[redacted]

Coordinated Science Laboratory

UNIVERSITY OF ILLINOIS - URBANA, ILLINOIS

EXPERIMENTS ON THE PERFORMANCE OF AN AUTOMATIC AIR DEFENSE SYSTEM

By H. Wallace Sinaiko & L. Shpiner

REPORT R-113 JANUARY 1960

COORDINATED SCIENCE LABORATORY
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

Contract DA-36-039-SC-56695
D/A Sub-Task 3-99-01-002

The research reported in this document was made possible by support extended to the University of Illinois, Coordinated Science Laboratory, jointly by the Department of the Army (Signal Corps and Ordnance Corps), Department of the Navy (Office of Naval Research), and the Department of the Air Force (Office of Scientific Research, Air Research and Development Command) under Signal Corps Contract DA-36-039-SC-56695.

TABLE OF CONTENTS

Page

Summary and Conclusions 113- 5

Introduction 113- 7

Method 113- 8

Experiments:

I. Effects of Target Load, Defense Strategy, and Number of Available Weapons. 113-12

II. Validity of Four-run vs. Ten-run Data Samples 113-23

III. Comparison of System Operation Against Whole and Partial Scripts 113-25

Acknowledgements 113-28

Appendix A. Data Tables for Experiment I 113-29

Appendix B. Analysis of Variance Tables for Experiment I 113-31

SUMMARY AND CONCLUSIONS

Three experiments were done with the Cornfield System operating in an air defense context in a fully automatic mode. In each experiment the system was programmed to do automatic threat evaluation, weapon selection, and weapon control. The program--ICON II in the Illiac computer--also made automatic recordings of four aspects of system performance: target penetrations, target kills, kill distance, and weapon assignments.

Experiment I studied the effects of three variables, and their interactions, on the system: target load, defense strategy, and number of weapons. Load was simulated in three 30-minute scripts containing 22, 29, and 37 targets, respectively. Defense strategy was varied in two ways: all weapons (interceptors) were treated equally and were disposed on a circle 30 miles distant from the protected point; or, of the available weapons, one was put on restricted assignment status and stationed over the protectee while the remaining fighters were distributed symmetrically. Number of weapons available varied from 3 through 6.

Results of Experiment I were as follows:

a. As target loads increased there were more bombings, more targets killed, and more weapon assignments made.

b. Load did not affect kill range.

c. Adding interceptors resulted in fewer bombings, more kills, greater kill distance, and more assignments and deassignments of weapons.

d. Use of defense-in-depth strategy (i.e. one restricted interceptor) produced fewer bombings, fewer kills of non-critical targets, and a decrease in average kill range.

e. Heavy target loads had a more adverse effect on performance when the number of available weapons was low.

f. Kill distances remained relatively constant from one load to another for each number of interceptors employed except in the case of 3 fighters. In the latter situation, as loads increased the average kill range also increased, probably because the small number of available weapons got out to extended distances and never were free long enough to return to station.

g. The increase in the number of weapon assignments with greater loads and more weapons was not linear. As both target numbers and numbers of available weapons increased, the frequency of assignments and deassignments was relatively higher. This probably reflected the computer's greater activity in making continuous pairings of all weapon/target combinations.

h. The defense-in-depth strategy was most effective when only 3 or 4 weapons were available.

Experiment II tested the hypothesis that data samples of four runs would yield essentially the same results as samples of 10 runs of the Cornfield System. A single script containing 60 targets, and lasting 30 minutes, was run against the system programmed to operate fully automatically. Six interceptors were used in each run. Results supported the hypothesis since the observed differences between the two sample sizes were slight and not statistically significant. This held for each of four measures of system performance.

Experiment III tested the hypothesis that a particular script--the one used in Experiment II--could be divided into three 10-minute scripts and that results from each of these would be comparable with their counterparts in the longer script. This hypothesis was verified for all but one of 12 comparisons made.

INTRODUCTION

For about two years this laboratory has carried on a program of experimentation with a complex computer system, known as Cornfield, in the area of tactical decision making. In 1958 an experiment--ARTFUL--investigating the performance of Cornfield under varying degrees of human intervention was done*. As a result of this experiment and other local experience with the system, many questions arose regarding the possible effects certain variables would have on the Cornfield System or other similar systems.

Since the performance of Cornfield was generally very good in the ARTFUL experiment irrespective of whether the system operated in a fully automatic mode or with some degree of human intervention, questions about the way the simulated air defense battle was fought were raised. How would the system perform if a different defense strategy, i.e. disposition of weapons, were employed? How much of the behavior of the system was due to the particular script (number of pattern of attacking raids) used in ARTFUL? Would Cornfield's ability to "fight the battle" have changed if more defensive weapons had been available? And, what sorts of interactions, if any, would there have been between these variables? This report summarizes a series of experiments conducted during the past 15 months, which was set up to answer these and other questions. All runs of the system were done in a fully automatic mode since the focus was primarily on electronic, rather than human, components of the system.

---

* See CSL Report R-104

METHOD

The System

The Cornfield System has been described in detail previously*. The present series of experiments concentrated on the control and decision-making functions of the system. These included automatic threat evaluation, weapon selection and assignment, and weapon control. The ICON II** Control program was used in all runs. No manual intervention was permitted in any of the runs in this series so that all results are those for a truly "untouched-by-human-hands" system.

System Mission

The task of Cornfield during these experiments was identical with that in ARTFUL: the system was to defend a vital area, 20 miles in diameter. At the start of each run interceptors were stationed 30 miles from the force center on bearings that provided equal azimuthal coverage. That is, when three interceptors were used they were stationed at 120° bearings from center, five interceptors would be stationed at 72° bearings, and so on. Any target which penetrated the 20-mile vital area would be counted as a bombing. As described earlier, interceptors were automatically assigned and vectored and, following kills or deassignments for other reasons, were automatically vectored back to their stations and orbited there.

Target Generation

Defensive weapons, in all cases synthetic maneuverable interceptors, were simulated in two ways. Early in the series 15J-1C target generators,

---

* See CSL Reports R-35, R-36.

** See CSL Report R-104, Appendix B; CSL Report R-106 (in press).

each "flown" by a member of the laboratory staff, received control orders automatically from the Illiac. During the last two-thirds of the experiments automatically generated interceptors were used instead of the less reliable mechanical 15J-1C units. Scripts containing pre-programmed raids were generated from punched type inputs to the TASC computer via a standard tape reader. Interceptions of targets were evaluated by Illiac, which were programmed to apply a range criterion in order to judge the success of attempted kills. As in the ARTFUL experiment the kill criterion was five-miles between an interceptor and its target. When an interception attempt was judged successful by Illiac a signal to the tracking computer erased the target so that it neither appeared on the displays nor was reconsidered by the threat evaluation routine of the control program.

