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FINAL REPORT

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DEVELOPMENT OF A COMBAT MODEL WITH A MINIBATTLE STRUCTURE

by

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CHAPTER 1

INTRODUCTION & SUMMARY

Objective

- 1.1 The primary objective of this work has been to build a combat model based on an alternative approach to the traditional simulations and Lanchester-type models. The approach in question involves modelling the decomposition of a main battle into a number of smaller firefights and then resolving the attrition in each of those firefights.
- 1.2 A further objective has been to better understand the relevant processes involved in the decomposition and to try and find relationships between what can broadly be described as battle input and output variables.

Background

- 1.3 The chief assumption underlying the approach taken here was first postulated by Payne [A]. Specifically that in the course of a medium or large-scale battle, many largely independent, small-scale engagements (or minibattles) will occur - some in parallel, i.e. overlapping in time, and some in series with the survivors from earlier minibattles being funnelled into one of several future minibattles. This assumption was corroborated by the work of Rowland at DOAE [B].
- 1.4 It is this assumption that frees us from having to consider every possible interaction between opposing weapon systems and transforms the attrition process from one involving a single battle between two large forces fighting over a lengthy time period into one involving several small firefights, each lasting for only a short time interval.

Previous Work

- 1.5 This work follows on directly from a study which was aimed at investigating the general feasibility of modelling

combat in this way [C]. That study (and this one) made extensive use of data from armour/anti-armour combat trials held in Europe and the USA. Many of these trial scenarios were decomposed using a set of rules and assumptions about the nature of minibattles. Once decomposed, various features of their constituent minibattles were examined such as force sizes, force ratios, durations, etc. Some of these features fitted well-known statistical distributions very well and this was later utilised in the model. Trying to equate the parameters of these distributions with physical scenario parameters, however, proved much more difficult. Indeed, it is hard to see how this can be accomplished without much more information regarding the terrain and deployments being made available as well as similar information from other trials being conducted over different terrain types and with a variety of force ratios.

- 1.6 Some of the results of the data analysis from the previous study which have been used in the prototype model are presented in Chapter 2.

Data Analysis

- 1.7 As part of the study, some further analysis of combat trials data was carried out. Of particular interest were the activity levels of the individual weapon systems on each side and also the variation in the total activity of each side during the battle.
- 1.8 The activity levels of individual weapon systems were well fitted by statistical distributions. Furthermore, the study of variation in total force activity with time through the battle produced interesting statistics on force utilisation. These results are presented in Chapter 3.

Attrition Methodologies

- 1.9 A means of resolving attrition is an obvious requirement for any model of combat. Different model structures, however, are likely to require different attrition methodologies. Methods generally deemed suitable for medium-scale engagements involving hundreds of weapon systems may be completely unsuitable for small-scale engagements involving only a handful of weapon systems. Some work in this field has recently been completed by Choi [D]. Since the prototype model that has been developed resolves attrition at the minibattle level, force-on-force type models are inappropriate.

- 1.10 An existing one-on-one stochastic duel model - 'MATADOR' - has been modified and included in the prototype model in its simulation form as an attrition routine for such minibattles. The possible use of other stochastic duel models will also be discussed - particularly in a pre-processing role.
- 1.11 In addition an attrition routine based on generating inter-kill times has been developed and is currently incorporated in the prototype model as the means of resolving attrition in all but the one-on-one minibattles. A detailed account of how this routine works is given in Chapter 4 where the issue of attrition is discussed further.

Model Description

- 1.12 The prototype model that has been developed attempts to give the main battle under consideration a more explicit structure than is normally the case with other combat models. That is not to say that these other models do not contain or impose their own structure on the battle but simply that those which do generally do so in a more implicit way. Moreover, it cannot yet be argued that the structure presented here results in a better or more realistic model. It may be that some quite different structure is preferable or that different structures are required to model different kinds of battles even at the same level. At the very least, however, the structure presented here provides a framework in which to discuss the relevant issues related to battle decomposition.
- 1.13 The model decomposes a main battle into two lower levels. The first level is made up of a number of sub-battles although if the battle is of a fairly low level e.g. Company versus Platoon, there may only be one such sub-battle. These sub-battles reflect the terrain, force deployments and the commanders' high-level decisions.
- 1.14 The second level consists of a number of minibattles - some taking place in parallel and some taking place in series. The minibattles are the result of statistically decomposing the sub-battles using the results from earlier data analysis. The sub-battles are first split into a series of time frames and a number of independent minibattles then take place within each time frame. Destroyed weapon systems are removed from further consideration and the survivors are free to be sampled again in some future minibattle. A fuller description of how the decomposition process is modelled is given in Chapter 5.

CHAPTER 2

MINIBATTLE CHARACTERISTICS

Introduction

- 2.1 This chapter presents a summary of some of the results obtained in the preceding study [C] which have been used in the prototype model in some way. In that study, using a set of rules and assumptions about the nature of minibattles, several combat trials were examined and decomposed into sequences of minibattles. The resultant minibattles were then analysed for clues as to how they might be modelled, and some important minibattle characteristics were derived.
- 2.2 The combat trials data came from two sets of armour/anti-armour trials held in Europe and the USA. The European trials were part of the Chinese Eye series while the American trials were part of the ARCOMS series.

Rules Used to Identify Minibattles

- 2.3 The set of rules used to define the minibattles consisted of the following :
- a) Only weapons which are firing or being fired at are included in the force ratio for a minibattle. An engagement starts with the first trigger pull.
 - b) An engagement ends when either one side is annihilated or a period of one minute or longer elapses without a trigger pull, or new weapons join the minibattle (see Rules c & d).
 - c) If a weapon, which is not involved in any other minibattle, joins a minibattle less than two minutes after the start of that engagement, then it is counted as part of that minibattle. If, however, it joined in more than two minutes after the start of the engagement, then a new minibattle is started.
 - d) If a weapon which is already involved in one minibattle becomes involved in another, then the two minibattles are amalgamated as one new minibattle.

Force Ratios in Minibattles

- 2.4 Applying these rules to seventeen ARCOMS trials and ten Chinese Eye trials resulted in the following statistics regarding the force ratios in minibattles. Here, the force ratio has been defined as the ratio of attackers to defenders taking part in the engagement i.e. firing or being fired at.

Force Ratio Statistics - Chinese Eye

battle	mini-battles	mean	mode	median	variance	standard deviation
4	29	1.42	1	1	0.68	0.83
5	19	2.29	1	2	2.23	1.49
6	23	1.04	1	1	0.26	0.51
7	22	1.79	1	1.5	0.91	0.95
8	26	1.79	1	1.5	1.61	1.27
12	26	2.41	1	2	2.92	1.71
13	8	2.63	1	2	3.41	1.85
14	14	2.14	2	2	1.36	1.17
18	38	1.64	1	1	1.45	1.20
19	50	1.65	1	1	1.14	1.07

Table 2.1

Force Ratio Statistics - ARCOMS

battle	mini-battles	mean	mode	median	variance	standard deviation
11	26	1.71	1	1	1.67	1.29
12	7	1.04	1	1	0.28	0.53
13	17	1.63	1	2	0.55	0.74
14	20	1.13	1	1	0.44	0.66
15	21	1.43	1	1	0.54	0.73
16	26	1.59	1	1	1.25	1.12
17	18	1.61	2	1.5	0.67	0.82
18	18	1.19	1	1	0.32	0.57
19	20	1.50	1	1	1.11	1.05
20	23	1.35	1	1	0.35	0.59
21	24	2.01	1	2	1.45	1.20
22	14	1.18	1	1	0.24	0.49
23	17	1.99	1	2	1.05	1.03
24	16	1.42	1	1	0.49	0.70
25	37	1.61	1	1.5	0.71	0.84
26	21	1.24	1	1	0.47	0.69
27	16	1.55	1	1	1.33	1.15

Table 2.2

- 2.5 The overall mean minibattle force ratio (defined as the ratio of attackers to defenders) for the Chinese 1/e trials was 1.78 with a standard deviation of 1.24. The corresponding figures for the ARCOMS trials were 1.50 and 0.92.
- 2.6 Guided by the work of Rowland [B], an attempt was made to relate the mean minibattle force ratio in a battle to the mean separation of defending weapon systems.
- 2.7 Rowland pointed out that the relationship between density of forces and mean local odds was strongly influenced by phenomena which he described as lateral division of defence and longitudinal division of attack. The former occurs when the attack is concentrated at a particular point - usually on a flank - and the defending force is divided by an obstacle or terrain feature. This results in a fraction of the defending force being unable to engage the attacking units and a rise in the local force ratio. The latter occurs when the attacking force is engaged while advancing across a series of transverse ridges and leads to a reduction in the local force ratio.

Force Sizes in Minibattles

2.8 In addition to examining the force ratios in minibattles, the individual force sizes of attackers and defenders making up the minibattles were also studied. It was found that the distributions of attacker (red) and defender (blue) force sizes both followed negative binomial distributions. In most cases, in fact, they followed the special case of the geometric distribution.

2.9 The negative binomial distribution is a discrete distribution with probabilities given by :

$$\text{prob}(j) = \binom{k+j-1}{j} p^k (1-p)^j ; j = 0, 1, 2, \dots$$

where j is the discrete random variable, k is a distribution parameter known as the 'No. of successes' and p is a distribution parameter known as the 'event probability'.

2.10 The geometric distribution occurs when $k=1$ and its set of probabilities are therefore given by :

$$\text{prob}(j) = p(1-p)^j ; j = 0, 1, 2, \dots$$

2.11 Figures 2.1 and 2.2 show the distributions of red and blue force sizes, respectively, in minibattles from the Chinese Eye trials. Figures 2.3 and 2.4 show the corresponding distributions from the ARCOMS series of trials. The histograms represent the observed frequencies of force sizes while the overlaid curves represent the expected frequencies given by the geometric distribution. The parameters of the geometric distributions were estimated from the sample data and the goodness of fit was confirmed in each case by chi-squared tests.

