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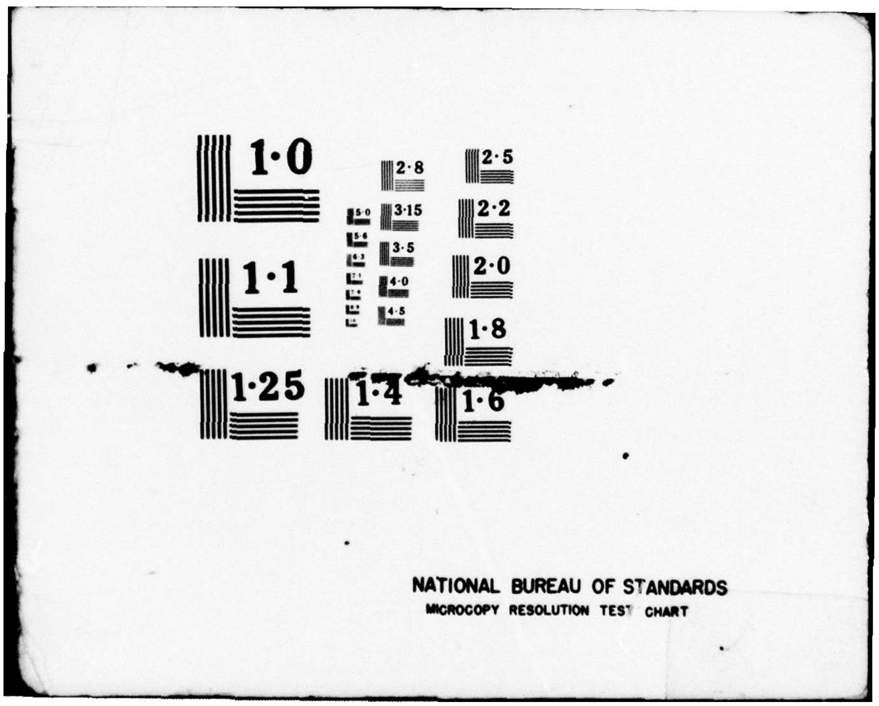
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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

6 TARGET ALLOCATION IN THE AIR DEFENSE AIR-TO-GROUND ENGAGEMENT (ADAGE) MODEL.

9 Master's thesis

by

10 David Arthur Grover

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Thesis Advisor: S.H. Parry

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Target Allocation in the Air Defense Air-to-Ground Engagement (ADAGE) Model

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TABLE OF CONTENTS

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LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

This chapter includes a summary of this report and the background of the development of the model used for this study.

A. THESIS SUMMARY

As well as providing a summary of the thesis, Chapter I includes a short history of the Air Defense Air-to-Ground Engagement (ADAGE) model. The model consists of an incursion submodel and a campaign submodel. The computational flow of the campaign submodel is briefly discussed. Chapter II describes the problem of determining which target allocation scheme results in the greatest destruction of blue targets. This includes a description of the six allocation schemes studied. The factors and their respective levels of the experimental design used to generate the necessary data are described. Many simplifying modifications were made to the campaign model for the purposes of this study. Chapter III presents a new model which is suitable for assessing the air-to-ground battle. Also, it describes each modification and the rationale for its inclusion. The resulting form of the submodel as it was used in this study is described in detail. The analysis of the model output is described in Chapter IV. The primary tool used was Mean Value Differential Analysis. The raw model output and the MVDA output provide the basis for comparing the effects of factor levels on the percent of the blue targets remaining. Additionally, the survivability of red aircraft is discussed. Chapter V lists the conclusions drawn from the observations made in Chapter IV. Appendix A provides flowcharts of some selected model subroutines. Appendix B includes several figures which graphically portray the analysis in Chapter IV. Model output and Mean Value Differential Analysis output for one experimental unit is also included.

B. HISTORICAL BACKGROUND

The Air Defense Air-to-Ground Engagement (ADAGE) model was designed to analyze the effectiveness of various mixes of weapons systems which provide air defense to the division. ADAGE consists of two submodels; a Monte Carlo Incursion model and an expected value Campaign model. The Incursion model assesses the results of one-on-one engagements while the Campaign model uses the output of Incursion to simulate the many-on-many engagements.

1. Origin of the Campaign Model

At the request of the Combat Development Branch of the United States Army Air Defense School (USAADS), the Army Material Systems Analysis Activity (AMSAA) developed the Campaign (CAMPIN) submodel in early 1977. Along with the Incursion submodel, it was originally intended to be a quick running model to be used in support of the "Division Air Defense Gun, Cost and Operational Effectiveness Analysis". It uses a variety of procedures for target allocation. For example, if the user wants to maximize blue target destruction, the model selects the targets and red aircraft flight and attack profiles which result in the greatest expected target damage.

2. Original Configuration of the Campaign Model

Figure 1 provides a macro-view of the computational flow. The CAMPIN model is provided with output from the Incursion submodel along with the other necessary parameter settings.

a. Target Allocation

The major function of this model is to determine which blue targets are to be attacked by which red aircraft types. Three allocation procedures are modelled. The first is a fixed scheme (i.e. the fraction of the total number of aircraft allocated against a target type is fixed by input) which minimizes the expected number of aircraft losses. The model accomplishes this by maximizing the probability that an aircraft would survive the ingress, attack, and egress portions of a raid. Also a fixed scheme, the second method maximizes the ratio of target destruction to aircraft losses. Target destruction is a function of the fraction of the targets destroyed. The third procedure is proportional i.e. the allocation for each day is dependent upon the results of the previous days. Like the second, this scheme also maximizes the ratio of target destruction to aircraft losses. The selected procedure governs the target and attack and flight profile selections of the model except

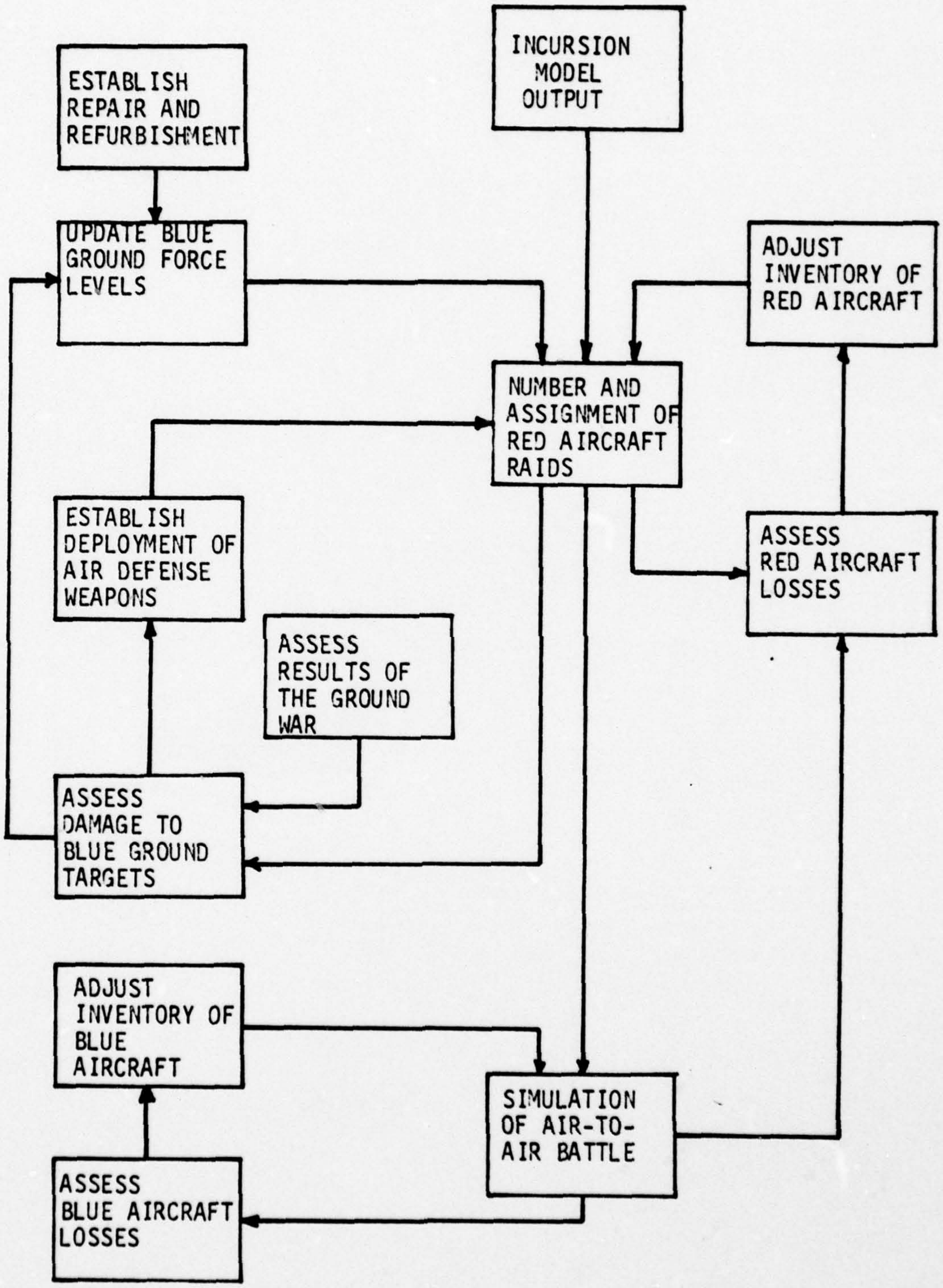

Figure 1. Campaign Model

for the first day where these decisions are made by the user through input.

b. Blue Target Destruction

The damage to blue targets as a result of red aircraft attacks and as a result of hostile action by red ground forces is computed. The effects of repairs to damaged and out of action blue equipment are accomplished by a daily upward adjustment to the blue force level. The magnitude of the change is set by input. After target damage and force refurbishment are posted, a current distribution of air defense weapons systems is calculated.

c. Red Aircraft Losses

Losses of red aircraft include those due to blue interceptors and blue ground fire. In the computation of losses due to blue air defense systems, aircraft survivability is computed for the ingress, attack, and egress portions of the raid.

d. Blue Accountability

Records of blue ammunition expenditure are maintained. The losses of blue interceptor aircraft as a result of the air war are computed and recorded.

e. Termination and Output

When all the effects of one day of war are calculated and recorded, the battle termination decision is made. There are three conditions which will cause termination: if blue force levels drop below an input established cutoff level or red force levels drop below an input established cutoff level or if the number of days of battle reaches its cutoff. If the simulation is terminated, summaries of red aircraft raids, red aircraft destruction, ground target damage, fire unit damage, blue target status histories, blue aircraft losses, and blue ammunition expenditures are provided. Additionally, output includes a written record of all aircraft-target allocation assignments. If the simulation is not ended, the entire procedure is repeated using starting levels equal to the force levels at the end of the day just completed.

3. Necessary Changes to the Model

During the conduct of the "Division Air Defense Gun COEA" it became apparent that changes in the model were needed. For that reason, in mid 1977, a contract was awarded to SRI International of Menlo Park, California to program the necessary changes. These included streamlining the program to improve its computational efficiency and strengthening portions of the program to enable it to evaluate high altitude missile systems such as PATRIOT. The output routine was to be enhanced to provide additional output on ordnance and ammunition expenditures. Finally, an additional allocation scheme based on Lagrange multipliers was to be added to the model.

II. NATURE OF THE PROBLEM

This study analyzed the results of six different allocation schemes. The objective was to determine which procedure resulted in the greatest sustained attrition of blue ground forces. The analysis was conducted using a four way full factorial experiment. The allocation scheme was one factor and is discussed in the next section. The remaining factors, which are described later, included the attack profile selection, the aircraft to target ratio, and the target value assignments.

A. ALLOCATION SCHEME ALTERNATIVES

Each of the alternative allocation schemes evaluated each aircraft type-target type combination in search of the "optimum" combination. In this context, "optimum" refers to either minimizing aircraft losses, maximizing target destruction, or maximizing target destruction divided by aircraft losses. Once that combination was determined, a percentage of the aircraft formation was allocated against the target. (From now on, the formation will be referred to as a raid point. The size of the raid point was set by input.) This procedure was repeated for the remaining aircraft and target types until all of the aircraft had been assigned. Basically, the differences between the schemes arose in the computation of a maximization factor, the determination of the percentage of a raid point assigned to a target, and the manner in which excess aircraft, if any, were allocated. The two Lagrange multiplier procedures varied somewhat from this form and will be discussed in detail below.

1. Fixed; Minimize Aircraft Losses

Within this fixed scheme, the optimum combination is the one which minimizes the aircraft losses by maximizing the aircraft survivability during a raid. The percentage or weight of a raid point that is allocated to the target types is fixed by input throughout the simulation. If these input weights provide for any unassigned aircraft, they are allocated to the target which provides for the greatest survivability of the aircraft. For example, the maximization factor ROPT is equal to the probability of an aircraft of type i surviving a raid on a target of type j.

$$\text{ROPT} = \text{PSIN} \times \text{PSVT} \times \text{PSEG} \tag{1}$$

where

ROPT - The maximization factor for aircraft i against target j is computed for each combination.

PSIN - The probability that an aircraft i will survive the ingress portion of a raid on target j.

PSVT - The probability that an aircraft i will survive the attack portion of a raid on target j.

PSEG - The probability that an aircraft i will survive the egress portion of a raid on target j.

Assume that the fixed percentages of Aircraft Type 1 are .25 against Target Type 1, .30 against Target Type 2, .15 against Target Type 3, and .20 against Target Type 4. This assignment accounts for only 90% of the available aircraft of type one. Therefore, under this scheme, the excess aircraft are assigned to the target type which has the largest value of the maximization factor ROPT.

2. Fixed; Maximize Target Destruction Divided By Aircraft Losses

The maximization factor ROPT for this fixed scheme is the expected target damage divided by the probability of aircraft loss for each aircraft type – target type combination.

$$\text{ROPT} = \text{DAMR}/(1 - (\text{PSIN} \times \text{PSVT} \times \text{PSEG})) \qquad (2)$$

where

DAMR - The fraction of target damage to target j as a result of an attack by aircraft i.

Again, the percentage of a raid point that is allocated to each target type is fixed by input. After all aircraft-target combinations are evaluated if excess aircraft are available, they are assigned to the target which maximizes the following function of ROPT.

$$ROPT \times TGTN \times PNLG \times PVAL \times FWOR \qquad (3)$$

where

ROPT - The maximization factor.

TGTN - The number of targets of type j present.

PNLG - The probability that an aircraft of any type could acquire a target of type j.

PVAL - The percent of a target of type j remaining.

FWOR - The initial target value (military worth expressed in points) of a target of type j as it is assigned by the red force.

3. Proportional; Maximize Target Destruction Divided By Aircraft Losses

The maximization factor for this proportional scheme is that shown in Equation (2) above. The percentage of a raid point assigned to a target is variable for this procedure because it is dependent upon the results of the previous sortie. The allocation percentages or weights and the assignment of any excess aircraft is based on the maximization of the function shown in Equation (3).

4. Proportional; Maximize Target Destruction

The only difference between this proportional scheme and the previous one is in the computation of the maximization factor ROPT. In this case, it is equal to the expected target damage.

$$ROPT = DAMR \qquad (4)$$

5. Lagrangian (1); Maximize Target Destruction

The maximization factor for the Lagrangian schemes is again that shown in Equation (4). The percent of a raid point that is allocated to a target is a function of a set of Lagrange multipliers calculated in the following manner. The full derivation of the Lagrangian allocation technique is discussed by Everett [Ref. 1] and modified by Furman [Ref. 4]. The total number of aircraft of type i is the number allocated against each target type summed over the target types.

$$W_i = \sum_{j=1}^{J} n_j w_{ij} \qquad (5)$$

where

W_i - The total number of aircraft of type i.

J - The number of target types.

n_j - The number of targets of type j.

w_{ij} - The number of aircraft of type i allocated against one target of type j.

A lambda vector of size equal to the number of target types is computed for each aircraft type. The computation of lambda is shown in Equation (6). The number of aircraft of type i to be allocated against a single target of type j (w_{ij}) is computed as shown in Equation (7).

$$\lambda_i = \mathrm{EXP}\left\{\frac{\left[\sum_{j=1}^{J} w_{ij} + \sum_{j=1}^{J}\left\{\ln(-V_j \ln q_{ij})/\ln q_{ij}\right\}\right]}{\left[\sum_{j=1}^{J} \frac{1}{\ln q_{ij}}\right]}\right\} \tag{6}$$

$$w_{ij} = (1/\ln q_{ij}) \ln(-\lambda_i/(V_j \ln q_{ij})) \tag{7}$$

where

- V_j - The target value or military worth of a target of type j.
- q_{ij} - The fraction of a target of type j surviving an attack from an aircraft of type i.
- λ_i - The Lagrange multipliers for an aircraft of type i.

