set for the Comparison of BAGSIM and MATADOR

Case	Blue Data						Red Data					
	$1/\mu$	a	b	p	n	h	$1/\mu$	a	b	p	n	h
1	10	8	10	.7	4	.2	10	7	8	.9	4	.2
2	100	8	10	.4	25	.4	10	7	8	.6	4	.05
3	100	8	10	.7	4	.4	10	5	4	.5	4	.01
4	10	2	15	.9	5	.1	100	7	8	.7	25	.2

Notations : μ - detection rate by movement
a - inter-firing time for the first shot (◇)
b - inter-firing time for the subsequent shots (◇)
p - single shot kill probability
n - number of rounds
h - detection probability by firing signature
◇ The inter-firing times of both sides are constant in both cases.

Table 6 : Comparison of BAGSIM and MATADOR

Results

Case	MATADOR Results (Analytic Results)			BAGSIM Results (Simulated Results)			χ^2_{total}
	Pr (B)	Pr (R)	Pr (N)	Pr (B)	Pr (R)	Pr (N)	
1	.3790	.6208	.0001	.3807	.6192	.0001	
1	18950 (+)	31040 (+)	5 (+)	19035 (*)	30960 (*)	5 (*)	.59
2	.1397	.8471	.0132	.1428	.8448	.0124	
2	6985 (+)	42355 (+)	660 (+)	7140 (*)	42240 (*)	620 (*)	5.94
3	.1536	.8158	.0307	.1506	.8185	.0309	
3	7680 (+)	40790 (+)	1535 (+)	7530 (*)	40925 (*)	1545 (*)	3.50
4	.9553	.0447	.0000	.9547	.0452	.0000	
4	47765 (+)	2235 (+)	0 (+)	47735 (*)	2260 (*)	0 (*)	.30

Notation : Pr (B) - Probability of a Blue win
Pr (R) - Probability of a Red win
Pr (N) - Probability that Neither win which is the result from that one of sides has jockeyed.
\+ the observed numbers for 50,000 engagements
* the expected numbers for 50,000 engagements.

4. Conclusions

The BAGSIM model has been developed to be used as an experimental tool for land combat at the battle group level.

The analysis comparing BAGSIM with some of the existing stochastic duel models has shown that the BAGSIM processes work correctly.

Hence BAGSIM can be used as an experimental tool necessary for studies about combat modelling. Using BAGSIM, for instance, the applicability of the traditional Deterministic and Exponential Lanchester Models to the direct-fire many-on-many engagement has been well examined[4]. Further, BAGSIM can help not only to identify sensitive parameters for the development of a new analytic model at the battle group level, but also to verify such a model.

References

1. C. J. Ancker, "One-on-One Stochastic Duels," Military Application Section, ORSA, US, 1981.
2. C. J. Ancker and A. V. Gafarian, "The Validity of Assumptions Underlying Current Uses of Lanchester Attrition Rates," TRAC-WSMR-TD-7-88, US, 1988.
3. M. R. Bathe, "Modelling Combat as a Series of Mini Battles," Report, TRASANA-LA-14-84, US, 1984.
4. S. Y. Choi, "Applicability of the Lanchester Model to the Many-on-Many Direct-Fire Engagement," MORS. K, Vol. 16, No. 1, pp. 67~93.
5. A. V. Gafarian and C. J. Ancker, "The Two-on-One Stochastic Duel," NRQL, Vol. 31, pp. 309~324, 1984.
6. K. Wand and R. J. Wilson, "MATADOR : A Model of a Stochastic Tank Duel," ORS/02/85, Cranfield Institute of Technology, UK, 1985.

- Annex A : EVENT-SEQUENCED Structure

The EVENT-SEQUENCED structure is itemised using Fortran-77 structure

```
♠ display [event time table]
IF end-condition is satisfied THEN
    END
ELSE
    choose the earliest event to be enacted
ENDIF
IF the earliest event is 'no-engagement' THEN
    IF there are opponents on the line-of-sight and not jockeyed THEN
        select a target
        reset up the event of 'detection' and its event time
    ELSE
        this event goes on until the line of sight is
        established or the jockeying manoeuvre is finished
    ENDIF
    goto the [event time table]
ELSEIF the earliest event is 'detection' THEN
    IF the target is within the maximum range to fire THEN
        reset the event of 'firing' and its event time
    ELSE
        reset the event of 'no-engagement'
    ENDIF
    goto the [event time table]
ELSE (the earliest event is 'firing')
    fire at the target
    IF the target is killed THEN
        IF all the opponents are killed THEN
            END
        ELSEIF the firing combatant requires jockeying manoeuvre THEN
```

```
            reset the event of 'no-engagement'
            reset the event time to be occured after
            jockeying manoeuvre
            IF there are combatants in the opposite side
            intending to switch to new targets
            because they are aiming at the jockeying target THEN
                reset the event of 'no-engagement'
                reset event times to the simulation clock time
            ENDIF
            IF there are combatants in his side
            intending to switch to new targets
            because they are aiming at the killed target THEN
                reset the event of 'no-engagement'
                reset event times to the simulation clock time
            ENDIF
        ELSE
            IF there are combatants in the opposite
            side detecting by the signature of the firer THEN
                reset the event of 'firing'
                reset event times
            ENDIF
            IF there are combatants in his side
            intending to switch to new targets
            because they are aiming at the killed target THEN
                reset the event of 'no-engagement'
                reset event times to the simulation clock time
            ENDIF
        ENDIF
    ELSE
        IF the firing combatant requires jockeying manoeuvre THEN
            reset the event of 'no-engagement'
            reset the event time to be occurred after
```

```
          jockeying manoeuvre
          IF there are combatants in the opposite side
          intending to switch to new targets
          because they are aiming at the jockeying target THEN
              reset the event of 'no-engagement'
              reset event times to the simulation clock time
          ENDIF
      ELSE
          IF there are combatants in the opposite
          side detecting by the signature of the firer THEN
              reset the event of 'firing'
              reset event times
          ENDIF
          IF the same target is still exposed THEN
              fire again
          ELSE
              reset the event of 'no-engagement'
          ENDIF
      ENDIF
  ENDIF
ENDIF
goto the [event time table]
```