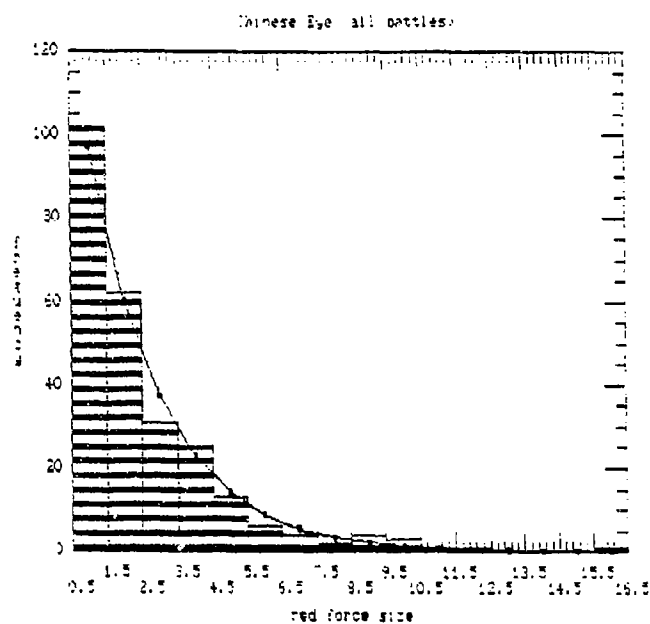


Figure 2.1

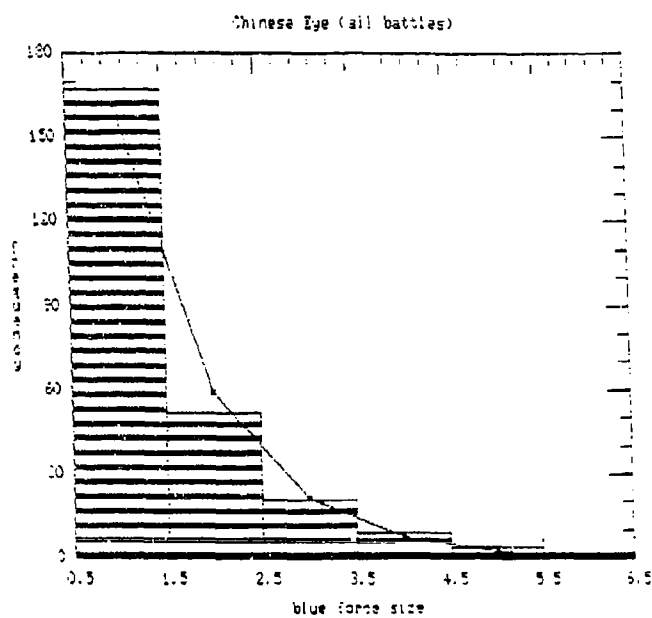


Figure 2.2

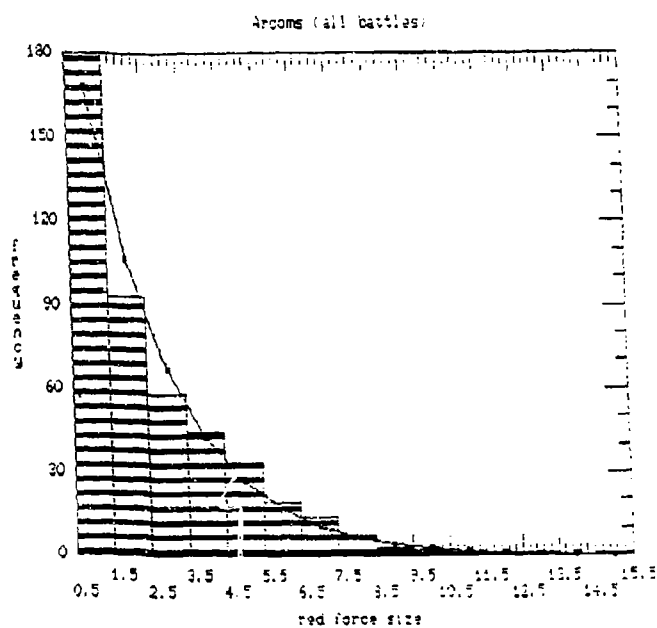


Figure 2.3

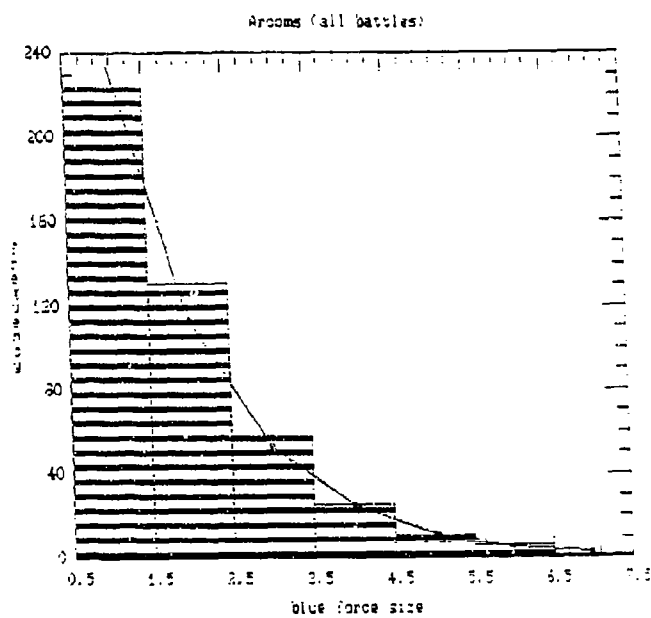


Figure 2.4

2.12 It is evident, then, that the majority of minibattles involve only small numbers of weapon systems. Table 2.3 shows the frequency of occurrence of small minibattles where we have defined 'small' as being up to two weapon systems on either side.

Frequency of Occurrence of Small Minibattles

	<u>Chinese Eye</u>	<u>ARCOMS</u>
	%	%
1 on 1	35	32.5
2 on 1	22	16
2 on 2	4	7.5
Total	61	56

Table 2.3

Conditional Force Size Distributions

2.13 It was also found that the size of the red force in minibattles was conditional on the size of the blue force and vice versa. Examining the frequencies of red force sizes in minibattles with the same blue force size showed that the conditional red force size also followed the negative binomial distribution but that the parameters of the distribution changed as the value of the blue force size considered increased. Figure 2.5 contains a histogram showing the distribution of red force sizes in all of the Chinese Eye minibattles with a blue force size of one. Figure 2.6 contains a similar histogram for a blue force size of two. Plots of the corresponding geometric distributions have again been overlaid and chi-squared tests can confirm the goodness of fit. Similar results were produced for a blue force size of three but for higher values, there were too few minibattles to provide a large enough statistical sample. Clearly, however, as the blue force size in a minibattle increases, so does the mean value of the conditional red force size distribution.

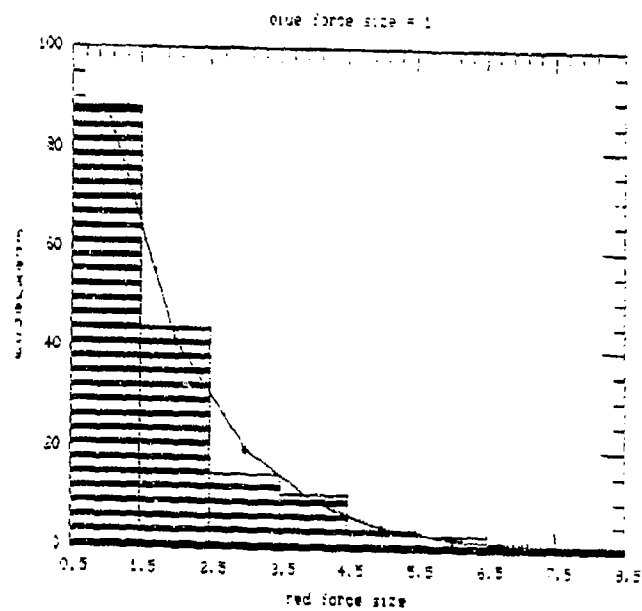


Figure 2.5

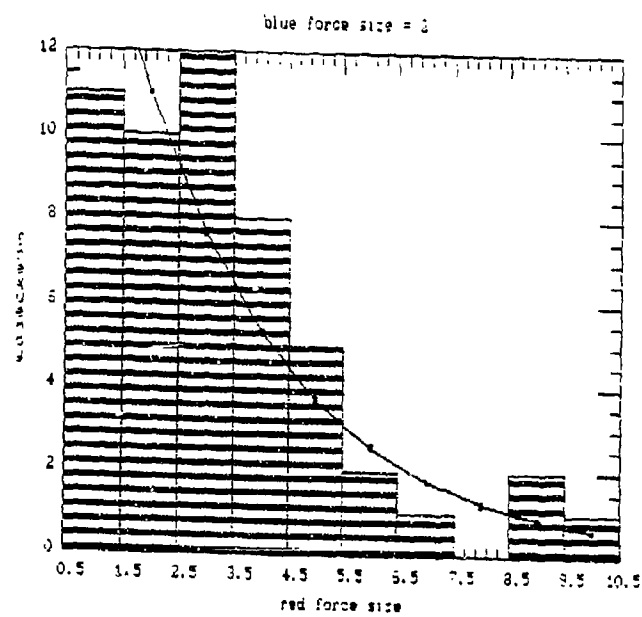


Figure 2.6

Minibattle Durations

- 2.14 There was some variation in the mean duration of minibattles from scenario to scenario which was only to be expected since there were variations in terrain, visibility and deployments in all of the scenarios which clearly affect the mean exposure durations. Nonetheless, minibattle durations appear to follow negative exponential distributions.
- 2.15 No significant trend in minibattle duration as a function of battle time was apparent.

CHAPTER 3

DATA ANALYSIS

Introduction

- 3.1 The results presented here were obtained by analysing data from the ARCOMS series of armoured combat trials held at Fort Hood, Texas. A total of twenty-four separate battles were studied.
- 3.2 An area of particular interest was the distribution of firing activity among weapon systems, in terms of both how the involvement of individual weapon systems was distributed and how the level of total activity displayed by each side varied as the battle progressed.

Definitions of Activity

- 3.3 The level of activity or involvement that a weapon system displays during a battle can be defined in more than one way. A very strict definition might only include the time spent engaging enemy weapons i.e. the time spent firing and preparing to fire. A less strict definition might also include the time spent trying to detect an enemy weapon at which to fire. Less strict still, if it is really the level of a weapon system's involvement in a battle that is of interest then surely the time that a weapon spends under attack, i.e. being fired at, must be included as well. Consequently, we have two different types of involvement (or activity) which are defined as follows.
- a) aggressive activity, where the weapon system in question is firing or preparing to fire
 - b) passive activity, where the weapon system in question is simply a target i.e. it is being engaged by an enemy weapon but is not firing itself.
- 3.4 Naturally, the case will often arise where a weapon system is both firing and coming under fire at the same time. For our purposes, however, such a situation has been included in the category of aggressive activity.

Whole Force Activity Levels

- 3.5 Having now defined what is meant by activity, Figure 3.1 shows the variations in the mean number of weapon systems on each side involved in aggressive activity as functions of elapsed battle time. These figures, and all the other figures presented here unless otherwise stated, have been averaged over the twenty-four separate battles.

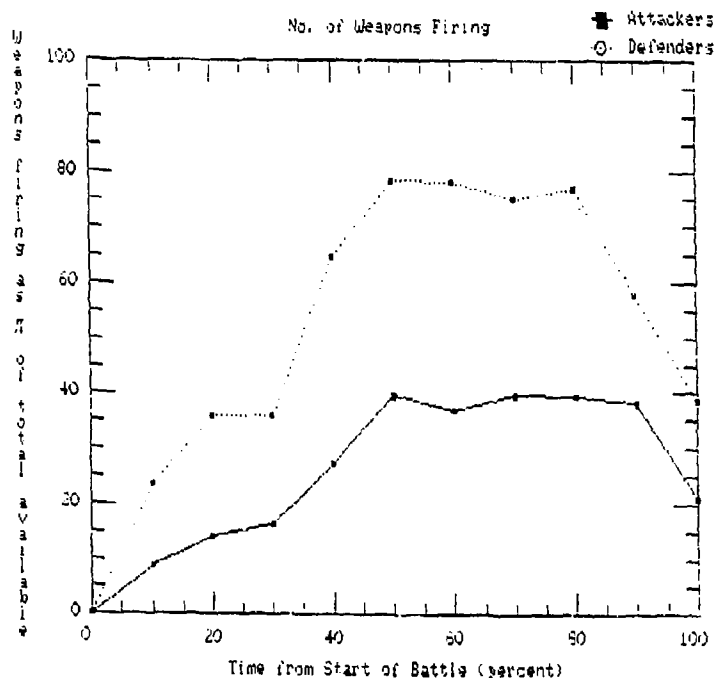


Figure 3.1

- 3.6 In order to find comparable results from each of the battles analysed, the fact that each battle lasted for a different length of time had to be taken into account. This was achieved by splitting each battle up into ten time zones covering the entire battle from first shot to last. Within each battle, the time zones are of equal length but obviously this length varies from battle to battle. Hence, the X-axis on the above graph shows elapsed battle time as a percentage rather than as an explicit time.
- 3.7 The graph shows the number of weapon systems involved in aggressive activity as a percentage of the total number available at that time i.e. for each time zone, the number of

weapons firing at least one shot in that time zone was recorded for each battle and these numbers were then summed over all the battles and divided by the total number of survivors in that time zone to give the values displayed.

- 3.8 In order to resolve queries concerning the proportion of available time that is actually spent engaging the enemy at various stages of a battle, Figure 3.2 shows the fraction of total time spent in the aggressively active state as a function of elapsed battle time. These results take into account the lengths of engagement sequences unlike those in Figure 3.1 which treat all firing events occurring in the same time zone the same regardless of their length. Like Figure 3.1, Figure 3.2 also takes account of the varying number of survivors when calculating the total time available for action in each of the time zones.

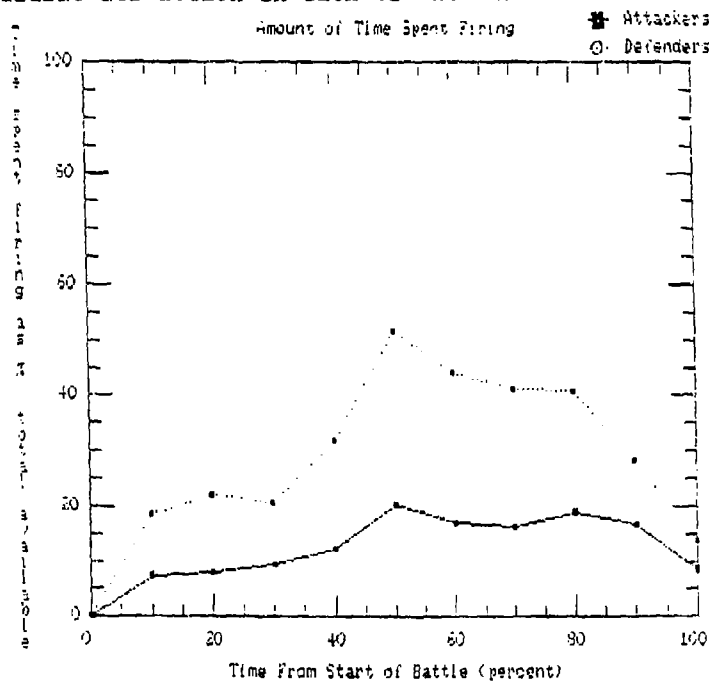


Figure 3.2

- 3.9 Figure 3.3 shown below corresponds to Figure 3.1 in that the values plotted are the numbers of weapons actively involved as proportions of the total number of weapons available in each time zone. However, the definition of activity has now been broadened to include passive activity as previously defined i.e. the time spent being shot at without returning fire.