Data Recording

As was done in ARTFUL, an automatic data observing and recording program (DOPE) was used to measure and summarize the results of each run. The following information was recorded by DOPE: assignments of interceptors to raids and deassignments of interceptors from raids. For each of these classes of events, the time, identity of raid and interceptor, position of interceptor were recorded. Also, automatic statistical and sorting routines were used to tabulate and summarize the DOPE recordings. These routines computed such measures as mean and standard deviation of kill range, number of each type of deassignment, and the like.

Scripts

The influence of scripts was one of the principal variables investigated in these experiments and several different scripts were used. Table 1 summarizes script characteristics. All scripts were 30-minutes long, had in common a 125 mile radius radar range, and all targets produced

strong signals with no background noise. With few exceptions, most of the nearly three hundred runs in these experiments were limited to the first

Table 1

Summary of Script Characteristics

SCRIPT	NUMBER OF TARGETS	DESCRIPTION
33N	22 total 10 critical*	Omni-direction; speeds 300-650 knots.
OLN	29 total 13 critical	Same as 33N with 7 added targets
1NN	37 total 17 critical	Same as OLN with 8 added targets
2K0	60 total all critical	Three waves of 20 targets each
2K2	20 total all critical	Wave 1 of 2K0 script; omni-directional, turning targets, 400-800 knots
2K4	20 total all critical	Wave 2 of 2K0 script; omni-directional, groups of targets, 400-800 knots
2K6	20 total all critical	Wave 3 of 2K0 script; omni-directional, all radial (straight-in) targets, 400-800 knots

* Critical targets are those which were programmed to penetrate the vital zone if not successfully intercepted.

three scripts in Table 1: 33N, OLN, and 1NN. The first of these--33N--was the so-called "heavy load" script used in the ARTFUL experiment and the other two scripts were modifications of 33N made by adding targets.

Dependent Variables

Several measures of system performance were derived from the DOPE observations. For each experimental condition the system was run four times so that performance measures would provide variance estimates as well as averages. Results of the experiments will be reported in terms of the following measures:

a. Penetrations. This was a tabulation of the number of raids reaching the 20-mile vital zone.

b. Kill range. The average (mean) range of kills in miles for all targets judged successfully intercepted.

c. Kills. The total number of targets killed.

d. Assignments. The number of pairings or assignments of weapons to targets.

EXPERIMENT I: EFFECTS OF TARGET LOAD, DEFENSE STRATEGY, AND NUMBER OF AVAILABLE WEAPONS

The major experiment in this series was an investigation of the effects of three variables on the performance of the Cornfield System. These variables, and the conditions under which they were introduced were as follows:

a. Target load. This refers to the number of raids flown against the system. Target load was controlled by the use of three different scripts containing totals of 22, 29, and 37 targets each. These scripts were 33N, OLN, and lNN and will be referred to in later sections as light, moderate, and heavy, respectively. (See Table 1 for description of the scripts.)

b. Defense strategy. This variable had to do with the stationing of interceptors and the rules by which they could be assigned automatically by the ICON II program. Under one condition, all interceptors were disposed at equidistant angles along a 30-mile ring surrounding the vital area; the control program treated each interceptor as having equal assignment capability in terms of the criteria used to select weapons. This first condition of defense strategy will be referred to as "symmetrical". The second condition, known as "defense-in-depth" (D.I.D.), always kept one of the available interceptors on a restricted assignment status with its station directly over the center of the vital area. The remaining interceptors were disposed symmetrically. Under the D.I.D. condition ICON II was programmed to assign the overhead fighter only as a backstop, with assignments permitted only when the kill could occur within 20 miles distance from the protectee.

c. Number of available weapons. Four variations in the number of interceptors used were: 3, 4, 5, or 6. In the symmetrical defense mode all interceptors had stations distributed equally on the 30-mile circle (i.e. at 120°, 90°, 72°, or 60° separations). In D.I.D. runs all but the restricted fighters were distributed similarly on the 30-mile circle.

General

Results of the experiment are shown graphically in Figures 1, 2, 3, and 4. (Appendix A contains tables which present averages for each measure of performance in terms of the major independent variables.)

Target Load

With the exception of the kill range measure, all differences between load levels were statistically significant at the 1 o/o level of confidence. (Appendix B contains analysis of variance tables.) In general, increased target loads resulted in more bombings, more targets killed (but proportionally fewer kills to the total number of targets available), and an increase in weapon assignments and deassignments about proportional to the increase in targets. Average kill range did not vary significantly with load.

Number of Interceptors

For each performance measure there were statistically significant differences as the number of weapons was increased: raid penetrations dropped, more targets were killed, average kill ranges increased, and the number of assignments and deassignments increased. In the latter case the change was not linear, the major difference occurring when the number of available interceptors went from 3 to 4.