If any of the aircraft allocation weights w_{ij} are negative, those target types are eliminated and a new set of Lagrange multipliers is computed based on the reduced set of targets. The new allocation weights are then computed. This procedure is repeated until all the aircraft allocation weights are greater than or equal to zero. In other words, only nonnegative numbers of aircraft can be allocated against a target. Based on the final set of allocations, the expected target damage is computed for each aircraft-target combination.

$$D_{ij} = V_j (1 - q_{ij}^{w_{ij}}) n_j \tag{8}$$

where

D_{ij} - The expected damage to all of the targets of type j due to an attack by an aircraft of type i.

The expected damage D_i achieved by an aircraft of type i against all target types is then computed as follows.

$$D_i = \sum_{j=1}^{J} D_{ij} \tag{9}$$

D_i represents the total expected target damage for the entire inventory of aircraft type i. Equation (10) shows the expected damage per aircraft of type i.

$$DMT = D_i/W_i \tag{10}$$

The expected damage per aircraft type (DMT) is then used to determine the aircraft type which has the greatest expected target damage. That aircraft type is allocated in accordance with the computed allocation weights w_{ij}. That aircraft type is then eliminated and the target values are reduced by the amount of damage sustained. This entire procedure is repeated until all aircraft types are allocated. A significant feature of this procedure is that target damage due to one aircraft type is computed based on the effects of the other aircraft types. This is a major departure from the previous four procedures in which the damage calculations were done for each aircraft separately and independently of the others. A finite number of repetitions equal to the number of aircraft types is required to accomplish complete allocation of the force.

6. Lagrangian (2); Maximize Target Destruction

This Lagrangian procedure differs from the first only in the manner in which optimum allocations are made. Instead of first allocating the most efficient aircraft with respect to the entire target array, this procedure allocates the most vulnerable target type. The aircraft-target combination with the largest D_{ij} as computed in Equation (8) is allocated in accordance with its computed allocation weight w_{ij}. This procedure is repeated until all aircraft are allocated. If any aircraft are remaining after all target types have been evaluated, those aircraft are allocated against the most vulnerable target.

B. DATA COLLECTION

In order to determine the most effective allocation scheme, an experiment was designed to produce data which could serve as benchmarks of the performance of each routine. Within this experiment, critical input values were varied for those parameters to which the model was thought to be sensitive.

1. Maximizing Schemes

a. Measures of Effectiveness

As indicated above, the primary measure of effectiveness was the percent of target value remaining. This value was examined for each target type separately and for the target array as a whole. These values provided a means of comparing each alternative at an identical point in time under nearly identical circumstances. A secondary measure of effectiveness which was not totally independent of blue target damage, was red aircraft losses. The rate of red aircraft losses was negatively correlated with the rate of destruction of the blue air defense fire units. Aircraft losses did, however, provide an indication of the red force's ability to cause damage to the blue ground forces.

b. Points of Analysis

Ten points of analysis were selected for each measure of effectiveness. For each experimental unit, the simulation was run for the equivalent of thirty days of combat, unless one of the battle termination conditions was met. The points of analysis selected were after each of the first six sorties and at the three, five, fifteen, and thirty day marks of the simulation. (For this model, a sortie was one attack by all available aircraft.) The data from sorties one through six permitted in-depth analysis of the early effects of combat. Intermediate results and an indication of the trend of battle were provided by the three and five day points. The last two points provided a measure of the long term capabilities of each system.

2. Experimental Design

The experimental design used to provide the above information was the four way full factorial design shown in Figure 2. A1 to A6 were the different allocation schemes, P1 and P2 were the profile selections, R1 to R3 were the ratios of red aircraft to blue targets, and T1 to T4 were the target value assignment schemes. For each experimental cell, the simulation provided a number of statistics on target and aircraft status. These included the percent of each target remaining and the percent of the entire target array remaining. For the secondary measure of effectiveness, the number of each aircraft type remaining was provided.

3. Factors

The factor of major concern was the allocation schemes which were discussed above. The remaining factors were considered in order to permit the detection of any unusual sensitivity to the parameter settings.

a. Profiles

Two different attack profiles were considered. The ingress and egress flight profiles were held constant throughout. For Profile 1 (P1), all aircraft utilized the same attack profile against all target types. This ensured that each allocation scheme was evaluated under identical

		R1				R2				R3			
		T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
P1	A1												
	A2												
	A3												
	A4												
	A5												
	A6												
P2	A1												
	A2												
	A3												
	A4												
	A5												
	A6												

Figure 2. Experimental Design

arbitrary conditions. To preclude the possibility of the arbitrarily selected profile adversely affecting one allocation scheme over another, the alternative attack profile system (P2) had each aircraft type attack each target type with the profile which provided the greatest expected target damage. The second system is the one a red commander would be expected to use.

b. Aircraft to Target Ratio

Three ratios of the total number of aircraft to the total number of targets were considered. Those ratios as shown in Table I were 3.31 to 1 (R1), 5.38 to 1 (R2), and 9.93 to 1 (R3). The purpose was to highlight any allocation scheme that was unduly affected by a high offense to defense ratio.

Table I. Force Ratios

RATIO	# OF AIRCRAFT	# OF TARGETS
3.31/1	96	29
5.38/1	156	29
9.93/1	288	29

c. Target Values

Target values were a key component of the model's decision making process. The results were expected to be sensitive to their initial settings. Six target types were used for this simulation. Their type, density, and relative locations are shown in Table II. The target values assigned by the blue force that were used in the original ADAGE model were based on extensive questioning of experienced combat leaders. The value of these targets as assessed by the red force was based on current intelligence estimates and red doctrine. Those original values seemed to place the greatest importance on the blue target types posing a threat to advancing red ground forces. The four target value systems considered are shown in Table III.

Table II. Target Types

TARGET #	TYPE	COUNT	LOCATION
1	Tank Co.	5	On FEBA
2	Tank Co.	6	In Reserve
3	Howitzer Battery	11	Behind Reserves
4	Depot	1	Div. Rear
5	HIMAD Btry (High Altitude Missile Air Defense system)	4	Div. Rear
6	Ammo Supply Pt.	2	Div. Rear

Table III. Target Value Assignments

TARGET #	T1	T2	T3	T4
1	587	660	600	425
2	587	660	600	425
3	587	725	300	600
4	587	190	125	1550
5	587	180	1550	175
6	587	440	400	1750

T1 considered the case where all target types were assigned the same value, thus providing a base case. For T2, highest priority was given to those targets which appeared to pose the greatest threat to the red ground forces. In T3, target values were assigned to provide priority to the targets that presented the greatest threat to the red aircraft. T4 gave the highest priority to the blue critical assets (i.e. depots and ammunition supply points).

III. MODEL USED FOR THE STUDY

The objective of this chapter is to present a new model which, when used with appropriate parameter settings, can be used to assess the effects of the air-to-ground battle. This reduced model is the result of major modifications to some subroutines and the elimination of others. Generally, the portions that were eliminated included features which complicated the computational flow and clouded the effects of the target allocation procedures. Additionally, the allocation computations were enhanced to include three more allocation schemes. Two of these, developed by SRI International, were modified to be compatible with this model. As a result, the reduced Campaign model is more transparent and easier to use.

A. DELETIONS FROM THE CAMPAIGN MODEL

The following aspects of CAMPIN were deleted to highlight the pertinent results of the study.

1. Equipment Repair and Refurbishment

Damaged and non-operational equipment was returned to action on a daily basis at a rate established by input. This rate of return was in fact a fraction of the total force initially employed. Its effect would therefore be identical regardless of the allocation scheme adopted. It was determined that it would not provide additional information to the study.

2. Ground Warfare Assessments

The destruction of blue targets as a result of ground warfare was accomplished using a fixed expected value. In accordance with input, a specified fraction of the force remaining was destroyed daily. While the rate of loss in the ground war was dependent on the overall blue loss rate, resulting variations in the ground war losses for different allocation schemes were not considered.

3. Optimum Flight and Attack Profile Selection

In order to insure that each allocation procedure was evaluated under the same circumstances, it was necessary to control the selection of the flight and attack profiles of the red aircraft. The original model provided for optimum selection based on the current tactical situation. This procedure was circumvented so that profiles were established in input and used as a control variable in the analysis.

4. First Day Profile and Allocation

Through input parameters, the model fixed flight and attack profiles and allocation weights to reflect the initial deployment of forces. On the first day, the attack concentrated on those targets which were considered critical, without regard for the selected allocation scheme. This procedure greatly reduced the visible effect of the allocation scheme on some target configurations. In order to get an unbiased look at the effect of each procedure, the first day feature was deleted and each scheme was evaluated throughout the entire war.

5. Effects of Blue Interceptors

The losses of red aircraft due to engagement with blue interceptors were dependent upon the level of red and blue aircraft remaining and the probability of engagement. Therefore, the loss rate of red aircraft to blue interceptors would vary with each allocation scheme employed. After a discussion with SRI International personnel familiar with the Campaign model, it was decided that the difference in loss rates between competing allocation schemes would be slight. For that reason blue air was not modelled in the study.

6. Employment of Multiple Red Aircraft Configurations

The original model had the capability of simulating red aircraft in three modes; 1) bombers or air-to-ground attack aircraft, 2) escort or air-to-air attack aircraft, and 3) rotary wing attack aircraft. Since the blue interceptor aircraft had previously been deleted, the presence of red escort aircraft would serve no purpose in the model. It was also concluded that the results of helicopter engagements would not substantially enhance the information derived from the fixed wing air-to-ground engagements. The model was therefore further simplified by considering only the bombers and air-to-ground attack aircraft.

7. Effects of "Good" and "Poor" Weather Conditions

Based on input parameter values, a fraction of the simulation time was "good" weather and the remainder was "poor". Engagements were run under both conditions and the overall result was computed by taking the weighted average. For example, assume that 60% of the time "good" weather is experienced and let G and W represent the results of engagements under "good" and "poor" weather respectively. The overall result is shown in Equation (11).

$$\text{Overall Result} = .60G + .40W \qquad (11)$$

Again, since this study was concerned with the comparison of allocation schemes, this feature was not considered necessary. The entire study was conducted with the results derived under "good" weather conditions. However, with appropriate input parameter settings, poor weather and night conditions could be simulated.

8. Blue Ammunition Expenditures

The model provided a procedure for counting the ammunition expenditures of the blue air defense weapons systems. This procedure was not used to control or impede the use of the air defense systems, so its deletion had no effect on the analysis of different allocation procedures.

9. Computation of Suppressive Activity

Antiaircraft suppression in the area of the target was divided into three levels; 1) no activity, 2) hostile firing present without any suppressive effect, and 3) effective suppression fires present. The levels were used only to select the optimum attack profile. Since that feature was deleted, retention of the suppression calculation was not required.

10. Target and AD Fire Unit Arrays

The original target array of nineteen targets as shown in Table IV was reduced, for the purposes of this study, to the six target types shown in Table II.

Table IV. Blue Target Types

1.	Tank Company (Zone 1)
2.	Mechanized Infantry Company (Zone 1)
3.	Tank Company (Zone 2)
4.	Mechanized Infantry Company (Zone 2)
5.	Tank Company (Zone 3)
6.	Mechanized Infantry Company (Zone 3)
7.	Command Post
8.	Special Ammunition Supply Point
9.	Ammunition Supply Point
10.	Howitzer Battery (Zone 3)
11.	Howitzer Battery (Zone 4)
12.	Rear Installation
13.	Improved HAWK Battery
14.	Vulcan Fire Unit (Zone 1)
15.	Vulcan Fire Unit (Zone 2)
16.	Chaparral Fire Unit
17.	Lance Battery
18.	Forward Logistics
19.	Attack Helicopter Company

Additionally, based on the current air defense weapons in the field, CAMPIN modelled the ten air defense systems shown in Table V. Those systems marked by an asterisk were incorporated in the model for this study.

Table V. AD Weapon Types

	1.	M-16 Rifle
	2.	M-60 Light Machine Gun
*	3.	M-2 50 Cal on a Tank
	4.	M-2 50 Cal on an Armored Veh
	5.	TOW
	6.	105mm Tank Gun
*	7.	Improved HAWK
	8.	Chaparral
	9.	Vulcan
	10.	Redeye

11. Output

The output was reduced to include only the information pertinent to the study. That output was printed after each sortie instead of at the end of each day.

B. ADDITIONS TO THE CAMPAIGN MODEL

The additional allocation schemes that were of interest in the study were added to the CAMPIN model.

1. Proportional Scheme Maximizing Target Destruction

This allocation procedure was added to provide an alternative proportional scheme.

2. Lagrange Multiplier Procedures

The two Lagrange Multiplier procedures discussed above were developed at SRI International. They provided alternate means of maximizing the expected target damage.

C. REDUCED MODEL DESCRIPTION

Below is a description of the CAMPIN model as it was used in this study. Flowcharts are provided in Appendix A for those subroutines indicated.

1. Flowchart

Figure 3 shows a schematic view of the computational flow between subroutines. The double headed arrows represent the CALL and RETURN commands in the program code. ISORT was the number of the red aircraft sortie currently being flown. The value of ICONT was established in Subroutine ASSESS. It was set to zero only if one or more of the termination conditions were met.

2. Subroutine Description

The description of each subroutine includes the structure of the subroutine and the necessary input and output parameters.

a. Subroutine TACTIC

Subroutine TACTIC called Subroutines PROFIL and ALLOC to establish the maximization factors and to determine the resulting target allocations.

b. Subroutine PROFIL

The primary purpose of Subroutine PROFIL was to compute the value of the maximization factor RO[illegible] for its subsequent use in Subroutine ALLOC. Necessary information for this computation included the distribution of air defense fire units and their probabilities of participation as computed by Subroutine SETFU and the aircraft survival probabilities provided by Subroutines FLYER and FLYVT. Additionally, FLYVT computed the expected fraction of target damage. With this information and a designated

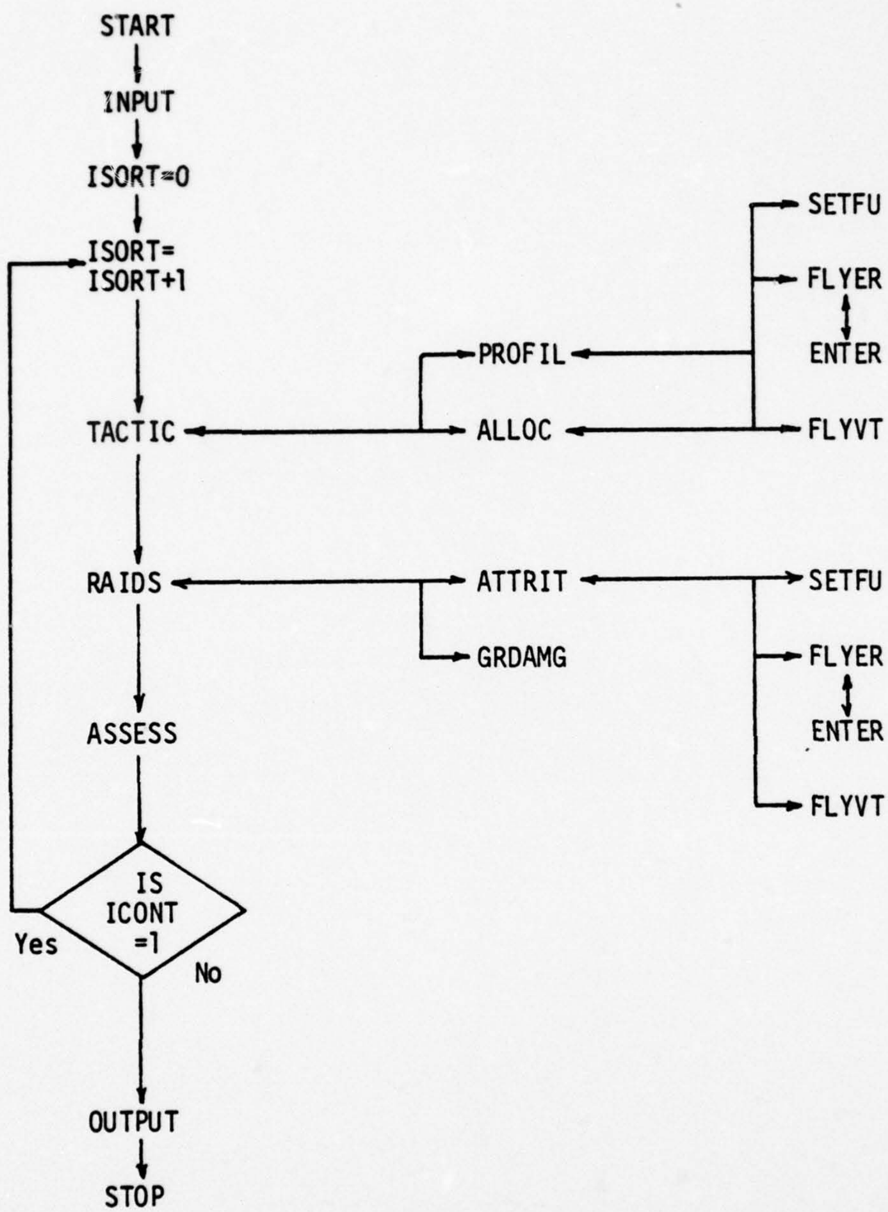

Figure 3. Campaign (CAMPIN) Schematic

allocation procedure, the maximization factor was calculated as shown in Equations (1), (2), and (4). They are repeated below for convenience.

$$\text{ROPT} = \text{PSIN} \times \text{PSVT} \times \text{PSEG} \tag{12}$$

$$\text{ROPT} = \text{DAMR}/(1-(\text{PSIN} \times \text{PSVT} \times \text{PSEG})) \tag{13}$$

$$\text{ROPT} = \text{DAMR} \tag{14}$$

Subroutine PROFIL then computed the expected number of aircraft killed by a target per raid point. A flowchart of Subroutine PROFIL is located in Appendix A.

c. Subroutine SETFU

The distribution of air defense fire units was computed using the fact that the defended area was divided into four regions as shown in Figure 4. Subroutine SETFU computed the expected number of air defense fire units located in front of a given region that would engage an aircraft. For example, a raid point is going to attack a target located in Region 3. SETFU computes the total number of fire units of each type that are located in Regions 1 and 2. These totals are then multiplied by the probability that the fire unit will engage. The resulting figure was the expected number of fire units that would engage the raid point.