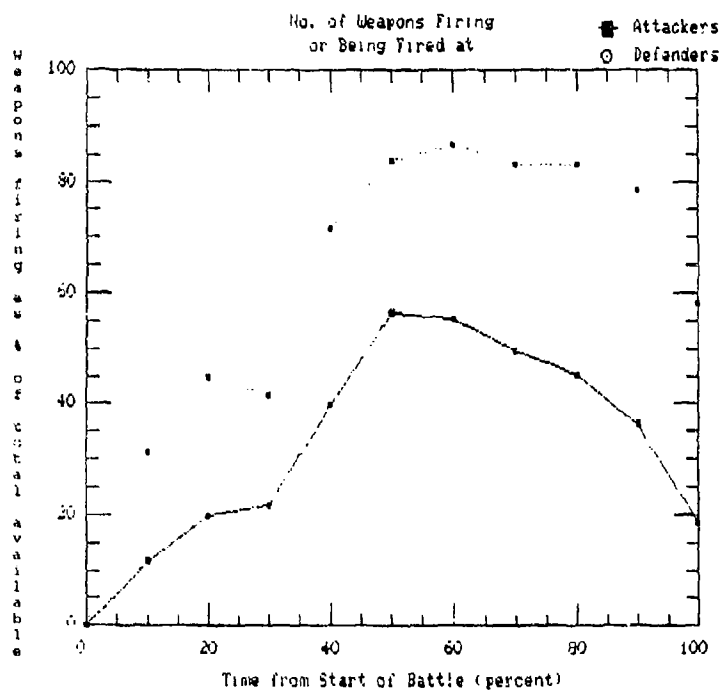


Figure 3.3

3.10 Likewise, Figure 3.4 corresponds to Figure 3.2 in that the values plotted show the time spent in an active state as a proportion of the total time available in each time zone but again the definition of activity has been changed to include passive activity as well.

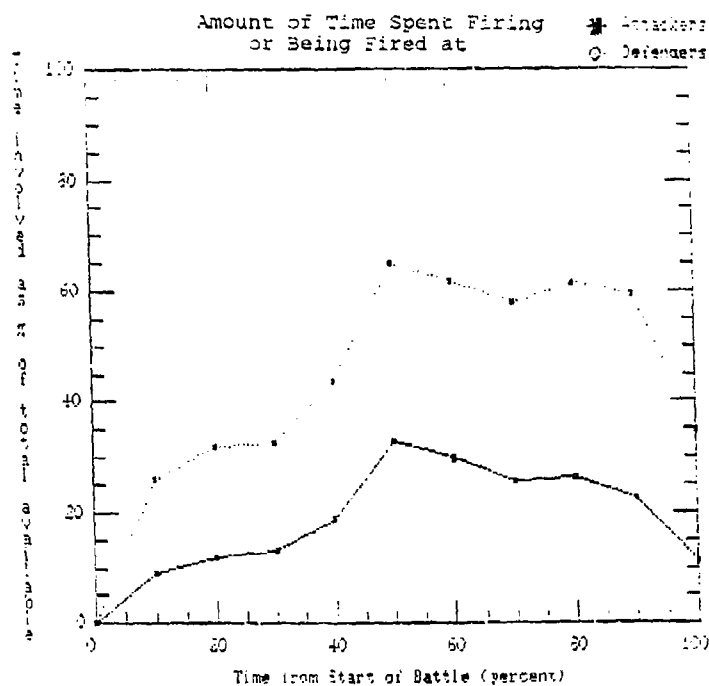


Figure 3.4

Activity Times of Individual Weapon Systems

3.11 Now turning our attention to the total time spent in an active state by an individual weapon system during a battle, Figures 3.5 and 3.6 show the distributions of the total time in seconds that individual weapon systems spent aggressively involved in a battle. Figure 3.5 corresponds to attacking forces and Figure 3.6 to defending forces.

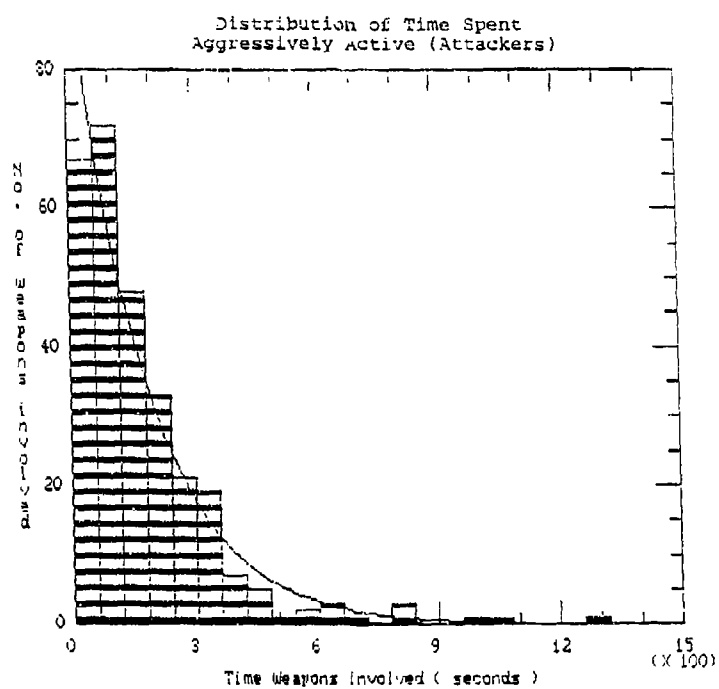


Figure 3.5

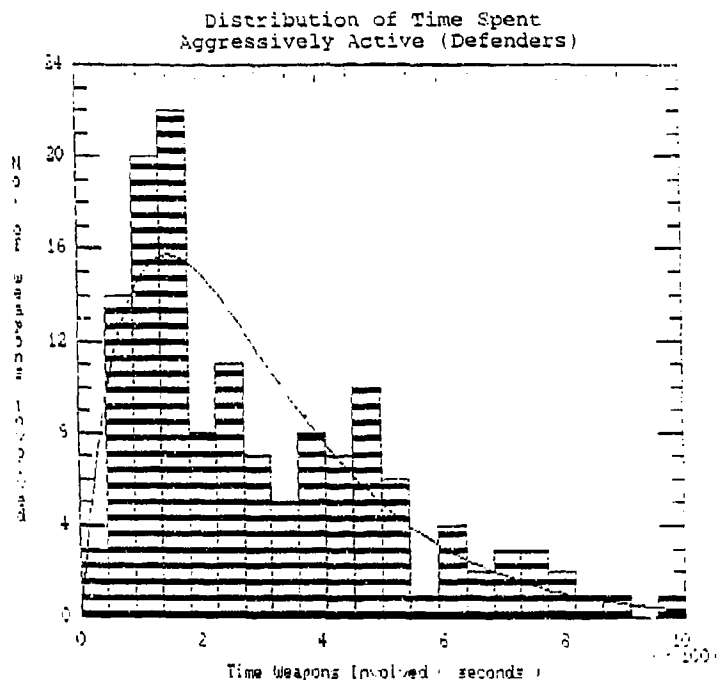


Figure 3.6

- 3.12 The distribution of time spent in the aggressive state by individual attackers appeared to follow the negative exponential distribution with a mean of 175 seconds. The defenders' time distribution, however, seemed to follow the two-stage Erlang distribution with a mean of 297 seconds. Overlaid plots of these probability distributions appear on the graphs for comparison. The chi-squared tests shown in Tables 3.1 and 3.2 confirm the goodness of fit given by these distributions at the 5% level.

Chi-square Test

	Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chi-square
at or below	60.00	60.00	67	93	3.0529410
	60.00	120.00	72	59	2.3680940
	120.00	180.00	48	42	.9558438
	180.00	240.00	33	30	.4002737
	240.00	300.00	21	21	.0000733
	300.00	360.00	19	15	1.1514597
	360.00	420.00	7	11	1.1885230
	420.00	480.00	5	7	.8185161
	480.00	540.00	1	5	3.4879072
	540.00	660.00	5	6	.3148986
above	660.00		7	6	.0393313

Chi-square = 14.3779 with 9 d.f. Sig. level = 0.109504

Table 3.1

Chi-square Test

	Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chi-square
at or below	45.45	45.45	4	5	.34501
	45.45	90.91	14	12	.24572
	90.91	136.36	20	15	1.54865
	136.36	181.82	22	16	2.55719
	181.82	227.27	3	15	5.16667
	227.27	272.73	11	13	.42534
	272.73	318.18	7	12	1.36177
	318.18	363.64	5	10	1.43370
	363.64	409.09	3	3	.00913
	409.09	454.55	7	7	.00517
	454.55	500.00	10	5	1.57736
	500.00	590.91	7	3	1.13815
	590.91	681.82	6	5	.15810
above	681.82		11	3	1.17637

Chi-square = 17.6489 with 11 d.f. Sig. level = 0.09094

Table 3.2

3.13 Broadening our definition of activity again to include aggressive and passive activity, Figures 3.7 and 3.8 show the new distributions that result. Figure 3.7 corresponds to attackers and Figure 3.8 to defenders.

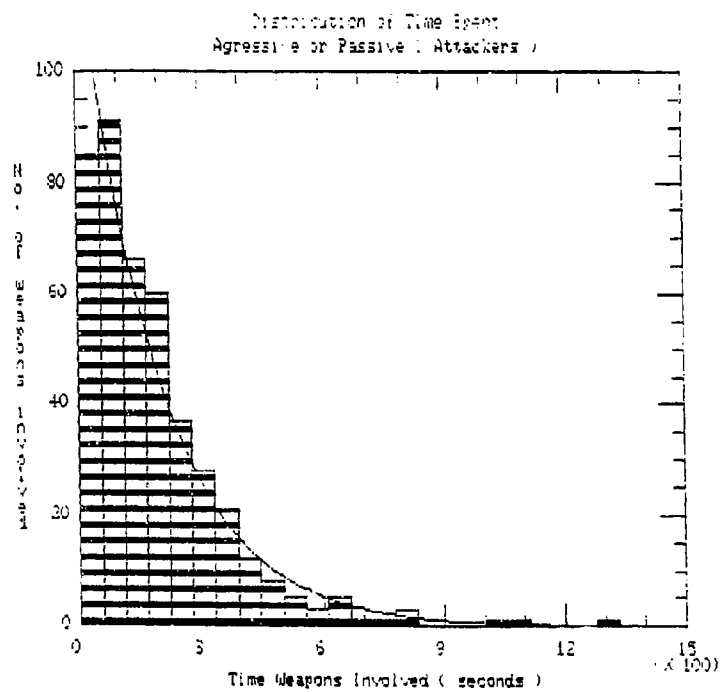


Figure 3.7

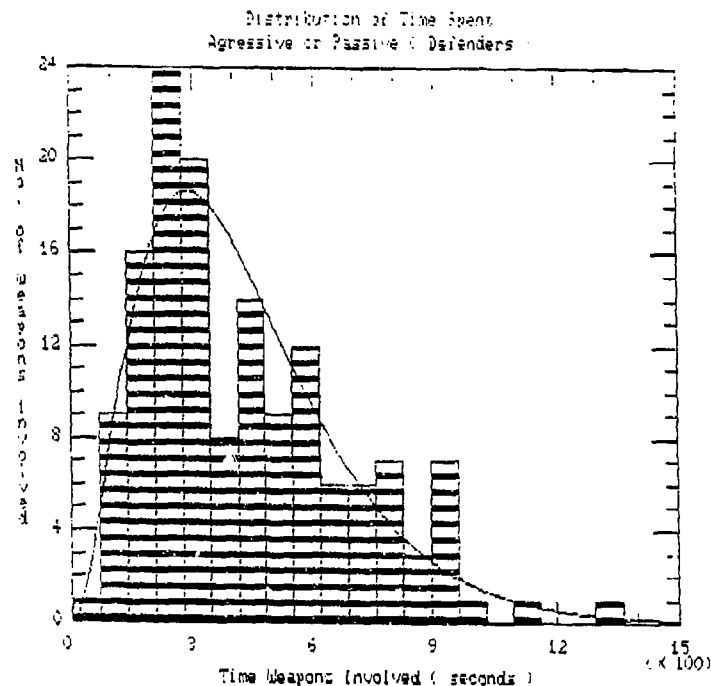


Figure 3.8

3.14 The distribution of time spent either aggressively or passively active by attackers was still approximated by negative exponential distribution - this time with a mean 187 seconds. The new results for the defenders, however, were now fitted by a three-stage Erlang distribution reflecting the generally greater level of involvement expected. The mean value this time was 430 seconds. Again overlaid plots of these probability distributions appear on the graphs for comparison and the corresponding chi-square tests are shown in Tables 3.3 and 3.4. They confirm goodness of fit of these distributions to the results at 5% significance level.