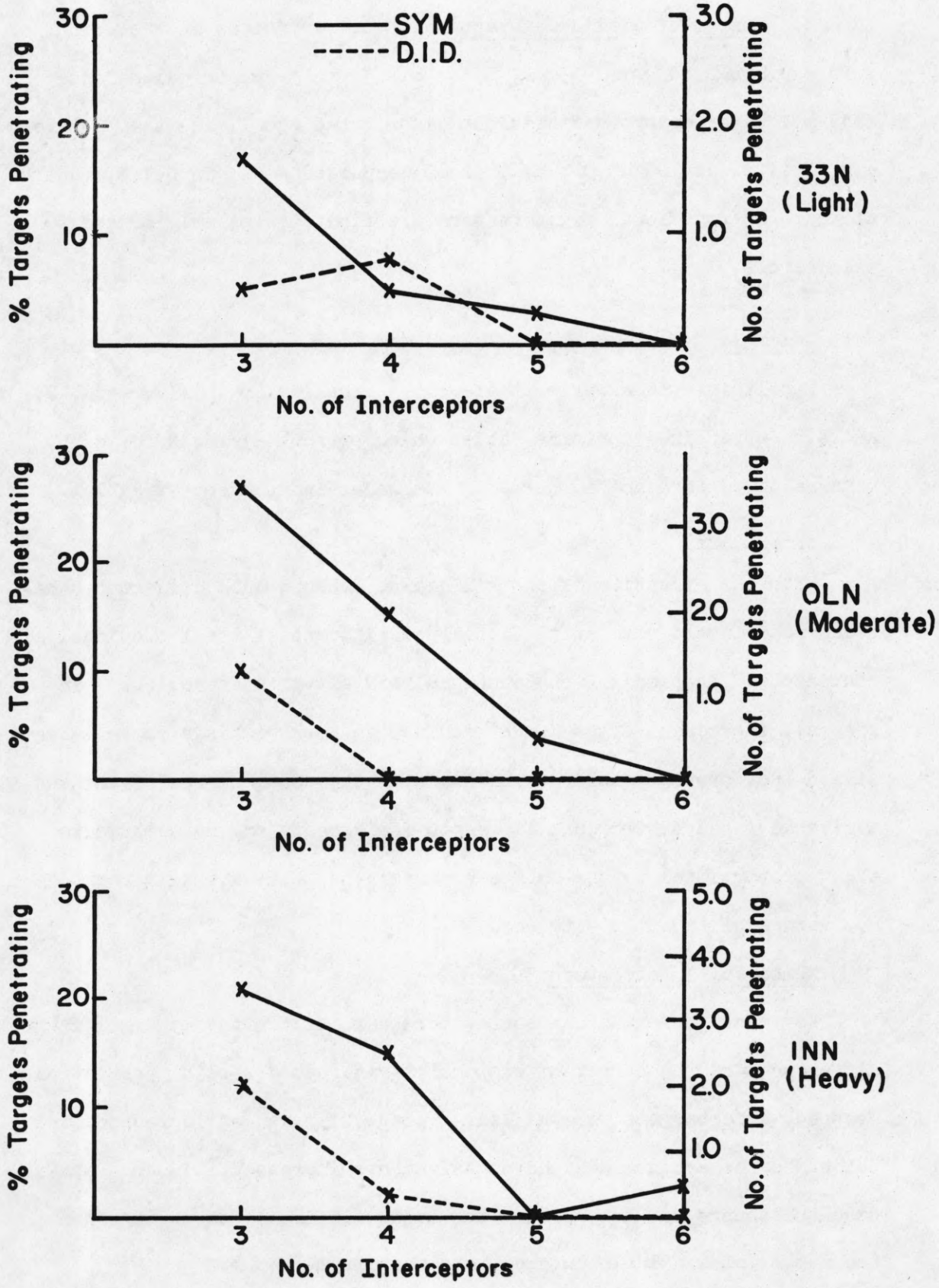

FIGURE 1 TARGET PENETRATIONS AS A FUNCTION OF LOAD, DEFENSE STRATEGY, AND NUMBER OF INTERCEPTORS.

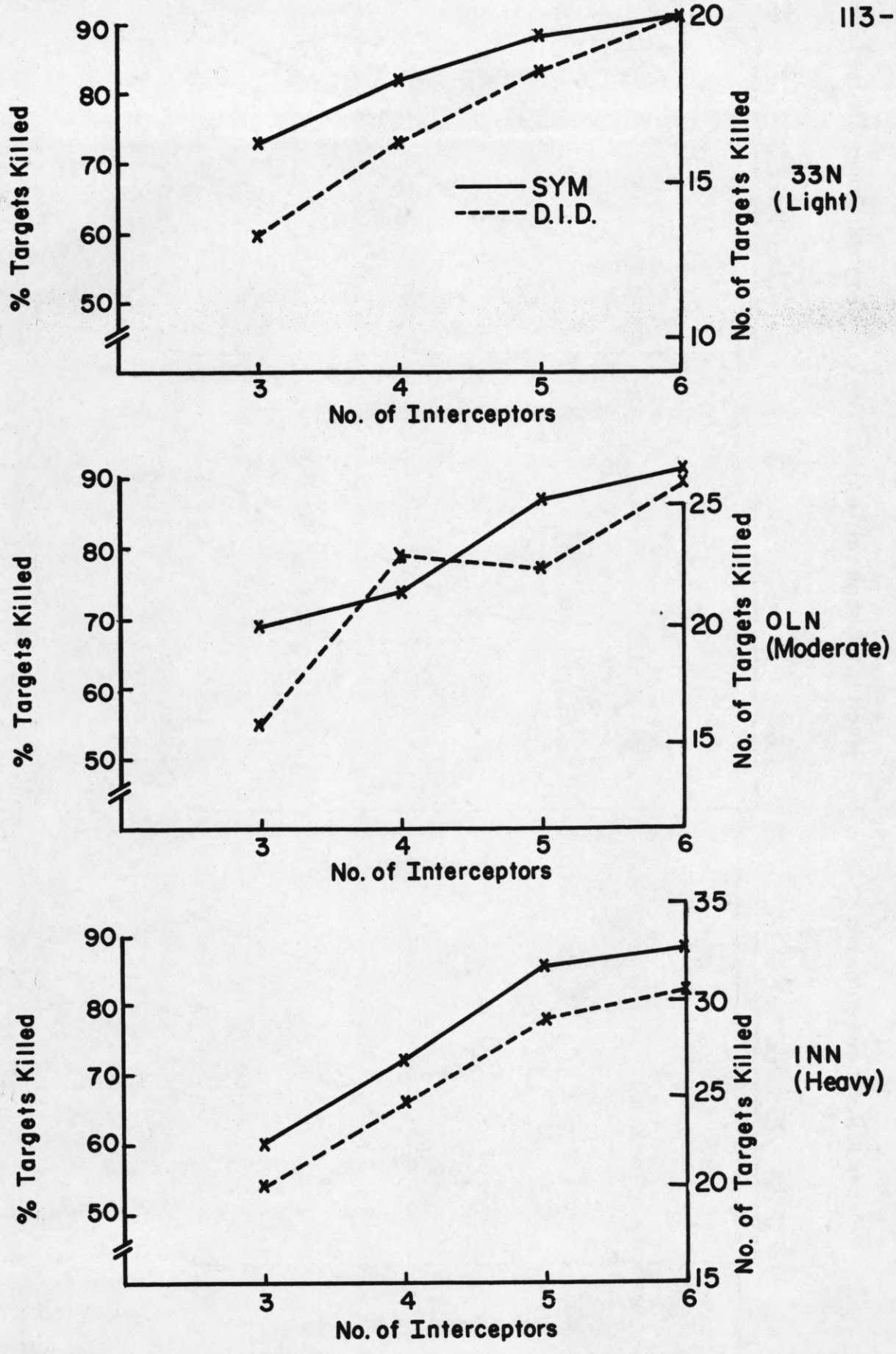

FIGURE 2 TARGET KILLS AS A FUNCTION OF LOAD, DEFENSE STRATEGY, AND NUMBER OF INTERCEPTORS.

