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ENVIROSAT—2000 Report

Optimum Management Strategies for the NOAA Polar-orbiting Operational Environmental Satellites, 1985-2000

VOLUME 2

April 1985

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

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W.H. Eskite, Jr., and W.P. Bishop

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April 1985

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PREFACE

This report, Optimum Management Strategies for the NOAA Polar-orbiting Operational Environmental Satellites, 1985 to 2000, is published in three volumes.

Volume I is an independent document, covering the purpose and methods of the analysis and reporting its conclusions. A comprehensive discussion of the analysis process is provided. Sample data sets and summaries of case study results are included. Conclusions are developed in this volume.

Volume II presents a description of the analysis approach. Data collection and data compilation methods are explained and the procedures for comparing and evaluating case studies are examined. Figures and tables are used to illustrate findings.

Volume III provides the time-series graphical representations of the 121 satellite deployment and failure scenarios that were the case studies of the analysis. The statistics and other tabulations that were used in the analysis are included.

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I. INTRODUCTION

This study is aimed at determining the best way to operate the Polar-Orbiting Environmental Satellite (POES) system for the rest of the century, and to determine how many satellites NOAA should procure for that period so that the system can be managed in an optimum manner. The study covers both the two-satellite system that has been traditional, and the one-satellite system that has been considered during the last few years.

The optimum management approach for either a one-satellite or a two-satellite POES system is one which will: (1) provide fully reliable data services at all times, (2) respond to the highest priority needs of the National Weather Service (NWS) and the rest of the user community at large, (3) provide some additional services above those minimally acceptable, and (4) keep the long-term costs at the lowest possible level.

In managing the POES system, the most important service goal is to ensure that data from at least one satellite are available 100 percent of the time, preferably from satellites in an early afternoon (PM) orbit. This is the minimum acceptable service goal if the POES is to meet the highest priority NWS requirements for data from the polar-orbiting satellites.

The first objectives of this study of the long-term Polar-Orbiting Environmental Satellite system are to understand fully the possible and probable launch failures or failures on-orbit before the end of the design lifetimes of the satellites, and to understand the impact of these failures on services to the National Weather Service and the larger user community.

Based on this understanding, the study's objectives are to define a management approach for the POES system that will:

a. Mitigate the interruptions in services to data users to the maximum extent possible.

b. Provide optimum data services to the NWS and the rest of the user community at the lowest possible cost.

The final objective is to determine the prudent number of satellites for which to plan during the next 15 years for either the two-satellite system or the one-satellite system.

The methodology used in this study was to model the long-term (15 years) POES system under a variety of assumptions about satellite on-orbit lifetimes, fixed launch schedules, and possible intervals to call-up launches of replacement satellites after failures. System performance statistics and long-term costs were

derived or calculated from these models (called scenarios). Models and derived statistics were developed for both one-satellite and two-satellite systems, with every effort made to ensure that all assumptions were applied uniformly to both systems.

We found no elegant way to provide an ab initio probability analysis based on present designs of sensors, spacecraft, and launch vehicles. Therefore, we used "brute force" and analyzed over 120 scenarios to derive the principles; we then applied these to "realistic" scenarios.

Using the more than 120 different combinations of management principles and failure sequences, management principles were determined that best met service goals at the most reasonable cost. We varied the number and timing of launch failures within reasonable bounds based on past experience. We varied the timing of on-orbit failures using past experience as a guide. And we varied the lifetimes of the satellites within the range of past experience.

Against these, different management approaches were applied. The baseline was to launch on the schedule assumed in the budget planning scenarios. To this were added call-up with different assumed delays (ranging from 4 to 9 months). We extended the timing of nominal launches in some tests. We took advantage of extended lifetimes (above nominal design life) as best we could. We took advantage of early warnings of imminent on-orbit failure in some tests. Finally, we tested the system management approaches that seemed to provide the best services at the lowest cost against the most severe sequence of events that we felt was likely over the next 15 years.

II. DATA COLLECTION AND COMPILATION

A. DATA COLLECTION

In this study, data collection was in the form of models (scenarios) developed by varying satellite lifetimes on-orbit, launch intervals, the number of launch failures, and so forth. Each set of scenarios was designed to examine some particular aspect of the 15-year operation of the POES and its costs. The modeling was done in a series of five phases. All plotted scenarios appear in Volume 3, Appendix A, Phases of the Data Collection and the Plotted Scenarios, and the tables included in this chapter list the page numbers in the appendix for each scenario.

1. Phase A

In the first phase, the basic assumptions usually made in planning and budgeting for the POES (including launch failures and failures on-orbit as discussed in Volume 1) were used:

- Planned 24-month on-orbit life.
- Regularly scheduled launches at:
  18-month intervals for a one-satellite system,
  12-month intervals for a two-satellite system.

Then, in sequential scenarios, launch and premature failures on-orbit were introduced, both singly and in combinations, into the modeling. The number of failures of each type was varied from none to a number that was considered most likely, based on the history of the POES program since 1970. For the Case I one-satellite system, two or three launch failures combined with two premature failures on-orbit over the 15-year period are about equally likely (see the section on probabilities later in this chapter and in Volume 3, Appendix C). For the Case II two-satellite system, three or four launch failures combined with three premature failures on-orbit in 15 years are most likely. Given the history of the POES since 1970, larger or smaller numbers of failures than these are very unlikely. However, for analytical purposes, fewer failures of both types in various combinations were modeled, including the unlikely (but still possible) scenarios in which two of the launch failures were consecutive.

This phase of the modeling assessed and quantified the effects of these combinations of failures on system performance (responsiveness to the needs of the NWS and other users of POES data), on the number of satellites launched, on the total POES cost, and on the unit cost to successfully acquire data from space. It was assumed that no replacement satellites would be launched following either type of failure, and that all satellites not experi-

encing premature failure would fail at the end of their design life. Models that make other assumptions about on-orbit life are developed in later phases.

In Table II-1, the scenarios in Phase A are listed, along with the assumed number of launch failures and/or premature failures on-orbit. Fifteen scenarios for a one-satellite system are listed under Case I, and 24 scenarios for a two-satellite system are listed under Case II.

2. Phase B

The performance of satellites failing without replacements in Phase A do not meet the POES management goals. Therefore, in Phase B, replacement launches were called for after launch failures. To test the consequences if on-orbit lifetimes were increased, changes in the design lifetimes were introduced into the modeling. These two groups of scenarios are developed for both Case I and Case II.

Table II-1

Scenarios in Phase A

Case I - One-satellite system

Scenario	Launch Failures	Premature Failures	Page Number in Appendix A
I-1	0	0	A-12
I-2	0	1	A-13
I-3	0	2	A-14
I-4	1	0	A-15
I-5	1	1	A-16
I-6	1	2	A-17
I-7	2	0	A-18
I-8	2	1	A-19
I-9	2	2	A-20
I-10	3	0	A-21
I-11	3	1	A-22
I-12	3	2	A-23
I-13	1+2	0	A-24
I-14	1+2	1	A-25
I-15	1+2	2	A-26

Table II-1 (Continued)

Case II - Two-satellite system

Scenario	Launch Failures	Premature Failures	Page Number in Appendix A
II-1	0	0	A-27
II-2	0	1	A-28
II-3	0	2	A-29
II-4	0	3	A-30
II-5	1	0	A-31
II-6	1	1	A-32
II-7	1	2	A-33
II-8	1	3	A-34
II-9	2	0	A-35
II-10	2	1	A-36
II-11	2	2	A-37
II-12	2	3	A-38
II-13	3	0	A-39
II-14	3	1	A-40
II-15	3	2	A-41
II-16	3	3	A-42
II-17	4	0	A-43
II-18	4	1	A-44
II-19	4	2	A-45
II-20	4	3	A-46
II-21	2+2	0	A-47
II-22	2+2	1	A-48
II-23	2+2	2	A-49
II-24	2+2	3	A-50

Note that when the numbers 1+2 or 2+2 appear under Launch Failures, the scenarios examine the effects if two of the launch failures are consecutive.

In the first group of scenarios, on-orbit lifetimes were held at 24 months, the conventional program/budgeting assumptions, as were fixed launch schedules of 18 months for a one-satellite system and 12 months for a two-satellite system. Replacement intervals of 9 and 4 months for a one-satellite system, and of 6 and 4 months for a two-satellite system, were modeled.

In the second group of scenarios, the expected on-orbit life was extended to 28 months. The approximate average life of the recent POES that successfully achieved orbit was 30.5 months, so a 28-month average is still conservative, as it should be for an

operational POES system. Similarly, the fixed launch schedules for Case I and Case II were extended by 4 months (to 22 and 16 months, respectively). Again, replacement launches after a launch failure of 9 and 4 or 6 and 4 months were modeled for direct comparison with the first group of scenarios in this phase.

In Phase B and subsequent phases, only those scenarios with no assumed failures, those producing the least negative impact on services to the users (with a probability approaching zero that the POES will be so successful that there will be no failures at all), and those combinations of launch and premature failures that appear the most likely (highest probability) were modeled.

As a special Phase B analysis of the two-satellite system, a variation of Scenarios II-1, II-15, and II-16 was introduced in the modeling. A launch strategy was assumed in which the next satellite launched after a launch failure would always be launched into the afternoon orbit, even if the satellite that failed to achieve orbit had been intended for the morning orbit. This replacement launch strategy "protects" the afternoon satellite that provides services most important to the National Weather Service in its numerical weather forecasting. This launch strategy, one that NOAA program managers would normally adopt, is modeled in Scenarios II-25, II-26, and II-27. The improvement in system performance statistics using this launch strategy was sufficiently great that this strategy was applied to all other Case II scenarios in Phase C and subsequent phases, although there are occasional circumstances when the wise management of satellite resources will dictate an AM satellite launch after a launch failure.

As shown in Table II-2, there are 15 Case I one-satellite scenarios in Phase B, and 18 Case II two-satellite scenarios.

3. Phase C

The improved but still relatively poor program/service performance of those scenarios in Phase B with suggested fixed launch schedules of 22 and 16 months for Case I and Case II, respectively, suggested that the fixed launch schedules should be changed to 20 and 14 months. The rationale for this selection is that the increase in the launch intervals is one-half the 4-month extended on-orbit lifetimes.

The last six Phase B Case I one-satellite scenarios with 9- and 4-month replacement launches (Scenarios I-25 through I-30) were modeled assuming 20-month fixed launch schedules. Similarly, the last six Phase B Case II two-satellite scenarios with 6- and 4-month replacement launch schedules (Scenarios II-37 through

Table II-2

Scenarios in Phase B

Case I - One-satellite system

Scenario	Design Life (Months)	Fixed Launch (in mo.)	Call-up Launch (in mo.)	Launch Failures	Premature Failures	Page No. in Appn. A
I-16	24	18	9	0	0	A-51
I-17	24	18	9	2	2	A-52
I-18	24	18	9	3	2	A-53
I-19	24	18	4	0	0	A-54
I-20	24	18	4	2	2	A-55
I-21	24	18	4	3	2	A-56
I-22	28	22	0	0	0	A-57
I-23	28	22	0	2	2	A-58
I-24	28	22	0	3	2	A-59
I-25	28	22	9	0	0	A-60
I-26	28	22	9	2	2	A-61
I-27	28	22	9	3	2	A-62
I-28	28	22	4	0	0	A-63
I-29	28	22	4	2	2	A-64
I-30	28	22	4	3	2	A-65

Case II - Two-satellite system

Scenario	Design Life (Months)	Fixed Launch (in mo.)	Call-up Launch (in mo.)	Launch Failures	Premature Failures	Page No. in Appn. A
II-25	24	12	0	0	0	A-66
II-26	24	12	0	3	3	A-67
II-27	24	12	0	4	3	A-68
II-28	24	12	6	0	0	A-69
II-29	24	12	6	3	3	A-70
II-30	24	12	6	4	3	A-71
II-31	24	12	4	0	0	A-72
II-32	24	12	4	3	3	A-73
II-33	24	12	4	4	3	A-74
II-34	28	16	0	0	0	A-75
II-35	28	16	0	3	3	A-76
II-36	28	16	0	4	3	A-77
II-37	28	16	6	0	0	A-78
II-38	28	16	6	3	3	A-79
II-39	28	16	6	4	3	A-80
II-40	28	16	4	0	0	A-81
II-41	28	16	4	3	3	A-82
II-42	28	16	4	4	3	A-83

II-42) were modeled with 14-month fixed launch schedules. The six Phase C scenarios for each case are listed in Table II-3.

4. Phase D

The next set of assumptions tested in the modeling relates to the nature of the premature failure of a satellite on-orbit. In Phases A, B, and C all the premature failures were assumed to be sudden, catastrophic, and without warning. This was the failure mechanism of NOAA 8.

However, from the probability perspective, it is perhaps more likely that there will be a partial early failure. This situation occurred with NOAA 6, the only POES of the currrent generation

Table II-3

Scenarios in Phase C

Case I - One-satellite system

Scenario	Design Life (Months)	Fixed Launch Schedule (Months)	Call-up Launch Schedule (Months)	Launch Failures	Premature Failures	Page No. in Appn. A
I-31	28	20	9	0	0	A-84
I-32	28	20	9	2	2	A-85
I-33	28	20	9	3	2	A-86
I-34	28	20	4	0	0	A-87
I-35	28	28	4	2	2	A-88
I-36	28	20	2	3	2	A-89

Case II - Two-satellite system

Scenario	Design Life (Months)	Fixed Launch Schedule (Months)	Call-up Launch Schedule (Months)	Launch Failures	Premature Failures	Page No. in Appn. A
II-43	28	14	6	0	0	1-90
II-44	28	14	6	3	3	1-91
II-45	28	14	6	4	3	1-92
II-46	28	14	4	0	0	1-93
II-47	28	14	4	3	3	1-94
II-48	28	14	4	4	3	1-95

of satellites that suffered a partial failure, resulting in a decision to replace the satellite before it became totally unusable.

In Phase D it was assumed that the same number of premature failures modeled in Phase C would occur, but that the failures would be less than catastrophic, and that there would be some early evidence in the telemetry data that the satellite was doing poorly, with failure imminent. It was also assumed that this early evidence would appear 4 months before the satellite's failure to acquire Prime Mission Data (images and soundings). As a result of detecting this early evidence, a replacement satellite would be called up and launched on the same call-up schedule used for replacements after a launch failure. All other variables considered in Phase C (design life, fixed launch schedules, replacement launch schedules, etc.) were applied consistently in Phase D in order to evaluate the impact on service statistics, and on the unit cost to successfully acquire Prime Mission Data, if only the assumptions about the nature of early failures were changed.

In addition to this part of the analysis, three Phase B Case II two-satellite scenarios (Scenarios II-31, II-32, and II-33, which assumed 24-month design life and 12-month launch intervals) were modeled again in Scenarios II-49, II-50, and II-51, applying the assumption of early indications of premature failure discussed above. The performance statistics and unit cost to acquire data if the two-satellite baseline system were to experience premature failures with early evidence, rather than the sudden failure modeled in Phase B, were directly compared. The six Case I and nine Case II Phase D scenarios are listed in Table II-4.

5. Phase E

Two forms of extended on-orbit lifetimes that exceed the present satellite design lifetimes of 24 months were modeled in Phase E:

- Lifetimes of 32 months (the average life of the current POES that were orbited successfully is approximately 30.5 months) were examined specifically to determine the impacts of longer planned lifetimes on performance statistics and costs.

- Lifetimes that exceed the nominal design life, based on experiences of the current POES satellites, which have had on-orbit lifetimes of 29, 41, 37, and 15 months were modeled.