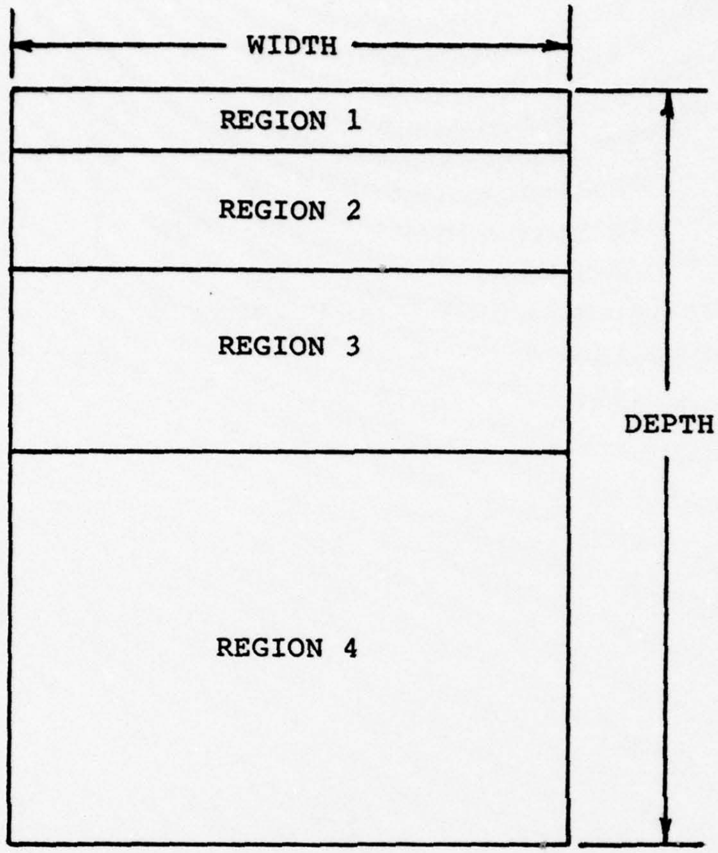

Figure 4. Defended Area

d. Subroutine FLYER

Subroutine FLYER computed the probability that an incoming or outgoing aircraft would survive an engagement by an air defense fire unit. The computation was dependent upon the configuration of the fire unit. If the air defense unit was a high altitude missile air defense (HIMAD) system, the number of fire units that engage a raid point on the ingress or egress leg of an attack on a target was set equal to the number of fire units defending the target times the probability that the fire unit would participate. In the event that the fire unit was of any other type, Subroutine ENTER was called to compute the number of fire units forward of the penetration depth required for the target. (For this study, the distance into the defended area that an aircraft had to penetrate was equal to the depth of the target.) The number of fire units that engage a raid point was set equal to the number of fire units forward of the penetration depth for the target times the lateral coverage of the fire unit divided by the width of the defended area. In other words, if sixty fire units are forward of the target, each with lateral coverage of one kilometer and the defended area is twenty kilometers wide, the expected number of fire units participating is: (60 fire units)(1 kilometer)/(20 kilometers) = 3 fire units. The probability of one aircraft surviving the ingress or egress portion of the raid was then computed. A detailed flowchart of Subroutine FLYER is provided in Appendix A.

e. Subroutine ENTER

Subroutine ENTER computed the number of fire units that could engage an aircraft on its ingress or egress leg. This total included all of the fire units in forward regions plus the fire units in the region of the target that are inside the penetration depth.

f. Subroutine FLYVT

Subroutine FLYVT computed the expected number of fire units that would engage a raid point in the attack, and the probability that an aircraft would survive the attack. The fraction of target damage, also computed by FLYVT, was dependent upon the configuration of the target. If the target was an area target or a point defended target, the fraction of target damage DAMR was computed as shown in Equation (15). If the target was an undefended point target, the fraction of target damage was computed using Equation (16). A flowchart of Subroutine FLYVT is provided in Appendix A.

$$DAMR=PDCV(1-(1-(PDMG/ELL))^{(STAN \times TSOR)}) \tag{15}$$

$$DAMR=PDCV(1-(1-PDMG)^{(STAN \times TSOR)}) \tag{16}$$

where

PDCV - The probability of detecting a target of type j and being able to maneuver into position to attack it.

PDMG - The fraction of target damage to a target of type j due to one weapon released by an aircraft of type i.

ELL - The number of critical elements remaining in a target of type j.

STAN - A damage to target per weapon conversion factor.

TSOR - The expected number of aircraft surviving to attack the target.

g. Subroutine ALLOC

The allocation schemes were discussed in detail and will not be repeated here. A flowchart of Subroutine ALLOC is provided in Appendix A.

h. Subroutine RAIDS

Subroutine RAIDS used the attrition of red aircraft computed by Subroutine ATTRIT to determine the number of aircraft destroyed per sortie, the number of aircraft of each type destroyed during the war, and the total number of aircraft killed during the war. With this information, RAIDS updated the inventories of red aircraft. Subroutine GRDAMG was called to compute the attrition of blue targets.

i. Subroutine ATTRIT

Subroutine SETFU was called to establish the distribution of air defense fire units. Aircraft survival probabilities and the expected fraction of target damage were provided by Subroutines FLYER and FLYVT. With this information Subroutine ATTRIT computed the number of aircraft of type i destroyed by a target of type j and the total number of aircraft of type i destroyed during the sortie.

j. Subroutine GRDAMG

The primary purpose of Subroutine GRDAMG was to compute the expected fraction of damage sustained by blue ground forces and air defense fire units. Once the damages were computed, the subroutine updated the status of all blue target types. Using the allocation weights and the probabilities of aircraft survivability, the number of aircraft surviving to attack the target was computed. As in Subroutine FLYVT, the computation of the expected fraction of target damage was dependent upon the configuration of the target. If the target was an area target or a point defended target, the computation was done using Equation (15). For an undefended point target, Equation (16) was used. The target values of each target type were adjusted downward to reflect the sustained damage. Finally, the number of fire units in each region was adjusted by the amount of damage. A flowchart of Subroutine GRDAMG is provided in Appendix A.

k. Subroutine ASSESS

Subroutine ASSESS evaluated the status of each force to make the battle termination decision. The aircraft inventory for the next sortie was established, and if the number of aircraft available dropped below the cutoff, red was declared dead and the battle ended. If the simulation was not ended, starting target values for the next sortie were established. If the percent of target value remaining for the entire array dropped below the cutoff, blue was declared dead and the run ended. If the number of sorties flown reached its cutoff, the simulation was ended; if not, the sortie counter was incremented and the entire procedure was repeated.

IV. ANALYSIS OF RESULTS

The primary tool of analysis used was a Mean Value Differential Analysis algorithm. The algorithm computed the Grand Mean, submeans, and submean differentials of the data provided by the full factorial experiment used in this study. It provided the mean value differentials for the main effects and all interaction effects. Sample output from MVDA and sample output from the Campaign model are provided at the end of this report. Figures 5 through 21, which are a graphical portrayal of the analysis, are in Appendix B.

A. INITIAL OBSERVATIONS

A preliminary review of the model output provided justification for simplifying some portions of the analysis.

1. Profile Alternatives

When the attack profile was the same for all aircraft-target combinations (P1), target types 1 and 2 (Tank Companies) were destroyed at a significantly slower rate than the other target types. This was due to a very low expected fraction of damage to the target per weapon delivered by an aircraft using the given profile. Target types 1 and 2 accounted for thirty-eight percent of the targets modelled. Because of the disparity in rates of destruction, target types 1 and 2 severely biased the statistics on the percentage of the entire array remaining.

Consequently, during the analysis, only the simulation runs modelling optimum profiles (P2) were reviewed.

2. Ratio Alternatives

Alternative aircraft-to-target ratios were simulated to provide a measure of allocation scheme sensitivity to changes in the offense/defense force ratio. In most cases, the 9.93 to 1 ratio forced the blue target values to zero very early in the simulation. Because of the rapid decline in target values, there was very little difference in the output over the remaining factors. Detailed analysis is presented only for the 3.31 to 1 and 5.38 to 1 offense to defense ratios.

3. Allocation Alternatives

Six different allocation schemes were simulated to evaluate differences between the three basic procedures (i.e. Fixed, Proportional, and Lagrangian). The model output and MVDA output revealed differences between the procedures. However, in most cases, within each procedure, there was little or no difference between schemes using different optimization functions. To further reduce the scope of the analysis, only the three allocation schemes listed in Table VI were analyzed in detail.

4. Analysis Point Reduction

A review of the model output showed that under most circumstances the last four analysis points (i.e. three day, five day, fifteen day and thirty day) did not provide any

Table VI. Allocation Schemes Analyzed

2.	Fixed; Maximize Target Destruction over Aircraft Losses
4.	Proportional; Maximize Target Destruction
6.	Lagrangian (2); Maximize Target Destruction

additional information. So, the following analysis concentrates on the first six sorties.

B. ALLOCATION SCHEMES

Figures 5 through 8 depict the mean fraction of the target array remaining for sorties one through six. Each figure represents one of the target value systems. All are plotted with a force ratio of 3.31 to 1 (R1). The data for a force ratio of 5.38 to 1 (R2) show the same trends.

1. Under Target Value System 1

Figure 5 provides a view of the base case performances of each allocation scheme. The proportional procedure was consistently more productive for the red force than the alternate schemes. For the case where all targets have equal value, there was very little difference between the fixed and Lagrangian procedures.

2. Under Target Value System 2

Using this system, priority was given to those targets posing the greatest threat to the advancing red ground forces. Those targets (Tank Companies and Howitzer

Batteries) represented eighty-nine percent of the target value of the entire array. Again, as shown in Figure 6, the proportional procedure clearly dominated. Note however that the Lagrangian procedure was better than the fixed when tanks and artillery tubes were emphasized. The relative fractions of the target array remaining are very similar for the two target value systems considered thus far.

3. <u>Under Target Value System 3</u>

Seventy-five percent of the target array was represented by the 50 cal machine guns mounted on tanks and the Improved HAWK batteries. Even though only seventy-five percent of the array was given priority, under this system of target values, all of the allocation schemes did better with respect to red than under target value systems 1 and 2. Figure 7 shows that the fixed and Lagrangian procedures gave similar results while the proportional scheme again dominated.

4. <u>Under Target Value System 4</u>

The critical assets, which accounted for thirty-eight percent of the value of the target array, were given priority under this system. Changes are present in Figure 8 which do not appear until after the third sortie. At that time the fixed and proportional schemes appear to be better than the Lagrangian. This may be explained in part by studies completed by SRI International which show that the Lagrangian allocation system loses its efficiency after four or five repetitions. The performance of all allocation procedures was below that of the base case shown in Figure 5.

C. AIRCRAFT-TO-TARGET RATIOS

Figures 9 through 12 show the mean fraction of the target array remaining for the first six sorties. Each force ratio is depicted with each of the target value systems. Results are presented only for the proportional allocation scheme which maximizes target destruction. As expected, the production of the 5.38 to 1 force ratio was significantly better than the 3.31 to 1 ratio. The 3.31 to 1 (R1) ratio is used for all further analysis. As in Figures 5 and 6, the relative performances under target value systems 1 and 2 (Figures 9 and 10) are nearly identical. Under target value system 3, where air defense fire units were given priority, Figure 11 shows that both ratio levels resulted in greater destruction than the respective levels for the base case of Figure 9. Again, when the blue critical assets were given higher priority, Figure 12 shows that system was less productive than the base case. The difference between R1 and R2 was not affected by the use of the different target value systems.

D. TARGET VALUE SYSTEMS

Figures 13 through 20 show the destruction of each target type during the first six sorties for the four target value systems. As before, the proportional allocation scheme maximizing target destruction is used with selected targets also evaluated under the Lagrangian procedure.

1. Target Type 1

As shown in Figure 13, there was no significant difference until sortie 3 where target value system 3 outperformed the others and target value system 4 lagged behind. Since the tanks were equipped with the M-2 50 cal machine gun, target types 1 and 2 were considered priority targets under target value systems 2 and 3.

2. Target Type 2

The comments about target type 1 are equally applicable to target type 2 as can be seen in Figure 14. The relative performance of the target value systems was poorer for the red force than that for target type 1. This is explained by the fact that the aircraft must penetrate deeper to engage target type 2. Figure 15 shows the contrast between the proportional and Lagrangian schemes that was alluded to earlier. Under the Lagrangian allocation scheme, target degradation was more severe for the first four sorties, but the proportional scheme was dominant by sortie six.

3. Target Type 3

Artillery units were the most prevalent target type on the battlefield. This in part explains the high target destruction rates shown in Figure 16. The results of the different target value systems were about the same except for target value system 3 where the air defense forces were given the priority. Because target destruction was so severe, by sortie six there was no difference betwteen any of the systems.

4. Target Type 4

As should be expected, target type 4, which is a critical asset, was severely degraded when target value system 4 was employed. Figure 17 shows that systems 2 and 3 provided results poorer than that of the base case. Under a Lagrangian allocation scheme, Figure 18 shows that while the target value systems maintained the same order, target destruction levels were higher for each.

5. Target Type 5

The Improved HAWK firing batteries were totally destroyed during the first sortie when target value system 3 was used. It is shown by Figure 19 that target value systems 2 and 4 were poorer than the base case.

6. Target Type 6

Target Type 6 was a hardened critical asset that was not affected by any of the target value systems. What difference there was, is shown by Figure 20 where target value system 4 is slightly better after sortie three.

E. AIRCRAFT LOSSES

Figure 21 is a typical example of the aircraft losses throughout the evaluation. The aircraft losses for each allocation scheme are plotted for the first six sorties. A force ratio of 3.31 to 1 and the base case target value system were in effect. A plot of later sorties would not provide any additional information because by that time the blue forces were so severely attrited that they could not cause much additional damage to the aircraft types. The proportional allocation scheme had the lowest loss rate of aircraft which is substantiated by that scheme's dominance in the destruction of the blue target array. Because the aircraft losses under the Lagrangian allocation scheme were so large in the beginning, it explains the rapid drop in the productivity of that scheme in later sorties.

V. CONCLUSIONS

The above analysis highlighted some conclusions that can be drawn from this study. The proportional allocation scheme demonstrated dominance in every respect. The level of destruction of the blue target array was as good or better for the red force than any other scheme under all factor levels. Additionally, the proportional scheme resulted in the lowest losses of aircraft throughout the simulation. The Lagrange Multiplier allocation scheme started strongly with high rates of target destruction for the first few sorties. However, the high losses of aircraft made it impossible for the Lagrangian procedure to maintain the initial target destruction rates. By the sixth sortie, the performance lagged to the point where it, in many cases, was the worst procedure. Some observations were made on the target value systems. Target value system 3 gave higher target priority to the air defense units. In doing so, it removed the threat to attacking aircraft, resulting in higher target destruction rates for all of the allocation schemes. The worst target value system gave the highest priority to the blue critical assets. In this case there was a drop in the production of the allocation schemes. Using typical parameter input settings as were used in this study, it appears that a proportional allocation scheme maximizing target destruction and a target value system which gives greater priority to the air defense fire units will result in the greatest destruction of the blue target array by red aircraft.