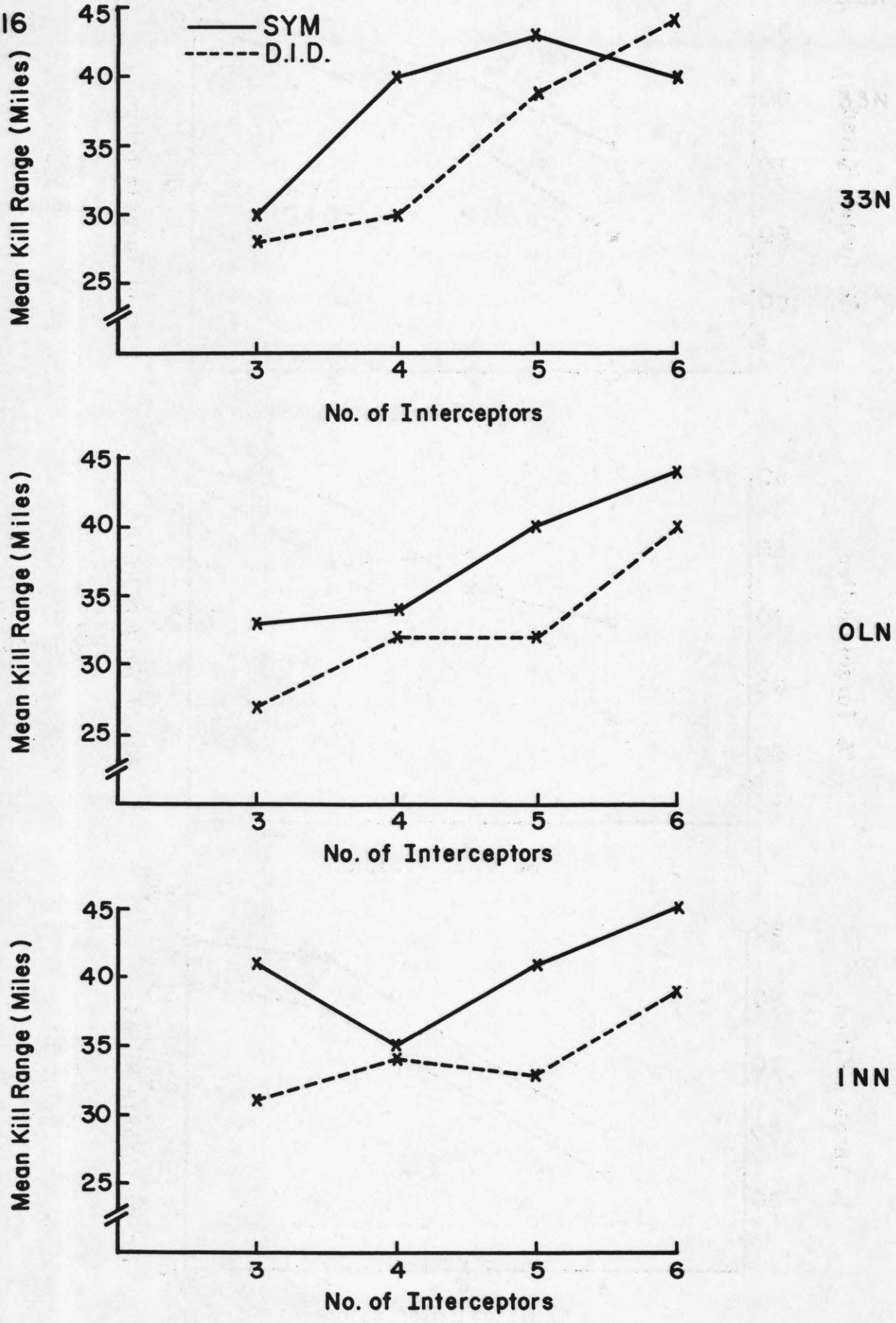

FIGURE 3 RANGE OF TARGET KILLS AS A FUNCTION OF LOAD, DEFENSE STRATEGY, AND NUMBER OF INTERCEPTORS.