Chisquare Test

	Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below		55.56	95	110	5.800
	55.56	111.11	91	82	1.002
	111.11	166.67	66	61	.432
	166.67	222.22	60	45	4.829
	222.22	277.78	37	34	.345
	277.78	333.33	28	25	.371
	333.33	388.89	21	19	.326
	388.89	444.44	12	14	.229
	444.44	500.00	8	10	.437
	500.00	555.56	5	8	.891
	555.56	611.11	3	6	1.241
	611.11	666.67	6	7	.236
above	666.67		7	9	.447

Chisquare = 16.637 with 11 d.f. Sig. level = 0.119082

Table 3.3

Chisquare Test

	Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below		136.36	10	10	.01487
	136.36	204.55	16	15	.10889
	204.55	272.73	24	18	2.01102
	272.73	340.91	20	19	.11908
	340.91	409.09	8	17	4.93303
	409.09	477.27	14	15	.06161
	477.27	545.45	9	12	.92673
	545.45	613.64	12	10	.44782
	613.64	681.82	6	8	.36942
	681.82	750.00	6	6	.00460
	750.00	818.18	10	8	.79684
above	818.18		10	8	.59201

Chisquare = 10.3859 with 9 d.f. Sig. level = 0.320156

Table 3.4

CHAPTER 4

ATTRITION METHODOLOGIES

An Inter-Kill Time Based Model

- 4.1 Many combat models, particularly the simulation type models, work by generating values for a host of physical variables such as time until detection, time for the next shot to land, etc. These values are usually generated by random sampling from appropriate distributions. Similarly, the resolution of chance events such as the outcome of a shot being fired at a target is achieved with the aid of pseudo-random numbers. The larger the number of physical variables which need to have random values generated for them and the more chance events which need to be resolved, the slower the model becomes.
- 4.2 It is probably fair to say, however, that the most significant events for most purposes are the kills. Consequently, designing a combat model which generates inter-kill times directly rather than one which generates a variety of other times and then seeks to manipulate these, is likely to result in a faster model. Furthermore, much of the detail of the other models could still be incorporated in an inter-kill time (IKT) based model by taking proper account of the components contributing to the times between successive kills for individual weapon systems.
- 4.3 Given the requirement for a fast attrition routine to resolve few-on-few combat, it was decided to build one based on the inter-kill time approach.

Notation

- 4.4 In order to describe this attrition routine, the following notation is introduced.

P_{ij} : single shot kill probability for a blue weapon of type i firing at a red weapon of type j
 P_{ji} : single shot kill probability for a red weapon of type j firing at a blue weapon of type i
 s : number of shots fired by an individual blue weapon before killing its target

s'' : number of shots fired by an individual red weapon before killing its target
 n : first parameter of the Erlang(n,v) distribution
 v : second parameter of the Erlang (n,v) distribution
 m_i : detection rate of blue weapon type i
 m''_j : detection rate of red weapon type j
 h''_j : probability that a red weapon of type j detects a blue weapon by firing signature from a single shot
 f_i : firing rate of blue weapon type i
 f''_j : firing rate of red weapon type j
 B : total number of blue weapon systems at battle start
 R : total number of red weapon systems at battle start
 b_i : number of blue weapon systems of type i
 r_j : number of red weapon systems of type j

Procedure

- 4.5 A brief explanation of the procedure will now be given before considering each of its aspects in turn.
- 4.6 The procedure works by generating a value of 'time until next kill' for each weapon system taking part in the engagement. Obviously not all of these kills will be realised as some weapon systems will be destroyed before being able to carry out their kills while others will find the targets they were firing at destroyed sooner by other weapon systems firing at the same targets. The next kill is achieved by the weapon system whose kill will occur next earliest in battle time.
- 4.7 As soon as a kill occurs, the destroyed weapon is removed from the battle and the kill it was due to make no longer takes place. The weapon system achieving the kill and any other weapon systems firing at the same target are then allocated new targets and have completely new inter-kill times generated for them. The time that the kill occurred serves as the epoch from which these new inter-kill times are considered. These weapons then have their new 'kill due' times calculated and compared with the still valid 'kill due' times of all of the other weapons. The earliest 'kill due' time determines the next kill to take place and the

whole process is repeated again and again until some terminating condition is finally reached. The terminating condition may consist of one side's annihilation or the achievement of a pre-set level of casualties such as 50% or the passage of a pre-set time limit.

- 4.8 In order to understand the procedure better it is necessary to understand how the inter-kill times are generated.

Detection Times

- 4.9 Each inter-kill time consists of two components - a detection time and a firing time. First we consider the detection time. A defending weapon system is generally concealed and stationary while an attacking weapon system is generally exposed and moving. This results in two different detection processes. While defenders will be able to detect attackers by their movement, attackers will only be able to detect defenders by spotting their firing signatures. Hence, for defenders a detection time can be generated by sampling from the negative exponential distribution with a suitable parameter as this is the standard method used for detection by movement. The only problem that remains is in fixing the size of the movement parameter. Things are not so straightforward when we consider the attackers, however.

- 4.10 An attacker of type j detects a defender firing a single shot with probability h_j . In a simulation, a random number would be generated for each attacker trying to detect a defender after every shot fired by a defender. If the random number was less than h_j , the detection event would occur, otherwise it would fail. To adopt this approach, however, would require the time of every firing event of every defender to be recorded and not just the inter-kill times. Moreover, a large number of random numbers would have to be generated and compared with the shot detection probabilities. Clearly if an IKT-based approach is to be faster than a simulation it must avoid this level of detail and find an aggregated way around the problem.

- 4.11 The aggregated approach that has been taken is to assume that the detection rate of an attacking weapon system of type j is equal to the product of its shot detection probability h_j and the total firing rate of the defenders ie.

$$m''_j = h_j \sum_i b_i f_i$$

Obviously if there was only one type of defending weapon system, this would simplify to

$$m''_j = B f h_j$$

The mean detection time of an attacking weapon system of type j is then found by simply taking the reciprocal of m''_j ie.

$$\text{Mean detection time} = 1/m''_j = 1/(h_j \sum_i b_i f_i)$$

Detection times for attackers can then similarly be sampled from the negative exponential distribution with m''_j as the parameter of the distribution.

Target Allocation

- 4.12 Having now found a way of generating a detection time for each weapon system, the next problem to consider is that of target allocation. We shall only consider simple allocation rules based on spreading fire as evenly as possible over the enemy weapon systems. For the attacker, however, this may be too simplistic as his detection of a target is dependent on the firing rates of the defenders and if the defenders have more than one type of weapon, each with a different firing rate, this will obviously influence the probability that a particular attacker will detect a particular defender. In such cases then, an appropriate weighting could be given to each type of defending weapon system such as :

$$b_i f_i / \sum_i b_i f_i, \quad i = 1, \dots, n$$

where there are n defending weapon types.
Fire would still be spread evenly within each weapon type.

Firing Times

- 4.13 Now the second component of the inter-kill time must be considered - the firing time. Remember that this is not the time it will take to fire just one shot but the time it will take to fire as many shots as are necessary to kill the target. Consequently before a firing time can be generated it is necessary to know the number of shots that will be fired to achieve the kill.
- 4.14 The value we are seeking is clearly an integer from the discrete geometric distribution given by :

$$p, (1-p)p, (1-p)^2p, (1-p)^{n-1}p, \dots$$

where p is the single shot kill probability.

We can sample a suitable random value from this distribution by firstly generating a pseudo-random number r from the uniform $(0,1)$ interval.

The lowest value of s satisfying

$$\sum_{n=1}^s p(1-p)^{n-1} > r$$

will be the correctly sampled number of shots fired to achieve the kill.

- 4.15 Now it is possible to generate the total firing time since the distribution of the time to fire a single shot is known and the number of shots that will be fired to achieve the kill is also known. The pdf of the Erlang (n,v) distribution is given by :

$$f(t) = v(vt)^{n-1} e^{-vt} / (n-1)!$$

Random variables from this distribution can be thought of as being the sum of n random variables from the negative exponential distribution with mean $1/v$. Hence the mean of the Erlang distribution is n/v . This is the mean time taken to fire a single shot. So if s shots are to be fired, either ns random variables can be summed from the negative exponential distribution with parameter v or s random variables can be summed from the Erlang (n,v) distribution or one random variable can be sampled from the Erlang (ns,v) distribution.

- 4.16 Using the above methods, inter-kill times are generated as required and the battle proceeds until some terminating condition is met. When used to model minibattles suitable terminating conditions would be the annihilation of one side or the passage of a pre-set time limit. In this way a relatively fast attrition routine can be obtained.

Stochastic Duel Models

- 4.17 In recent years, much research effort has been directed towards finding analytic solutions to small-scale engagements, or duels. This work was inspired by the realisation that both the deterministic and stochastic forms of the Lanchester equations were unsuitable for modelling combat involving only small numbers of weapon systems [E].

- 4.18 Prominent in this field has been the work of Ancker and Gafarian and some of their colleagues who have so far published analytic solutions for the one-against-one, the two-against-one and the two-against-two duels [F,G,H]. One of their main criticisms of the Lanchester-type models is the inherent assumption that weapon systems' inter-firing times are distributed negative exponentially. In the stochastic duel models, this is replaced by a more general function.
- 4.19 There are three drawbacks to using these particular analytic models in the prototype model developed. Two of these are modelling issues while the third is a computing problem. Firstly the analytic solutions which have been derived assume that all inter-firing times are independent. Given a scenario where the defender is concealed, however, and the attacker therefore detects the defender by firing signature, the attacker's firing times would clearly be dependent on the defenders'. Secondly, the engagement sequence only ends when a breakpoint is reached defined by the number of survivors remaining. There is no possibility of the engagement being terminated due to line-of-sight break. The third point is a practical one - namely, the amount of computing time quoted for obtaining solutions to the two-on-two duel.
- 4.20 This is not to say, however, that these particular models could not have a role to play in modelling minibattles. If they could be extended to incorporate a time limit as an additional parameter and could also take some account of firing dependence when one side is concealed, then they could be used directly as pre-processors. The larger the number of different weapon types, however, the more cases would have to be considered and the more time would have to be spent pre-processing. Similarly, the more variable input parameters (eg. maximum time limit) included in the calculations, the more cases there would be to consider for every potential combination of weapon types.
- 4.21 Before becoming disheartened by this seeming proliferation of pre-processing, however, it should be borne in mind that this would be a one-off investment in computing time paying dividends later in the form of faster resolution of attrition in minibattles. The main model could simply reference look-up tables in a data file to obtain the set of probabilities of all possible outcomes pertaining to the minibattle under consideration. These discrete probabilities could then be used to sample the outcome of the minibattle.
- 4.22 Naturally, most of the input parameters considered in the analytic solution are continuous variables. Consequently, it would be necessary to choose a set of discrete values for

each of these parameters for use in a series of analytic solutions. Situations requiring intermediate values of these parameters would then be resolved by interpolation. Care would have to be taken to ensure that a large enough range of values had been considered for each variable and that the intervals between the discrete points chosen were small enough to allow accurate interpolation. Should any value arise falling outside the range considered for that parameter, extrapolation of results should be avoided as it is often dangerous. Instead the range of that parameter for which analytic results have been obtained should be enlarged to include the new value.

- 4.23 The alternative to an analytic pre-processor is, of course, a simulation-based pre-processor. Exactly the same procedure would be gone through in terms of selecting sets of discrete values to obtain initial results from and then employing interpolation. Likewise, the same procedure would be used to sample the outcomes of minibattles from look-up tables in the computer compiled by the pre-processor. The only difference would be in how the pre-processing was done. Instead of running an analytic model once for each data set, a simulation model would have to be run thousands of times for each data set. Given the small number of weapon systems involved, however, the time factor should not prove prohibitive. Indeed, it may not be that much slower than the equivalent analytic model.