As of December 20, 1984, the on-orbit lifetimes of the recent POES system, as shown in Figure I-2 in Volume 1, were 29.5, 51.8,

Table II-4

Scenarios in Phase D

Case I - One-satellite system

Scenario	Design Life (Months)	Fixed Launch Schedule (Months)	Call-up Launch Schedule (Months)	Launch Failures	Premature Failures	Page No. in Appn. A
I-37	28	20	9	0	0	A-96
I-38	28	20	9	2	2	A-97
I-39	28	20	9	3	2	A-98
I-40	28	20	4	0	0	A-99
I-41	28	20	4	2	2	A-100
I-42	28	20	4	3	2	A-101

Case II - Two-satellite system

Scenario	Design Life (Months)	Fixed Launch Schedule (Months)	Call-up Launch Schedule (Months)	Launch Failures	Premature Failures	Page No. in Appn. A
II-49	24	12	4	0	0	A-102
II-50	24	12	4	3	3	A-103
II-51	24	12	4	4	3	A-104
II-52	28	14	6	0	0	A-105
II-53	28	14	6	3	3	A-106
II-54	28	14	6	4	3	A-107
II-55	28	14	4	0	0	A-108
II-56	28	14	4	3	3	A-109
II-57	28	14	4	4	3	A-110

40.6, and 15.1 months. It should be noted that the second satellite in this list, NOAA 6, was modeled as if its lifetime were 41 months rather than almost 52 months. This satellite showed irregular performance of the imager/sounder after 41 months, and the replacement satellite, NOAA 8, was launched. The NOAA 6 imager later stabilized and the satellite was placed in standby status. It was recalled to service upon the failure of NOAA 8. Similarly, the decision to replace NOAA 7, the third satellite in this list, was made after 37 months of service when the power supply showed serious signs of degradation and the imager/sounder evidenced signs of a deficiency in the lubrication of the scan mirror bearing. Therefore, 37 months was used in the modeling rather than 41 months.

For both the one-satellite and two-satellite systems, both of the aforementioned assumptions about on-orbit lifetimes were modeled with a 4-month launch call-up following all failures.

The first part of the Phase E modeling was designed to test the impacts on performance and costs if on-orbit reliability were improved. A satellite design life of 32 months was chosen, and the modeling followed the pattern of launch and premature failures used in earlier phases. As noted earlier, the strategy of launching into the afternoon orbit after a launch failure was not always applied in Phase E. There were several situations, particularly in those scenarios that follow the POES history, where a different strategy resulted in better operational use of the available satellites.

Two variations were examined in the modeling of satellite scenarios with 29-41-37-15-month lifetimes (this cycle repeated over the 15 years of the analysis). The first assumed that there would be no early indications of failure on-orbit. The second assumed that telemetry data would provide indications 4 months early that a total failure was likely for satellites with 29-, 41-, or 37-month lifetimes. Omitting early indications of failure of 15-month satellites closely follows history, since NOAA 8 failed without warning. Recognizing that both NOAA 6 and 7 had useful lifetimes longer than the 41- and 37-month figures used in the scenarios, the extended life scenarios modeled are still conservative.

The final variations modeled for both satellite systems used the exact history of the current POES, assuming satellite lifetimes of 29-41-0-37-15 months, where zero represents the launch failure of NOAA B in 1980. Modeling with and without early indications of on-orbit failure, as discussed previously, was repeated.

The 11 Phase E scenarios for each case are shown in Table II-5.

B. DATA COMPILATION

Various quantities were needed to compare the relative service effectiveness, system costs, and management strategies postulated in the more than 120 different scenarios plotted during this analysis of the long-term POES. Some of these quantities were derived directly from inspection of the plotted scenarios, and others were calculated.

The complete results of these inspections and calculations can be seen in Volume 3, Appendix D, Tabular Results of Data Collection and Compilation. Table II-6 is a sample of these tabular results, one of 10 tables in the appendix.

Table II-5

Scenarios in Phase E

Case I - One-satellite system

Scenario	Design Life (Months)	Fixed Launch Schedule (Months)	Call-up Launch Schedule (Months)	Launch Failures	Premature Failures	Page No. in Appn. A
I-43	32	22	4	0	0	A-111
I-44	32	22	4	2	2	A-112
I-45	32	22	4	3	2	A-113
I-46	29-33-37-15	On Failure	4	0	N/A*	A-114
I-47	29-33-37-15	On Failure	4	2	N/A*	A-115
I-48	29-33-37-15	On Failure	4	3	N/A*	A-116
I-49	29-33-37-15	On Failure	4	0	N/A**	A-117
I-50	29-33-37-15	On Failure	4	2	N/A**	A-118
I-51	29-33-37-15	On Failure	4	3	N/A**	A-119
I-52	29-33-0-37-15	On Failure	4	N/A	N/A*	A-120
I-53	29-33-0-37-15	On Failure	4	N/A	N/A**	A-121

Case II - Two-satellite system

Scenario	Design Life (Months)	Fixed Launch Schedule (Months)	Call-up Launch Schedule (Months)	Launch Failures	Premature Failures	Page No. in Appn. A
II-58	32	16	4	0	0	A-122
II-59	32	16	4	3	3	A-123
II-60	32	16	4	4	3	A-124
II-61	29-33-37-15	On Failure	4	0	N/A*	A-125
II-62	29-33-37-15	On Failure	4	3	N/A*	A-126
II-63	29-33-37-15	On Failure	4	4	N/A*	A-127
II-64	29-33-37-15	On Failure	4	0	N/A**	A-128
II-65	29-33-37-15	On Failure	4	3	N/A**	A-129
II-66	29-33-37-15	On Failure	4	4	N/A**	A-130
II-67	29-33-0-37-15	On Failure	4	N/A	N/A*	A-131
II-68	29-33-0-37-15	On Failure	4	N/A	N/A**	A-132

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* No early indications of on-orbit failure.

** Indications 4 months early that an on-orbit satellite is likely to fail.

Table II-6

Sample of Tabulated Results for Phase E

Case II - Two-Satellite Configuration

1 Scenario	2 Design Life (months)	3 Satellites		4 Launch Schedule (in months)		5 Launch Failures		6 Premature Failures in-orbit	7 Prime Mission Data (months)			8 Index of Program Performance	9 Prob-ability	10 Total Program Cost ($ C M)	11 Months of Mission Data	12 Index of Service Efficiency	13 Index of Cost Efficiency	NOTES
		Launch	Orbit	Fixed	Relaunch	Random	Conseq		Lost	Degraded	Dual							
58	32	12	12	16	4						164	383	0.002	17.28	262	0.0337	0.4786	
59	32	16	13	16	4	3		3	4	2	140	342	0.063	22.20	245	0.9419	0.3627	
60	32	17	13	16	4	4		3	4	2	136	337	0.053	23.43	243	0.7808	0.3415	
61	Cycle 1	11	11		4			In Cycle	2	14	133	323	0.003	15.75	238	0.0424	0.5250	
62	Cycle 1	13	10		4	3		In Cycle	4	15	123	305	0.075	17.94	230	1.0000	0.4350	
63	Cycle 1	14	10		4	4		In Cycle	4	16	120	300	0.055	19.63	228	0.7214	0.4122	
64	Cycle 2	12	12		4			In Cycle			156	375	0.002	17.23	258	0.0328	0.4796	
65	Cycle 2	14	11		4	3		In Cycle		4	148	360	0.063	19.35	252	0.9815	0.4224	
66	Cycle 2	15	11		4	4		In Cycle		4	142	353	0.055	21.00	249	0.8487	0.3861	
67	Cycle 3	13	10		4	In Cyc		In Cycle	2	20	121	301	0.075	18.58	231	0.9869	0.4382	
68	Cycle 4	14	11		4	In Cyc		In Cycle		8	146	373	0.061	20.00	249	0.9947	0.4071	

Cycle 1 29-41-37-15 months on-orbit life with no early indications of on-orbit failure - relaunch 4 months after a failure

Cycle 2 29-41-37-15 months on-orbit life with early indications of on-orbit failure for all but 15 month satellites - relaunch 4 months after a failure

Cycle 3 29-41-0-37-15 months on-orbit life with no early indications of on-orbit failure - relaunch 4 months after a failure

Cycle 4 29-41-0-37-15 months on-orbit life with early indications for all but 15 month satellites - relaunch 4 months after a failure

1. Data Derived From Inspection

By inspecting the plotted scenarios, the periods of time during the 15 years of analysis when there were no satellite data in either the one-satellite system or the two-satellite system can be identified easily. By subtracting the number of the month in which a data gap starts from the number of the month in which the gap ends, the gap periods were derived. The result, referred to in this study as "lost" data, was entered in column 7 of Table II-6.

The number of satellites to be launched in each scenario was also determined from the plots and entered in column 3 of the table.

For the two-satellite system, other measures of system performance were similarly derived from inspection and entered in column 7 of Table II-6. They are:

- The number of months when data from satellites in both the afternoon and morning orbits were available (called "dual" data).
- The number of months in which data were available only from satellites in the afternoon orbit.
- The number of months in which data only from satellites in the morning orbit (called "degraded" data) were available.

2. Data Derived From Calculations

A number of quantities were derived from data developed by inspecting the plotted scenarios. As discussed in Chapter III, some of these calculated data are valuable in a "reconnaissance mode" in the analysis. Broad comparisons among the more than 120 plotted scenarios are made to single out those scenarios in either system configuration that appear to have a reasonable probability of offering services acceptable to the user community at the most reasonable long-term cost. These groups of scenarios were found using the Index of System Performance and the Index of Cost Efficiency, both of which are discussed below. Then more direct comparisons among the apparent "best" scenarios were made using system performance statistics and long-term system costs directly.

Index of Program Performance -- This index (see column 8, Table II-6) was calculated for each scenario in recognition that:

- It is extremely important that Prime Mission Data (images and soundings) are provided continuously - a month without

any satellite data has a greater "negative" impact on NWS operations than does a month in which degraded (AM satellite only) data are available, according to comments by the NWS.

- AM satellite only (degraded) data, while of value to NWS and others in the larger user community, are less important than data from satellites in the preferred afternoon orbit.

- Concurrent acquisition of global data by satellites in both the morning and afternoon orbits has a greater value to NWS and other users than data from satellites with a single equatorial crossing time.

These considerations led to the conclusion that an objective evaluation was needed of how well a one-satellite or a two-satellite system, subjected to the number and types of satellite failures postulated in each of the scenarios, would respond to the data and service needs of the NWS and the rest of the user community. Such a measure should do more than to just count the number of months of various levels of service provided.

Therefore, the Index of Program Performance (IPP) was developed to evaluate how well the users were being served. The formula for this measure of performance is:

$$IPP = 180 - (A \times Loss) - (B \times Degraded) + (C \times Dual)$$

where:

180 is the number of months in the analysis,
A is a multiplier reflecting the serious consequences of data gaps,
B is a multiplier recognizing that degraded data are less valuable than PM or dual data,
C is a multiplier that recognizes that the users receive a "bonus" when dual data are available,
Loss is the number of months in which there are data gaps,
Degraded is the number of months in which only AM data are available, and
Dual is the number of months in which both AM and PM data are available.

The IPP for each scenario was calculated (and entered in column 8 of Table II-6) by using the multipliers: A = 2.5, B = 1.25, and C = 1.25. These values reflect the above noted impacts on the user community. Other analysts may choose different values. However, the IPP is used to calculate another index (discussed below), and since this second index is normalized to improve comparisons among all the scenarios, it is unlikely that the choice of differ-

ent IPP multipliers, if applied uniformly to all scenarios, would change significantly the conclusions that are drawn later in this analysis.

Probabilities That Assumed Failures Will Occur -- A number of alternate system models (groups of scenarios in which the same number of launches were attempted) were examined. A large range of combinations of successes, launch failures, and premature failures is possible for every model. To identify the most realistic combinations, and to provide a quantitative measure of system performance in terms of meeting the POES objectives, the probabilities of the events assumed in the scenarios occurring were analyzed.

The data base used in this analysis was derived from the history of the POES program starting with the launch of TIROS M in 1970. This 15-year history is a valid guide in predicting the probability of events occurring during the next 15 years.

Conventional computation methods were used in the probability analysis. For each model considered, a probability value to every possible result was calculated, including the full mix of successes, launch failures, and premature failures on-orbit for satellite series of a given length. Additionally, a probability value of the likelihood of encountering two consecutive launch failures was calculated. Combinations of concurrent launch failures and premature failures are included in the scenarios.

Probabilities, which are entered in column 9 of Table II-6, are discussed further in Volume 3, Appendix C, Probabilities of Launch or Premature Failures.

Index of Service Efficiency -- The Index of Program Performance values for the various scenarios range from a low of 15 to a high of 390, the maximum possible value in this analysis when using the multipliers discussed above. The scenarios with the highest values are invariably those with no launch or premature on-orbit failures. Given the history of the POES and the state-of-the-art in space technology, it is virtually impossible to operate any similarly complex remote sensing system from space for 15 years without any failures. The probability of no failures is virtually zero (0.0001 to 0.003), based on the analyses reported in Volume 3, Appendix C.

Therefore, the Index of Service Efficiency (ISE) was created, which combines the objective measure of how well a given system would meet the POES operational objectives (the IPP) with the

probability that services at least equal to those derived from the plotted scenarios (with their assumed failures and other characteristics) would be available.

ISE values were calculated for each scenario by multiplying its Index of Program Performance and its probability of occurrence. The lowest calculated values (0.007) were for scenarios with excellent service coverage, but with very low probabilities that these excellent services would be available. The highest calculated values (22.875) were for scenarios with projected service statistics that were very good to excellent, and with a high probability that services at least that good would be available, because the postulated system management practices would reduce or eliminate the effects of the inevitable failures.

Index of Service Efficiency values, as calculated and entered in column 12 of Table III-6, were first normalized to facilitate later analysis by dividing all calculated ISE figures by the highest calculated figure, resulting in ISE values that range from zero to 1.0000.

Total Program Cost (TPC) -- The TPC for each scenario includes the cost to fabricate, check out, and launch the required number of satellites. Other POES program costs, such as systems operations, data processing, and research and development, are not included. The cost for each scenario was calculated (and entered in column 10 of Table II-6) in terms of "$C million," where "C" equals the launched cost of a single satellite, whether the launch was successful or not. In today's costs, "C" is roughly 75 million.

Inflation was applied to the cost of each satellite in a given scenario at an assumed annual rate of 6 percent. For more information on the computation of long-term costs, see Volume 3, Appendix B, Scenario Cost Calculations.

These TPCs, which range from $8.43 to $28.08 C million, are useful in judging the merit of a given set of planning assumptions and system management practices from the budget perspective, but by themselves are not sufficient for a thorough analysis of the POES and its long-term cost effectiveness.

The TPC figures do not indicate whether one or more sets of scenarios with the same 15-year cost (for example, there are more than 30 scenarios with the same $23.2 C million cost) are more effective in meeting user requirements. The TPC figures do not indicate whether a system management concept costing less in the long term can provide the same or better services to the users. Finally, they do not indicate if spending slightly more would provide significantly better services.

Months of Mission Data (MMD) -- To identify optimum management approaches, a method was developed that relates the money spent to the data services successfully provided - a coarse cost/benefit measure.

The first step was to determine for each scenario how many MMD were acquired successfully as the result of the total investment. Similar to the Index of Program Performance, a formula was devised that reflects the same sorts of values for months in which different levels of service were available to the users.

This formula is:

MMD = 180 - (D x Loss) - (E x Degraded) + (F x Dual)

where:

180 is the number of months in the analysis,
D is a multiplier reflecting the serious consequences of data gaps,
E is a multiplier recognizing that degraded data are less valuable than PM or dual data,
F is a multiplier that recognizes that the users receive a "bonus" when dual data are available,
Loss is the number of months in which there are data gaps,
Degraded is the number of months in which only AM data are available, and
Dual is the number of months in which both AM and PM data are available.