APPENDIX A

SUBROUTINE FLOWCHARTS

This appendix includes flowcharts for the more involved subroutines of the Campaign model. Included is the PROFIL, FLYER, FLYVT, ALLOC, and GRDAMG subroutines.

SUBROUTINE PROFIL

Enter

Subroutine SETFU is called to compute the fire unit distribution.

The penetration depth to target j = the depth of target j - the ordnance stand off range.

Subroutine FLYER computes the probability that aircraft i will survive to complete the ingress and egress portions of a raid on target j.

Subroutine FLYVT computes the probability that aircraft i will survive the attack portion of a raid on target j and computes the ensuing percent of target damage to target j.

The maximization factor is computed for each allocation scheme.

If the allocation scheme seeks to minimize aircraft losses, the maximization factor is the survival probability for aircraft i computed by FLYER and FLYVT.

If the allocation scheme is to maximize the ratio of target destruction to aircraft losses, the maximization factor = the fraction of target damage/ the probability of aircraft kill.

If the allocation scheme seeks to maximize the target damage, the maximization factor = the fraction of target damage.

The number of aircraft i killed by target j per raid point = the number of aircraft i in a raid point - the number of aircraft i in a raid point that survive all three legs of the raid.

Return

SUBROUTINE FLYER

Enter

The probability of survival against each fire unit configuration is computed.

If fire unit k is not a HIMAD system, Subroutine ENTER computes the number of fire units k forward of the penetration depth for target j.

The number of fire units k that engage a raid point of aircraft i on its ingress or egress leg of an attack on target j = the number of fire units k forward of the penetration depth for target j x the full lateral coverage of fire unit k / width of the defended area.

If fire unit k is a HIMAD system, the number of fire units k that engage a raid point of aircraft i on its ingress or egress leg of an attack on target j = the number of fire units k defending target j x the probability of a fire unit k engaging an aircraft which is on its ingress or egress leg of an attack on a target in region 1.

The probability that an aircraft i will survive the ingress or egress leg of an attack on target j = the probability of an incoming or outgoing aircraft surviving an engagement from fire unit k raised to the power (the number of fire units k that engage aircraft i on its ingress or egress leg / the number of aircraft i per raid point).

Return

SUBROUTINE FLYVT

Enter

The number of fire units k that engage aircraft i which is attacking target j = the number of fire units k defending target j x the probability that a fire unit k will engage an aircraft i attacking a target j in region l.

The probability that aircraft i will survive the attack on target j = the probability of an attacking aircraft i surviving an engagement from fire unit k raised to the power (the number of fire units k that engage aircraft i / the number of aircraft i per raid point).

Expected fraction of target damage is computed for each target configuration.

If target j is an area or point defended target; the fraction of target damage = the probability of detecting and converting target j x 1 - (1 - the fraction of damage of target j per weapon / the number of critical elements remaining in target j) raised to the power (the damage conversion factor x the number of aircraft i surviving to reach target j).

If target j is an undefended point target; the fraction of target damage = the probability of detecting and converting target j x 1 - (1 - the fraction of damage to target j per weapon) raised to the power (the damage conversion factor x the number of aircraft i surviving to reach target j).

Return

SUBROUTINE ALLOC

Enter

If fixed weighting is used; i.e. ICRIT=1 or 2, the dummy variable used to find a maximum comparison value is set to -1. The amount of unassigned allocation weight =1.

The percent of a raid point of aircraft i allocated against target j = the fixed allocation weight for aircraft i against target j.

The amount of unassigned allocation weight = the previous amount of unassigned allocation weight - the fixed allocation weight for aircraft i against target j.

If ICRIT=1, the comparison value = the maximization factor for aircraft i against target j.

If ICRIT=2, the comparison value = the number of targets j x the probability of engaging target j x the maximization factor for aircraft i against target j x the percent of target value remaining for target j x the initial target value for target j.

Set the dummy variable to the value of the maximum comparison value. If it is less than zero, aircraft i cannot attack any target.

If proportional weighting is used; i.e. ICRIT =3 or 4, the dummy variable used to find the maximum comparison value is set to -1.

A

B

C

A B C

The amount of proportional allocation weight for aircraft i against target j = the number of targets j x the probability of engaging target j x the maximization factor for aircraft i against target j x the percent target value remaining for target j x the initial target value of target j.

The percent of a raid point of aircraft i allocated against target j = the amount of proportional allocation weight for aircraft i against target j.

If the amount of proportional allocation weight for aircraft i against target j is greater than the dummy variable used to find the maximum comparison value, then the dummy variable is set equal to the amount of proportional allocation weight for aircraft i against target j.

If the total amount of proportional allocation weight for aircraft i against target j is zero, aircraft i cannot attack any target.

Otherwise, the percent of a raid point of aircraft i allocated against target j = itself x the weighting factor for aircraft i in clear weather / the total amount of proportional allocation weight for aircraft i against target j.

The unassigned allocation weight = 1 - the weighting factor for aircraft i in clear weather.

The aircraft i can attack at least one target and the remaining unassigned allocation weight is greater than zero, the percent of a raid point of aircraft i allocated against the target which maximizes the dummy variable = itself + the unassigned allocation weight. Otherwise, the percent of a raid point of aircraft i allocated against target j remains unchanged.

D E

D

E

The weight distribution of aircraft i against target j = the percent of a raid point of aircraft i allocated against target j.

The red aircraft losses are computed as in Subroutine ATTRIT.

Return

If the Lagrangian method is used, i.e. ICRIT =5 or 6, the necessary dummy variables are initialized to zero.

The number of raid points of aircraft i = the number of aircraft i remaining / the number of aircraft i per raid point.

The target value remaining for target j = the initial target value for target j x the percent of target value remaining for target j.

For those targets that are dead, the target value is zero and the allocation weight is zero.

The fraction of target j surviving an attack by aircraft i = 1 - the maximization factor for aircraft i against target j.

The denominator of the exponent of e (C1) in the equation for lambda of aircraft i = the sum of the number of targets j / the natural log of the fraction of target j surviving an attack by aircraft i.

If ICRIT =6.

If ICRIT=5.

The second term of the numerator of the exponent of e (TEM) in the equation for lambda of aircraft i = the sum of the number of targets j x the natural log of (- the target value remaining for target j x the natural log of the fraction of target j surviving an attack by aircraft i) / the natural log of the fraction of target j surviving an attack by aircraft i.

F

G

F G

Lambda of aircraft i = EXP{(the number of raid points of aircraft i + TEM) / C1}.

The number of raid points of aircraft i allocated to target j = the natural log of (lambda of aircraft i / (- the target value remaining for target j x the natural log of the fraction of target j surviving an attack by aircraft i)) / the natural log of the fraction of target j surviving an attack by aircraft i.

The total damage to target j = the target value remaining for target j x (1-(the fraction of target j surviving an attack by aircraft i raised to the power (the number of raid points of aircraft i allocated against target j / the number of targets j))).

If any of the values for the number of raid points of aircraft i allocated to target j are negative, those targets j are eliminated and a new reduced set of lambda's are computed until all values are greater than or equal to zero.

The total damage to target j per raid point = the total damage to target j / the number of raid points of aircraft i.

For the aircraft i, target j combination that results in the maximum damage to target j per raid point, allocate that aircraft i in accordance with the computed allocations.

The new target value remaining for target j = the previous target value remaining - the damage to target j / the number of targets j.

The number of raid points allocated = the sum of the raid points of aircraft i allocated to target j x the number of targets j.

The weight distribution of aircraft i against target j = the number of targets j x the raid points of aircraft i allocated to target j / the number of raid points of aircraft i.

H I

H

I

The red aircraft losses are computed as in Subroutine ATTRIT.

Return

If ICRIT=6, lambda for aircraft i and the allocation weights for aircraft i against target j are computed as in ICRIT=5.

The aircraft i-target j combination which maximizes target destruction, aircraft i is allocated against target j in accordance with lambda.

The number of unassigned aircraft i is reduced by the amount allocated.

The remaining target value of target j is reduced by the expected amount of target damage.

A new set of lambda's is calculated and the procedure is repeated until all aircraft are assigned.

The red aircraft losses are computed as in Subroutine ATTRIT.

Return

SUBROUTINE GRDAMG

Enter

The number of aircraft i that attack target j = the number of raid points per sortie for aircraft i x the weight distribution for aircraft i against target j x the number of aircraft i per raid point surviving to reach target j.

The total number of aircraft i that survive to attack targets = the sum of all aircraft i that attack targets.

The total number of aircraft i that survive to attack target j = the sum of all aircraft i that attack target j.

Expected fraction of target damage is computed for each target configuration.

If target j is an area or point defended target; the fraction of target *damage* = the probability of detecting and converting target j x 1- (1 - the fraction of damage of target j per weapon / the number of critical elements remaining in target j) raised to the power (the damage conversion factor x the number of aircraft i surviving to reach target j).

If target j is an undefended point target; the fraction target damage = the probability of detecting and converting target j x 1 - (1 - the fraction of damage to target j per weapon) raised to the power (the damage conversion factor x the number of aircraft i surviving to reach target j).

The new target multiplicative factor = the previous target multiplicative factor x (1 - the ratio of percent target damage to the number of targets) raised to the power (the number of raid points for aircraft i x the weight distribution of aircraft i against target j).

A

A

The new percentage of target value remaining for target j = the previous percent of target value remaining for target j x the target multiplicative factor for target j.

The new number of fire units k remaining to defend target j = the previous number of fire units k remaining to defend target j x the fire unit multiplicative factor for fire unit k.

If target j is a fire unit, the new number of fire units k in region l = the previous number of fire units k in region l - the change in the number of fire units k remaining to defend target j. If this is negative, it is set to zero.

If target j is a fire unit 2 (HIMAD), the new number of fire units 2 remaining to defend target j = the previous number of fire units 2 remaining to defend target j x the fire unit multiplicative factor for fire unit 2.

Return

APPENDIX B

GRAPHICAL ANALYSIS

This appendix provides several figures which support the discussion of the analysis in Chapter IV. These graphs include Figures 5 through 21. Throughout this appendix, the following abbreviations are used.

A2 - Fixed allocation scheme maximizing the ratio of target destruction to aircraft losses

A4 - Proportional allocation scheme maximizing target destruction

A6 - Lagrangian allocation scheme maximizing target destruction

R1 - Offense to defense force ratio of 3.31 to 1

R2 - Offense to defense force ratio of 5.38 to 1

T1 - Target value system 1 with all targets having equal value

T2 - Target value system 2 with priority given to targets posing the greatest threat to the advancing red ground forces