'Matador' - A One-on-One Duel Model

- 4.24 'Matador' is a model of the one-on-one duel developed by Wand [I,J]. It exists in both analytic and simulation forms and the simulation version has been modified and incorporated into the prototype model as an attrition routine for one against one minibattles.
- 4.25 This attrition routine considers an engagement between two weapon systems in terms of various key attributes which are represented by a number of parameters describing the detection time distributions, the inter-firing time distributions and the single shot kill probabilities. An engagement continues until one side is killed or a pre-set time limit is reached. The time limit represents the ending of a line-of-sight between the two weapon systems.
- 4.26 Results from running the simulation with the data set in Table 4.1 are shown in Figures 4.1 to 4.3. These show the

effect that the minibattle duration has on the probabilities of the various outcomes.

- 4.27 This data set is not intended to be realistic and is used for comparative purposes only. For each different value of minibattle duration, 5000 replications of the model were run.

	<u>Defender</u>	<u>Attacker</u>
Mean detection time	12s	100s
Mean time for 1st shot to land after detection	8s	10s
Mean time for subsequent shots to land	4s	5s
Probability of detecting by firing signature	0.2	0.2
Single shot kill probability	0.2	0.2
Max. No. of shots fired before jockeying	4	4

Table 4.1

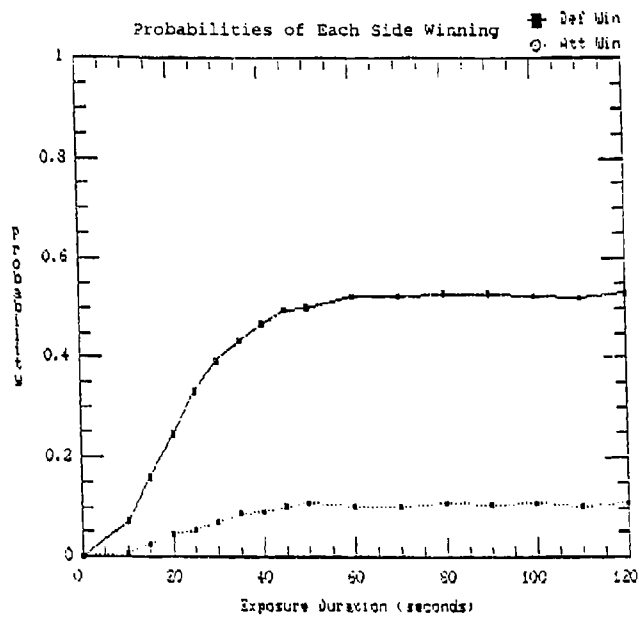


Figure 4.1

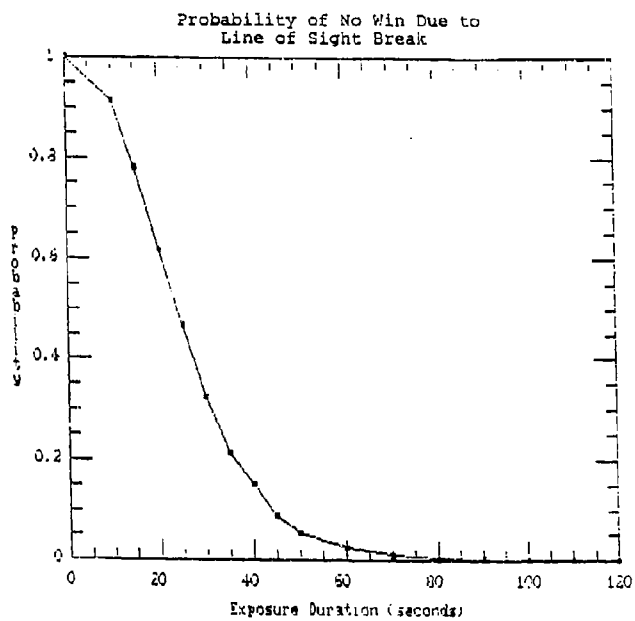


Figure 4.2

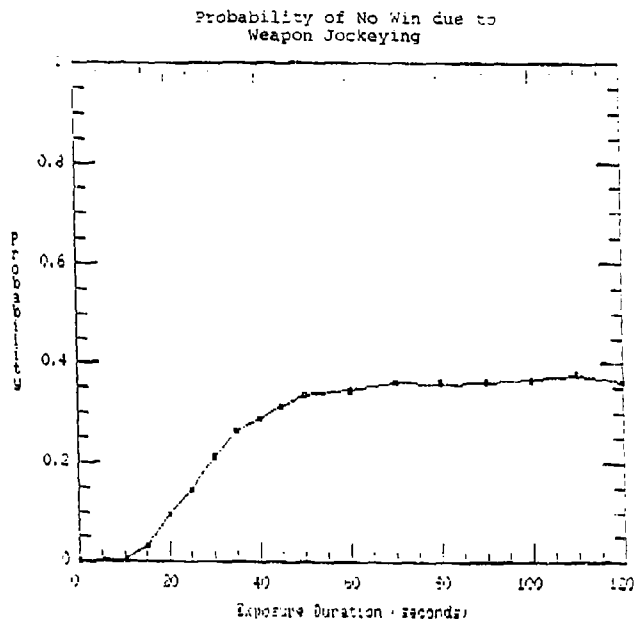


Figure 4.3

4.27 If a large number of replications were going to be performed, then it would probably be worthwhile running the analytic version of 'Matador' as a pre-processor. The outcomes of the duels could then simply be sampled from fixed probabilities of either side winning or of no win occurring. The main problem with this approach is in incorporating the maximum time parameter representing line-of-sight break in the analytic formulation. While possible, the analytic model does not yet exist in this form. As stated before, however, pre-processing could still be undertaken with simulation models although these would need to be run thousands of times for each data set in order to generate reliable figures for sampling.

CHAPTER 5

OUTLINE DESCRIPTION OF THE PROTOTYPE MODEL

Introduction

- 5.1 The prototype model that has been developed is intended for use up to the level of attacking regiment versus defending battlegroup. Detailed data at this level of combat was not available, however, and the data analysis which has been performed involved combat at lower levels.
- 5.2 The model decomposes a main battle into two lower levels (assuming that the battle is large enough.) The first of these levels is made up of what have been termed 'sub-battles' while the second level consists of a number of minibattles. Both of these concepts are defined and discussed below.
- 5.3 Fairly detailed scenario data are required in order for the model to run and these data are read from input files created beforehand by the user running set-up programs.
- 5.4 The model is written in FORTRAN 77 and should be able to run on any IBM compatible PC.

Sub-Battles

- 5.5 A sub-battle is essentially a component of the main battle comprising a number of engagements within an identifiable and predictable area over a predictable time period. The number, size and nature of these sub-battles as well as their locations (both spatially and temporally) are mainly the result of high-level factors such as the positions taken up by the defenders, the axes of advance selected by the attackers, the terrain being fought over and the tactics employed by either side. It is evident that many of these factors can be grouped together under the heading of 'command decisions' and it is asserted, therefore, that the first level decomposition of the battle is largely deterministic and heavily influenced by the commanders on either side. The identification of these sub-battles should therefore be a matter for military judgement.

5.6 Sub-battles occur over a wide range of space and time. The more dispersed the main battle is, the easier they are to identify. Sub-battles taking place at the same time are independent in that weapon systems within a given sub-battle can only engage and be engaged by other weapon systems in the same sub-battle but weapon systems can leave one sub-battle and join another provided that this course of action was indicated by the model user at the beginning. The nature of the scenario will determine the extent to which forces flow between sub-battles. Different initial deployments made by the commanders will usually result in different sets of sub-battles and different flow patterns between the sub-battles. These flows can be parallel or serial in nature ie. forces may flow from one ongoing sub-battle to another or stay in a sub-battle until its completion and then join a new one at some later time. It is possible to think of the main battle as consisting of a network of sub-battles.

5.7 Should careful study of the scenario reveal that the initial set of sub-battles chosen was likely to result in too much restriction by virtue of the independence assumption, then some of the sub-battles could be amalgamated into larger ones. Sub-battles can range in size from a very few to a very large number of participating weapon systems.

Time Frames

5.8 A sub-battle begins with the decision to engage the enemy, often some time after the first opportunity to do so has occurred and ends either when one of the sides is annihilated or when the forces can no longer engage each other. The lifetime of a sub-battle is split into a series of time frames, each of random duration except the last which must be truncated in order that its end coincides with the end of the sub-battle.

5.9 Since weapon systems can join or leave a sub-battle while it is still ongoing, the start of a new time frame presents a good opportunity to update the number of participants on each side. This is achieved by firstly updating the positions of the weapon groups by taking account of their movement rates and the length of the previous time frame and then comparing those new positions to the points where they enter and leave sub-battles. This has the effect of updating the pools of weapon systems from which the minibattles are sampled.

Minibattles

- 5.10 Within each time frame a number of minibattles take place. As indicated above, the weapon systems taking part in these are sampled from the pools of available weapons updated each time frame.
- 5.11 Each minibattle is fought out until one of the sides is annihilated or until the pre-determined maximum duration is reached. This maximum duration represents the effect of line-of-sight break and is sampled from the negative exponential distribution as this was the distribution followed by minibattle durations in the trials data. Should a minibattle's maximum duration take it past the end of a time frame, then it is truncated so that its end coincides with that of the time frame.
- 5.12 The number of weapon systems taking part on each side of a minibattle are sampled from appropriate distributions. Here, use is made of the earlier data analysis where the minibattle force sizes were found to be well described by negative binomial distributions. The procedure is to firstly sample a blue force size from one distribution and then to sample a red force size from another distribution which is conditional on the result of the blue sample. The reason that an independent sample cannot be made for each force size is that the value of one variable is conditional on the value of the other as was shown in the section entitled 'Conditional Force Sizes' in Chapter 2. The distribution of minibattle force ratios which results from this approach is consequently very similar to that observed in the trials data.
- 5.13 The number of minibattles occurring in each time frame and the number of weapon systems taking part in each one obviously helps determine the amount of firing activity taking place. It is known from the data analysis that not all of the weapon systems still alive on the battlefield will take an active part in the fighting - in fact a very significant proportion of them will not, especially among the attackers. Part of this phenomenon can be explained by the nature of the terrain denying some weapon systems inter-visibility with the enemy. Much of it, however, must be attributed to the tactics presumably adopted by most of the attackers of heading for their objective as fast as possible either without stopping at all or stopping only to fire from the short halt when spotting an enemy firing signature. Whatever the reason for this 'under activity', it is clear that to model a battle under the assumption that every weapon system which can take part will take part is unrealistic. Extending control over how much firing activity occurs in the model can be done in several ways. The method

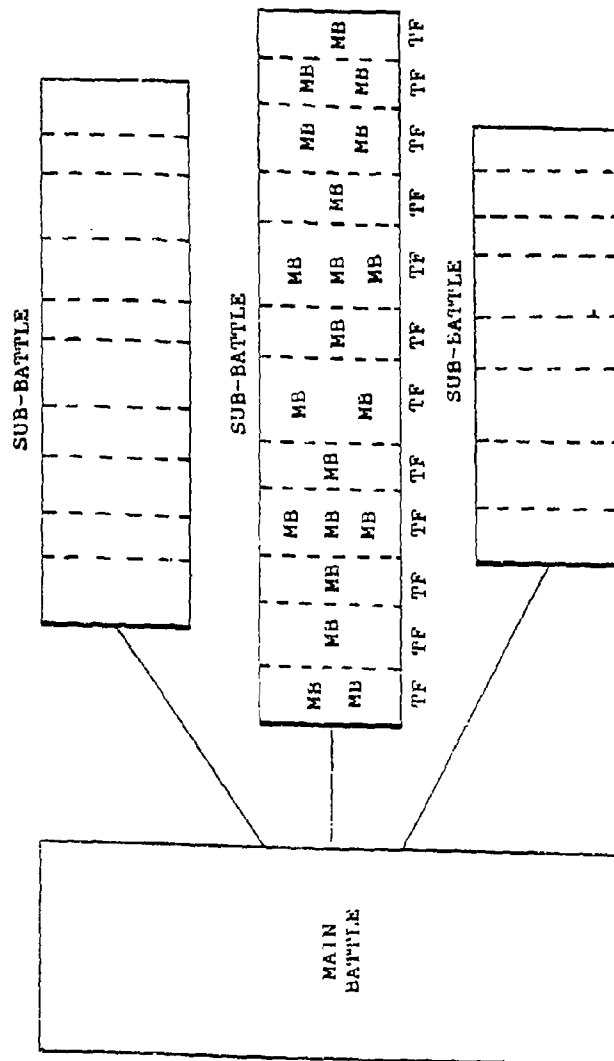
that has been chosen is to sample the number of minibattles occurring in any given time frame. The maximum number of minibattles which can occur in a time frame is simply equal to the number of weapon systems belonging to the smaller of the two pools of available weapons (there is one pool for the attacker and one for the defender). So, for example, if there were four defending weapon systems and ten attacking weapon systems available to fight in a particular time frame, the maximum number of minibattles which could occur would be four - each involving just one defender. Naturally, there could be any number up to four with any number of combatants on each side as long as the total number of participating defenders did not exceed four and the total number of participating attackers did not exceed ten. The number of minibattles is then sampled from the uniform distribution with a lower bound of zero and an upper bound given by the maximum number possible. Force sizes for these minibattles are then obtained by random sampling, obviously with the same constraints on the total numbers involved.