As in the calculation of the IPP, the choice of values for D, E, and F used in this analysis are arbitrary, but they are consistent in relative value with those used in calculating the IPP. The figures used were: D = 1.0, E = 0.5, and F = 0.5. Comments in the discussion of the IPP about the analytical impact of choosing other values are equally applicable here.

Index of Cost Efficiency (ICE) -- The objective in developing this index was to derive a relative unit of measure which would:

- Reflect the monthly cost to acquire satellite data successfully.
- Be structured such that scenarios with the lower monthly cost would have the higher relative index value.
- Be weighted so that systems with the lowest long-term cost would have the greatest index value.

The ICE values for each scenario were calculated in several steps. First, the Total Program Costs were divided by the Months of Mission Data. Costs to acquire data successfully calculated in this fashion ranged from a low of about $3.6 million per month for one of the one-satellite scenarios (Scenario I-49) to a high of about $9.7 million per month for one of the two-satellite scenarios (Scenario II-24), assuming that the value for "C" used in the cost calculations is 75 million.

To convert these monthly costs so that scenarios with the lowest monthly costs had the highest relative index value, the calculated monthly costs (in $C million) were subtracted from 1.0000.

Next, to facilitate comparisons among scenarios with different Total Program Costs, the indices calculated above were weighted in such a way that systems with lower TPCs would have higher relative index values. Thus, if two scenarios with the same monthly costs to acquire data successfully have different long-term costs, the one with a lower TPC will have a higher ICE value. To accomplish this, the highest TPC of all the scenarios, $28.08 C million, was divided by each individual scenario's TPC. The monthly cost derived above was then multiplied by this ratio. The resulting ICEs ranged from a low of about 0.8804 for one of the two-satellite scenarios (Scenario II-51) to a high of 3.1714 for a few of the one-satellite scenarios (e.g., Scenario I-50).

Finally, the ICE was normalized the same way as the ISE: the calculated relative index value for each scenario was divided by the highest figure, resulting in ICEs that range from 0.2787 to 1.0000. These figures were entered in column 13 of Table II-6.

COMPARISON AND EVALUATION

The comparison and evaluation of the different POES system management approaches is in five sections:

1. Comparisons within Case I one-satellite phases
2. Comparisons between Case I one-satellite phases
3. Comparisons within Case II two-satellite phases
4. Comparisons between Case II two-satellite phases
5. Comparisons between Case I and Case II scenarios

Both the Index of Service Efficiency and the Index of Cost Efficiency were used, and more detailed data about system performance and cost were taken from the tables in Volume 3, Appendix D, or extracted directly from the plotted scenarios in Volume 3, Appendix A. The indices were used in a "reconnaissance mode" to screen the larger data set, selecting those groups of scenarios worthy of more careful scrutiny. Patterns and trends were examined in each group of scenarios in a particular phase, and for each phase relevant conclusions were drawn. All scenarios for either the one-satellite system or the two-satellite system were then compared, and some groups of scenarios were selected for more thorough consideration. The best of the one-satellite scenarios were compared with the best of the two-satellite scenarios. The conclusions drawn at each step of the analysis are reported in this chapter, and summarized in Volume 1.

A. COMPARISONS WITHIN CASE I SCENARIOS FOR THE ONE-SATELLITE SYSTEM

1. Phase A Analysis

This group of 15 scenarios represents likely outcomes if the one-satellite system envisioned in the normal budget planning process, shown on Figure I-1 in Volume 1, were subjected to the number and types of failures that the POES history from 1970 (including the operational history of the five NOAA satellites of the current design) would indicate are likely in the next 15 years.

These scenarios have similar operational characteristics: design life of 24 months; satellites launched on a fixed schedule of 18 months; no replacement satellites launched following either a launch failure or a premature failure on-orbit. All scenarios envision the launch of the same number of satellites, and thus have the same cost. The POES history leads to the conclusion that, during the next 15 years, there will be up to three launch failures and up to two premature failures on-orbit. From the

probabilities calculated as discussed in Volume 3, Appendix C, the highest and lowest probabilities among these 15 one-satellite scenarios are listed in Table III-1.

Table III-1

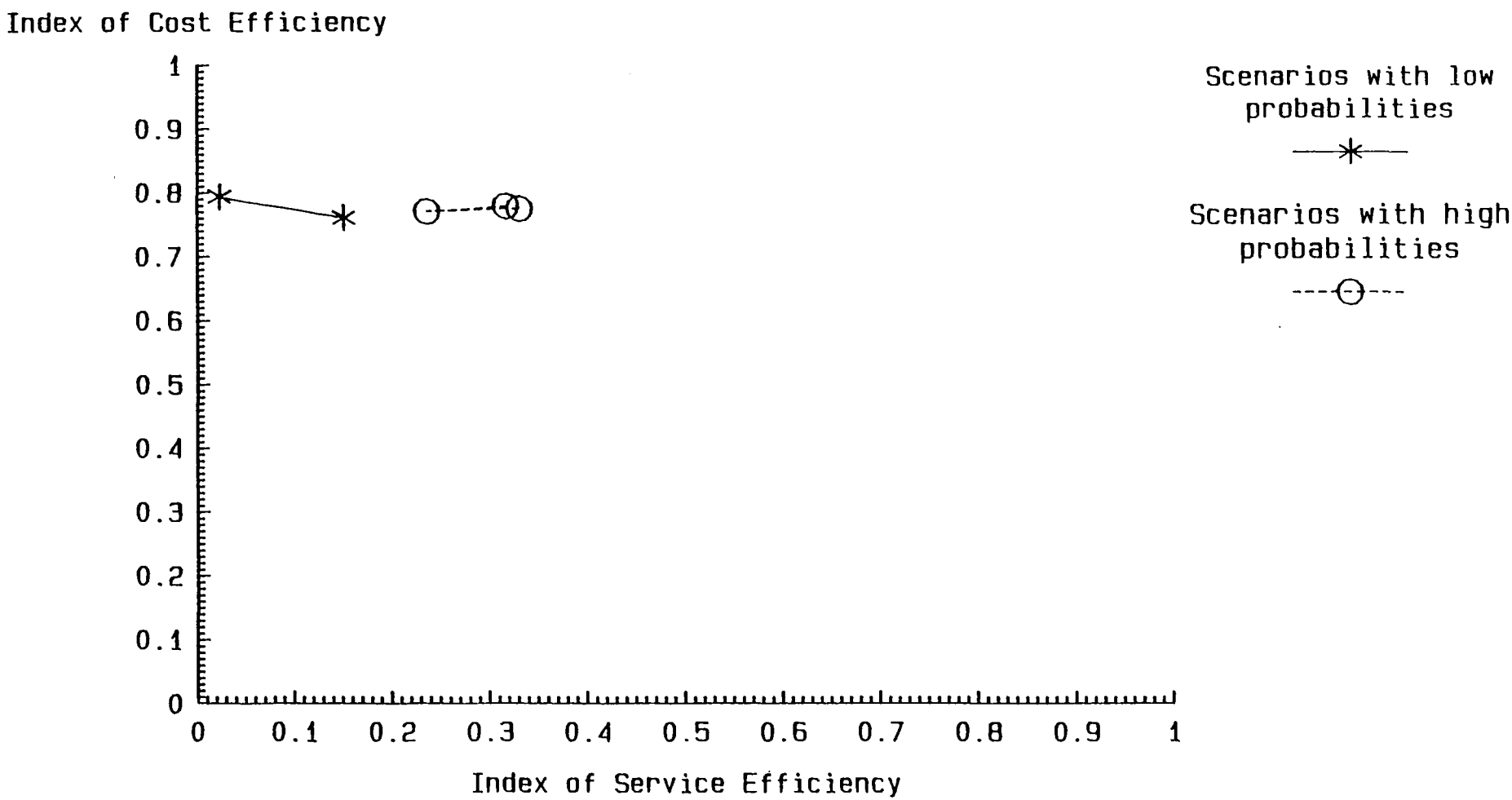
Probabilities of failure
in a one-satellite system

Scenario	Launch Failures	Premature Failures	Probabilities
I-9	2	2	0.084
I-12	3	2	0.077
I-11	3	1	0.072
I-6	2	1	0.069
I-1	0	0	0.003

The plots of the Index of Service Efficiency versus the Index of Cost Efficiency (called "ISE-v-ICE" in this report) figures for each of these five scenarios are shown in Figure III-1. None of these scenarios has ISE values higher than 0.3305, indicating that services to the users are poor. The high ICE values (circa 0.7900) indicate that the long-term costs are relatively low. Since services are poor, the cost-effectiveness of this management plan is degraded.

Only the scenario with the lowest probability (Scenario I-1) results in no loss of satellite data. In other words, the probability approaches zero that the one-satellite system described in Phase A will meet the POES management goal of providing satellite data from at least one satellite 100 percent of the time. Replacement of failed satellites is not normally considered in conventional budget planning for a one-satellite system. As a result, there will be data gaps of 30 to 54 months over the 15-year period (17 to 30 percent of the time). According to the plotted scenarios (see Volume 3, Appendix A), individual periods in which no satellite data would be available could be as short as 6 months. If a premature failure is followed by a launch failure, gaps could be as long as 24 months. Each launch failure causes a data gap of 12 months if there are no replacements.

Figure III-1
Phase A - One-Satellite System
"ISE-v-ICE"



24-month design life, 18-month launch schedule,
no replacement satellites after failures

2. Phase A Conclusions

The minimum POES management goal is to provide data from at least one satellite at all times. Conventional budget planning for the one-satellite system does not specifically include replacing satellites that fail on launch or prematurely on-orbit. The history of the POES program since 1970 leads to the conclusion that failures are inevitable during the next 15 years. Without replacements in this one-satellite POES system, there probably will be data gaps up to 30 percent of the time over the next 15 years. Individual periods in which no satellite data will be available are likely to be 6 to 24 months long. This POES management plan cannot meet the needs of the National Weather Service and other users.

3. Phase B Analysis

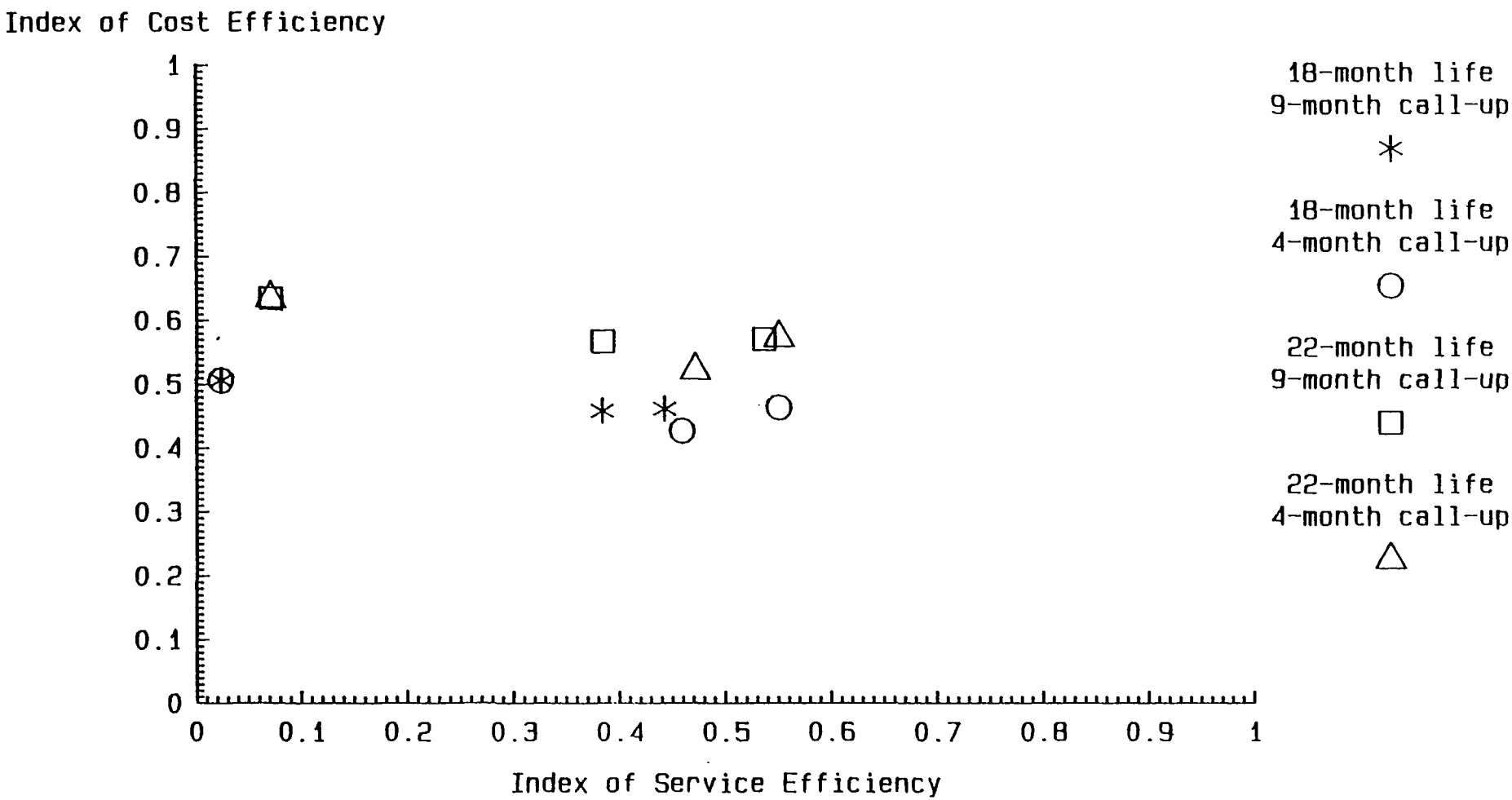
The first six scenarios in Phase B examine the effects of replacement launches being called for following only after launch failures. They retain the 24-month design life and 18-month launch interval used in Phase A. Nine- and 4-month call-up periods following launch failures are modeled. The "ISE-v-ICE" results are plotted in Figure III-2: 9-month call-ups are shown with asterisks, and 4-month call-ups are shown as circles.

If satellites that fail are not replaced, the average Index of Service Efficiency is 0.2587. The 9-month call-up after launch failures increases this average to 0.4672, an 80 percent improvement as the ISE measures performance. The 4-month call-up further increases this average to 0.5049. The ISE for the 4-month call-up is 95 percent higher than if there are no replacements, and 8 percent higher than for the 9-month call-up. The average Index of Cost Efficiency is lower. The reduction from 0.7900 to around 0.5000 is an indication that long-term costs are higher. Some of the reduction in the ICE is offset because of the greater availability of data services, meaning that the funds invested in the system are being used more effectively.

Table III-2 lists pertinent performance statistics for these six scenarios.

Without replacements for satellites that fail at launch, there will be no satellite data 20 percent of the time (36 months). Replacing these satellites in 9 months reduces periods without data to 10 percent (18 months). A 4-month replacement further reduces gap periods to 7 percent (12 months). Four launch failures, one of which follows a premature failure in orbit, produce data gaps of 30 percent (54 months), 15 percent (27 months), and 9 percent of the time (16 months) if there are no replacements or replacements are launched in 9 or 4 months, respectively.