T3 - Target value system 3 with priority given to the blue air defense units

T4 - Target value system 4 with priority given to the blue critical assets

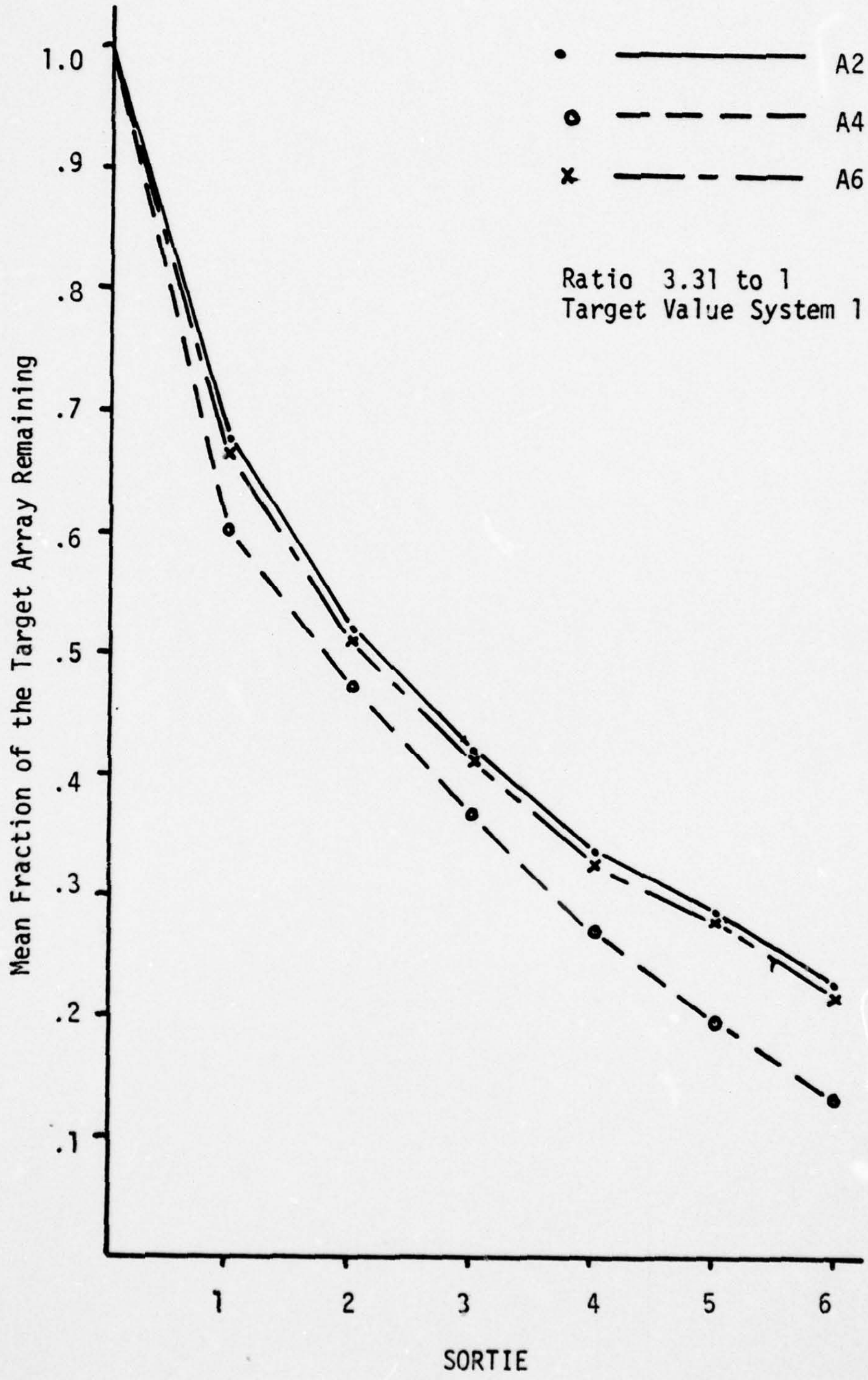

Figure 5. Allocation Schemes with Target Value System 1

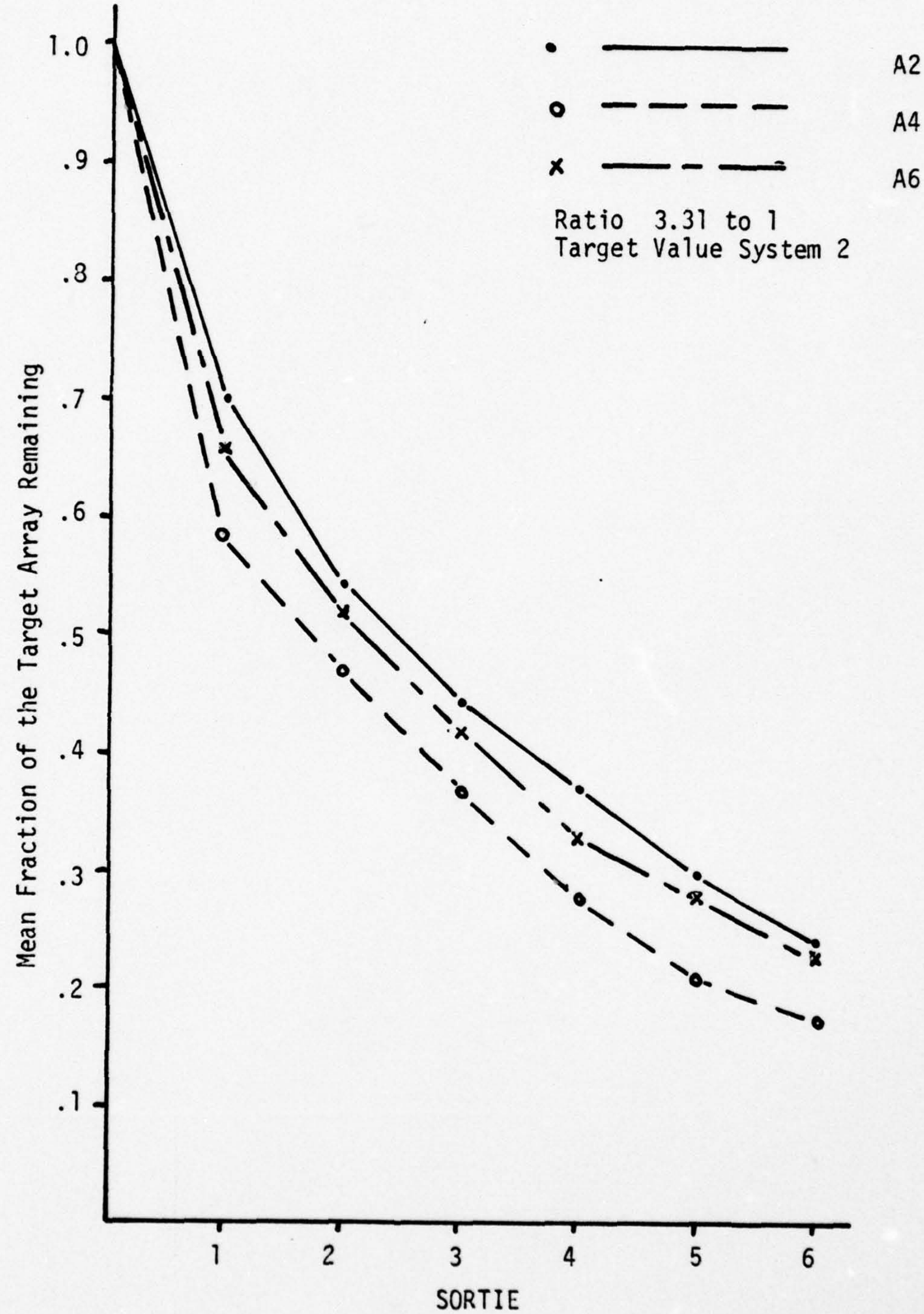

Figure 6. Allocation Schemes with Target Value System 2

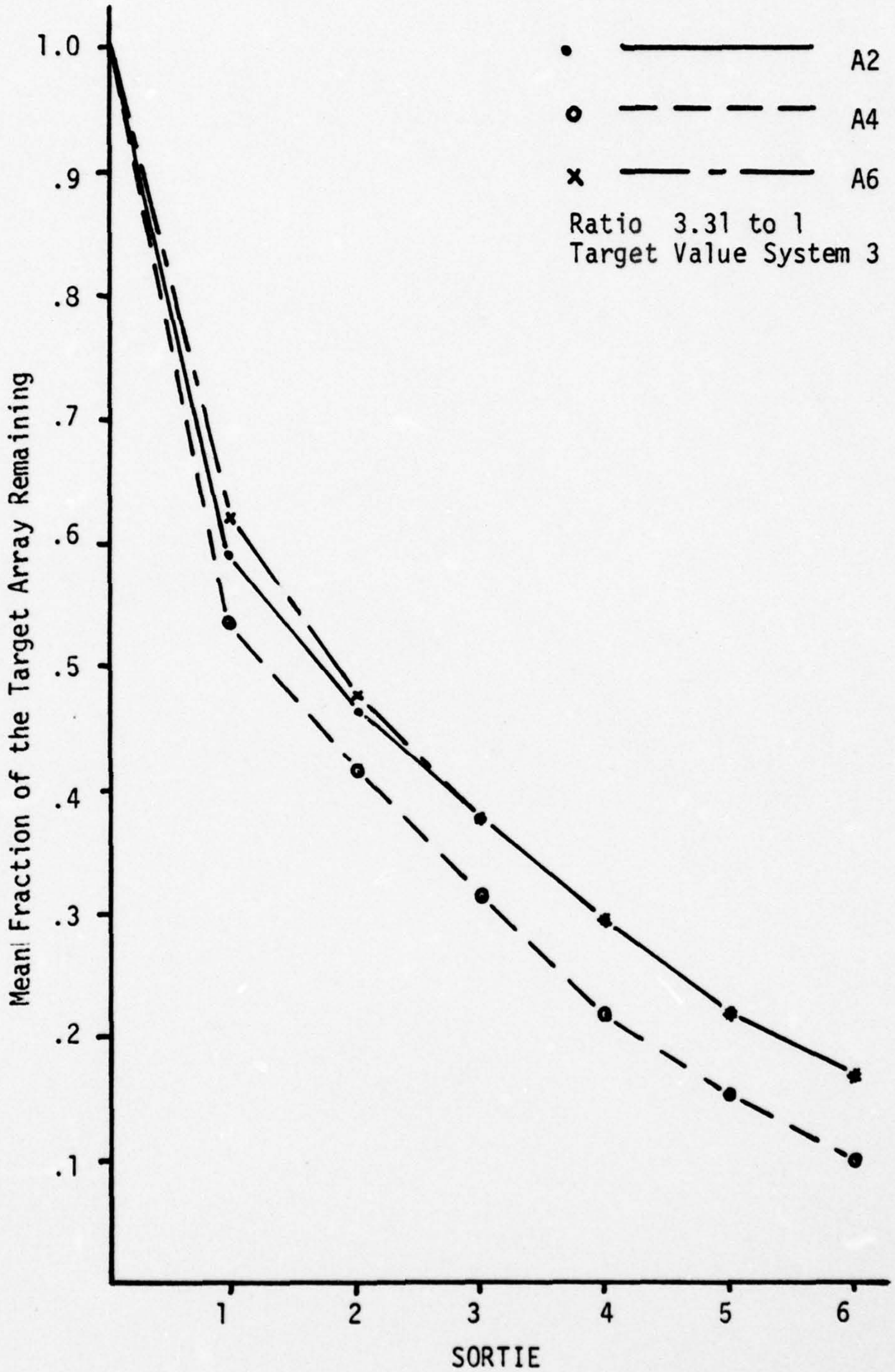

Figure 7. Allocation Schemes with Target Value System 3

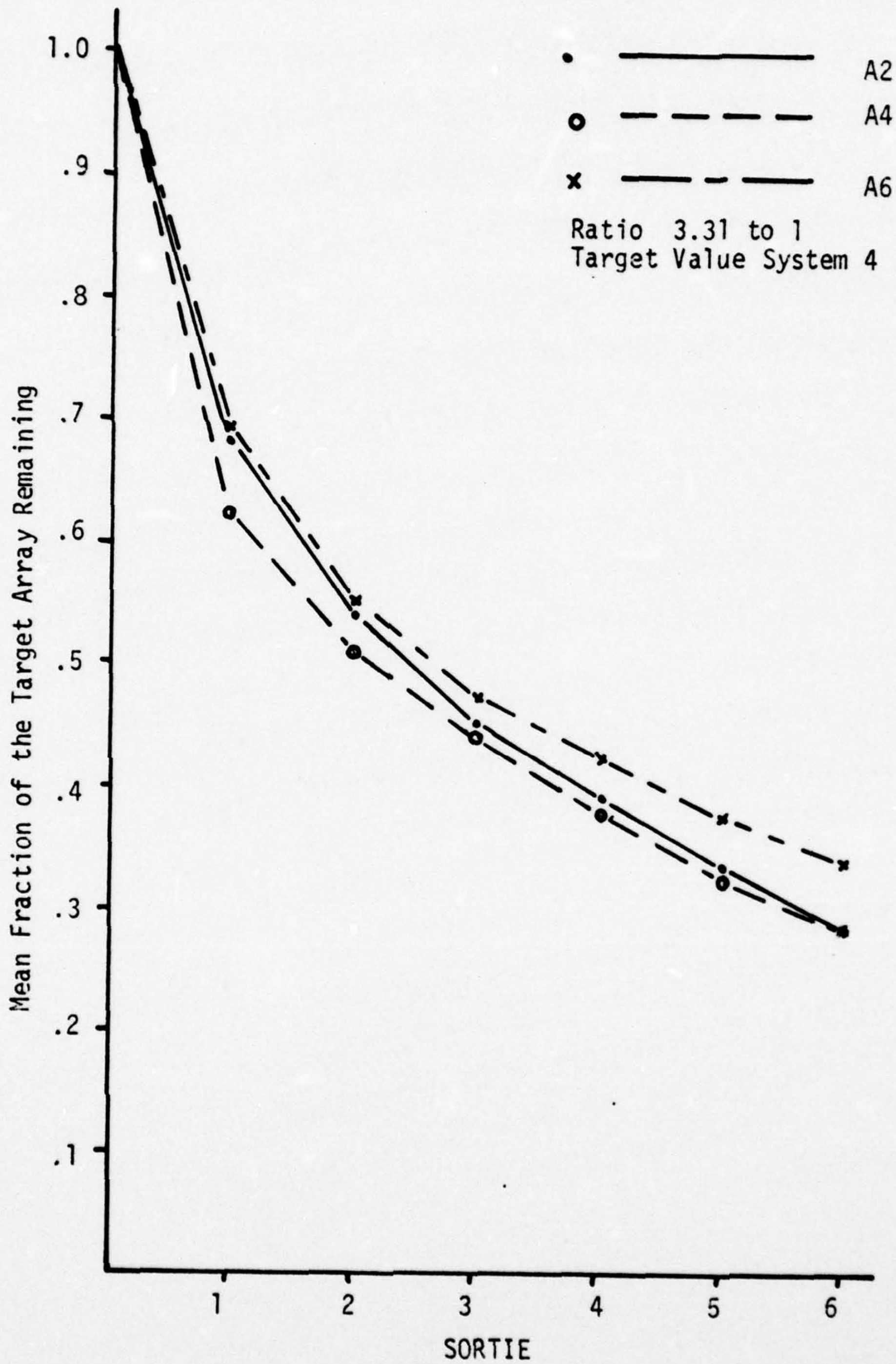

Figure 8. Allocation Schemes with Target Value System 4