5.14 The time frame lengths are sampled from the uniform distribution with a minimum of two minutes and a maximum of three minutes. This seemed reasonable since they have to be short enough to allow sufficient updating of the weapon systems' positions and hence of the weapon systems available and be long enough to have a few minibattles start and finish at random times within them, though obviously these minibattles may overlap one another since they will not have any weapon systems in common.

5.15 Any weapon systems killed in a minibattle are removed from further consideration. The survivors at the end of one time frame are free to be sampled in future minibattles in future time frames until they leave the sub-battle. Hence weapon systems jump from minibattle to minibattle in a random manner within a sub-battle but their movement between the sub-battles is controlled at a higher deterministic level. Figure 5.1 illustrates the relationships between sub-battles, time frames and minibattles.

Attrition in Minibattles

5.16 Once the force sizes in each minibattle within a particular time frame have been established, the individual weapon systems taking part in each one are randomly selected from the available weapons pools for that time frame. Each minibattle is then resolved in turn. For minibattles consisting of just one weapon system on each side, an attrition routine based on one-on-one duels is chosen but for all other sizes of minibattle, an attrition routine based on inter-kill times is currently employed.



TF TIME FRAME

MB MINIBATTLE

Example of a Main Battle Decomposition

Figure 5.1

Input Files

5.17 The scenario information which the model needs to run is provided by three input files. These files are created by the model user running set-up programs beforehand. The three files contain three separate types of information :

- 1) weapon system characteristics
- 2) composition of weapon groups
- 3) force deployments

5.18 Each set-up program asks the model user questions about one of the above areas. The file on weapon system characteristics includes such information as single shot kill probabilities, firing rates, ranges, etc. The weapon systems are gathered into groups and each group consists of a number of weapon systems of the same type and having the same deployment. The second file contains information regarding the size of each weapon group and the specific weapon systems which comprise them. The third file contains the positions taken up by the blue defending forces and the attack paths followed by the red forces.

5.19 Positional information is entered in the form of six-figure map references. Map squares 1km by 1km are assumed. The defending forces are assumed to be static although they may start somewhere else and then move up to their intended deployment. The attackers are assumed to follow a number of different routes and these are described by straight lines connecting together a number of waypoints. The co-ordinates of these waypoints are entered along with the group's starting time. Some groups will follow the same route but with a time lag between them. The model calculates the time that each of the waypoints is reached by each group by considering the distances involved and the speeds of the groups.

Output Files

5.20 The model is stochastic in nature and therefore requires a large number of replications for each scenario before useful results are obtained.

5.21 Important summary information such as the number of wins achieved by each side and the mean number of survivors on each side are sent to one output file. Information regarding the outcomes of each individual replication are sent to a separate output file.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Data Analysis

- 6.1 It has been shown how the data analysis undertaken in both this study and the previous one [C] helped lay the foundations for the development of a combat model based on the concept of battle decomposition. In order to make the model more generally applicable, however, a wider range of data is required. More combat trials data including specific information on terrain, force posture and force deployments as well as data on trials with different initial force ratios (not just three to one) would help both in determining relationships between scenario parameters and decomposition parameters and in verifying the prototype model.
- 6.2 The analysis of force activity levels has shown that it is not safe for a model to assume that simply because a weapon system has inter-visibility with enemy weapon systems, it can be included in the attrition process until it is killed. The number of weapon systems actively involved in the firing process (and hence in the attrition process) at any given time is often much less than the number of weapon systems available to take part.
- 6.3 Some other areas which have been suggested for possible future analysis include the following [K] :
- a) The effect of C^3 on minibattles.
 - b) The effect of artillery on minibattles.
 - c) Factors affecting the start and end of minibattles.
 - d) The effect of human factors on minibattles.
 - e) The relationship between organizational hierarchies and the weapons involved in minibattles.
 - f) Explicit information on unengaged weapon systems.
 - g) Historical investigation of the higher level spatio-temporal-organizational decomposition.
 - h) The use of Petri nets to model battle evolution.

- 6.4 While detailed testing in order to verify the prototype model's output may result in changes to some of the model's internal parameters, it is not envisaged that there will be any major changes to the model's structure. It may be possible, however, to somehow relate parameters such as the mean minibattle duration to measures of exposure such as the 'In View' and 'Out of View' distributions which can in turn be estimated from scenario parameters [L].

Attrition Methodologies

- 6.5 There are currently two attrition routines incorporated in the model, both of which are stochastic in nature. One is the simulation version of the one-on-one stochastic duel model 'MATADOR', modified to include a time limit to the duel while the other - used for all other sizes of minibattle - is a method based on generating kill times. It is planned to include additional, alternative attrition routines in the future.
- 6.6 It had been hoped to include stochastic duel models for the resolution of attrition in minibattles up to the two-on-two level. However, it appears that the analytic models available do not yet contain two features which we regard as important in the modelling of minibattle attrition. These are a maximum time limit for the engagement and a dependence of the attackers' firing time distribution on that of the defenders when the defenders are concealed. The intention was to use these models as pre-processors, providing the probabilities of all the various outcomes from which individual minibattle outcomes could have been directly sampled. This would have made the model much faster.
- 6.7 This approach is still possible if detailed simulations up to the two-on-two level are used as pre-processors instead of the analytic models. This would lead to more time being spent on pre-processing as a large number of replications would be required for each size of minibattle and for each new scenario. The time that it would take to design and develop these small-scale simulation models would be considerably less than that required to incorporate the necessary additional features in existing analytic models, however.
- 6.8 It is envisaged that another attrition routine such as the one based on inter-kill times would still be required for larger minibattles otherwise too much time would be spent on the pre-processing task. Alternatively, some fast analytic solution to few-on-few minibattles may yet be discovered which, if fast enough, would make the extra pre-processing worthwhile.

Battle Structure

- 6.9 The model imparts a much more explicit structure on a main battle than most other combat models do. It decomposes such a battle into two lower levels.
- 6.10 The first level involves the model user in identifying a suitable set of sub-battles to represent the main battle. The main battle can then be thought of as consisting of a network of these sub-battles with suitable force flows taking place between them. This first level decomposition is deterministic in nature, being the product of known high level factors such as force deployments, terrain and the tactics employed by either side. Ideally, it should be determined with the use of military judgement.
- 6.11 At the second level, each of the sub-battles is decomposed into a number of minibattles. The duration of each sub-battle is split into a series of randomly sampled time frames and within each time frame a number of independent minibattles occur. The second level decomposition is stochastic in nature and utilises the results of the earlier data analysis.
- 6.12 This proposed structure emphasises that a main battle is characterised by high level order - the nature of which is largely determined by the interaction of the two force commanders' decisions - and low level disorder where a host of random elements come into play. These random elements are difficult to account for without performing large numbers of replications and examining the distribution of results.
- 6.13 At the very least, the model provides a framework to examine and discuss various concepts related to battle structure and decomposition.

Data Input

- 6.14 At present the model reads the input information it needs to run from three separate input files created beforehand by the model user. Much of this information is positional data entered by the user in the form of six-figure grid references. These are obtained by studying a map of the proposed battlefield with the intended force deployments marked on it.

6.15 The entry of this information would be considerably enhanced if instead of reading positions from a map and then entering these at the keyboard, the user could deploy groups of forces directly onto a digitised map of the battlefield appearing on his VDU. This would be achieved with the use of a 'mouse'. Such a graphical representation would also aid the user in identifying an appropriate set of sub-battles for the scenario being considered.

6.16 Furthermore, since many scenarios will feature the same weapon systems or at least have some in common, it would be worthwhile creating a small database of weapon systems and their characteristics. This way only the types of weapon systems participating in a particular scenario would have to be entered directly by the user and all of their relevant attributes would be fed automatically from the database to the model.

Widening the Scope of the Model

6.17 It is recommended that in order to consider more complex scenarios, some additional features - not all related to the study of battle decomposition - are included in the model, such as the effects of artillery. Currently this could simply be estimated by some rule of thumb or be calculated in more detail by some indirect fire model, before passing on the reduced starting forces to the decomposition model. Clearly it would be easier if only one model had to be considered. Another battlefield effect not currently accounted for which could be included in the future is that of minefields.

6.18 The role of attack helicopters on the battlefield seems likely to assume increasing prominence in the future. With this in mind, their future incorporation in the model would provide a useful enhancement. The precise nature of their representation, however - whether or not they could somehow be included in the decomposition process, for example - requires a great deal of consideration. Data from combat trials involving helicopters in the battle would undoubtedly help.

Parallel Processing

6.19 The model's structure has parallel aspects to it at both the sub-battle and minibattle levels. Such a structure should make it amenable to the technology of parallel processing. A number of sub-battles or a number of minibattles could then be processed simultaneously, thus reducing the time taken for each replication. It is recommended that the feasibility

of such an approach be investigated with a view to developing a parallel version of the model.

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APPENDIX

USER GUIDE

General Information

- A.1 The Battle Decomposition Model is a direct fire model of combat intended for use up to and including the Blue Battle Group / Red Regiment level. It has been developed as a result of research into the fragmented nature of combat and is intended to permit the testing of various hypotheses concerning the structure of the direct fire battle. No provision has yet been made for the inclusion of indirect fire effects. This is partly because the series of combat trials which provided the data for the study ignored the indirect fire element but is also to allow more straightforward comparisons with other direct fire models (or the direct fire components of models which contain both direct and indirect fire.)
- A.2 The model has been written in FORTRAN 77 on an IBM - compatible PC (Research Machines Nimbus VX) under the MS-DOS operating system (Version 3.2). This PC contains an Intel 80386 processor and a maths co-processor. These are recommended for fast running of the model.

Inputting Data

- A.3 The model has been compiled as a number of separate modules. The first three modules (WEAPON.FOR, GROUP.FOR and DEPLOY.FOR) are concerned with the input data which must be provided by the user in order to run the model. After the user has answered a series of questions, three separate input files are created which the model accesses later. These input files still exist after the model has finished running so if the user wishes to run the model at a later date with the same scenario information, he simply enters the names of the relevant input files when asked.
- A.4 As the names of the modules imply, the first input file is concerned with weapon system characteristics; the second with the composition of weapon groups, and the third with force deployments. These will be discussed in turn.

A.5 When creating a new weapon systems file, the following information is required :

1. A file name - this should not exceed 6 characters and will be automatically appended with the file extension '.WEP'.
2. The number of red and blue weapon types - up to a maximum of 5 on each side.
3. The firing rates in rounds per minute of each red and blue weapon type.
4. The single shot kill probabilities for every firer-target combination.

A.6 When creating a new groups file, the following information is required :

1. A file name - this should not exceed 6 characters and will be automatically appended with the file extension '.GRP'.
2. The number of red and blue groups. A group consists of a number of weapon systems of the same type moving together along the same route at the same time. The maximum number of groups allowed is 30 for red and 20 for blue.
3. Default numbering for groups (Y/N). If the user answers 'yes' to this question for both sides, then the groups will be referred to as group 1, group 2, ..., group n for one side and group 1, group 2, ..., group m for the other side where there are n groups on one side and m groups on the other side. If some other numbering system is required, the user should answer 'no' to the question and then indicate the numbers by which he wants each of the groups in turn referred to. The largest number which can be used to reference a blue group is 20 and the largest number which can be used to reference a red group is 30.
4. Default numbering for weapon systems (Y/N). As above, only here the largest number that can be used to reference a blue weapon system is 50 and the largest number that can be used to reference a red weapon system is 110. If the user answers 'yes' to this question, then the weapon systems in group 1 will be referred to as weapon 1, weapon 2, ..., weapon n1 where there are n1 weapons in group 1. The weapon systems in group 2 will be referred to as weapon n1+1, weapon n1+2, ..., weapon n1+n2 where there are n2 weapons in group 2, and so on for all the other groups.

5. The type of weapon system belonging to each group. This involves entering the appropriate number between 1 and 5 for each group.

6. The number of weapon systems belonging to each group. The maximum number allowed is 10.

A.7 When creating a new deployment file, the following information is required :

1. A file name - this should not exceed 6 characters and will be automatically appended with the file extension '.DEP'.

2. The number of different red routes. A maximum of 20 is allowed. Each red group follows a route (attack path) represented by a series of map co-ordinates connected by straight lines. Several groups can follow the same route, either together or with time lags between them. Small differences in the routes taken by different groups are unimportant.