Figure III-2
Phase B - One-Satellite System
"ISE-v-ICE"



24-month design life, 18- or 22-month launches,
9- or 4-month replacements after launch failures

Table III-2

Data loss in a one-satellite system with a 24-month design life and 18-month launch interval, with and without call-up at 9- and 4-month intervals after launch failures

Scenarios with	Data Loss in Months		
	Without Call-up	9-Month Call-up	4-Month Call-up
No launch or premature failures	0	0	0
Two launch failures and two premature failures	36	18	12
Three launch failures and three premature failures	54	27	16

Inspection of the scenario plotted in Volume 3, Appendix A, shows that with a 9-month call-up, individual gap periods would be 3 months following each launch failure, 6 months following each premature failure, and 15 months if a launch failure immediately follows a premature failure. With a 4-month call-up, no data gaps occur after a launch failure, a 6-month gap follows a premature failure and, in the case of a premature failure followed by a launch failure, the gap would be 10 months.

The last nine scenarios in this phase of the analysis of the one-satellite system examine the impact on services and costs if the design--life were increased from 24 to 28 months, and the fixed launch schedule increased from 18 to 22 months, with and without call-ups at 9- and 4-months intervals. Performance data for this 28-month system are listed in Table III-3. The long-term cost for such a POES management approach without call-ups is 19 percent lower than that of the baseline one-satellite system. Nine satellites would be required if all satellites and launches were successful.

The "ISE-v-ICE" plots for the 28-month scenarios with a 9-month call-up are shown with squares in Figure III-2; those with a 4-month call-up appear as triangles. As can be seen in this figure, there is little to distinguish between performance of the one-satellite systems with 28-month and 24-month lifetimes. The

higher ICE values for the 28-month life reflects this system's lower long-term costs.

Comparing the performance statistics for the 28-month life system (Table III-3) with those for the 24-month life system (Table III-2) leads to the same general conclusion about services from these two one-satellite systems.

Data gaps from the system with a 28-month design life without call-ups are 22 percent higher (44 versus 36 months) than from a 24-month design life system, because satellites are launched less frequently. Data gap periods with either a 9- or 4-month call-up are identical for both of these one-satellite systems. The longest probable periods without any satellite data are generally the same for both systems. When a launch failure immediately follows a premature failure, data gaps in the 28-month system could be 2 to 4 months longer than those in the 24-month system.

The POES management approach with a 28-month design life probably would meet the long-term needs of the users as well as would the 24-month design life system, given that launch failures are offset by calling for replacements.

Long-term costs of the 28-month system would range from 19 percent less than the baseline cost if there were no replacement launches, to 3 percent less if launch failures were replaced in

Table III-3
Data loss in a one-satellite system with a 28-month design life and 22-month launch interval, with and without call-up at 9- and 4-month intervals after launch failures

Scenarios with	Data Loss in Months		
	Without Call-up	9-Month Call-up	4-Month Call-up
No launch or premature failures	0	0	0
Two launch failures and two premature failures	44	18	12
Three launch failures and three premature failures	66	27	16

4 months. Neither of these two POES management approaches meets system management goals. Possible mechanisms to improve services from the 28-month life system are explored in later phases.

4. Phase B Conclusions

1. Replacing satellites 9 months after launch failures in the 24-month design life POES one-satellite system with an 18-month launch schedule provides some improvement in services to the users. The long-term costs of the system would be 8 percent higher. A 4-month call-up would all but eliminate data gaps from launch failures, further improving services. The cost is 15 percent higher than if there were no replacement launches, or the same cost to 7 percent more than the costs of the system with the 9-month call-up. This system management plan does not meet the POES goal of providing data from at least one satellite at all times, because there would be no satellite data 6 to 15 percent of the time over the next 15 years.

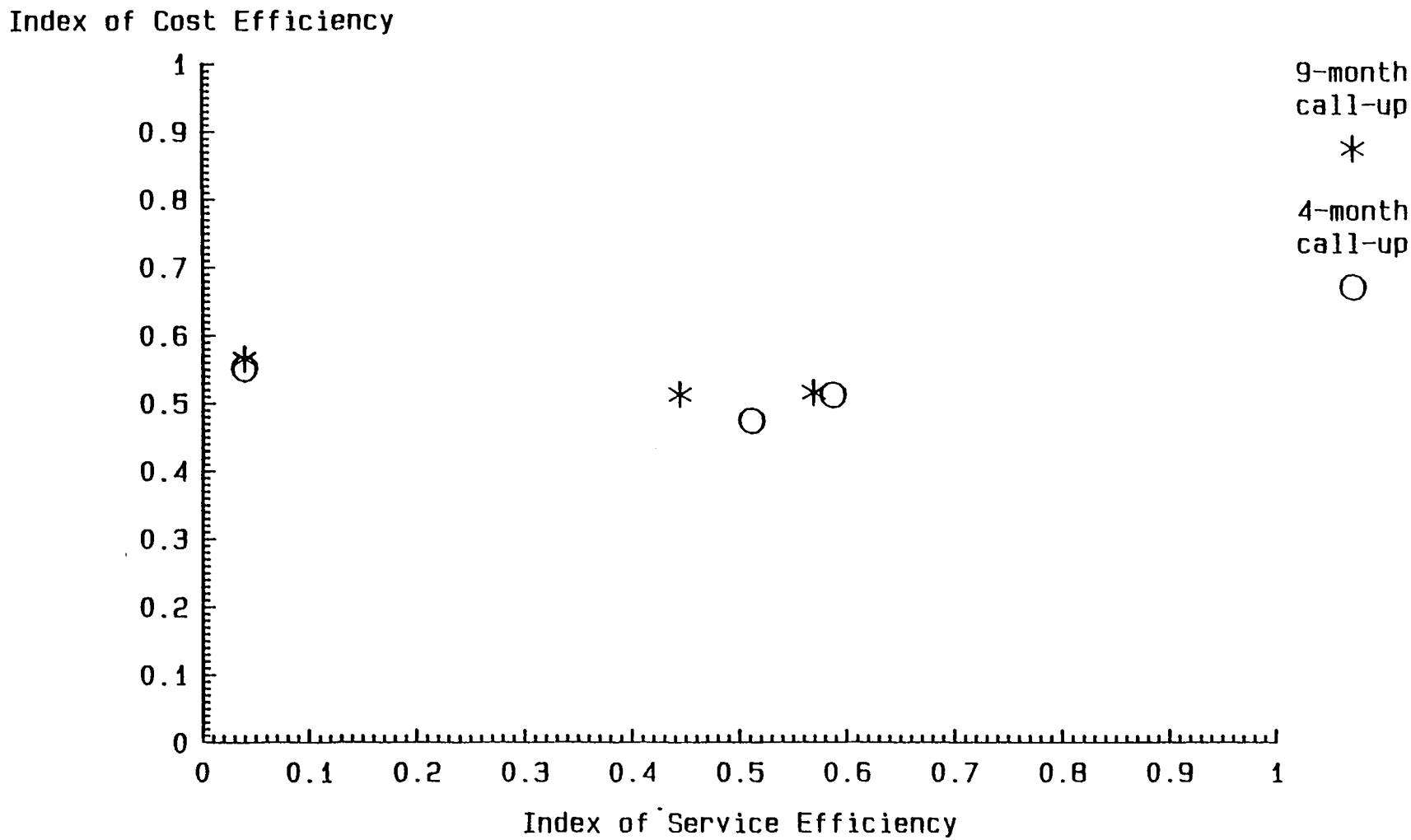
2. The one-satellite POES management approach based on a design life of 28 months and a launch schedule of 22 months is more desirable because it probably provides about the same level of services, at a long-term cost that is about 17 percent less than that of the 24-month system. The 28-month design life system does not meet the POES management goal of providing data from at least one satellite at all times because there would be no satellite data 6 to 16 percent of the time.

5. Phase C Analysis

The six one-satellite scenarios plotted in Phase C test improvements in services and the impact on costs if the 28-month design life system were to have a launch interval of 20 rather than 22 months. The "ISE-v-ICE" points for these scenarios are shown in Figure III-3: those for 9-month replacements after a launch failure with asterisks, and those for a 4-month replacement with circles.

The 20-month call-up moves the ISE points further to the right in this figure, showing that services to the users have been improved. The average ISE for scenarios with a 20-month launch interval and replacements after launch failures is 0.5281, and that of scenarios with a 22-month launch interval is 0.4849. This difference represents a 9 percent improvement in services. The average ICE of the scenarios with a 20-month launch interval is 9 percent lower (0.5031 versus 0.5573), reflecting that while its costs are 11 percent higher, better services result in more efficient use of the funds spent.

Figure III-3
Phase C - One-Satellite System
"ISE-v-ICE"



28-month design life, 20-month launch interval,
replacements 9 or 4 months after launch failures

The Phase C scenario with the 28-month design life and 20-month launch schedule has costs about 10 percent higher than the same system with a 22-month launch interval, because one more satellite is required.

The data in Table III-4, compared with that in Table III-2, show that using the 20- versus 22-month launch interval reduces data gaps in the long term. If there is a 9-month call-up, data voids are reduced by 8 percent. The reduction is 4 percent if there was a 4-month call-up. The longest single period of no data using the 22-month launch interval is 15 months. Under a 20-month launch interval, this figure is reduced to 13 months.

6. Phase C Conclusions

The use of a 20-month rather than 22-month launch interval for a system with a 28-month design life marginally increases services to the users. However, periods of a year or more in which there are no satellite data would still occur. These extended data gaps are unacceptable to the National Weather Service and other users. The 11 percent increase in cost over the system with the 22-month launch interval is not justified by the modest improvement in services.

Table III-4

Data loss in a one-satellite system with a 28-month design life and 20-month launching interval, with and without call-up at 9- and 4-month intervals after launch failures

Scenarios with	Data Loss in Months		
	Without Call-up	9-Month Call-up	4-Month Call-up
No launch or premature failures	0	0	0
Two launch failures and two premature failures	34	10	0
Three launch failures and three premature failures	58	19	12

7. Phase D Analysis

Analysis of the scenarios examined thus far demonstrates that calling up replacements following launch failures in a one-satellite system can reduce or eliminate data gaps resulting from satellites that do not successfully achieve orbit. The analyses also show that substantial data gaps can still result from premature failures on-orbit.

When 9-month call-ups are introduced into Phase B and Phase C planning, some of the data gaps resulting from launch failures are eliminated. Of the remaining gaps (between 10 and 27 months over 15 years), 82 percent are attributable to premature failures on-orbit. The 4-month call-up eliminates all gap periods resulting from launch failures as the scenarios were modeled. All remaining gap periods, therefore, were due to premature failures. Gaps during the 15-year period can still occur as much as 15 percent of the time, and individual gap periods can still be a year or more. This performance falls far short of the POES management goals designed to be responsive to the needs of the National Weather Service and other users of POES data and services.

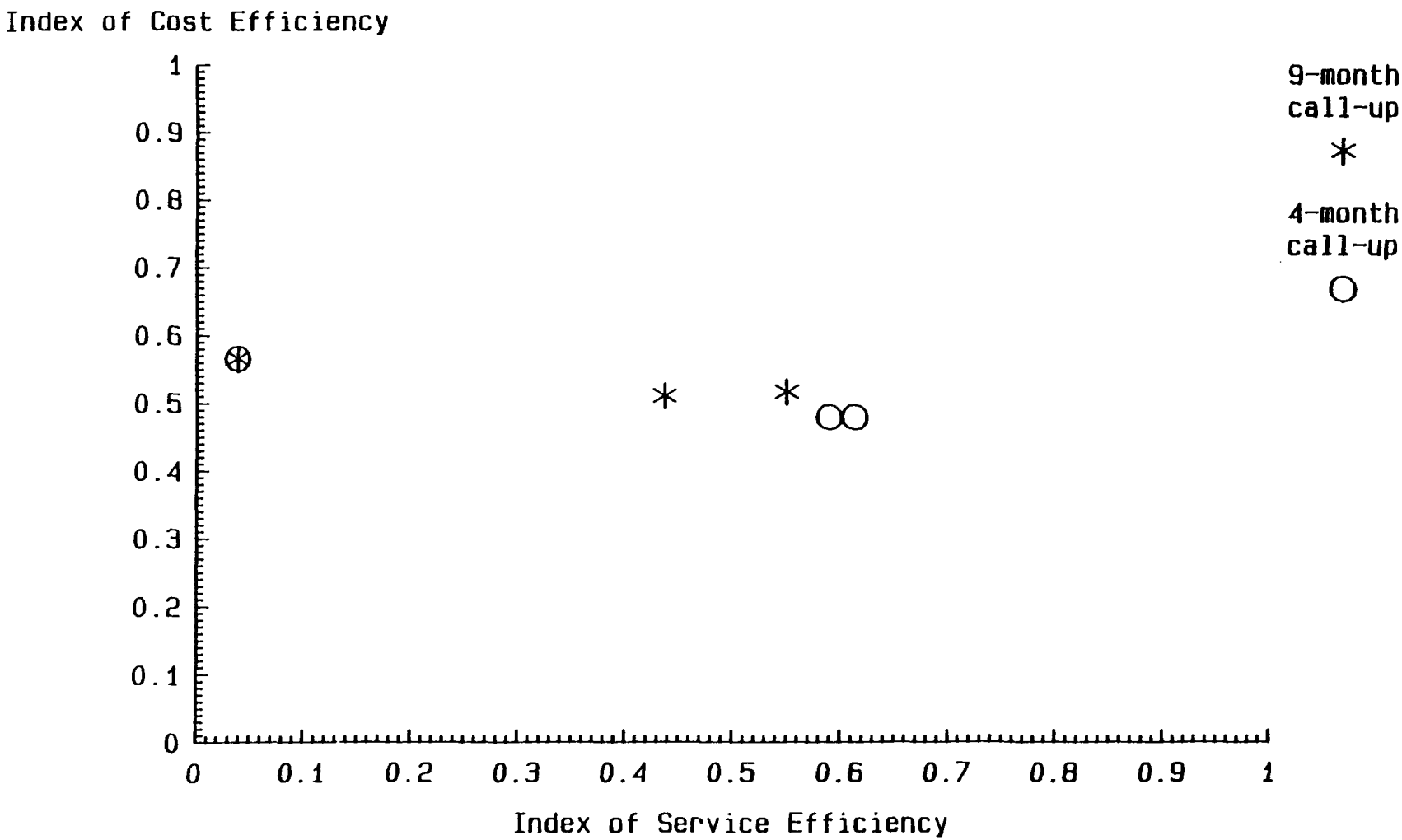
In Phase D, the capability to call up a replacement satellite when a satellite on-orbit fails before the end of its design life was added to the modeled system (28-month design life one-satellite POES system with a 20-month launch interval).

Premature failures were modeled as if there were indications in the telemetry data 4 months early that a satellite was doing poorly and that failure was imminent. It was assumed that the satellites would be unable to provide Prime Mission Data (images and soundings) 12 months before the end of the design life. Assuming satellite failures earlier or later in their life cycles than 12 months could change the number of satellites launched over 15 years (and the long-term system costs), but in all probability changing the period before premature failure would not affect the relative system performance statistics in the long term.

The six one-satellite scenarios in Phase D model the effects of a 9- or 4-month call-up after either a launch failure or a premature failure on-orbit. The "ISE-v-ISE" points for the 9-month call-up are shown in Figure III-4 as asterisks. Circles are used to indicate the data points for the 4-month call-up.

The ISE points have moved still further to the right, indicating that improvements are still being made in services over those from scenarios in earlier phases. The average ISE for these scenarios is 0.5438 if satellites which fail prematurely are

Figure III-4
Phase D - One-Satellite System
"ISE-v-ICE"



28-month design life, 20-month launches, with replacements after launch or premature failures

replaced, 0.5282 if they are not. The improvement in services from a 4-month call-up are more significant than those for the 9-month call-up (the average 4-month ISE increases from 0.5495 to 0.5934). There is almost no change in the average ISE for the 9-month call-up scenarios, whether replacements are for launch failures or all satellite failures. Replacing satellites that fail prematurely on-orbit increases the long-term cost by as much as 4 percent over the cost if only launch failures are replaced. The average ICE for these scenarios declines from 0.5201 to 0.4968, even though more money is being spent, because more data are being collected.