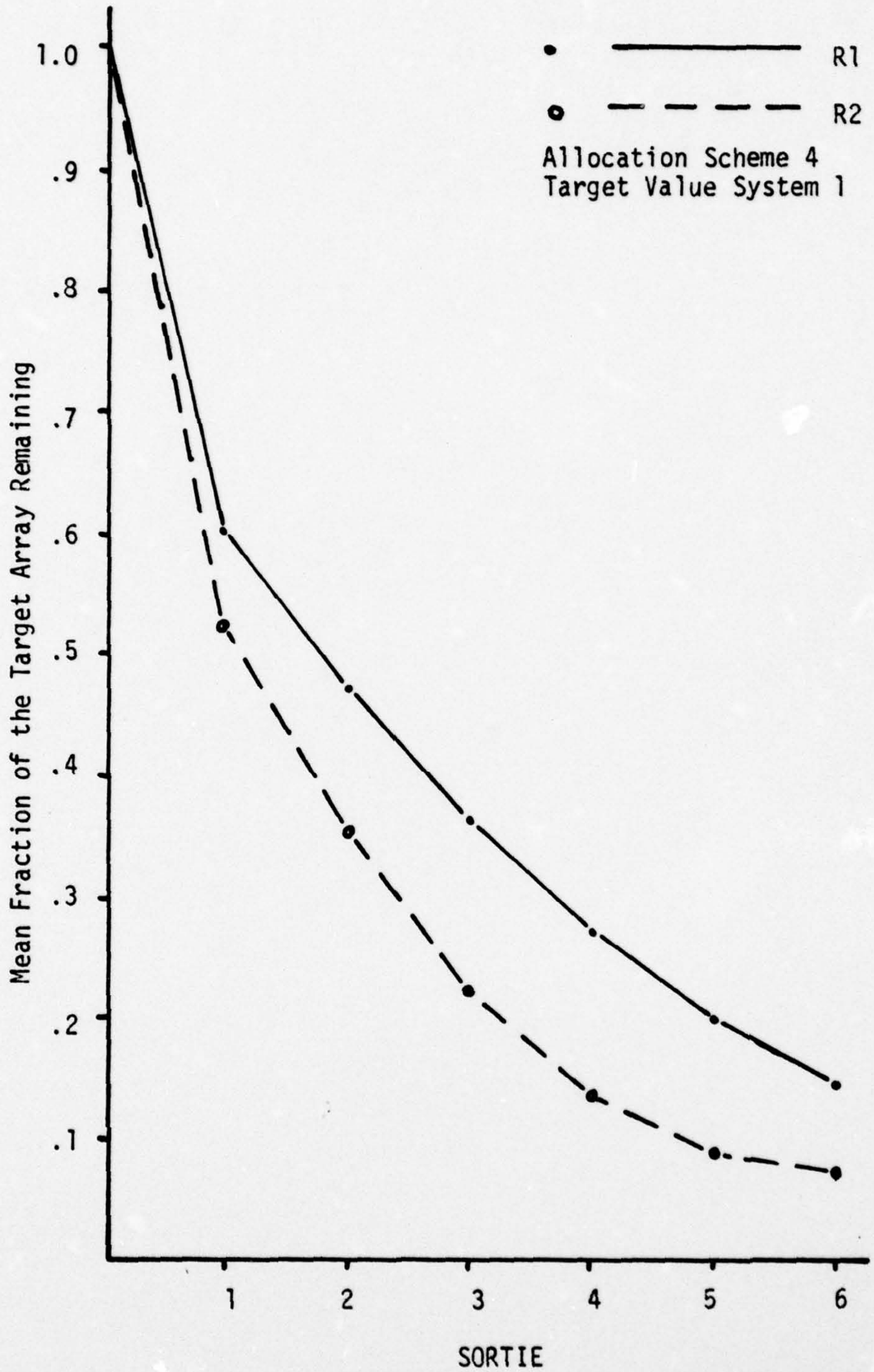

Figure 9. Ratio Levels with Target Value System 1

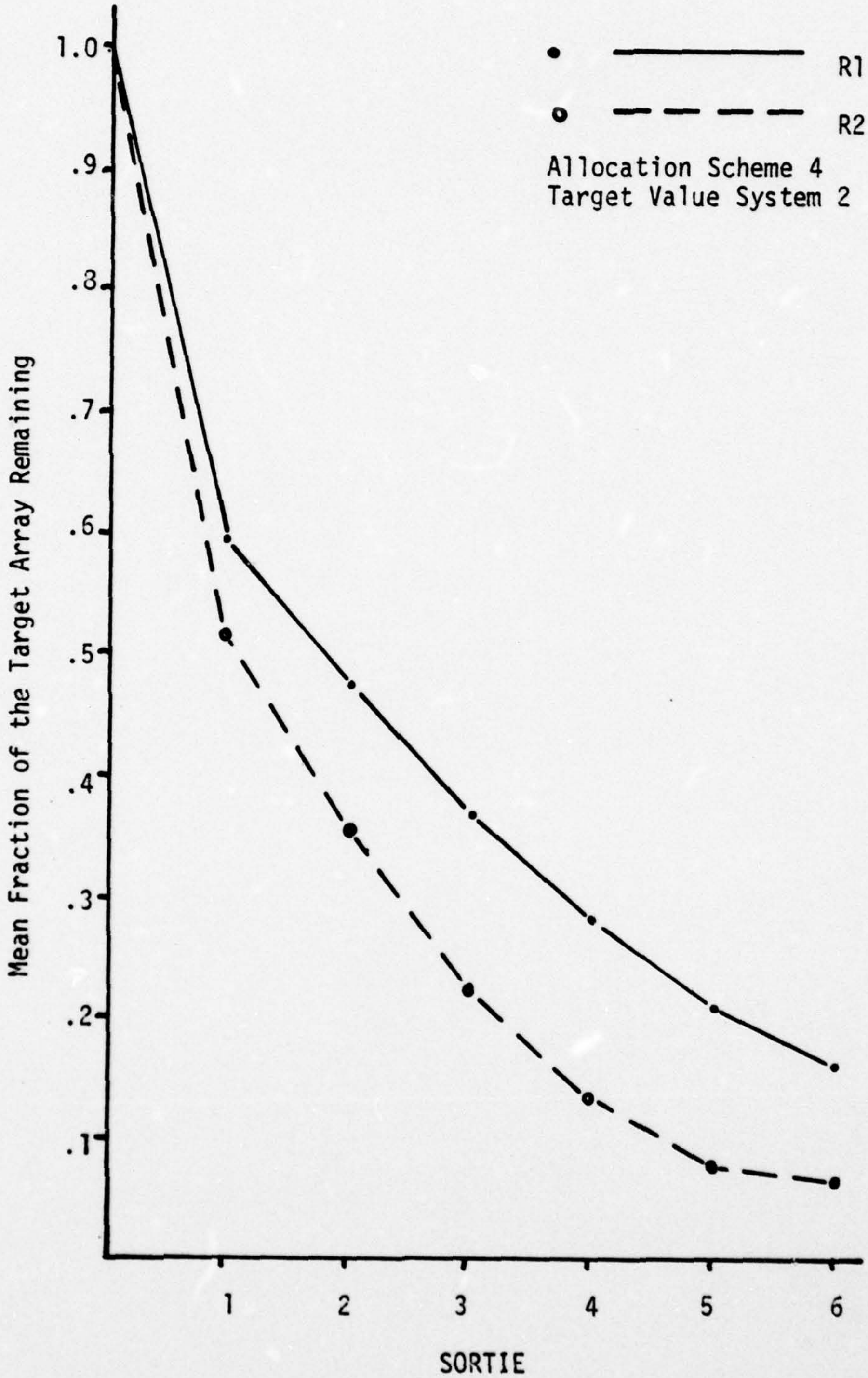

Figure 10. Ratio Levels with Target Value System 2

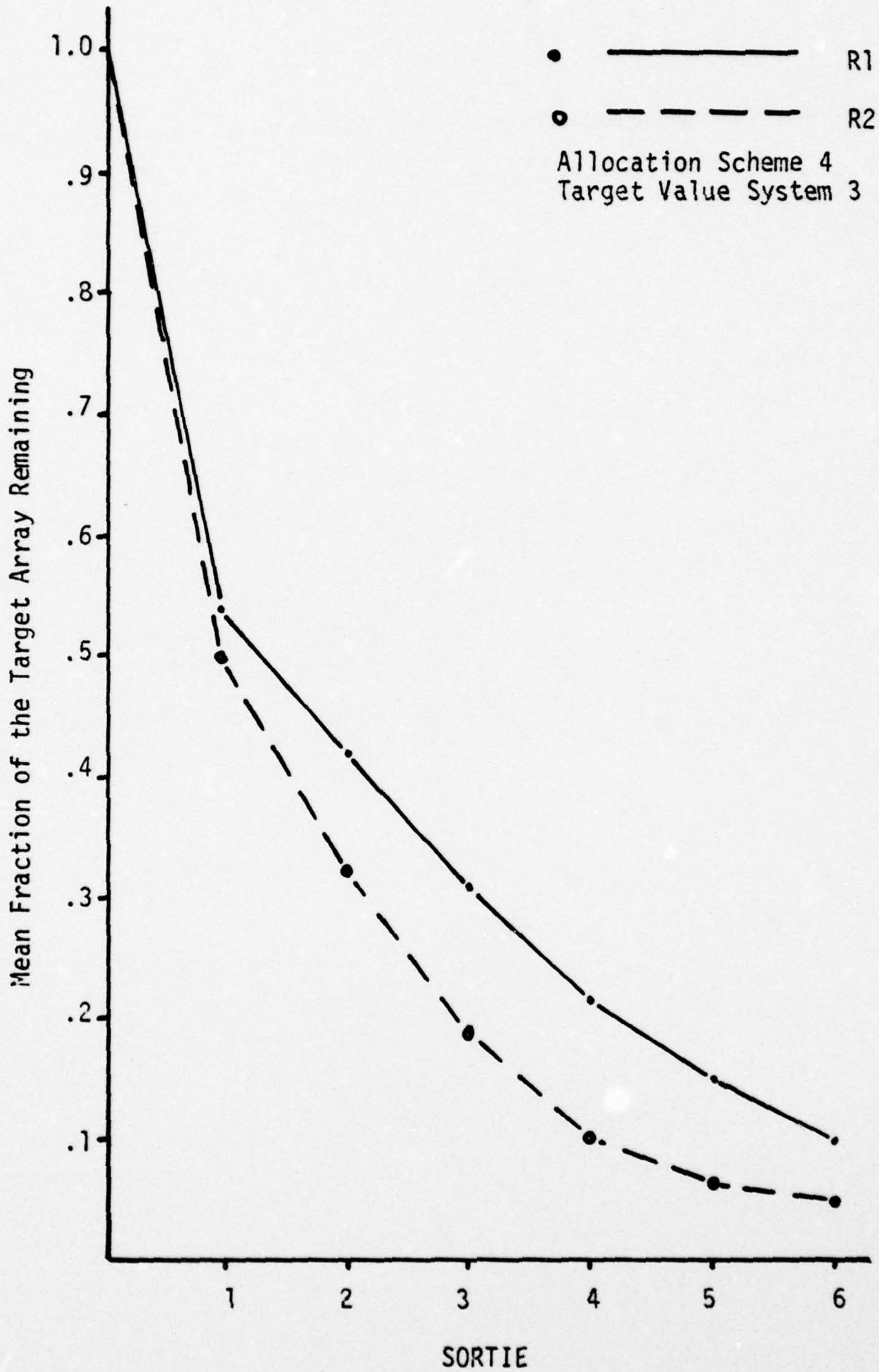

Figure 11. Ratio Levels with Target Value System 3

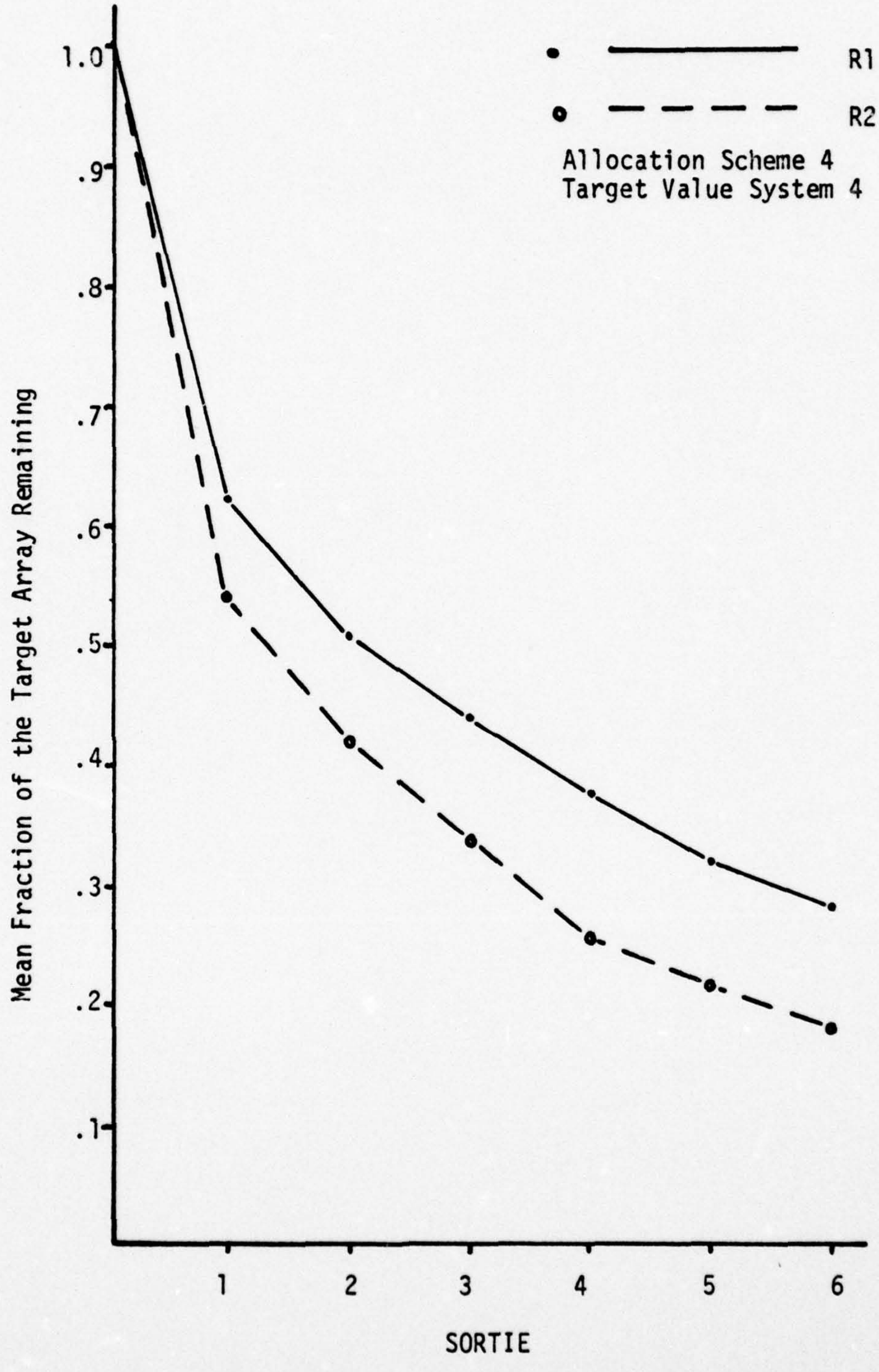

Figure 12. Ratio Levels with Target Value System 4

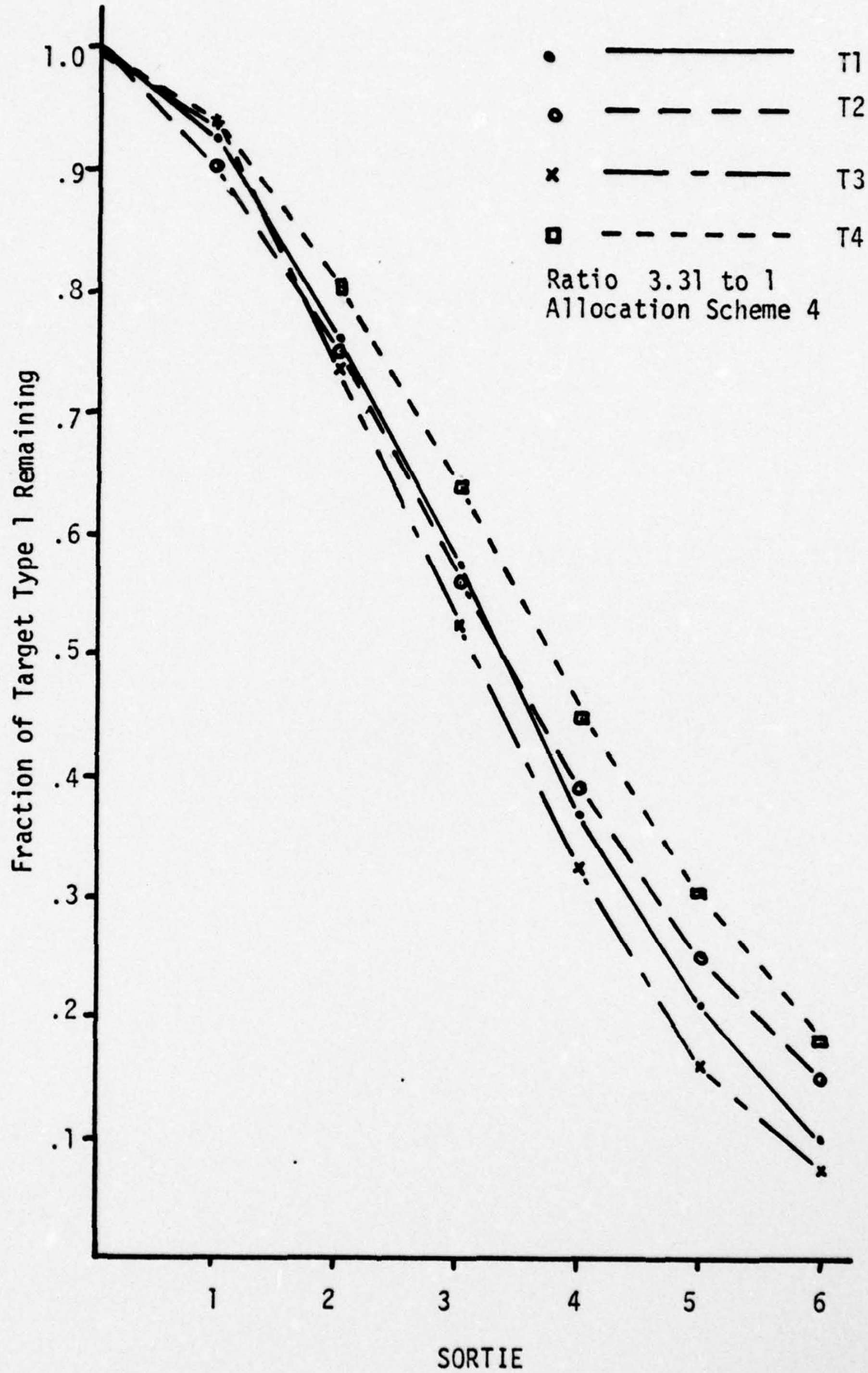

Figure 13. Target Type 1 (Tanks) with Target Value Systems