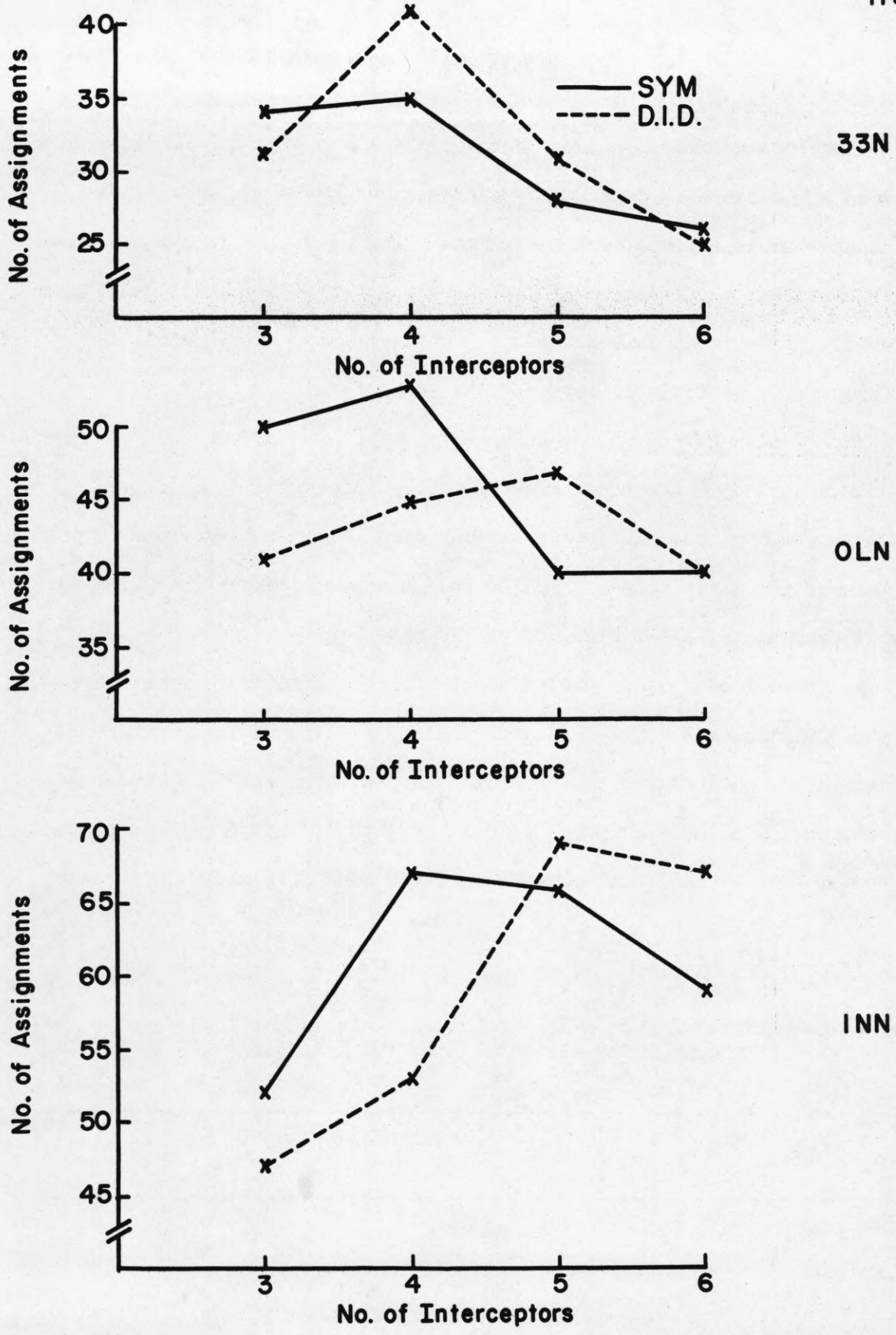

FIGURE 4 FREQUENCY OF WEAPON ASSIGNMENT AS A FUNCTION OF LOAD, DEFENSE STRATEGY, AND NUMBER OF INTERCEPTORS

Defense Mode

Three of the four measures showed statistical significant differences between the defense-in-depth and symmetrical distributions of weapon stations. These effects were as follows: during D.I.D. runs there were fewer bombings, fewer target kills, and a shorter average kill range than under the symmetrical defense mode. Number of weapon assignments made did not vary significantly between these conditions.

Interaction Effects

In addition to the above effects of the three main experimental variables, there were also statistically significant interactions between certain of these variables.* Following are those interactions which were significant at the 1 o/o level of confidence.

a. Number of weapons and target load interacted in terms of three of the four measures: total targets killed, kill range, and number of assignments. With respect to target kills, at each load more interceptors successfully shot-down more raids. But, the relative gain in performance was greater as loads increased. (This effect is shown in Table 2).

Table 2

Interaction of Number of Weapons and Target Load:
Target Kills (Percentage of Total Targets)

LOAD	NUMBER OF WEAPONS 3	4	5	6
Light	68 o/o	77 o/o	86 o/o	91 o/o
Moderate	62 o/o	77 o/o	82 o/o	87 o/o
Heavy	57 o/o	69 o/o	82 o/o	85 o/o

* Interactions are variations in the data due to combined effects of two or more experimental conditions.

In other words, heavier scripts did not affect the system as adversely when more weapons were available as when only a few interceptors were provided.

Average range at which targets were killed, as a function of load and number of weapons, is shown in Table 3.

Table 3

Interaction of Number of Weapons and Target Load:
Average Kill Range (Miles)

LOAD	NUMBER OF WEAPONS 3	4	5	6
Light	29.0	34.8	40.9	41.9
Moderate	30.0	33.3	36.5	41.8
Heavy	36.0	34.4	37.0	42.0

The interaction effect here is a curious one: with only three interceptors available the average kill range increased as target loads built up. And, while at each load level the average kill range was greater for more interceptors, increases in target load did not result in greater kill ranges for 4, 5, or 6 interceptors.

With respect to the frequency of weapon assignments, these always increased as target loads went up. However, as more weapons were available relatively more assignments and deassignments were made. For example, in light load script runs 32 and 29 assignments were made for 3 and 5 interceptors, respectively. At heavy loads assignments went to 49 and 68 for 3 and 5 interceptors. This relationship is shown in Table 4.

Table 4

Interaction of Number of Weapons and Target Load:
Weapon Assignments

LOAD	NUMBER OF WEAPONS 3	4	5	6
Light	31.6	38.0	29.1	26.0
Moderate	45.3	48.5	43.3	39.6
Heavy	49.3	60.3	67.6	63.1

b. There were also three significant interactions between the number of weapons and defense mode variables. First, while raid penetrations were higher when fewer interceptors were available, this effect was most pronounced in the symmetrical defense mode. Put another way, the D.I.D. strategy was most effective when relatively few weapons were available. With as many as 6 interceptors no raids penetrated under either defense mode. Table 5 shows this effect.

Table 5

Interaction of Number of Weapons and Defense Mode:
Raid Penetrations

DEFENSE MODE	NUMBER OF WEAPONS 3	4	5	6
Symmetrical	2.8	1.7	0.3	0.0
D.I.D.	0.6	0.3	0.0	0.0

It has been shown earlier that, in general, average kill ranges decreased when the D.I.D. mode was used (because of the restricted status of the overhead interceptor). However, with more interceptors available, average kill ranges tended not to drop as much under D.I.D. conditions. This was probably because the restricted interceptor did relatively little when 5 or 6 interceptors were provided. Table 6 summarizes this interaction.

Table 6

Interaction of Number of Weapons and Defense Mode:
Kill Range (Miles)

DEFENSE MODE	NUMBER OF WEAPONS 3	4	5	6
Symmetrical	34.8	36.3	41.5	42.8
D.I.D.	28.6	32.0	34.8	40.9

The third interaction between number of interceptors and defense mode occurred in terms of weapon assignments. The effect here was an unusual one: with 3 or 4 interceptors the frequency of weapon assignments was lower in D.I.D. than in symmetrical disposition runs; with 5 or 6 interceptors this effect was reversed. There is no readily apparent explanation for this. Table 7 shows the data to illustrate this interaction.

Table 7

Interaction of Number of Weapons and Defense Mode: Weapon Assignments

DEFENSE MODE	NUMBER OF WEAPONS 3	4	5	6
Symmetrical	44.8	51.6	44.4	41.6
D.I.D.	39.2	46.2	48.9	42.3

EXPERIMENT II: VALIDITY OF FOUR-RUN VS. TEN-RUN DATA SAMPLES

Background

This experiment was done to verify the assumption that as few as four runs of the Cornfield System under any unique condition would provide stable data which could be compared statistically with other unique conditions.* In the present study we were concerned only with data samples from the automatic mode of operating Cornfield. No comparison of runs were made with human operators in the system so inferences about the validity of small samples (four runs) should not be made concerning man-operated systems.