Comparing the figures on data loss in Table III-5 with those in Table III-4 shows that calling up a replacement satellite after a premature failure does not significantly improve the performance statistics if the call-up period is 9 months. The long-term costs do not change from the costs of the same scenarios that replace satellites only after launch failures.

Table III-5

Data loss in a one-satellite system with a 28-month design life and 20-month launch interval, with and without call-up at 9- and 4-month intervals after launch or premature failures

Scenarios with	Data Loss in Months		
	Without Call-up	9-Month Call-up	4-Month Call-up
No launch or premature failures	0	0	0
Two launch failures and two premature failures	34	12	0
Three launch failures and three premature failures	58	16	0

A 4-month call-up following premature failures dramatically improves services to the users. Data gaps are totally eliminated from the scenarios as plotted in Volume 3, Appendix A, except when premature failures occur immediately before a launch failure. In this particular case (not modeled in Volume 3, Appendix A), a 4-month data gap would occur.

This 28-month design life POES management plan with a 20-month launch interval and replacements for all satellites that fail on launch or prematurely on-orbit would cost 8 percent more if there were two launch failures, or the same if there were three. The average cost would be 4 percent higher than it would be if only launch failures triggered call-ups. The number of satellites that will fail over the next 15 years is uncertain, and it is likely that costs for this system, which replaces satellites that fail prematurely in 4 months, would be the same as that of the same system with replacements only after launch failures.

8. Phase D Conclusions

1. It is a near certainty that managing the one-satellite POES system based on a 28-month design life, 20-month launch interval, and 4-month call-up after launch or premature failure would result in meeting fully the POES management goal of providing data from at least one satellite 100 percent of the time over the 15 years of this analysis.

2. In all probability, the 15-year cost of such a management plan will be the same as or perhaps slightly lower than the cost of the one-satellite baseline system, which is based on a design life of 24 months with 18-month fixed launch intervals, and with no replacements after a failure.

9. Phase E Analysis

Phase E examined two ways to reduce the long-term costs of the one-satellite system below those of the baseline system, or of the system which appears "best" in the Phase D analysis. The first approach was to determine the impacts on services and costs if the satellites could be depended upon to provide 32 months of on-orbit service. Three such scenarios were modeled with a 22-month launch interval and a 4-month call-up after all failures. The presumption was retained in these scenarios that there would be indications of imminent failure in the telemetry data 4 months before a satellite fails to provide Prime Mission Data. These three scenarios can be compared directly with the "best" scenarios in Phase D.

Implicit in this approach is the assumption that before NOAA adopts such a POES management plan, the agency would conduct in-depth analyses of all possible failure mechanisms of satellite sensors and spacecraft components. Necessary changes (e.g., provide dual electrical and electronic wiring, additional redundancy, more fuel for on-orbit maneuvering) would have to be made to ensure extended on-orbit lifetimes. In this study of the POES

management, no attempt was made to identify any required changes to the spacecraft or the sensor systems, or the time or resources needed to implement them. This study focused on the results of improvements in reliability permitted by planning on a 32-month design life.

The "ISE-v-ICE" data points for these three extended-life scenarios are shown as asterisks in Figure III-5. The average Index of Service Efficiency of scenarios with two or three launch failures increased from 0.5934 for the "best" Phase D scenario with a 28-month design life, 20-month launch interval, and replacement of all failed satellites in 4 months, to 0.6334 for the Phase E 32-month extended-life scenario. The average Index of Cost Efficiency of the extended-life scenario increased from 0.4796 to 0.5244. This one-satellite plan would be more cost effective because both system plans would result in satellite data probably being available 100 percent of the time, but the costs of the extended-life plan would be lower.

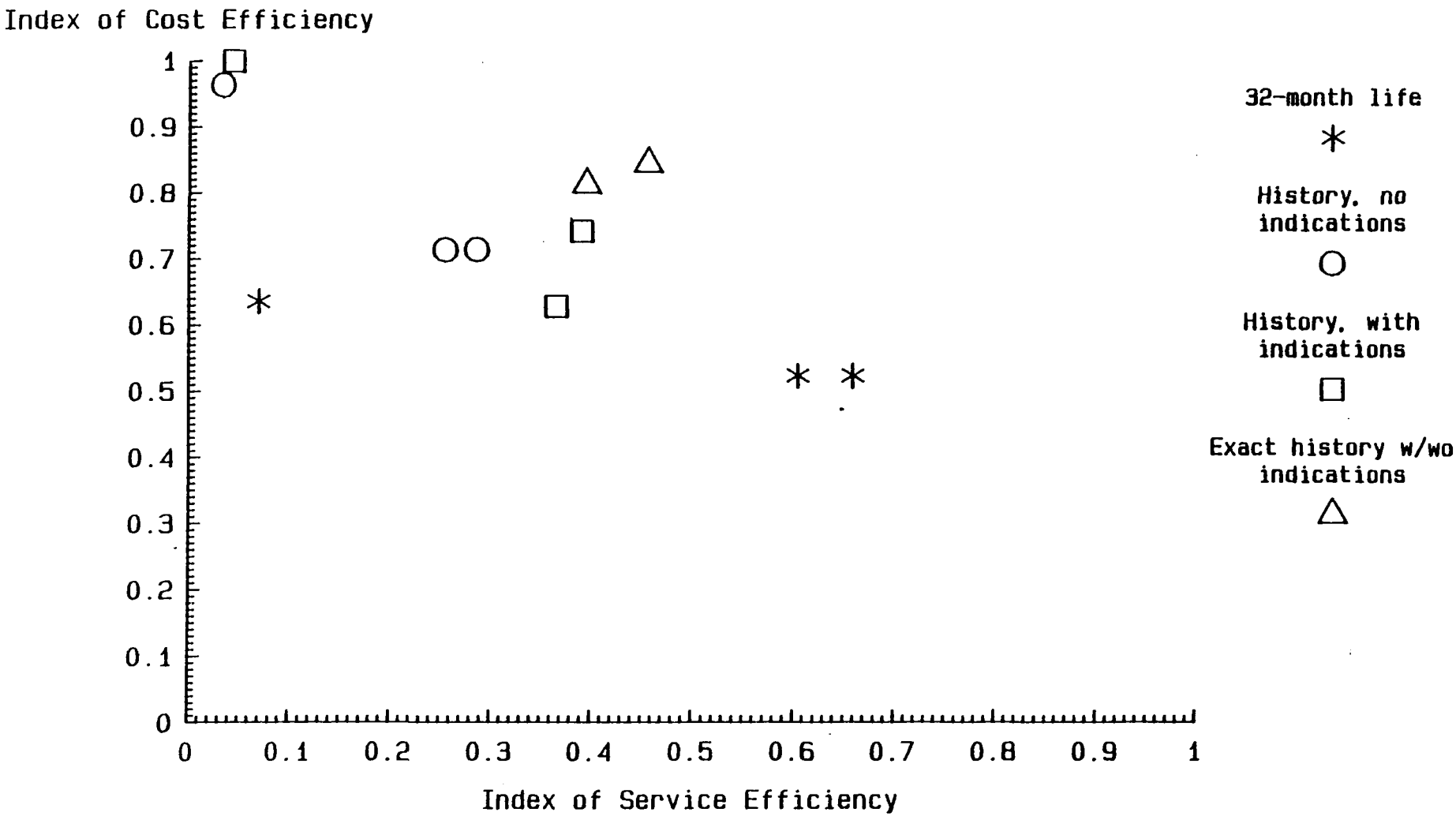
The second approach to examining extended lifetimes in the one-satellite POES system parallels similar extended-life studies of the two-satellite system discussed later. This approach examined the impacts if the one-satellite system management plan assumed that satellites launched over the next 15 years followed more or less exactly the events that have occurred in the past. Eight scenarios examine this assumption.

The first six assume on-orbit lifetimes of 29, 41, 37, and 15 months (the history of the four satellites of the current design that successfully achieved orbit), with this cycle repeated over the 15 years of analysis. Including those satellites with a 15-month life in this cycle automatically includes premature failures. In these six scenarios, it was assumed that there would be two or three launch failures over the next 15 years. Replacement launches were scheduled in 4 months when there was a failure.

The first three of these scenarios assumed no early indications of premature failure. Their "ISE-v-ICE" points are plotted as circles in Figure III-5. The next set of three scenarios, the "ISE-v-ICE" points for which are plotted as squares, are the same as the first three, except it was assumed there would be indications of on-orbit failure 4 months before the failure of satellites with lifetimes of 29, 41, or 37 months. Replacements would be launched at the end of that 4 months. Omitting the early indications of failure for satellites with a 15-month on-orbit life closely follows POES history, because NOAA 8 failed in that manner.

The last two one-satellite scenarios examined used the exact history of recent POES satellites of the current design, which

Figure III-5
Phase E - One-Satellite System
"ISE-v-ICE"



32-month or POES lifetime, w/wo indications of early failure, 4-month call-up

had lifetimes of 29, 41, 0, 37, and 15 months. The zero in this cycle represents a launch failure. Following this pattern for the one-satellite system results in assuming only one launch failure in the next 15 years, an assumption that is probably overly optimistic, given the results of these studies of probabilities. In the first of these scenarios, no early indications of premature failure are assumed. In the second, early indications are assumed for satellites with lifetimes of 29, 41, or 37 months. Figure III-5 shows the "ISE-v-ICE" points for these two scenarios as triangles.

Figure III-5 shows that services from one-satellite scenarios following the POES recent history are not as good as those from either the 32-month extended-life system or the "best" Phase D scenario with a design life of 20 months, a 20-month launch interval, and replacements launched in 4 months for all failed satellites. Costs of the POES-history scenarios are lower, with higher ICEs. Two of these scenarios have the lowest cost (and highest Index of Cost Efficiency) of all the more than 120 scenarios modeled in this analysis of the POES management. These two scenarios are based on following the POES history, with and without early indications of premature failure triggering the launch of replacement satellites. Their very low ISEs indicate that according to our analyses of probabilities, the number of assumed launch failures as these scenarios were modeled is unrealistically low.

Table III-6 lists the pertinent performance statistics for all Phase E extended-life scenarios for the one-satellite system.

The 32-month extended design life, if it could be achieved in the future, probably would meet the POES management objective of avoiding all periods in which there are no satellite data. Its cost would be about 10 percent less than that of the baseline system or the "best" of the Phase D management plans.

Costs of POES management plans for the one-satellite system based on following the POES history, with or without early indications of on-orbit failure, are substantially lower than those of the baseline or "best" systems. They are between 60 and 80 percent of the cost of the plan for a system with a 28-month design life, 22-month launch interval, and 4-month call-up.

All scenarios based on following the POES history would result in data losses between 2 and 16 percent of the time over 15 years. Data gaps of 4 months would be common, in some cases occurring as many as 5 times during the 15-year planning period. Data gaps of 8 months could occur two or three times in 15 years in some

Table III-6

Data loss in a one-satellite system with extended lifetimes and call-up 4 months after launch or premature failures

Scenarios with	Data Loss in Months	
	Without Early Indications	With Early Indications
32-month design life and 22-month launch interval	Not modeled	0
POES history with		
No launch failures	20	4
Two launch failures	28	12
Three launch failures	29	16
Exact POES history	20	8

circumstances. This level of system performance does not meet the needs of the National Weather Service, and thus does not meet the minimum POES management goals.

10. Phase E Conclusions

1. The 32-month extended-life one-satellite management plan could be adopted in the future if the required satellite systems analyses and improvements in reliability were made. Such a plan probably would meet the basic needs of the National Weather Service for data from one satellite at all times. It would cost about 10 percent less than other acceptable POES management alternatives. Estimates of savings do not consider the cost of making the improvements in on-orbit reliability needed to depend on a 32-month design life.

2. A one-satellite POES management plan based on anticipating that the POES history of the two-satellite system will be repeated for the one-satellite system does not meet the needs of the National Weather Service. Periods without satellite data of 4 to 8 months would not be unusual. Over the long term, there would be data gaps between 2 and 16 percent of the time.

B. COMPARISONS BETWEEN CASE I SCENARIOS FOR THE ONE-SATELLITE SYSTEM

Sixteen of the 53 one-satellite scenarios were selected for more detailed comparison and evaluation. The 16 scenarios are eight

pairs, in which each pair includes either two or three launch failures, combined with two premature failures. Other characteristics of design life, launch intervals, etc., are the same. The "ISE-v-ICE" points for these 16 scenarios are plotted in Figure III-6. When reviewing this figure, the following points should be noted:

1. Both the Index of Service Efficiency (ISE) and the Index of Cost Efficiency (ICE) have been normalized as discussed in Chapter III. The highest ISE for any scenario has a value of 1.000. As will be seen later, this highest value is for one of the two-satellite scenarios. Similarly, the highest ICE is 1.000. This value has been calculated for Scenario I-49, the one-satellite scenario based on following POES history, assuming early indications of premature failure. This scenario had not been plotted in Figure III-6 because its level of service to the user community is unacceptable, as reported in the Phase E conclusions.

2. The scales and limits of the axes of Figure III-6 have been changed to spread the data on the 16 selected scenarios to make analysis more convenient.

3. For the reasons listed below, the "ISE-v-ICE" data points for 37 one-satellite scenarios were not plotted:

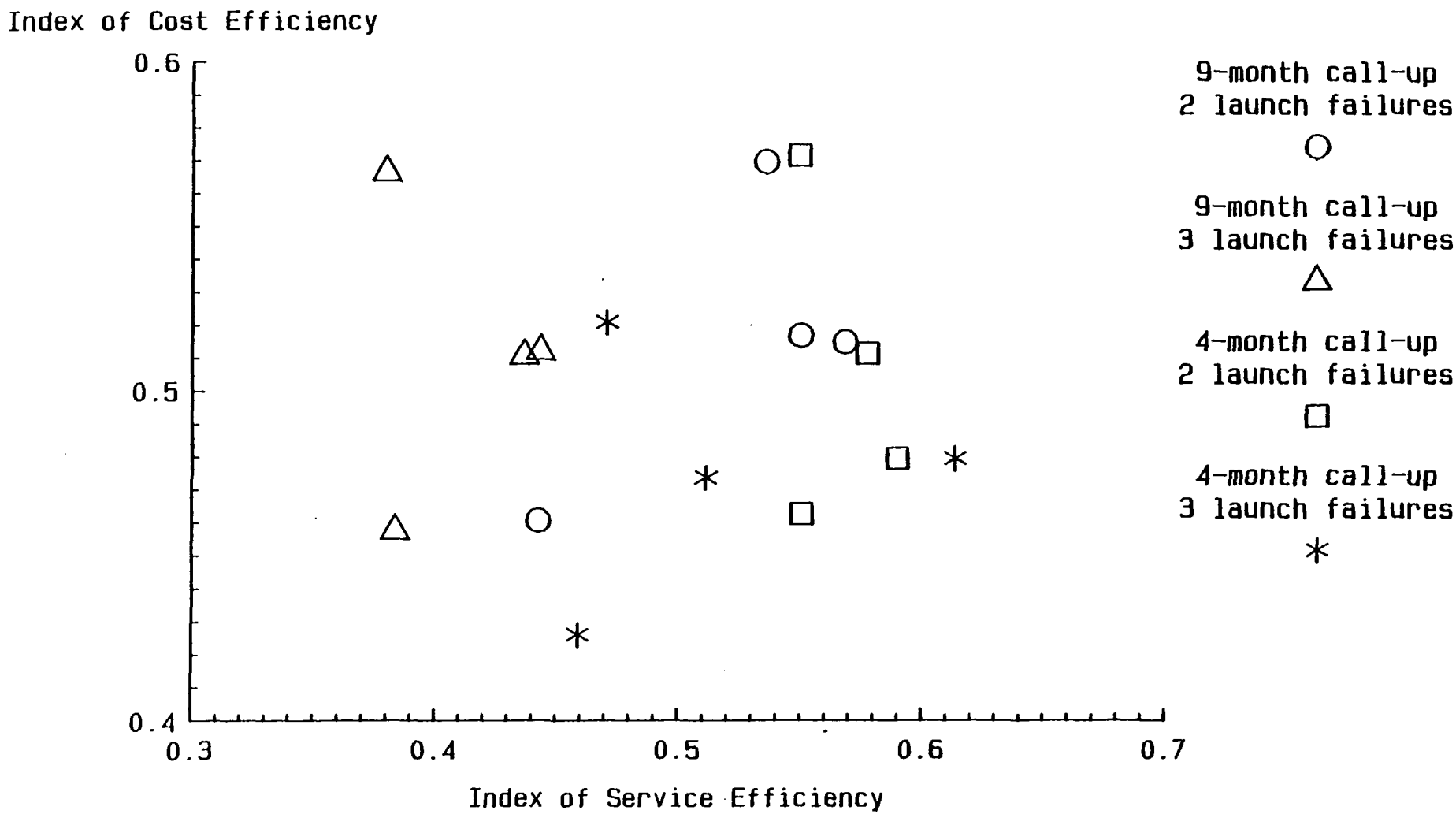
- All 15 Phase A scenarios were omitted because a one-satellite system without replacements cannot meet the minimum POES management goal.