3. The number of waypoints for each red route. A maximum of 10 is allowed. A waypoint is a six-figure map reference used to indicate points on the route where direction changes. Waypoints are required for the start point of the route, the end point of the route and any intermediate points along the way where the route significantly changes direction. For example, the route shown below can be adequately approximated by using just four waypoints.



Figure A-1

4. The three-figure Northing and three-figure Easting for each red waypoint. It is assumed that the map references are with respect to 1km by 1km grid squares i.e. the third digit in a reference is measured in tenths of kilometres. For example, the distance between the two points (000,100) and (000,110) is assumed to be 1 km.

5. The number of red groups taking each route. A maximum of 30 for any one route is allowed.

6. The reference numbers of the red groups taking each particular route. These must be entered in march order i.e. in the order that they leave the start point.

7. The time that the first group on each route leaves the start point. This time is measured in minutes from the start of the scenario and is 0.0 if this movement coincides with the start of the scenario. This obviously provides a good way of fixing the start points for each route.

8. The time lags between successive groups moving along the same route. These are measured in minutes and equal 0.0 for groups leaving the start point at the same time.

9. The average speed in km/hr of the groups on each route. Groups travelling along the same route are assumed to be travelling at the same speed. This speed is constant throughout the scenario.

10. The number of different blue routes. A maximum of 20 is allowed. It is expected that most of the blue groups will be in static defensive positions. For such groups a route will consist of a single point but these must be included in the figure for the total number of routes. Blue groups may start elsewhere and move up to their final positions but they will not be included in any fighting until reaching them.

11. The number of waypoints for each blue route. A maximum of 10 is allowed.

12. The three-figure Northing and three-figure Easting for each blue waypoint. The remarks made at (3.) apply here as well.

13. The number of blue groups taking each route. A maximum of 20 for any one route is allowed.

14. The reference numbers of the blue groups at each static location or on each route.

15. The time that each static group is in position ready to fight and that each moving group leaves its start point. Both of these times are measured in minutes from the start of the scenario.

16. The number of sub-battles. This must be decided by examining a map showing the proposed deployments marked on it.

17. The number of blue groups taking part in each sub-battle.

18. The reference numbers of these blue groups.

19. The number of sub-battles that groups on each red route will be involved in.

20. Which sub-battles these are for each red route.

21. The points along each route where the leading group joins each sub-battle. As each route consists of a number of legs, each of the entry points is entered as a leg of the route and the fraction of that leg completed when the entry point is reached.

22. The points along each route where the leading group leaves each sub-battle. Similarly, each of these is entered as a leg of the route and the fraction of that leg completed when the exit point is reached.

23. Are the the entry and exit points of all the other groups on the same route the same as those of the leading group ? (Y/N)

24. If not then the entry and exit points of all the other groups on the route must be entered as well.

SAMPLE MODEL RUN

Getting Started

A.8 After typing 'BDM', the user currently has four options. These are as follows :

1. Create a new weapon systems file
2. Create a new weapon groups file
3. Create a new deployment file
4. Run the model

The model can only run if the data files corresponding to the first three options above have already been created. If a completely new situation is to be studied, new data files will have to be created but sometimes it will be appropriate to use previously created files eg. if exactly the same group composition is going to be used again or exactly the same weapon systems with no change in any of the characteristics.

Creating a New Weapon Systems Data File

A.9 When creating a new weapon systems data file, the following questions are asked. (The answers shown here relate to the example.)

Enter output file name (up to 6 characters)
TEST

Enter number of blue weapon types (up to 5)
3

Enter firing rate in rnds/min of blue weapon type 1
3

Enter firing rate in rnds/min of blue weapon type 2
2

Enter firing rate in rnds/min of blue weapon type 3
0

Enter number of red weapon types (up to 5)
1

Enter firing rate in rnds/min of red weapon type 1
2

Enter Single Shot Kill Probability of blue weapon type 1
against red weapon type 1
0.22

Enter Single Shot Kill Probability of blue weapon type 2
against red weapon type 1
0.25

Enter Single Shot Kill Probability of blue weapon type 3
against red weapon type 1
0

Enter Single Shot Kill Probability of red weapon type 1
against blue weapon type 1
0.04

Enter Single Shot Kill Probability of red weapon type 1
against blue weapon type 2
0.02

Enter Single Shot Kill Probability of red weapon type 1
against blue weapon type 3
0.03

Creating a New Weapon Groups File

A.10 When creating a new weapon groups data file, the following questions are asked. (The answers shown here relate to the example.)

Enter output file name (up to 6 characters)
TEST

Enter number of blue groups (up to 20)
6

Do you want default numbering for the groups ie. the group
reference numbers to run from 1 to the number of blue
groups? (Y/N)
Y

Do you want default numbering for the blue weapons ie. the
weapon reference numbers to run from 1 to the number of blue
weapons? (Y/N)
Y

Weapon type of blue group 1
1

How many weapon systems are in group 1 ? (up to 10)
4

Weapon type of blue group 2
1

How many weapon systems are in group 2 ? (up to 10)
4

Weapon type of blue group 3

2

How many weapon systems are in group 3 ? (up to 10)

2

Weapon type of blue group 4

2

How many weapon systems are in group 4 ? (up to 10)

2

Weapon type of blue group 5

1

How many weapon systems are in group 5 ? (up to 10)

1

Weapon type of blue group 6

3

How many weapon systems are in group 6 ? (up to 10)

2

Enter number of red groups (up to 30)

3

Do you want default numbering for the groups ie. the group
reference numbers to run from 1 to the number of red groups?
(Y/N)

Y

Do you want default numbering for the red weapons ie. the
weapon reference numbers to run from 1 to the number of red
weapons? (Y/N)

Y

Weapon type of red group 1

1

How many weapon systems are in group 1 (up to 20)

10

Weapon type of red group 2

1

How many weapon systems are in group 1 (up to 20)

10

Weapon type of red group 3

1

How many weapon systems are in group 1 (up to 20)

10

Creating a New Deployment File

A.11 When creating a new deployment data file, the following questions are asked. (The answers shown here relate to the example.)

Enter output file name (up to 6 characters)
TEST

Enter number of different red routes (up to 20)
2

Enter number of waypoints for route 1 (up to 10 including start & end points)
6

Enter three-figure Northing of waypoint 1
804

Enter three-figure Easting of waypoint 1
481

Enter three-figure Northing of waypoint 2
793

Enter three-figure Easting of waypoint 2
473

Enter three-figure Northing of waypoint 3
780

Enter three-figure Easting of waypoint 3
472

Enter three-figure Northing of waypoint 4
772

Enter three-figure Easting of waypoint 4
470

Enter three-figure Northing of waypoint 5
771

Enter three-figure Easting of waypoint 5
465

Enter three-figure Northing of waypoint 6
747

Enter three-figure Easting of waypoint 6
468

How many red groups take this route ?
1

Enter their reference numbers in march order

2

Enter time in minutes that group 2 leaves its starting point

0

Enter average speed in km/h of groups on route 1

6

Enter number of waypoints for route 2 (up to 10 including start & end points)

5

Enter three-figure Northing of waypoint 1

800

Enter three-figure Easting of waypoint 1

483

Enter three-figure Northing of waypoint 2

780

Enter three-figure Easting of waypoint 2

472

Enter three-figure Northing of waypoint 3

772

Enter three-figure Easting of waypoint 3

470

Enter three-figure Northing of waypoint 4

771

Enter three-figure Easting of waypoint 4

465

Enter three-figure Northing of waypoint 5

747

Enter three-figure Easting of waypoint 5

468

How many red groups take this route ?

2

Enter their reference numbers in march order

3

1

Enter time in minutes that group 3 leaves its starting point

0

Enter time in minutes that group 1 leaves its starting point

3

Enter average speed in km/h of groups on route 2

6

Enter number of different blue routes (up to 20)

Note that a static group has a route consisting of 1 point.

5

Enter number of waypoints for route 1 (up to 10 including start & end points)

1

Enter three-figure Northing of waypoint 1

766

Enter three-figure Easting of waypoint 1

477

How many blue groups take this route ?

1

Enter their reference numbers in march order

1

Enter time in minutes that group 1 is in position

0

Enter number of waypoints for route 2 (up to 10 including start & end points)

1

Enter three-figure Northing of waypoint 1

766

Enter three-figure Easting of waypoint 1

454

How many blue groups take this route ?

1

Enter their reference numbers in march order

2

Enter time in minutes that group 2 is in position

0

Enter number of waypoints for route 3 (up to 10 including start & end points)

1

Enter three-figure Northing of waypoint 1

763

Enter three-figure Easting of waypoint 1

462

How many blue groups take this route ?

1

Enter their reference numbers in march order

3

Enter time in minutes that group 3 is in position

0

Enter number of waypoints for route 4 (up to 10 including start & end points)

1

Enter three-figure Northing of waypoint 1

774

Enter three-figure Easting of waypoint 1

458

How many blue groups take this route ?

1

Enter their reference numbers in march order

4

Enter time in minutes that group 4 is in position

0

Enter number of waypoints for route 5 (up to 10 including start & end points)

1

Enter three-figure Northing of waypoint 1

764

Enter three-figure Easting of waypoint 1

471

How many blue groups take this route ?

2

Enter their reference numbers in march order

5

6

Enter time in minutes that group 5 is in position

0

Enter time in minutes that group 6 is in position

0

Enter number of sub-battles

2

Enter number of blue groups in sub-battle 1

3

Enter reference numbers of these groups

2
3
4

Enter number of blue groups in sub-battle 2

3

Enter reference numbers of these groups

1
5
6

How many sub-battles will red groups on route 1 be involved in ?

2

Which ones are they ?

1
2

Enter leg of route 1 where red group 2 enters sub-battle 1

3

Enter fraction of leg completed for the point where this group enters the sub-battle

0.1

Enter leg of route 1 where red group 2 leaves sub-battle 1

5

Enter fraction of leg completed for the point where this group leaves the sub-battle

0.4

Enter leg of route 1 where red group 2 enters sub-battle 2

5

Enter fraction of leg completed for the point where this group enters the sub-battle

0.4

Enter leg of route 1 where red group 2 leaves sub-battle 2

5

Enter fraction of leg completed for the point where this group leaves the sub-battle

0.8

How many sub-battles will red groups on route 2 be involved in ?

2

Which ones are they ?

1
2

Enter leg of route 2 where red group 3 enters sub-battle 1
2

Enter fraction of leg completed for the point where this
group enters the sub-battle
0.1

Enter leg of route 2 where red group 3 leaves sub-battle 1
4

Enter fraction of leg completed for the point where this
group leaves the sub-battle
0.4

Are the sub-battle entry and exit points the same for all
the other red groups on this route ? (Y/N)
Y

Enter leg of route 2 where red group 3 enters sub-battle 2
4

Enter fraction of leg completed for the point where this
group enters the sub-battle
0.4

Enter leg of route 2 where red group 3 leaves sub-battle 2
4

Enter fraction of leg completed for the point where this
group leaves the sub-battle
0.8

Are the sub-battle entry and exit points the same for all
the other red groups on this route ? (Y/N)
Y

Running the Model

A.12 Once the option to run the model has been selected, the
following questions are asked. Typical answers are shown.

Enter number of replications (up to 1000)
500

Enter minibattle sampling mode (1 or 2)
1

Enter mean minibattle duration in minutes
1.25

Enter minimum time frame duration
2.0

Enter maximum time frame duration
3.0

Do you want the default values for red force size
distribution ? (Y/N)
Y

Enter name of weapons file
TEST

Enter name of groups file
TEST

Enter name of deployment file
TEST

Enter name of output file (up to 6 characters)
OUT1

Scenario Example

A.13 This example represents a fairly typical scenario and shows how the previous sample inputs to the data files were derived.

A.14 The situation is that a Red tank battalion consisting of thirty MBTs is pushing South. A Blue combat team consisting of two tank platoons, two ATGW sections and an HQ Group of one MBT and two APCs has been tasked with denying the enemy penetration South through a wooded pass which appears to be Red's immediate objective. The deployments of the two forces are shown in Figure A-2 below.