Method

The Cornfield System was operated in the fully automatic mode against a script (2KO) containing 60 critical targets. Six interceptors were used in a symmetrical defense disposition. Measures of raid penetration, target kills, kill range, and weapon assignments were made automatically. The entire experiment consisted of ten runs. In order to text the validity of four-run samples data from the first four runs were compared statistically with that from all ten runs.**

Results

Comparison of the two samples for each of four measures is shown in Table 8. None of the mean differences was statistically significant

---

* This assumption underlay both the ARTFUL and CAREFUL experiments which have been published as CSL Reports R-104 and R-115, respectively.

** Fisher's t was used to test differences between means. The formula for t is:

$$t = \frac{M_1 - M_2}{\sqrt{\left(\frac{N_1\sigma_1^2 + N_2\sigma_2^2}{N_1 + N_2 - 2}\right)\left(\frac{N_1 + N_2}{N_1 N_2}\right)}}$$

where M_1 and M_2 are the sample means, σ_1^2 and σ_2^2 are the corresponding variances, and N_1 and N_2 are the numbers of cases in each sample.

Table 8

Comparison of Four-run and Ten-run Data Samples

MEASURE	MEAN*	T	SIGNIFICANCE OF DIFFERENCE
Raid Penetrations	20.5 18.9	.11	Not Significant
Target Kills	39.8 41.2	.33	Not Significant
Kill Range	30.0 30.4	.46	Not Significant
Assignments	131.0 123.7	.07	Not Significant

* Top mean is that for four-runs, bottom mean is for ten-runs.

indicating that the two samples, i.e. four and ten runs, may be considered to have been drawn from the same population.

We would conclude from this the fact that it was a sound procedure, in our operations of the fully automatic mode of the Cornfield System, to use samples as small as four runs. Whether small samples involving humans as sources of variability would be as stable is not known. It is likely, however, that factors such as learning, boredom, fatigue, and motivation would operate to increase the variability of performance, and therefore, necessitate larger samples. At present we have no data to offer in this regard.

EXPERIMENT III: COMPARISON OF SYSTEM OPERATION AGAINST WHOLE AND PARTIAL SCRIPTS

Background

The CAREFUL experiment* used two target loads, or scripts, each of 30-minutes duration. As in earlier experiments, all measures of system behavior were reported in terms of averages (means) over samples of the full 30-minute runs. Because of a number of practical problems such as the limited availability of the Illiac computer, runs of briefer duration would be desirable. The present experiment was a test of the hypothesis that results based on ten-minute runs would not differ significantly from those of longer (e.g. 30 minutes) runs where scripts in each case were comparable.

Method

The system was run only in the fully automatic mode. Measures of raid penetration, kills, kill range, and target assignments were made using the DOPE routine. In order to satisfy the assumption of comparability between scripts for the longer and shorter runs we used the heavy load script (2KO) from CAREFUL as follows. Ten runs were made against the full thirty-minute script. The script was subdivided into three ten-minute scripts, each corresponding to one wave of 20 targets from the full 2KO script. Ten runs against each separate wave were made. Six interceptors in the symmetrical defense mode were used as weapons. The hypothesis that brief runs would yield results comparable to 30-minute runs was tested by comparing average scores for Wave 1 of 2KO with the 10-minute script of that wave alone, Wave 2 with its equal, and so on.

---

* See CSL Report R-115.

Fisher's t-test* was used to test the significance of mean differences.

Results

Tables 9, 10, and 11 summarize the comparison of measures for the three waves of the 2K0 script with scripts 2K2, 2K4, and 2K6 (corresponding to Wave 1, Wave 2, and Wave 3 of 2K0). Of the twelve pairs of averages tested only one was of borderline statistical significance (5 o/o level) and one other approached significance (10 o/o level).

Table 9

Comparison of Short Duration Script with Portion of Longer Duration Script: I

MEASURE	MEAN*	t	SIGNIFICANCE
Raid Penetrations	6.9 6.9	0.0	Not Significant
Target Kills	13.4 13.2	0.22	Not Significant
Kill Range	35.2 35.0	0.97	Not Significant
Assignments	43.5 50.7	1.63	Not Significant

* Top mean is for Wave 1, 2K0; bottom mean is for 10 minute script, 2K2.

We have concluded from this experiment that it was valid, in obtaining data on the fully automatic system, to divide the 30-minute 2K0 script into three 10-minute scripts corresponding to the three waves of 2K0. It is important to recognize, however, that brief scripts may not, in other situations, be sufficient to exercise the system in all its aspects.

* See Footnote, page 23.

Table 10

Comparison of Short Duration Script with Portion of Longer Script: II

MEASURE	MEAN*	t	SIGNIFICANCE
Raid Penetrations	2.3 0.9	2.13	5 o/o level
Target Kills	17.8 19.1	2.09	10 o/o level
Kill Range	27.1 27.8	0.64	Not Significant
Assignments	55.1 52.1	0.81	Not Significant

* Top mean is for Wave 2, 2KO; bottom mean is for 10-minute script, 2K4.

Table 11

Comparison of Short Duration Script with Portion of Longer Script: III

MEASURE	MEAN*	t	SIGNIFICANCE
Raid Penetrations	9.7 9.5	0.28	Not Significant
Target Kills	10.2 10.7	0.74	Not Significant
Kill Range	30.8 30.2	0.53	Not Significant
Assignments	26.1 28.2	0.86	Not Significant

* Top mean is for Wave 3, 2KO; bottom mean is for 10-minute script, 2K6.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the following colleagues who contributed materially to these experiments.

C. H. Beigh conducted most of the early runs of Experiment I.

Mrs. Julia Berger and R. F. MacFarlane assisted in the production of the report.

H. G. Bobotek and P. G. Braunfeld were responsible for the initial ICON II program and its associated DOPE routines.

R. M. Brown, J. L. Divilbiss, L. S. Kypta, J. E. Stifle, and R. L. Trogdon were professional staff members whose contributions were generally in the area of equipment design, construction, and modification for these experiments. R. M. Brown also read the initial manuscript and made many valuable suggestions.

G. P. Cartwright served as laboratory assistant, computer operator, and statistical aide.

D. E. Coad and E. Neff were responsible for technical maintenance of the Cornfield System.

Mrs. Sandi Goldberg performed statistical analyses early in the experiments.

Miss Charlene Sprankel served as computer operator during Experiment I.

APPENDIX A

DATA TABLES FOR EXPERIMENT I

Table A-1

Effects of Target Load on System Performance

MEASURE*	TARGET LOAD LIGHT	MODERATE	HEAVY
Target Penetrations	0.28	0.91	1.03
Number of Targets Killed	17.69	22.56	27.10
Kill Range (Miles)	36.62	35.38	37.34
Weapon Assignments	31.18	44.16	60.06

* All figures are averages (means) for 32 runs under each script condition.