- For each of the eight pairs of scenarios that were plotted, there is another scenario in the set of three plotted in Volume 3, Appendix A, which determined the impact on a system with given characteristics if there are no failures. The likelihood of all satellites being successful over the next 15 years is so low that these eight points were not plotted.

- Three Phase B scenarios were plotted in Volume 3, Appendix A, to establish a baseline on how a system with a 28-month design lifetime, 22-month launch interval, and no replacement launches would perform. These scenarios were not plotted for reasons listed above.

- None of the 11 Phase E extended-life one-satellite scenarios were plotted. The 32-month system cannot be adopted until the required system improvements are made. Services to the users based on following the POES history were so poor that this POES management approach is inappropriate for the one-satellite system.

Figure III-6
Selected One-Satellite Scenarios
"ISE-v-ICE"



Sixteen of the best Case I scenarios, with
9- or 4-month call-up after all failures

Some important points can be noted when examining Figure III-6 and Table III-7, which summarize some of the quantitative data about these 16 one-satellite scenarios:

1. In general, scenarios with a higher Index of Service Efficiency always have a lower Index of Cost Efficiency as a reflection of the fact that more satellites are required to provide better services, which increases costs.

Table III-7
Performance characteristics of
16 selected Case I scenarios

Pair	Symbol Used in Figure III-6	Case I Scenario Number	Phase	Characteristics: Design Life (Months)	Characteristics: Launch Interval (Months)	Call-up after: Launch Failure	Call-up after: On-orbit Failure	Percent Data Loss Over 15 Years	Cost in $C Million
4-MONTH CALL-UP FOR REPLACEMENTS									
1	Square	41	D	28	20	yes	yes	none	14.40 to
	Asterisk	42	D	28	20	yes	yes		16.82
2	Square	35	C	28	20	yes	no	4 to 7	14.40 to
	Asterisk	36	C	28	20	yes	no		16.82
3	Square	29	B	28	22	yes	no	7 to 9	12.96 to
	Asterisk	30	B	28	22	yes	no		15.40
4	Square	20	B	24	18	yes	no	7 to 9	15.95 to
	Asterisk	21	B	24	18	yes	no		18.41
9-MONTH CALL-UP FOR REPLACEMENTS									
5	Circle	38	D	28	20	yes	yes	6 to 11	14.40 to
	Triangle	39	D	28	20	yes	yes		15.61
6	Circle	32	C	28	20	yes	no	6 to 11	14.40 to
	Triangle	33	C	28	20	yes	no		15.61
7	Circle	26	B	28	22	yes	no	10 to 15	12.96 to
	Triangle	27	B	28	22	yes	no		14.18
8	Circle	17	B	24	18	yes	no	10 to 15	15.95 to
	Triangle	18	B	24	18	yes	no		17.18

2. None of the one-satellite scenarios has an ISE value higher than 0.6138, meaning that there are two-satellite systems that provide better services.

3. Scenarios with a 4-month call-up provide better services to the users than do scenarios with a 9-month call-up -- the average ISE for scenarios with a 4-month call-up is 0.5407, that of those with a 9-month call-up is 0.4674.

4. In evaluating the eight pairs of scenarios, it is almost equally likely that there will be <u>either</u> two or three launch failures in the one-satellite system during the next 15 years. Therefore, it may be useful to consider the average of the ISE and ICE for each pair. These figures are included in the summary of information about the scenarios listed below:

- <u>Pair 1</u> - This is the best of the POES one-satellite management plans from the service perspective, as it is the only plan that eliminates all data gaps. This system plan assumes a 28-month life, 20-month launch interval, and 4-month call-up after all satellite failures. It also assumes that there will be early indications of premature failure on-orbit. The average ISE for this pair is 0.6020, the average ICE is 0.4796.

- <u>Pair 2</u> - The plan for this pair of scenarios is identical with that of the first pair, except that early indications of premature failure on-orbit are not assumed. This Phase C management plan offers reasonably good services to the users, with data gaps probably no more than 4 to 7 percent of the time. The average figures for the ISE and ICE are 0.5495 and 0.4927, respectively.

- <u>Pair 3</u> - This management plan is for a system with a design life of 28 months, a 22-month launch interval, and replacements launched 4 months only after launch failures. Services to the users from this system are not quite as good as those from the second pair. Data gaps are likely to occur 9 percent of the time. The costs are about 10 percent lower than those of the first two pairs of scenarios. The average ISE is 0.5111 and the average ICE is 0.5464.

- <u>Pair 4</u> - This pair of scenarios with a 24-month design life, 18-month launch interval, and replacements launched 4 months after launch failures provides the same level of service as the preceding pair. The costs are the highest of all the one-satellite scenarios with a 4-month call-up. Average ISE and ICE values for this pair are 0.5049 and 0.4448.

- Pair 5 - This pair provides the best services from a satellite system with a 9-month call-up after all failures. They are for a 28-month system, with a 20-month launch schedule. There would be data gaps 6 to 11 percent of the time, gaps that in all probability are higher than in any of the scenarios with a 4-month call-up. The costs are about the same as for other scenarios with a 4-month call-up, which provide better services. The average ISE for this pair is 0.4942 and the average ICE is 0.5140.

- Pair 6 - This pair has the same characteristics as pair 5, except that replacements would also be launched in 9 months following premature failures on-orbit. Services from scenarios in pairs 5 and 6 are about the same, with data gaps 6 to 11 percent of the time over the next 15 years. The costs and the average ISE and ICE are also the same for both pairs.

- Pair 7 - Services from these scenarios with a 28-month design life, 22-month launch interval, and replacements launched after launch failures are not as good as those from the preceding scenarios, since data probably will not be available 10 to 15 percent of the 15-year planning period. Costs are the lowest of the one-satellite scenarios selected for analysis. The average ISE is 0.4587. The average ICE of 0.5682 reflects the system's low costs.

- Pair 8 - These two scenarios in the one-satellite system with a 24-month design life, 18-month launch interval, and replacements launched only after launch failures offer the same poor services as Pair 7 (no data 10 to 15 percent of the time) and costs that are almost as high. Its average ISE is the lowest at 0.4131 and its average ICE is 0.4591.

It can be concluded that:

1. The optimum management plan for the one-satellite POES system is for 28-month lifetimes, with satellites launched on a regular schedule of 20 months. There must be 4-month call-ups following a launch failure or a premature failure on-orbit.

2. If there are indications of an imminent failure 4 months or more before an on-orbit satellite ceases to provide images and soundings, this POES management plan will assure that data from at least one satellite will be available at all times. If these early indications are not present, there could be periods of up to 4 months in which there are no satellite data. Such periods without satellite data probably would occur between 4 and 7 percent of the time over the next 15 years. The exception to these projections of service continuity occurs if a premature failure on-orbit is followed immediately by a launch failure, in which case a data gap of up to 8 months would result.

3. The costs of this POES one-satellite management plan are from 10 percent below to 5 percent above the cost of the baseline system now considered in budget planning, depending on whether there are two or three launch failures over the next 15 years.

C. COMPARISONS WITHIN THE CASE II SCENARIOS FOR THE TWO-SATELLITE SYSTEM

1. Phase A Analysis

It is recognized that in NOAA's management of the two-satellite POES, system planning has been based on a 4-month call-up after a launch failure. After the only premature failure on-orbit of the satellites in the current series (NOAA 8), program managers called for a replacement in 4 months. Circumstances prevented achieving this goal, but this attempt demonstrated that replacement launches after premature failures were a part of the system management plan. POES system managers, aware that a certain number of launch and premature failures would occur, expect that satellite lifetimes would be 24 months and that launch intervals would be 12 months, on average. Program managers expect some satellites to last longer than 24 months, and for some to fail sooner. Likewise, managers anticipate that with 4-month call-ups, actual launch intervals will be longer or shorter than the nominal 12 months. These system management plans are not well documented in the literature currently available, and people outside the POES management group who review the baseline system planning documents and budget requests may not be aware of this situation.

Phase A of this analysis of the two-satellite system sought to understand and document the impacts on satellite data services and system costs, if the system concept shown on planning charts for the two-satellite baseline system with a 24-month design life and 12-month launch interval (see Figure I-1 in Volume I) were managed without replacement launches.

In the analysis of the one-satellite system, the basic measure of how well a system meets the needs of the users was the period in which there would be no satellite data. This performance measure was retained in the analysis of the two-satellite system.

The two-satellite system offers a possible level of service that meets the basic requirement for satellite data 100 percent of the time, but all satellite data are not of equal value to the National Weather Service. Data from only the satellite in the morning orbit in a two-satellite system (called "degraded" data in this report) are not as valuable in numerical weather forecasting as are data from a satellite in the afternoon orbit under either a one-satellite or a two-satellite system.

Another measure of performance appropriate only to the two-satellite system is the amount of time when data are available concurrently from satellites in both the morning and afternoon orbits. These "dual" data, as they are called in this analysis, are more valuable to the NWS and other users for reasons discussed earlier.

The Phase A, Case II, data summary (see Volume 3, Appendix D) lists all three of these two-satellite performance measures -- data loss, degraded data, and dual data -- to determine how well the system used in conventional budget planning would perform if no replacements were launched after failures. Twenty-four scenarios were required to evaluate all the probable combinations of events in such a two-satellite system.

There would be no satellite data up to 20 percent of the time, with gap periods as long as 12 months possible as the scenarios were plotted. Up to 26 percent of the time (individual periods up to a year), the lack of a satellite in the afternoon orbit would make data available only from the satellites in the morning orbit. If there were no satellite failures, dual data would be available all of the time, a perception that one might get from examining the conventional budget planning charts. Satellite failures are inevitable, however, and dual data services are likely to be available in the baseline system only 33 to 40 percent of the time over the 15-year planning period.

Not all possible combinations of failures, including all satellites being successful, are equally possible. Table III-8 shows those six Phase A scenarios that analyses of probabilities suggest are the most to least likely to occur. The Index of Service Efficiency versus Index of Cost Efficiency points for these six scenarios are plotted as asterisks and circles in Figure III-7.

The range of Index of Service Efficiency values for those four scenarios with the highest probability form a tight group between 0.4361 and 0.4944. This range, which is lower than most one-satellite scenarios plotted in Figure III-6, indicates that these two-satellite services to the users would not be as good as those from other POES management plans. The ICE values for these scenarios are about half those of the one-satellite systems, reflecting their higher costs.

In the evaluation of the Case I one-satellite systems, probability analyses lead to the conclusion that there would be two or three launch failures over the next 15 years. The two-satellite system requires the launch of one-third more satellites, increasing the opportunities for launch and premature failures. The probability analysis of the two-satellite system leads to the conclusion that, over the next 15 years, the two-satellite system will experience three or four launch failures and three premature failures.

The first four scenarios listed in Table III-8 all have almost identical probabilities, confirming that the two-satellite system will experience three or four launch failures. It also appears from the figures in this table that two or three premature failures are equally likely. Since the objective of this study of the POES management system is to identify the worst probable events and to find the management plan that mitigates their effects on services to the users, the two-satellite systems were analyzed as if they would suffer three premature failures in the next 15 years.

Table III-8

Probabilities of failures in a two-satellite system

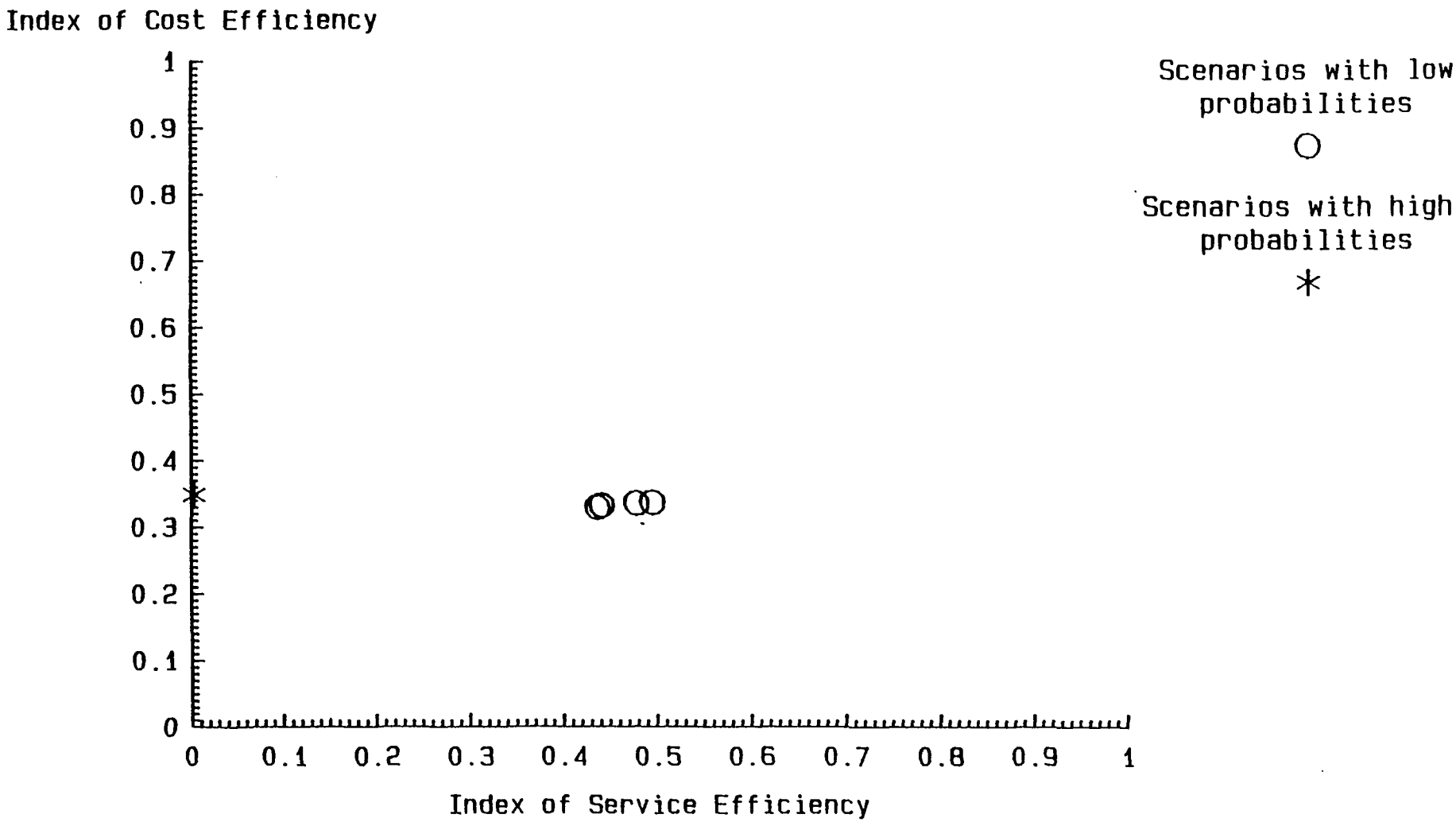
Scenario	Launch Failures	Premature Failures	Probabilities
II-16	3	3	0.058
II-20	4	3	0.057
II-19	4	2	0.056
II-15	3	2	0.052
II-3	0	1	0.002
II-1	0	0	0.0002

The average service performance statistics from these four most likely Phase A scenarios are: data gaps 8 percent of the time, only degraded data available 20 percent of the time, and dual data available 38 percent of the time.