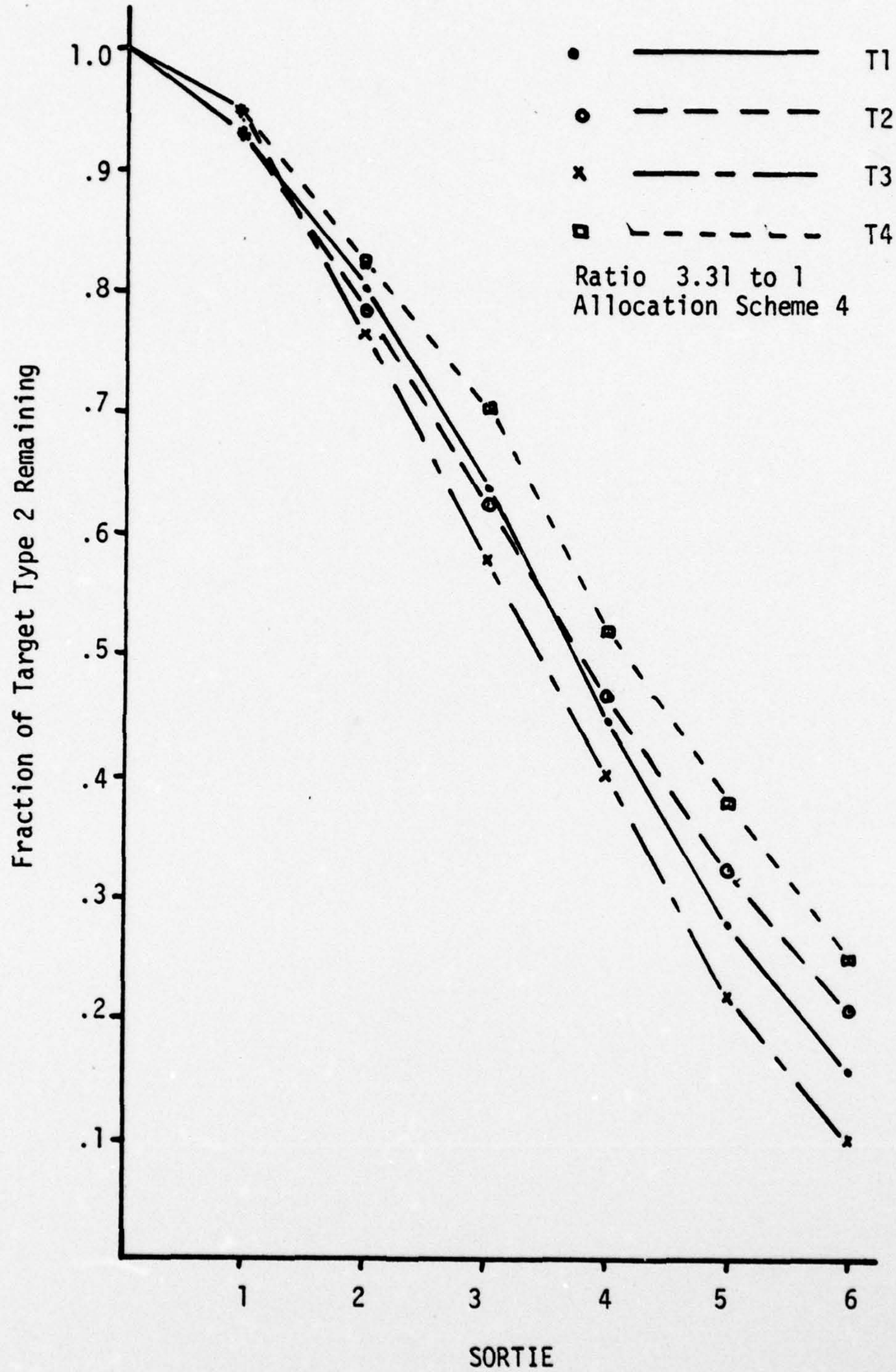

Figure 14. Target Type 2 (Tanks) with Target Value Systems

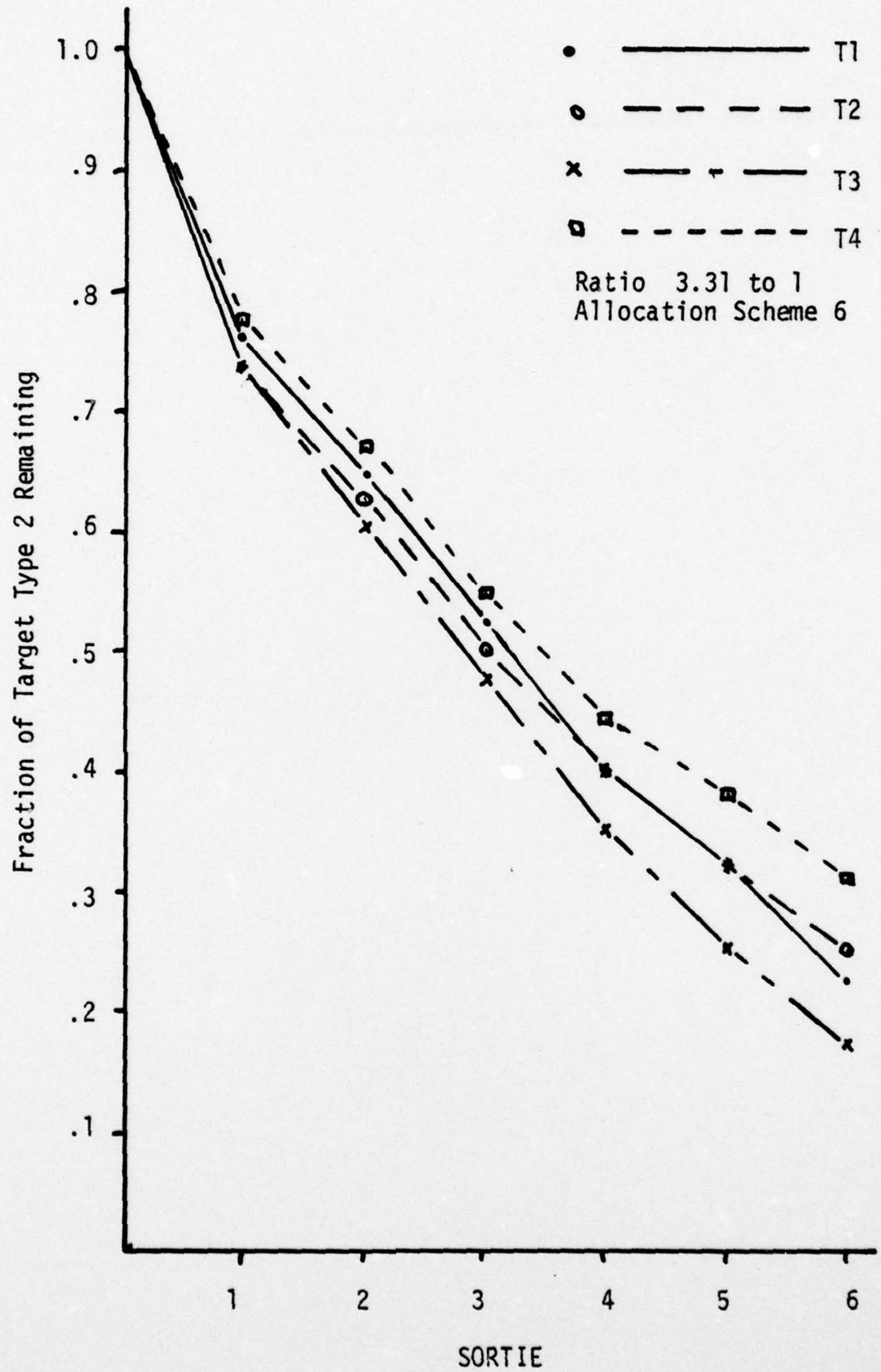

Figure 15. Target Type 2 (Tanks) with Target Value Systems (Lagrangian)

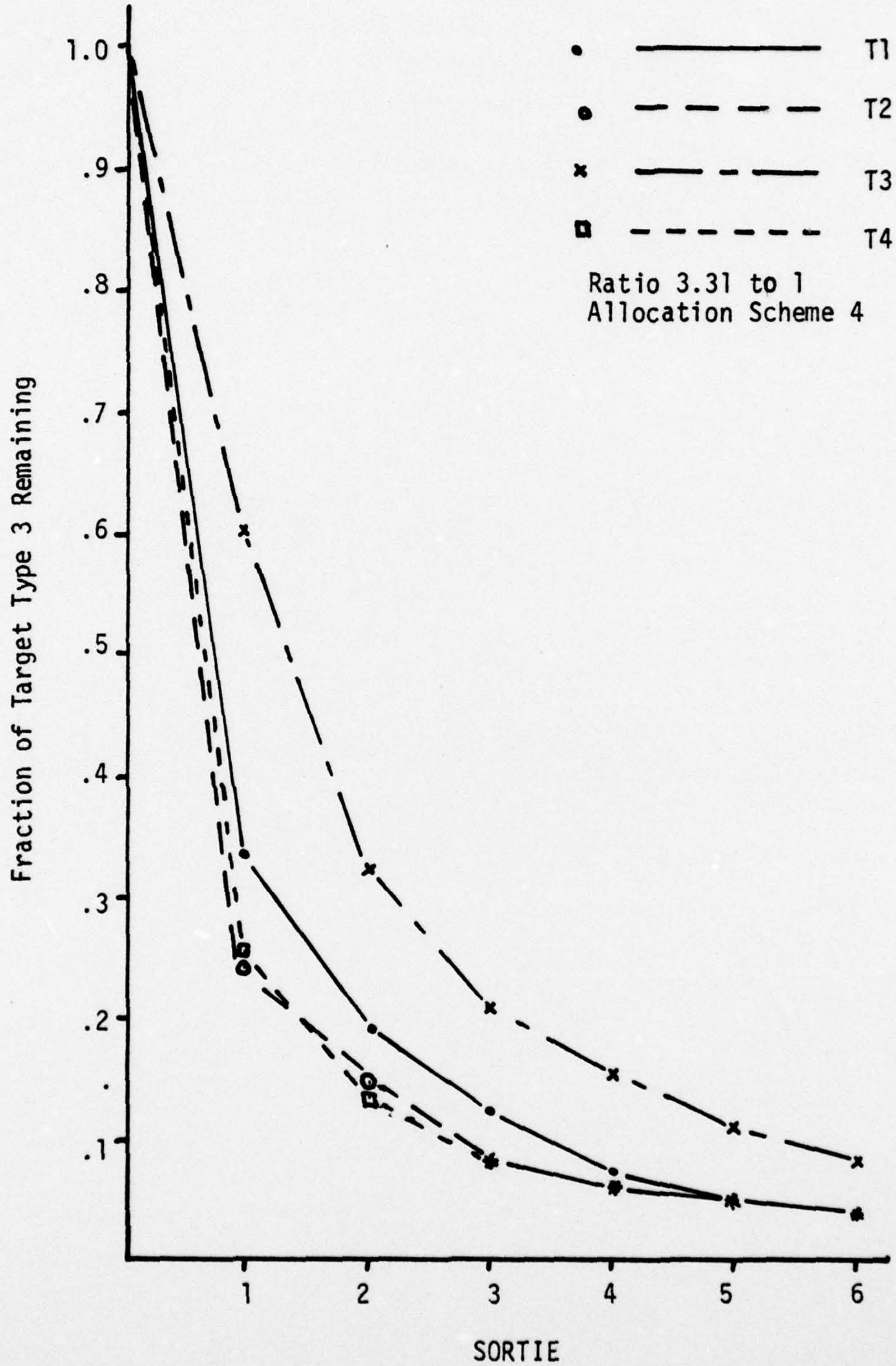

Figure 16. Target Type 3 (Howitzers) with Target Value Systems

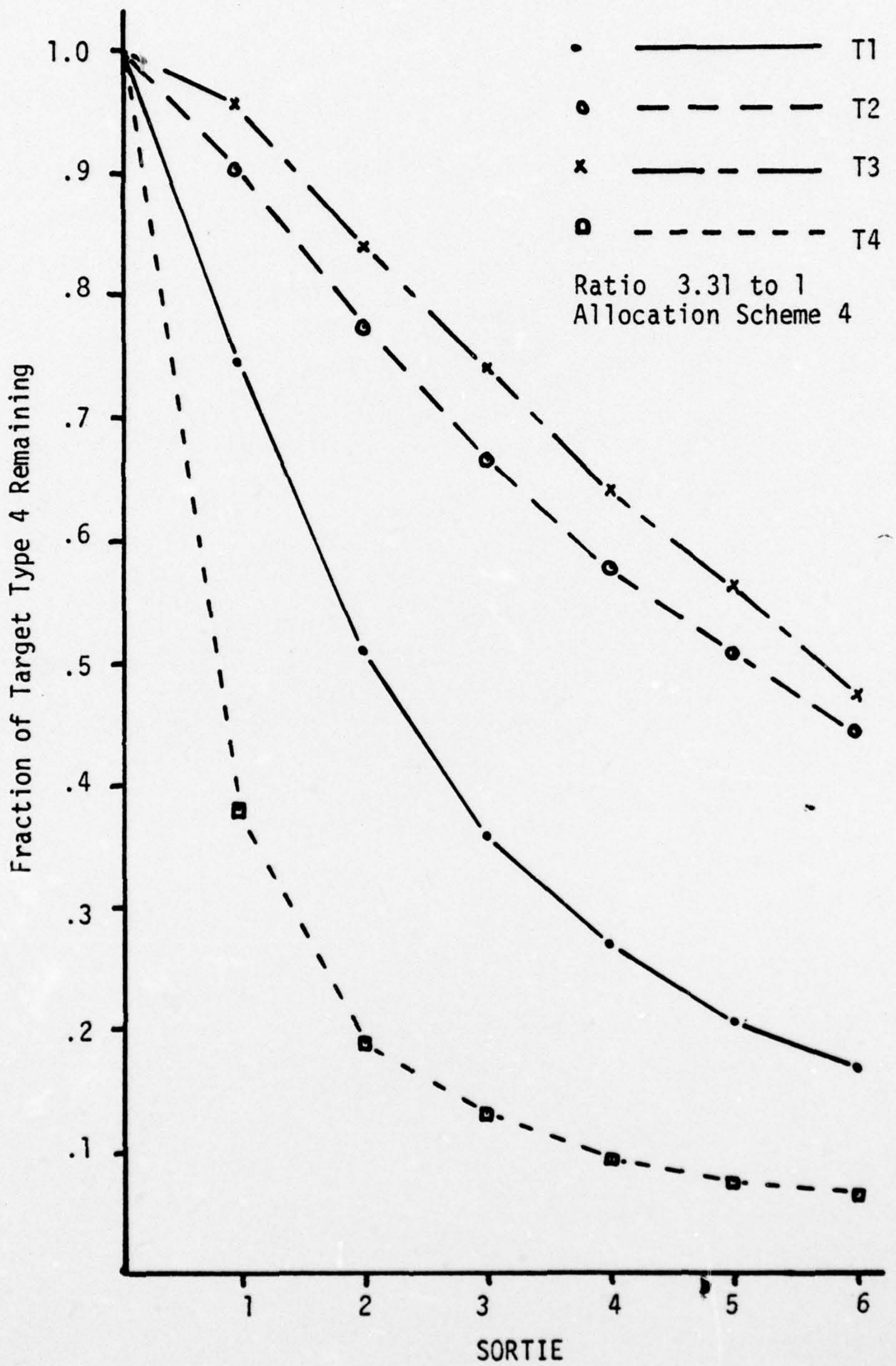

Figure 17. Target Type 4 (Depot) with Target Value Systems

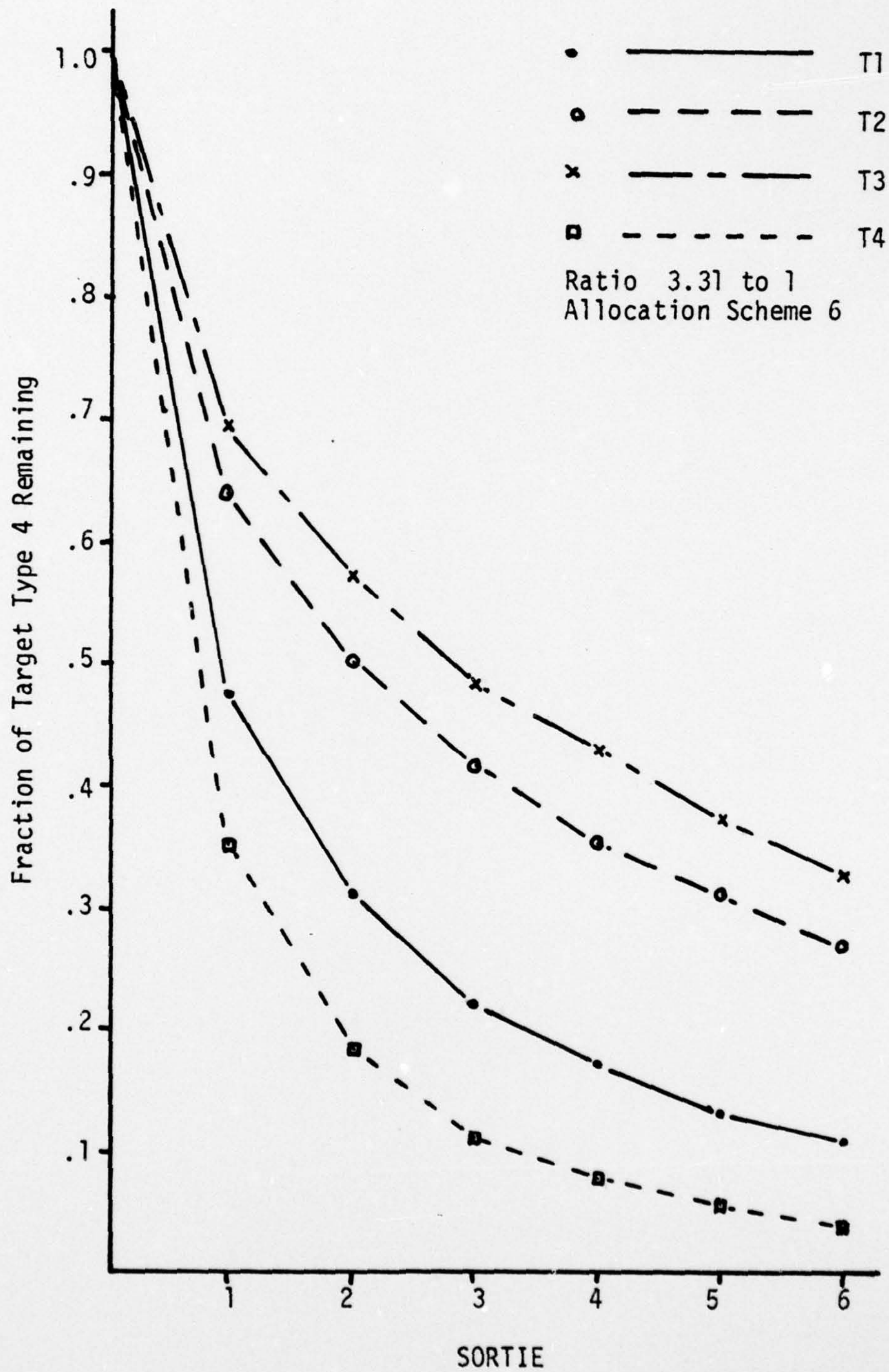

Figure 18. Target Type 4 (Depot) with Target Value Systems (Lagrangian)