Table A-2

Effects of Number of Interceptors on System Performance

MEASURE*	NUMBER OF INTERCEPTORS 3	4	5	6
Target Penetrations	2.04	1.00	0.12	0.00
Number of Targets Killed	18.00	21.60	24.30	25.90
Kill Range (Miles)	31.60	34.12	38.10	41.90
Weapon Assignments	24.04	48.90	46.66	42.91

* All figures are averages (means) for 24 runs with each number of interceptors.

Table A-3

Effects of Defense Mode on System Performance

MEASURE*	DEFENSE MODE	
	SYMMETRICAL	DEFENSE-IN-DEPTH
Target Penetrations	1.19	0.39
Number of Targets Killed	23.31	21.58
Kill Range (Miles)	38.83	34.06
Weapons Assignments	45.60	44.66

* All figures are averages (means) for 48 runs under each defense mode.

APPENDIX B

ANALYSIS OF VARIANCE TABLES FOR EXPERIMENT I

Table B-1

Analysis of Variance of Target Penetrations

SOURCE OF VARIATION	SUM OF SQUARES	df	VARIANCE ESTIMATE	F-RATIO
Between number of Interceptors (A)	64.25	3	21.417	36.736**
Between scripts (B)	6.271	2	3.136	5.379**
Between defense modes (C)	15.042	1	15.042	25.8**
Interactions: A x B	9.812	6	1.635	2.804*
A x C	11.041	3	3.68	6.312**
B x C	3.77	2	1.885	3.233*
A x B x C	5.647	6	.941	1.614
Within	42.0	72	.583	
Total	157.833	95		

** Significant at the 1 o/o level.

* Significant at the 5 o/o level.

Table B-2

Analysis of Variance of Target Kills

SOURCE VARIATION	SUM OF SQUARES	df	VARIANCE ESTIMATE	F-RATIO
Between number of interceptors (A)	863.116	3	287.705	139.257**
Between scripts (B)	1415.27	2	707.635	342.515**
Between defense modes (C)	71.76	1	71.76	34.734**
Interactions: A x B	86.729	6	14.455	6.997**
A x C	20.944	3	6.981	3.379*
B x C	2.523	2	1.262	
A x B x C	24.648	6	4.108	1.988
Within	148.75	72	2.066	
Total	2633.74	95		

** Significant at the 1 o/o level.

* Significant at the 5 o/o level.

Table B-3

Analysis of Variance of Kill Range

SOURCE OF VARIATION	SUM OF SQUARES	df	VARIANCE ESTIMATE	F-RATIO
Between number of Interceptors (A)	1452.53	3	484.18	70.27**
Between scripts (B)	63.52	2	31.76	4.61*
Between defense modes (C)	546.26	1	546.26	79.28**
Interactions: A x B	267.57	6	44.60	6.47**
A x C	85.70	3	28.57	4.15**
B x C	42.15	2	21.08	3.06
A x B x C	263.76	6	43.96	6.38**
Within	496.25	72	6.89	
Total	3217.74	95		

** Significant at 1 o/o level.

* Significant at 5 o/o level.

Table B-4

Analysis of Variance of Number of Weapon Assignments Made

SOURCE OF VARIATION	SUM OF SQUARES	df	VARIANCE ESTIMATE	F-RATIO
Between number of interceptors (A)	747.28	3	249.09	7.08**
Between scripts (B)	13386.27	2	6693.14	190.2**
Between defense modes (C)	21.09	1	21.09	.599
Interactions: A x B	1674.32	6	279.05	7.93**
A x C	500.79	3	166.93	4.74**
B x C	72.57	2	36.29	1.03
A x B x C	519.17	6	86.53	2.46
Within	2533.75	72	35.19	
Total	19455.24	95		

** Significant at the 1 o/o level.

AUTHORIZED DISTRIBUTION LIST
As of January 15, 1959

Number of Copies	Agency
2	Commanding General Redstone Arsenal Huntsville, Alabama Attn: Technical Library
1	Commanding General U.S. Continental Army Command Fort Monroe, Virginia Attn: ATSWD
1	Director Air University Library Maxwell Air Force Base, Alabama Attn: CR-4803a
1	Inspector of Naval Materiel Los Angeles, California For transmittal to: Litton Industries 336 North Foothill Road Beverly Hills, California
1	Hughes Research and Development Library Hughes Aircraft Company Culver City, California Attn: Miss Mary Jo Case
1 Progress Reports Only	Air Force Ballistic Missile Division Headquarters, Air Research and Development Command, USAF Post Office Box 262 Inglewood, California Attn: WDSOT-8-18777
1 Progress Reports Only	Air Force Ballistic Missile Division AQ, Air Research and Development Command, USAF Air Force Unit Post Office Los Angeles 45, California Attn: Technical Data Division
1	Director Jet Propulsion Laboratory California Institute of Technology Pasadena, California

Number of Copies	Agency
	Commanding Officer and Director U. S. Navy Electronics Laboratory San Diego 52, California
1	Attn: Library
1	Code 2800, C. S. Manning
1	Space Technology Laboratories, Inc. P. O. Box 95001 Los Angeles 45, California Attn: Tech. Info. Services Acquisition For: Contract AF04(647)-309
1	Director Office of Naval Research Branch Office 1000 Geary Street San Francisco, California
1	System Development Corporation 2500 Colorado Avenue Santa Monica, California
1	The RAND Corporation 1700 Main Street Santa Monica, California Attn: Library
1	Stanford University Electronics Research Laboratory Stanford, California
1	9560 S. C. Electronics Research P. O. Box 205 Mountain View, California
	Chief, Bureau of Aeronautics Department of the Navy Washington 25, D. C.
1	Attn: EL-402
1	TD-4
	Department of the Navy Office of Naval Research Washington 25, D. C.
1	Attn: Code 430
1	Code 437

Number of Copies	Agency
1	Chief of Naval Operations Development Planning Group (Op-07T) T-3 Building - Room 1610 17th and Constitution Aves., N.W. Washington 25, D. C.
1	Chief of Research and Development Office of the Chief of Staff Department of the Army Washington 25, D. C.
	Director of Research and Development Headquarters, United States Air Force Washington 25, D. C.
1	Attn: AFDRD-GW
1	Headquarters, Air Force Office of Scientific Research Air Research and Development Command United States Air Force Washington 25, D. C. Attn: SROP
	Department of the Army Office of the Chief Signal Officer Washington 25, D. C.
1	Attn: SIGRD
1	SIGRD-9-b
	Department of the Army Office of the Chief of Ordnance Washington 25, D. C.
1	Attn: ORDTR
1	ORDTB
	Chief, Bureau of Ships Department of the Navy Washington 25, D. C.
2	Attn: Code 280
1	Code 565-C
1	Code 810
1	Code 810B
1	Code 812
1	Code 820
1	Code 825
1	Code 830
1	Code 835