2. Phase A Conclusions

1. The two-satellite POES system envisioned in conventional budget planning is based on a design life of 24 months with satellites launched at 12-month intervals. This system probably will experience three or four launch failures and three premature failures over the next 15 years.

Figure III-7
Phase A - Two-Satellite System
"ISE-v-ICE"



24-month design life, 12-month launch interval,
failed satellites not replaced

2. This POES management plan, if replacement satellites were not launched after launch or premature failures, would probably meet the POES management goal of continuity of data services from at least one satellite 92 percent of the time over the next 15 years. Periods of 12 months or more in which there were no data would probably occur if a launch failure immediately followed a premature failure on-orbit. Only data from satellites in the morning orbit would be available to the National Weather Service 20 percent of the time, for periods up to a year. The needs of those users who require services from a dual satellite system would probably be met 38 percent of the time.

3. Phase B Analysis

In Phase B, two changes in the specifications of the baseline two-satellite system considered in Phase A were examined. First, replacing satellites that fail to achieve orbit were included. Then the design life was increased from 24 to 28 months, with the launch intervals increased from 12 to 16 months.

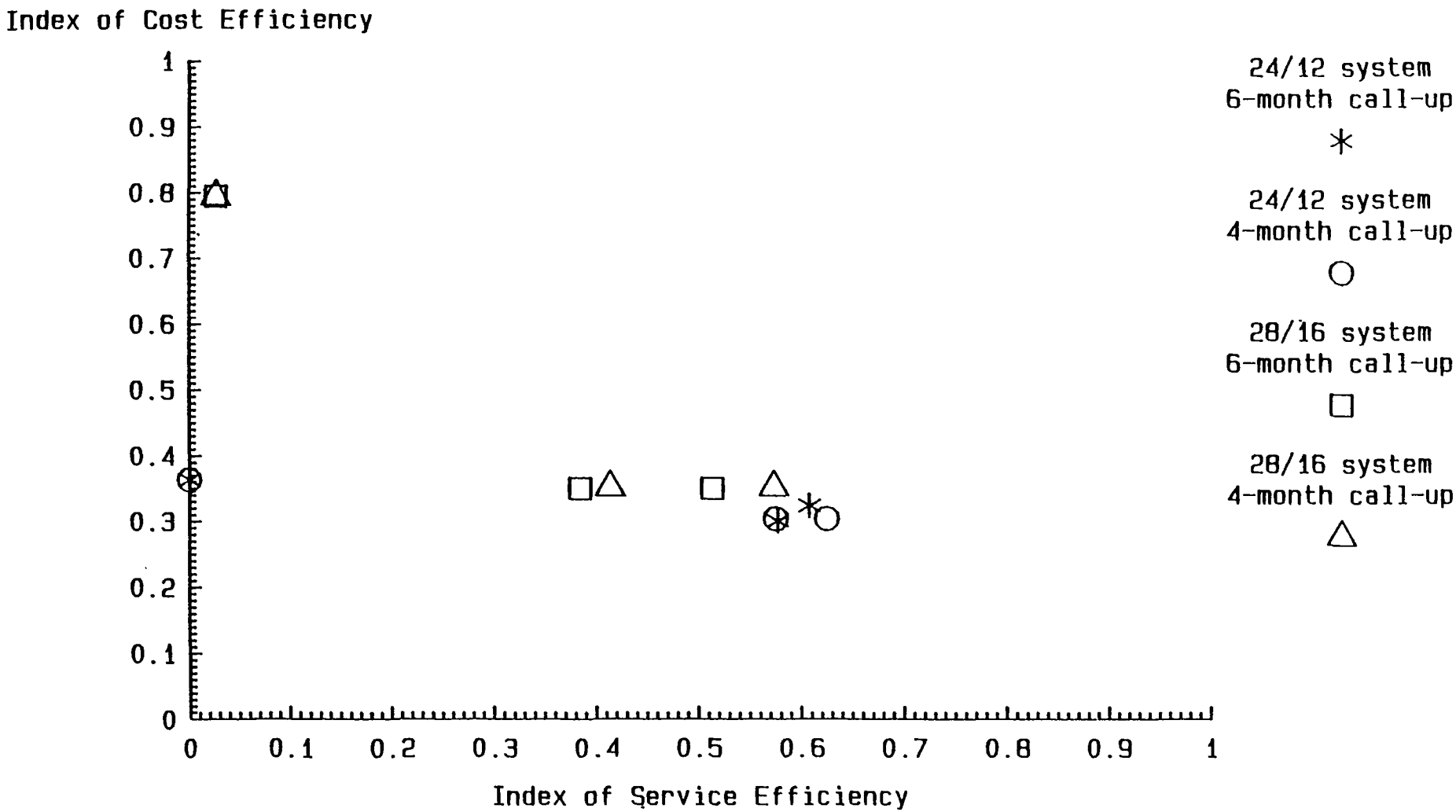
The first nine Phase B two-satellite scenarios determine the effects on services and costs if satellites in the 24-month design life system that fail on launch were replaced. The call-up interval usually used in planning the system is 4 months. To find out if a longer call-up interval would provide acceptable services to the users at a lower cost, call-ups at both 6- and 4-month intervals were modeled.

The "ISE-v-ICE" points for these nine scenarios are plotted on Figure III-8 and their service statistics are listed in Table III-9.

This figure shows that services are improved beyond those provided in the two-satellite baseline system without replacements for failed satellites. The average ISE of 0.5336 is not as high as that of the "best" one-satellite scenario (0.6020) because, as will be seen later, there are still data gaps from these two-satellite systems. The average value for the Index of Cost Efficiency is 0.3291, a very low figure compared to that of the "best" one-satellite system (0.4796).

Services with a 4-month call-up are better (ISE of 0.5468) than those with a 6-month call-up (ISE of 0.5206). Costs are higher for the 4-month call-up, resulting in lower cost efficiency (ICE of 0.3275 versus 0.3308) than for a 6-month call-up.

Figure III-8
Phase B - Two-Satellite System
"ISE-v-ICE"



24/12-month systems or 28/16-month systems,
6- or 4-month call-up after launch failures

Table III-9

Performance statistics for a two-satellite system with a 24-month design life and 12-month launch interval, with and without replacement launches at 6- or 4-month intervals after launch failures

Scenarios with	Data Services (% of the Time)		
	Loss	From AM Satellites Only	From Both AM and PM Satellites
WITH NO REPLACEMENTS LAUNCHED			
Three launch failures and three premature failures	13	7	47
Four launch failures and three premature failures	13	7	33
REPLACEMENTS LAUNCHED IN 6 MONTHS			
Three launch failures and three premature failures	7	7	57
Four launch failures and three premature failures	7	7	47
REPLACEMENTS LAUNCHED IN 4 MONTHS			
Three launch failures and three premature failures	4	7	60
Four launch failures and three premature failures	4	7	51

The pertinent data on services from these Phase B two-satellite scenarios are listed in the above table (Table III-9).

Introducing replacements in 6 months following a launch failure improves the service statistics over the next 15 years. As the scenarios were plotted, the percentage of time when there is no satellite data was reduced from 13 to 7. Dual data would be available 57 rather than 47 percent of the time if there were three launch failures, or 47 rather than 33 percent of the time if four launch failures occurred.

More significant improvements from the 6-month call-up occur in the individual periods in which services of a particular level probably would be available. Twelve-month periods with no satellite data could occur twice in the 15 years without replacements after launch failures. With a 6-month call-up, these periods probably would be 6 months long.

Depending on whether there were three or four launch failures, the longest period in which dual satellite services were available would increase from 36 to 42 months, or from 24 to 36 months at a time. The 6-month call-up does not change either the total time or the length of individual periods in which only degraded data were available. Introducing the 6-month call-up increases long-term costs by 5 percent if there were three launch failures, or by 10 percent if there were four.

Some improvements in services resulting from a 4-month call-up compared to no replacements were more dramatic. There would be no satellite data 4 rather than 13 percent of the time. The longest individual period without satellite data decreases from 12 to 4 months. The percentage of time over the next 15 years when dual satellite data were available increases from 47 to 60 or from 33 to 51, depending on whether three or four launch failures occurred. The longest individual period of dual data services increases from 36 to 48 months. There was no change in the times in which data only from satellites in the morning orbit would be available. Introducing the 4-month call-up increased the costs by 11 percent.

Comparing the performance with 4- versus 6-month call-up shows that the 4-month call-up further reduces from 7 to 4 percent the periods in which no satellite data would be available. Longest individual data gaps probably drop from 6 to 4 months. This shorter call-up period increases by about 4 percent the time during the next 15 years when dual satellite services are available. With 3 launch failures, long-term costs with the 4-month call-up are 6 percent higher than with a 6-month call-up. If there were four launch failures, costs do not change.

In examining a two-satellite system with a 28-month design life and 16-month launch interval, the first two scenarios listed in Table III-10 establish the baseline system performance statistics and costs if replacements were not launched following satellite failures. The other four scenarios show the effects on services if replacements are launched on 6- or 4-month call-up schedules.

Most service statistics resulting from adopting a system management plan for the 28-month design lifetime system with a 16-month launch interval are not as good as those from a system with a 24-month design life and 12-month launch interval.

Table III-10

Performance statistics for a two-satellite system with a 28-month design life and 16-month launch interval, with and without replacement launches 6 or 4 months after launch failures

Scenarios with	Data Services (% of the Time)		
	Loss	From AM Satellites Only	From Both AM and PM Satellites
WITH NO REPLACEMENTS LAUNCHED			
Three launch failures and three premature failures	13	20	15
Four launch failures and three premature failures	22	11	13
REPLACEMENTS LAUNCHED IN 6 MONTHS			
Three launch failures and three premature failures	7	16	34
Four launch failures and three premature failures	7	7	27
REPLACEMENTS LAUNCHED IN 4 MONTHS			
Three launch failures and three premature failures	4	16	38
Four launch failures and three premature failures	4	7	29

Periods of no satellite data are about the same for either system, given that replacements are launched on either 6-month or 4-month intervals. The 28-month system might provide data only from satellites in the morning orbit about twice as often. It is in the area of dual data services where the difference in performance is most remarkable. The 28-month system provides dual satellite services 27 to 38 percent of the time, compared to 47 to 60 percent for the 24-month lifetime system.

The "ISE-v-ICE" points for these six scenarios are plotted in Figure III-8 as squares and triangles. The average ISE value for

the four scenarios with replacements launched 4 months after a launch failure in a system with a 28-month design life and 16-month launch interval (0.4709) is lower than that of the POES two-satellite system with a 24-month design life and a 12-month launch interval (0.5964). This is an indication that services are not as good. The 28-month life system costs less, and its average ICE is higher (0.3507 versus 0.375 for the 24-month life system). However, this difference is not great compared to the Index of Cost Efficiency of the "best" of the one-satellite systems.

These conclusions about service levels are confirmed by comparing the data on the 28-month life system in Table III-10 with comparable data on the 24-month life system in Table III-9. Table III-11 compares these performance statistics directly.

However, the POES two-satellite management plan based on a 28-month design life and 16-month launch interval offers significant cost savings. This system would cost 20 to 24 percent less than the system with a 24-month design life and 12-month launch interval. In Phase C, the specifications of the 28-month system were changed to see if the performance statistics could be improved while retaining most or all of its cost advantages.

4. Phase B Conclusions

1. Instituting a 6-month call-up to replace satellites which fail to achieve orbit in the 24-month baseline system without replacements reduces by about one-half the periods in which no satellite data would be available. The longest periods without data from at least one satellite decrease from 12 to 6 months. Periods with dual satellite services increase from 33 or 47 percent of the time (depending on whether there were three of four launch failures) to 47 or 57 percent. Replacing satellites that do not achieve orbit increases long-term system costs by 5 to 10 percent depending on the number of launch failures.

2. Replacing satellites that fail on launch in 4 months reduces the 24-month baseline system's data gaps over 15 years from 13 percent to 4 percent. The longest probable periods of no satellite data would be reduced from 12 to 4 months. There is a 16 percent increase in the long-term availability of dual satellite data services. The 4-month call-up increases the cost of the baseline system without replacements by 11 percent.

3. Neither the 6- nor 4-month call-ups change the amount of time (7 percent) in which data from only satellites in the morning orbit would be available.

Table III-11
Comparison of data services from two-satellite systems
24-month design life, 12-month launch interval, or
28-month design life, 16-month launch interval
with and without replacements after launch failures

Type of Service	Percent of Time Services Available	
	24- and 12-Month System	28- and 16-Month System
Data lost		
Without replacement	13	13 to 22
6-month call-up	7	7
4-month call-up	4	4
Degraded data		
Without replacement	7	11 to 20
6-month call-up	7	7 to 16
4-month call-up	7	7*
Dual data		
Without replacement	33 to 47	13 to 15
6-month call-up	47 to 57	27 to 34
4-month call-up	51 to 60	29 to 38

* In plotting Scenario II-42 (see Volume 3, Appendix A), the 12th satellite was launched into the afternoon orbit when it followed the failure to launch the 11th satellite into the morning orbit. If the 12th satellite had been launched into the morning orbit (a choice the system managers could logically have made under the circumstances) and the orbital selections for the three remaining satellites in the scenario changed accordingly, this figure of 7 percent degraded data would have been 17 percent.

4. Using a 4- rather than 6-month call-up interval further reduces the 6-month call-up's 7 percent periods with no satellite data to 4 percent. The longest probable periods without data reduce from 6 to 4 months. Dual data services would be available more often over the next 15 years; the percentages increase from 57 to 60 if there were three launch failures and from 47 to 51 if there were four.

5. Changing the baseline system's design life to 28 months and its launch interval to 16 months reduces the cost of the

two-satellite system by 20 to 24 percent. Some performance statistics are degraded significantly. Periods when there are data only from satellites in the morning orbit increase from 7 percent in the 24-month system to 7 to 17 percent in the 28-month system, depending on the number of launch failures. Dual data services would be available about twice as often from the 24-month design life system (40 to 60 percent of the time) than from the 28-month life system (27 to 38 percent of the time).

6. Both the 24- and 28-month life systems, with 12 and 16 launch intervals, respectively, probably will meet the minimum POES management goal of providing data from at least one satellite between 93 and 96 percent of the time over the next 15 years. Individual periods of 12 months in which no satellite data are available can occur if replacements are launched 6 months after a launch failure, or up to 4 months if replacements are launched on a 4-month schedule. A premature failure followed immediately by a launch failure probably would increase by 6 to 12 months the length of these individual periods of no data.