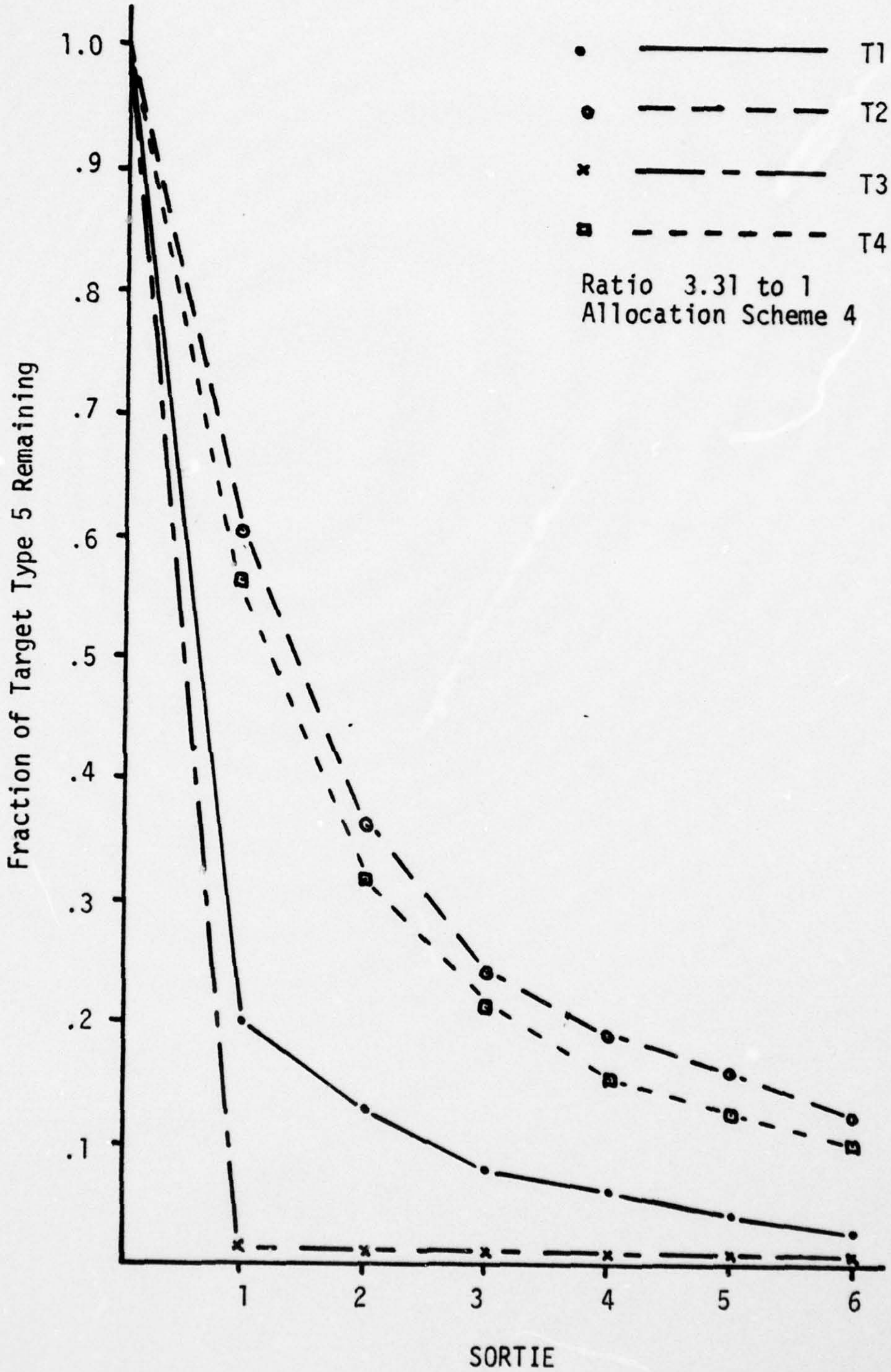

Figure 19. Target Type 5 (IHAWK) with Target Value Systems

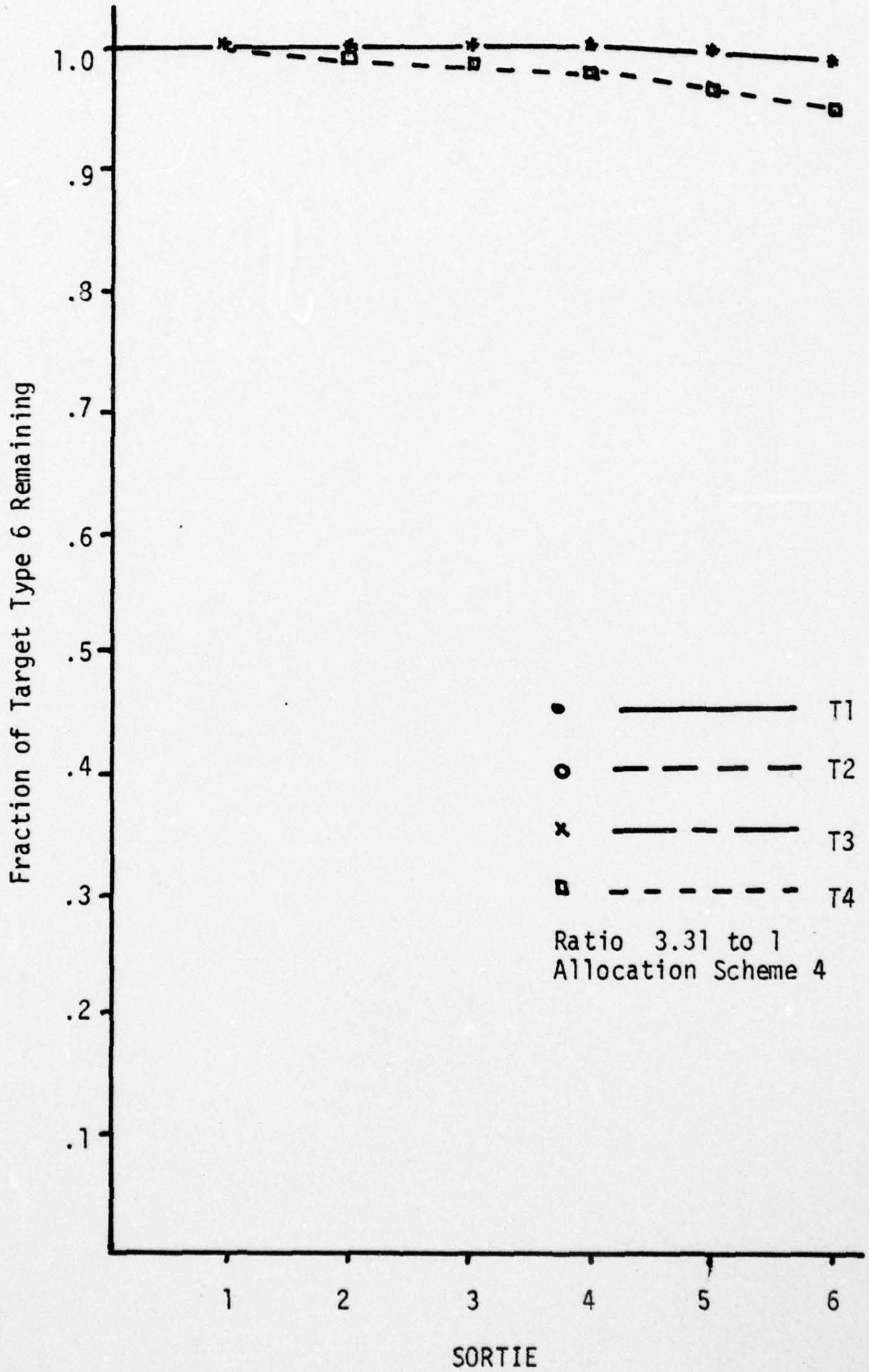

Figure 20. Target Type 6 (ASP) with Target Value Systems

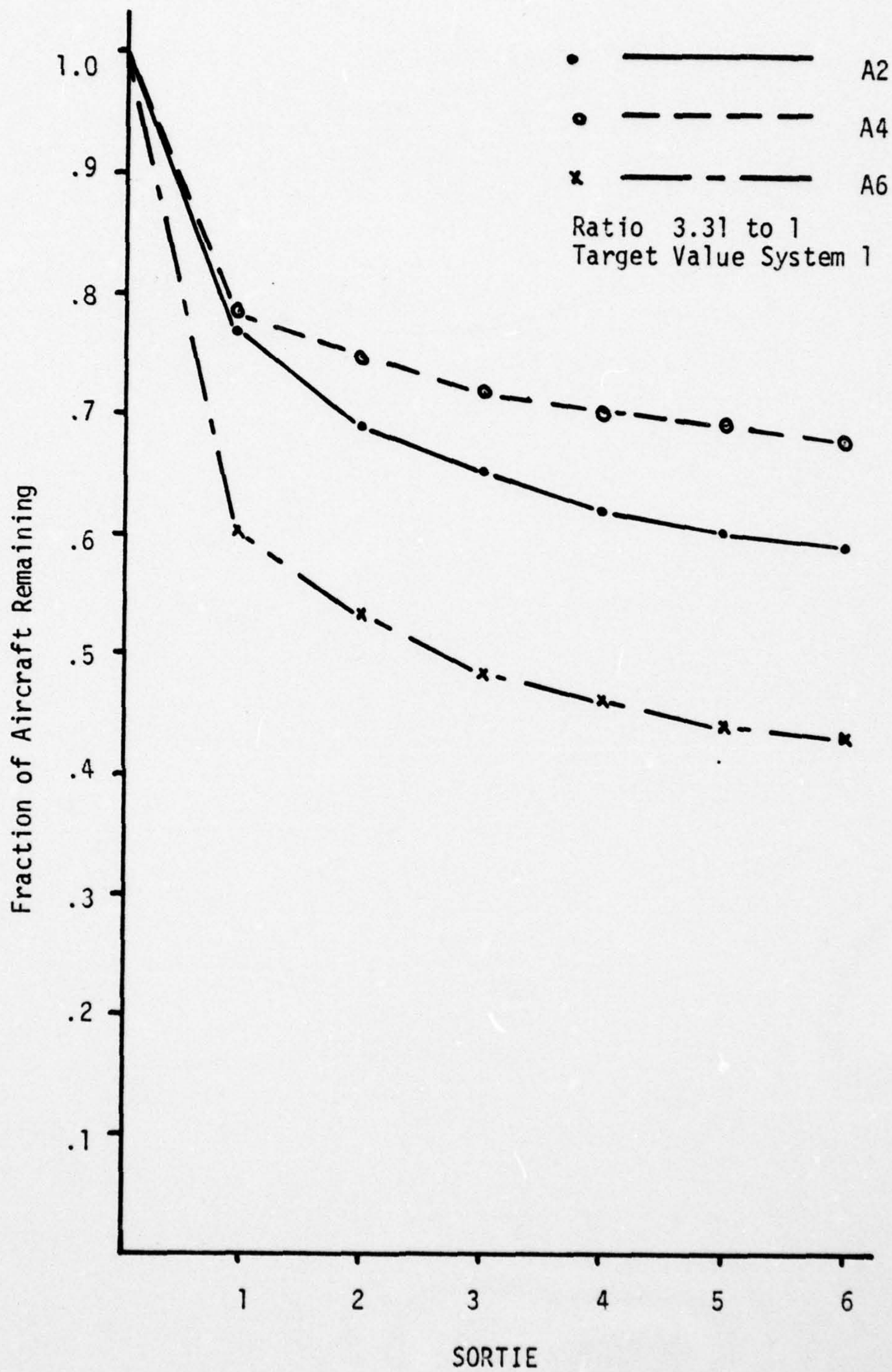

Figure 21. Typical Aircraft Losses for each Allocation Scheme

Below is a sample of the output from the CAMPIN model used for this study. This particular output is from the experimental cell with a ratio of 3.31 to 1, target value system 3 which gives priority to the air defense units, and the proportional allocation scheme which maximizes target destruction.

BATTLE RESULTS TABLE[1]

SORTIE	TARGET 1	TARGET 2	TARGET 3	TARGET 4	TARGET 5
1	0.93082	0.94111	0.60832	0.94500	0.02431
2	0.73567	0.77253	0.31921	0.84156	0.02006
3	0.52119	0.58256	0.20863	0.73929	0.01644
4	0.31672	0.39132	0.14974	0.64521	0.01352
5	0.15693	0.22236	0.11233	0.55905	0.01114
6	0.06697	0.10045	0.08406	0.47307	0.00899
7	0.03177	0.04123	0.05872	0.37445	0.00676
8	0.01670	0.02052	0.03729	0.26779	0.00458
9	0.00939	0.01136	0.02282	0.17803	0.00292
10	0.00552	0.00663	0.01393	0.11399	0.00182
11	0.00336	0.00403	0.00863	0.07243	0.00114
12	0.00212	0.00254	0.00550	0.04672	0.00073
13	0.00133	0.00159	0.00347	0.02969	0.00073
14	0.00089	0.00106	00.0232	0.01994	0.00073
15	0.00089	0.00072	0.00157	0.01355	0.00073
16	0.00089	0.00072	0.00109	0.00941	0.00073
17	0.00089	0.00072	0.00081	0.00701	0.00073
18	0.00089	0.00072	0.00081	0.00462	0.00073
19	0.00089	0.00072	0.00081	0.00000	0.00073

SORTIE	TARGET 6	SORTIE	TARGET 6
1	0.99957	11	0.88043
2	0.99818	12	0.81304
3	0.99644	13	0.70912
4	0.99435	14	0.57295
5	0.99182	15	0.39531
6	0.98837	16	0.19516
7	0.98261	17	0.04707
8	0.97218	18	0.00057
9	0.95448	19	0.00057
10	0.92564		

---

[1]Figures of the table represent the percent of the target remaining.

AIRCRAFT SURVIVAL RESULTS TABLE[2]

SORTIE	AIRCRAFT 1	AIRCRAFT 2	AIRCRAFT 3
1	52.00000	20.00000	24.00000
2	40.44693	15.54308	18.68376
3	39.66734	15.29094	18.40112
4	38.98500	15.05063	18.12013
5	38.42511	14.85634	17.88530
6	38.02463	14.71909	17.71457
7	37.77528	14.63471	17.60651
8	37.63570	14.58811	17.54485
9	37.55498	14.56126	17.50897
10	37.50517	14.54469	17.48682
11	37.47453	14.53451	17.47318
12	37.45575	14.52828	17.46481
13	37.44414	14.52443	17.45964
14	37.43671	14.52198	17.45631
15	37.42969	14.51966	17.45317
16	37.42297	14.51743	17.45018
17	37.41644	14.51525	17.44728
18	37.40991	14.51308	17.44438
19	37.40338	14.51090	17.44148

[1]Figures of the table represent the number of aircraft remaining.

Below is a sample of the output from the Mean Value Differential Analysis algorithm. This is an analysis of the model output from the first sortie. RATO represents the ratio level, TGTN is the target value system, and ALLC is the allocation scheme.

ANALYSIS OF ORDERED FACTORS -- RATO TGTN ALLC

GRAND MEAN = 0.602

MAIN EFFECT FACTOR -- RATO

LEVEL	DIFFERENTIAL FROM GRAND MEAN	SUB-MEAN
1	0.038	0.640
2	-0.038	0.564

SECOND ORDER TERMS -- RATO TGTN

LEVEL (FACTOR 1)	LEVEL (FACTOR 2)	DIFFERENTIAL FROM GRAND MEAN	SUB-MEAN
1	1	0.046	0.648
1	2	0.053	0.655
1	3	-0.002	0.600
1	4	0.056	0.658
2	1	-0.035	0.567
2	2	-0.034	0.568
2	3	-0.072	0.530
2	4	-0.012	0.590

THIRD ORDER TERMS -- RATO TGTN ALLC

LEVEL (FACTOR 1)	LEVEL (FACTOR 2)	LEVEL (FACTOR 3)	DIFFERENTIAL FROM GRAND MEAN	SUB-MEAN
1	1	1	0.068	0.670
1	1	2	0.068	0.670
1	1	3	-0.002	0.600
1	1	4	-0.002	0.600
1	1	5	0.088	0.690
1	1	6	0.058	0.660
1	2	1	0.098	0.700
1	2	2	0.098	0.700
1	2	3	-0.012	0.590
1	2	4	-0.012	0.590
1	2	5	0.088	0.690
1	2	6	0.058	0.660
1	3	1	0.048	0.650
1	3	2	-0.012	0.590
1	3	3	-0.062	0.540
1	3	4	-0.062	0.540
1	3	5	0.058	0.660
1	3	6	0.018	0.620
1	4	1	0.068	0.670
1	4	2	0.068	0.670
1	4	3	0.018	0.620
1	4	4	0.018	0.620
1	4	5	0.088	0.690
1	4	6	0.078	0.680
2	1	1	-0.032	0.570
2	1	2	-0.032	0.570
2	1	3	-0.082	0.520
2	1	4	-0.082	0.520
2	1	5	0.028	0.630
2	1	6	-0.012	0.590
2	2	1	-0.012	0.590
2	2	2	-0.012	0.590
2	2	3	-0.092	0.510
2	2	4	-0.092	0.510
2	2	5	0.018	0.620
2	2	6	-0.012	0.590
2	3	1	-0.062	0.540
2	3	2	-0.012	0.500
2	3	3	-0.012	0.500
2	3	4	-0.012	0.590
2	3	5	-0.012	0.590
2	3	6	-0.052	0.550
2	4	1	-0.022	0.580
2	4	2	-0.022	0.580
2	4	3	-0.062	0.540
2	4	4	-0.062	0.540
2	4	5	0.068	0.670
2	4	6	0.028	0.630

LIST OF REFERENCES

1. Everett, H. III, "Generalized Lagrange Multiplier Method for Solving Problems of Optimum Allocation of Resources," Operations Research, v. 11, p. 399-417, May-June 1963.

2. Metzger, J. J., ADAGE and Air Defense Division Level Model, paper presented at Military Operations Research Symposia, 40th, Monterey, California, 15 December 1977.

3. Naval Postgraduate School Report NPS-55Py75091, Studies of Mobility, Agility and Survivability in the Land Combat Environment, by S. H. Parry, p. 26-42, September 1975.

4. SRI International Report TR 5205-35, Program OPSTRA2: Effectiveness of an Area Defense with Overlapping, Threat-Specific, Coverages Against a Mixed, Optimally Allocated Offense, by G. G. Furman, p. 125-145, September 1969.

5. SRI International Report EGU 76-248, Proposal for Research, COEA for the Division Air Defense Gun, by R. de Sobrino, p. 1-18, 24 November 1976.

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