Number of Copies	Agency
	Chief of Naval Operations Navy Department Washington 25, D. C.
1	Attn: OP-51
1	OP-91
1	OP-551
1	OP-345
1	Head, Combat Direction Systems Branch (OP-345) Department of the Navy Room 4C-518 Pentagon Washington 25, D. C.
1	Bureau of Ordnance Department of the Navy Washington 25, D. C. Attn: Re4C
	Director Naval Research Laboratory Washington 25, D. C.
3	Attn: Code 5140
5 Progress Reports Only	National Aeronautics and Space Administration 1520 H Street, N.W. Washington 25, D. C.
1	Director National Bureau of Standards Washington 25, D. C. Attn: Dr. S. N. Alexander
1	Technical Library Code 142 David Taylor Model Basin Washington 7, D. C.
1	Commander Diamond Ordnance Fuze Laboratories Ordnance Corps Washington 25, D. C. Attn: Librarian

Number of Copies	Agency
1	Dr. J. Steinhardt Operations Evaluation Group Office of the CNO (OP03EG) Navy Department Washington 25, D. C.
1	Commander Air Force Armament Center Eglin Air Force Base, Florida Attn: Deputy for Operations
1	Radiation, Inc. Research Division P. O. Box 6904 Orlando, Florida
1	Chicago Midway Labs 6040 South Greenwood Avenue Chicago 37, Illinois Attn: Librarian
1	Commanding Officer Office of Naval Research Chicago Branch John Crerar Library Building 10th Floor, 86 East Randolph Street Chicago 1, Illinois
3	Director Ballistics Research Laboratory Aberdeen Proving Ground, Maryland Attn: Dr. L. A. Delsasso
1	Headquarters, Air Research and Development Command Andrews Air Force Base Washington 25, D. C. Attn: RDRC
1	Operations Research Office The Johns Hopkins University 6935 Arlington Road Bethesda, Maryland
1	Commander Naval Ordnance Laboratory White Oaks Silver Springs 19, Maryland Attn: Technical Library

Number of Copies	Agency
2	U. S. Navy Inspector of Ordnance Applied Physics Laboratory The Johns Hopkins University 8621 Georgia Avenue Silver Springs, Maryland
1	Commander Air Force Cambridge Research Center Laurence G. Hanscom Field Bedford, Massachusetts Attn: CRR
1	Librarian Instrumentation Laboratory Massachusetts Institute of Technology Cambridge 39, Massachusetts
1	Massachusetts Institute of Technology Lincoln Laboratory P. O. Box 73 Lexington 73, Massachusetts
1	Mr. Robert R. Everett Director The Mitre Corporation Lexington 73, Massachusetts
1 Unclassified Reports Only	Director Research Laboratory of Electronics Massachusetts Institute of Technology Cambridge 39, Massachusetts Attn: Mr. John Hewitt, Document Room
1	Sylvania Electric Products, Inc. 100 First Avenue Waltham 54, Massachusetts Attn: Contract DA-30-069-ORD-1166
1	Technical Documents Service Willow Run Laboratories University of Michigan Willow Run Airport Ypsilanti, Michigan

Number of Copies	Agency
1	Minneapolis-Honeywell Regulator Co. Aeronautical Division 2600 Ridgeway Road Minneapolis 13, Minnesota Attn: Dr. D. F. Elwell Marine Systems Group
1	Insmat, BuShips Insp. Officer 1902 West Minnehaha Avenue St. Paul 4, Minnesota For transmittal to Remington Rand Univac
20	Transportation Officer Fort Monmouth Little Silver, New Jersey Marked for: USASRDL Accountable Property Officer Building 2700 Camp Wood Area Inspect at Destination File No. 0060-PH-54-91 (5308)
1	Radio Corporation of America RCA Laboratories Division David Sarnoff Research Center Princeton, New Jersey Attn: Librarian
1	Mr. A. A. Lundstrom Bell Telephone Laboratories Whippany, New Jersey
1 Progress Reports Only	Mailing Zone M-51 Bell Aircraft Corporation P. O. Box 1 Buffalo 5, New York c/o Technical Library
1	Joseph P. Desmond, Librarian Cornell Aeronautical Laboratory Buffalo, New York
1	Commanding Officer Rome Air Development Center Griffiss Air Force Base, New York
1	W. L. Maxson Corporation 460 West 34th Street New York 1, New York

Number of Copies	Agency
1	New York University College of Engineering Research Division 401 W. 205th Street New York 34, New York Attn: Librarian For Contract DA 36-039-SC-84509
1	General Electric Company Defense Electronics Center Cornell University Ithaca, New York Attn: Mr. Leonard Bigelow
1 Progress Reports Only	Library Light Military Electronics Department General Electric Company Building 28-501 Schenedtady 5, New York
1	Light Military Electronic Equipment Department General Electric Company French Road Utica, New York For: Contract AF 33(600)-16934
3 No Progress Reports	Commanding Officer Office of Ordnance Research Box CM Duke Station Durham, North Carolina
1	President, U. S. Army Airborne and Electronics Board Continental Army Command Fort Bragg, North Carolina
1	Goodyear Aircraft Corporation Akron 15, Ohio For: Project MX 778 Contract W33-038 ac-14153
	Commander Wright Air Development Center Wright-Patterson Air Force Base, Ohio
2	Attn: WCOSI-3
1	WCLOT-2
1	WCLGTRS
1	WCLG

Number of Copies	Agency
1	WCLJY
1	WCLGN-5
1	WCLR
1	WCLRW-1
1	WCLJ
1	WCLRW-2
1	General Atronics Corporation One Bala Avenue Bala-Cynwyd, Pennsylvania For: Contract DA-36-039-SC-78335 Attn: Mrs. C. P. Lawless, Librarian
1	Commanding Officer Naval Air Development Center Johnsville, Pennsylvania Attn: Code AAEL
1	Commanding Officer Frankford Arsenal Philadelphia 37, Pennsylvania
1	President, U. S. Army Defense Board Continental Army Command Fort Bliss, Texas
1	Commander United States Air Force Security Service San Antonio, Texas Attn: CLR
10	Armed Services Technical Information Agency Arlington Hall Station Arlington 12, Virginia
1	Naval Ordnance Proving Ground Computation Center Dahlgren, Virginia Attn: R. A. Niemann