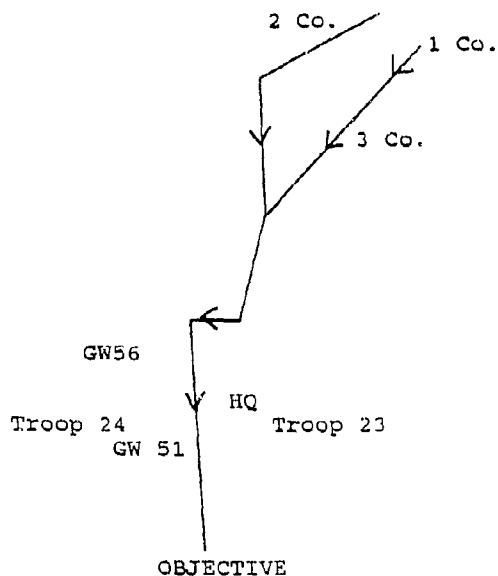


Figure A-2

Weapon Systems

A.15 There are four different types of weapon system taking part in this scenario - one belonging to the Red side and the other three belonging to the Blue side. As the different weapon types must be identified by a number, it would seem reasonable to designate the Red MBT as Red weapon type 1, the Blue MBT as Blue weapon type 1, the Blue ATGW as Blue

weapon type 2 and the Blue APC as Blue weapon type 3. Characteristics of each of these weapon types would be entered into the weapon systems data file.

Weapon Groups

A.16 Every weapon system is assigned to a group. Groups are composed of weapons of the same type, travelling together along the same route. In this scenario, each Red company consists of 10 MBTs travelling together so there are 3 Red groups which will be numbered from 1 to 3 for reference purposes. As the Red companies are already known as Companies 1, 2 and 3, it is logical for group 1 to equate with 1 Company, etc.

A.17 On the Blue side, 6 groups can be identified. These will be referred to as Blue groups 1 to 6 and are made up as follows. Troop 23 which contains 4 MBTs (i.e. 4 Blue type 1 weapons) will be known as Blue group 1. Troop 24 which also contains 4 MBTs will be known as Blue group 2. GW Section 51 which contains 2 ATGW (i.e. 2 Blue type 2 weapons) will be known as Blue group 3. GW Section 56 which also contains 2 ATGW will be known as Blue group 4. The Blue HQ contains 1 MBT and 2 APCs, and so has to be split into two groups as different weapon types are not allowed in the same group. The MBT (i.e. 1 Blue type 1 weapon) will be known as Blue group 5 and the APCs (i.e. 2 Blue type 3 weapons) will be known as Blue group 6. The compositions of these weapon groups would be entered into the weapon groups data file.

Deployment

A.18 It is evident from Figure A-2 that there are only two Red attack routes - one taken by 2 Company and one taken by 3 Company and 1 Company. These routes will be referred to as Red routes 1 and 2, respectively. Route 1 has six waypoints (including start and end points) while route 2 has five waypoints. Four of these waypoints are common to both routes. The grid references of each waypoint are obtained from the map of the area.

A.19 The Blue defence is static and all of the groups are in different locations apart from groups 5 and 6. Consequently, there are five Blue routes, each consisting of a single point. Again, the grid references of each Blue location are obtained from the map.

A.20 When there is more than one group on a particular route e.g. Red groups 1, 3, and these groups are travelling in a definite order, then when asked to enter the groups in march order, the leading group must be entered first, followed by the next leading group and so on. The time lags between the groups will then be entered in the same order. If groups leave together along the same route, however, then the order of entry is unimportant and there is no time lag between them. The routes taken by the various groups and the positional information would be entered in the deployment data file.

Sub-Battles

A.21 The number and composition of the sub-battles will depend on the orders that each side has. Details of when different groups join and leave will also depend on the speeds of attacking groups and the ranges of the various weapon types. In this example, it will be assumed that the movement orders are as shown in Figure A-2 and that Blue groups 2, 3 and 4 (i.e. Troop 24, GW 51 and GW 56) have been ordered to open fire when the first Red company comes into range. Blue groups 1, 5 and 6 (i.e. Troop 23 and the two HQ groups) must wait until the enemy has reached a certain point along its route before opening fire. The Blue groups' positions are such that when the enemy leaves the line-of-sight of Blue groups 2, 3 and 4, they almost immediately enter the line-of-sight of Blue groups 1, 5 and 6. At this time, they are also within range of Blue groups 1, 5 and 6.

A.22 Consequently, two separate sub-battles can be distinguished from this example. The first one involves Blue groups 2, 3 and 4 and all three Red groups while the second one involves Blue groups 1, 5 and 6 and the survivors of the three Red groups from the first sub-battle. The first sub-battle will begin when Blue decides to open fire. This will coincide with Red reaching a favourable position for Blue. This position will be referred to as the point where the leading Red group joins the sub-battle. Instead of entering grid references for the position, it is simpler to enter the leg of the red route which it lies on, followed by the fraction of the way along the leg where the 'entry point' is located. The same procedure is used to define 'exit points' where Red groups leave sub-battles. A Red group leaves a sub-battle when it can no longer be engaged by the defending Blue forces taking part in that sub-battle either because there is no longer a line-of-sight or because the Red group has passed out of range.

A.23 In this example, Red groups 1 and 3 enter Sub-Battle 1 (SB1)

on the 2nd leg of their route at a point 0.4 of the way along that leg. Red group 2 enters SB1 at the same point but since it has an extra leg on its route, this point corresponds to 0.4 of the way along the 3rd leg of this route. All three groups also leave SB1 and join SB2 at the same point. For Red groups 1 and 3, this corresponds to 0.4 of the way along the 4th leg of their route and for Red group 2, it corresponds to 0.4 of the way along the 5th leg of its route. Groups 1 and 2 then leave SB2, 0.8 of the way along leg 4 and group 3 leaves SB2, 0.8 of the way along leg 5.

- A.24 If the different Blue groups taking part in a particular sub-battle all begin engaging the enemy at the same time, then that time can be set to 0. If different groups are expected to enter the sub-battle at different times, however, the entry time of the earliest group should be set to 0 and the times of the other groups set relative to that time.

Trial Runs

- A.25 The results of some trial runs are presented in Table A-1. The scenario considered here is the one depicted earlier. Although the scenario details are the same in each case, a few of the model parameters were varied in order to see the effect that these would have on some output measures of interest such as the mean number of survivors on each side and the mean fractional exchange ratio (F.E.R.). Each model run comprised 500 replications.
- A.26 The input parameter (x REP) controls the shape of the geometric distribution pdf describing the red force size distribution in minibattles. The blue force size distribution was not varied. Maximum minibattle durations were sampled from the negative exponential distribution and the mean of this distribution is another input parameter that was varied. Finally, different values for the minimum and maximum time frame lengths were considered.
- A.27 All of the other parameters in Table A-1 are output parameters. The input force ratio is the ratio of red weapon systems to blue weapon systems that are available to take part at the start of a minibattle. The output force ratio is the ratio of red weapon systems to blue weapon systems that did take part in that minibattle where taking part is defined as either firing or being fired at. Predictably, both of these force ratios increased as the red force size distribution was gradually shifted to higher mean values. However, the output force ratio increased at a slower rate than the input force ratio. Also to be expected was the reduction in the mean number of minibattles with increasing time frame length since only one set of minibattles are generated for each time frame. If a more thorough investigation of the proportions of time spent involved in actual fighting shows that the distribution and number of minibattles produced by the model is inadequate then the relevant model parameters will have to be altered.
- A.28 Figure A-3 shows a typical network of minibattles. Obviously this represents a single replication and each replication will result in a slightly different network dependent on the precise nature of the flow of forces each time. The directed arrows show the direction of force flows between minibattles. Links are drawn between successive minibattles having at least one weapon system in common. If one or more weapon systems are taking part in a minibattle for the first time, this is indicated by a directed arrow entering the top of the minibattle node.

Trial Run Statistics

Serial (x REP)	Mean MB Length (mins.)	TF min (mins.)	TF max (mins.)	Input F.R.	Output F.R.	F.E.R.	Mean Blue Survivors	Mean Red Survivors	Mean No. MBs
1.	1.0	2.0	3.0	1.57	1.22	9.3	14.3	16.9	16.1
2.	0.8	2.0	3.0	1.80	1.31	8.5	14.3	18.2	16.1
3.	0.6	2.0	3.0	2.16	1.48	4.8	13.9	19.5	12.9
4.	0.4	2.0	3.0	2.69	1.69	3.9	13.8	20.9	12.0
5.	0.6	2.0	3.0	2.16	1.48	5.9	14.1	19.1	15.7
6.	0.6	2.0	3.0	2.14	1.52	5.2	13.9	18.6	15.6
7.	0.6	2.0	3.0	2.15	1.54	4.9	13.8	18.5	13.3
8.	0.6	2.5	3.5	2.18	1.52	4.9	14.0	20.5	11.1
9.	0.6	3.0	4.0	2.20	1.56	4.5	14.1	22.2	8.8
10.	0.6	3.0	4.0	2.18	1.61	4.1	13.9	21.0	9.2

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Associated Standard Errors (on 500 measurements)

Serial	Input F.R.	Output F.R.	Mean Blue Survivors	Mean Red Survivors	Mean No. MBs
1.	.009	.007	.04	.19	.21
2.	.010	.009	.04	.18	.21
3.	.013	.012	.04	.19	.18
4.	.017	.014	.05	.17	.18
5.	.014	.011	.04	.18	.22
6.	.014	.013	.05	.19	.19
7.	.013	.013	.05	.16	.17
8.	.015	.014	.05	.18	.17
9.	.016	.017	.05	.17	.17
10.	.018	.017	.05	.16	.15

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A typical network

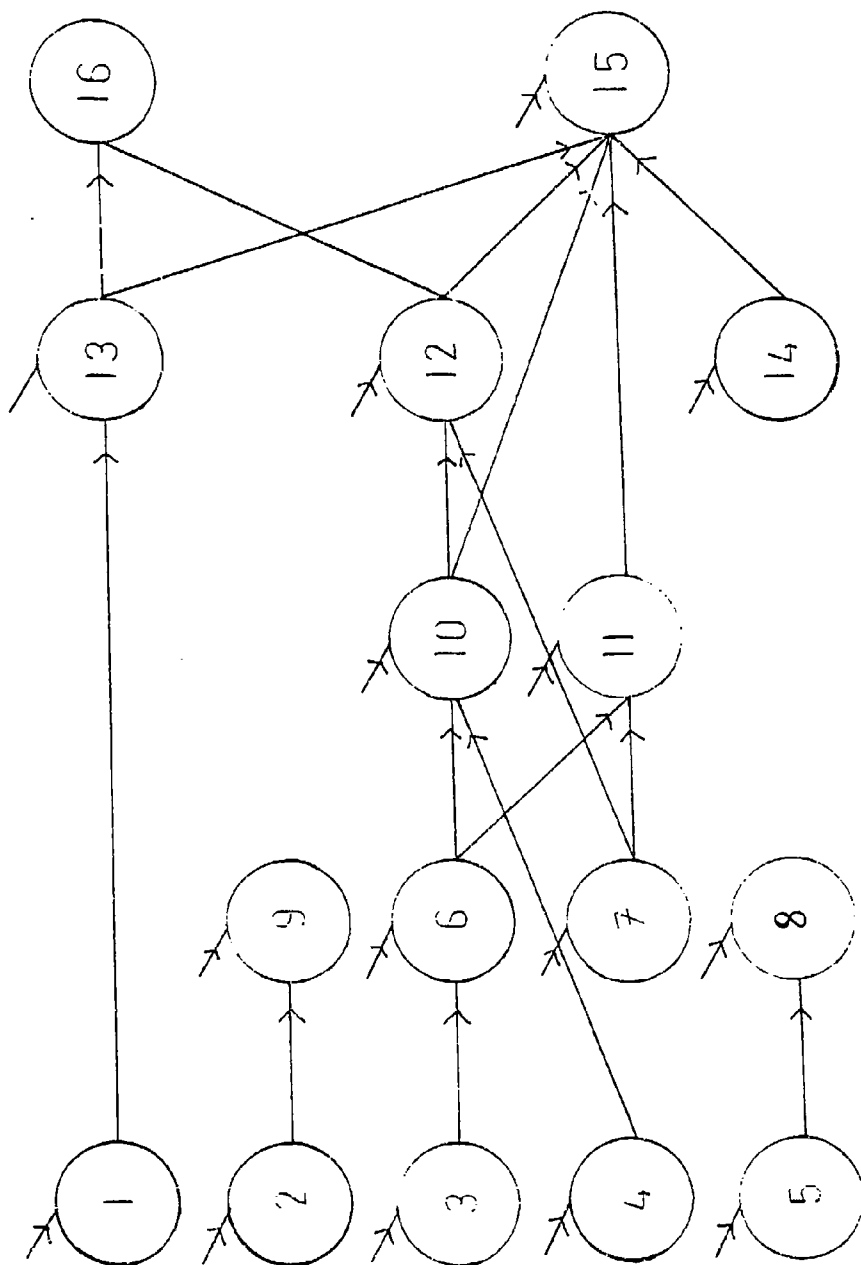


Figure A-3