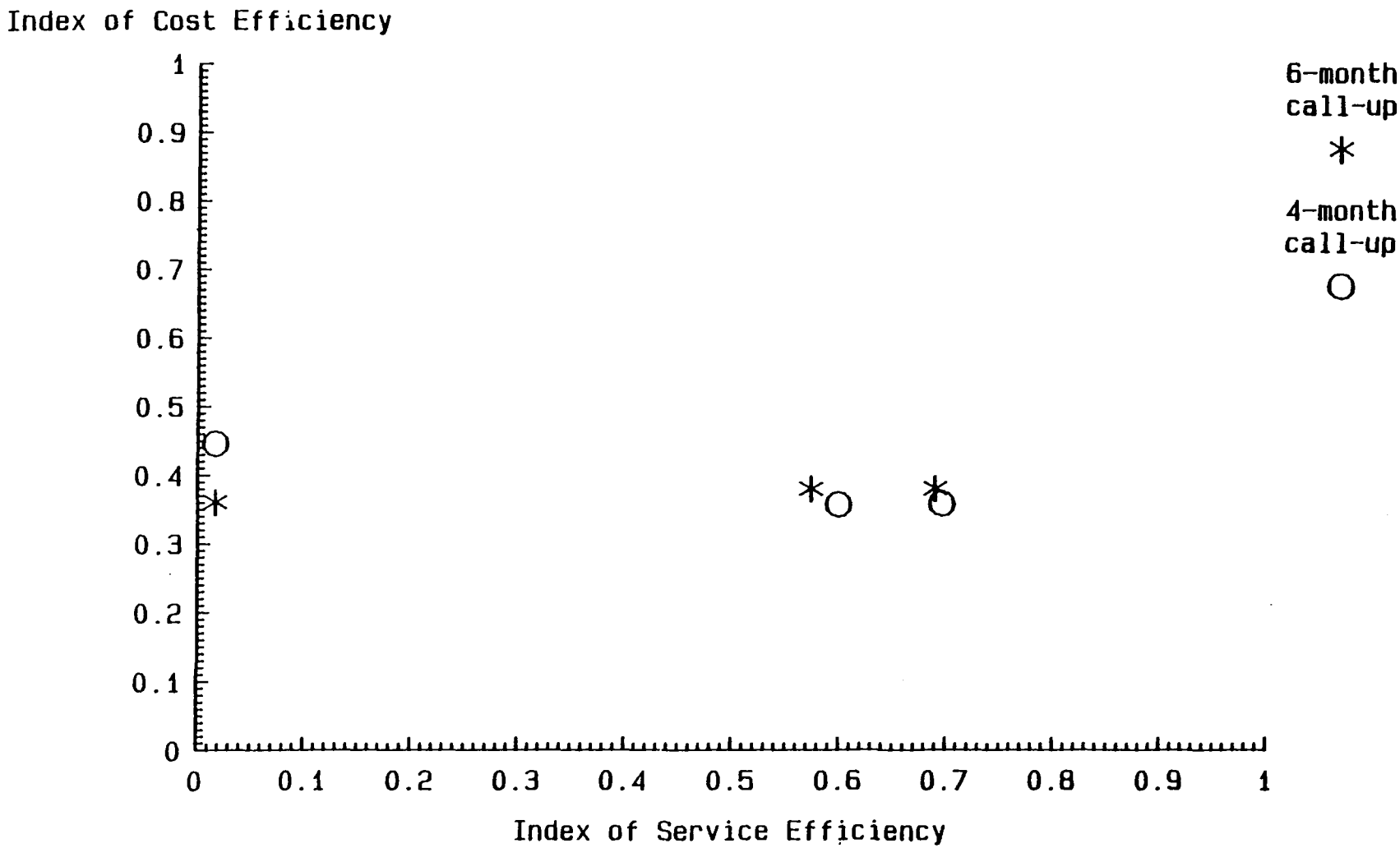
5. Phase C Analysis

The 28-month life system with 4- to 6-month replacement of satellites that fail to achieve orbit examined in Phase B had substantial cost advantages over the baseline system with a 24-month design life. Its performance was inadequate, however, The 24-month design life system had a launch interval of 12 months, or one-half the design life. In this phase, the launch interval of the 28-month system was changed so that it, too, was one-half of its lifetime, or 14 months.

The "ISE-v-ICE" points for the revised 28-month system are shown in Figure III-9. Asterisks were used to plot the points for the 6-month call-up after launch failures, circles for the scenarios with a 4-month call-up. Using the 14-month launch interval increased by 36 percent the services from the svstem, as the Index of Service Efficiency measures performance. The average ISE increased from 0.4709 to 0.6408. Improvements from the 6-month call-up were greater (41 percent) than for the 4-month call-up (31 percent). The reason for this difference is that the 4-month call-up in the same system with a 16-month launch interval had already eliminated some of the interruptions in data services that the 6-month call-up had not.

For the system with a 16-month launch interval, costs were the same whether the call-up interval was 4 or 6 months. Changing to the 14-month launch interval required the launch of one or two additional satellites over 15 years. Costs with a 6-month call-up increased 6 percent. The cost increase for a 4-month call-up

Figure III-9
Phase C - Two-Satellite System
"ISE-v-ICE"



28-month design life, 14-month launch interval,
launch failures replaced in 6 or 4 months

was 12 percent. Improved services from the 14-month launch interval results in average ISE values that are 2 to 9 percent higher than those of the 16-month launch interval scenarios, indicating that the funds spent were being used more efficiently.

Reducing the launch interval from 16 to 14 months makes substantial improvements in some types of data services. Periods without satellite data are reduced by about one-half. The length of the probable maximum period of no satellite data decreased from 6 to 2 months as the scenarios were modeled. There was no significant change in periods when data are available only from satellites in the morning orbit, because most of these periods are caused by premature failures on-orbit. The system with the 14-month launch interval provides dual data 30 to 50 percent of the time, depending on the schedule for replacing satellites that fail on launch. With the 16-month launch interval, individual periods in which dual data services are available were a maximum of 12 months. The shorter launch interval permits more overlaps with satellites on-orbit, increasing these periods to about 30 months.

Table III-12 directly compares the performance of these two versions of the 28-month system with replacements launched only after launch failures.

Table III-12

Comparison of data services from two-satellite systems
28-month design life, launch intervals of 16 or 14 Months
with replacements launched
6 or 4 months after launch failures

Type of Service	Percent of Time Services Available	
	28- and 16-month Systems	28- and 14-month Systems
Data lost		
6-month call-up	7	4
4-month call-up	4	2
Degraded data		
6-month call-up	7 to 16	7
4-month call-up	7 to 17	7
Dual data		
6-month call-up	27 to 34	40 to 52
4-month call-up	29 to 38	50 to 54

Comparing the performance statistics of the system with a 14-month launch interval in Table III-12 with those of the system with a 24-month design life and 12-month launch interval in Table III-11 shows that this 28-month system performs better in all categories except the periods of dual data services. Dual data probably would be available in the 24-month system between 47 and 60 percent of the time, depending on the number of launch failures and the replacement schedules. Comparable figures for this 28-month system are between 40 and 54 percent. Total gap periods from the 28-month system are 2 to 3 percent less, and periods when only data from satellites in the morning orbit are available are about the same.

As the scenarios are plotted, the 16-month launch interval system requires the launch of 14 satellites whether there are three or four launch failures replaced on either call-up schedule. Fifteen satellites would be launched for the 6-month call-up in the system with the 14-month launch interval. The 4-month call-up requires the launch of 16. Costs of this two-satellite system are 6 to 12 percent higher than if the launch interval were 16 months. The 28-month lifetime system with a 14-month launch interval costs 5 to 10 percent less than the baseline two-satellite system without replacements.

6. Phase C Conclusions

1. Reducing the launch interval from 16 to 14 months in the 28-month life two-satellite POES system significantly improves services. Data gap periods of 4 to 7 percent over the next 15 years are reduced by about one-half. The longest period without satellite data (6 months) probably would be reduced to 2 months. There is little impact on periods when data from only satellites in the morning orbit would be available. Periods when dual data services would be available would increase by 50 percent, from between 27 and 38 to between 40 and 54 percent of the time. Individual periods of dual data services probably would increase from 12 to 30 months.

2. The 28-month two-satellite system with a 14-month launch interval performs as well as or better than the 24-month system with a 12-month launch interval in avoiding data gaps and reducing periods when degraded data are available. Dual data services probably would be available about 6 percent more often from the 24-month system.

3. The two-satellite system with a design life of 28 months and a 14-month launch interval, with call-ups 4 months after only launch failures, costs 6 to 12 percent more than if the launch

interval is 16 months. Long-term costs are 13 to 15 percent less than the baseline 24-month system with replacements only after launch failures.

7. Phase D Analysis

A significant portion of the data gaps remaining in the services from the preceding two-satellite management plans is largely the result of satellites that fail prematurely on-orbit. In Phase D the impacts of services and costs if these premature failures were also replaced were explored. In the first three scenarios, such replacements were added in the 24-month baseline system with a 12-month launch interval and a 4-month call-up. The "ISE-v-ICE" points for these scenarios are plotted as asterisks in Figure III-10. The last six Phase D scenarios add replacements for premature failures at 6- and 4-month call-up intervals to the 28-month system with a 14-month launch schedule in Phase C. Circles are used to plot those scenarios with a 6-month call-up. Squares are used when the call-up interval is 4 months.

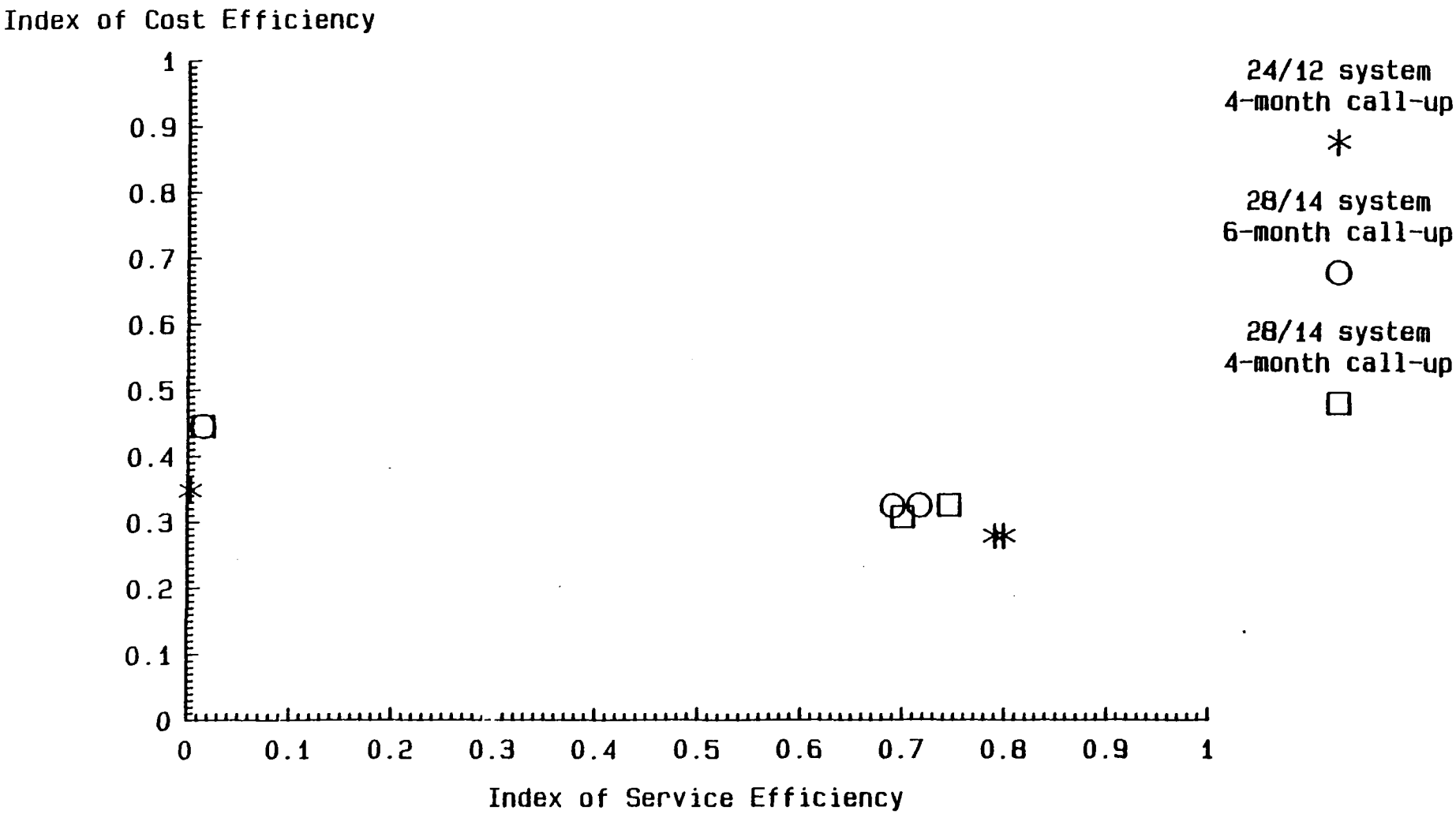
Services from a system with a design life of 24 months, 12-month launch interval, and replacements for all satellites failing before 24 months are 32 percent higher, as the Index of Service Efficiency measures performance, than from the same system with replacements only for launch failures. The average ISE is 0.7948 versus 0.6002. The average Index of Cost Efficiency for the 24-month system which replaces all satellites that fail before their design lifetimes is 0.2733, or 0.3034 if only launch failures are replaced. This reflects the cost to launch two more satellites.

Improvements in performance of the 28-month systems are more dramatic if replacements are orbited after both launch and premature failures. The average ISE when replacements are launched in 6 months increases from 0.5335 to 0.7140. The 4-month call-up shows less marked improvement: the average ISE increases from 0.6816 to 0.7231.

In the 28-month life system, 15 or 16 satellites are launched over 15 years if only launch failures are replaced, depending on whether there are three or four launch failures. Replacing premature failures as well increases to 17 or 18 the number of satellites required. Long-term costs increase 12 to 13 percent, but the funds spent produce more data. Thus the values of the Index of Cost Efficiency are relatively constant.

The tight grouping of the points on the right side of Figure III-10 indicates that all six scenarios perform equally well. Funds spent on the 28-month life system with a 14-month launch

Figure III-10
Phase D - Two-Satellite System
"ISE-v-ICE"



24/12-month system or 28/14-month system,
all failed satellites replaced in 6 or 4 months

interval are used more efficiently than those for the 24-month system, but the differences are not great.

Table III-13 summarizes the details on performance from these six Phase D two-satellite scenarios that call for replacements after launch or premature failures.

Table III-13

Performance statistics for two-satellite systems: 24-month life, 12-month launches, 4-month call-up: or 28-month life, 14-month launches, 6- or 4-month replacement of all satellites that fail before their design lifetime ends

Scenarios with	Data Services (% of the Time)		
	Loss	From AM Satellites Only	From Both AM and PM Satellites
24-MONTH LIFE, 12-MONTH LAUNCH INTERVAL, 4-MONTH CALL-UP			
Three launch failures and three premature failures	4	0	80
Four launch failures and three premature failures	4	0	77
28-MONTH LIFE, 14-MONTH LAUNCH INTERVAL, 6-MONTH CALL-UP			
Three launch failures and three premature failures	4	1	73
Four launch failures and three premature failures	4	1	70
28-MONTH LIFE, 14-MONTH LAUNCH INTERVAL, 4-MONTH CALL-UP			
Three launch failures and three premature failures	2	1	74
Four launch failures and three premature failures	2	3	70

Comparing the figures in Table III-9 for the 24-month system with a 4-month call-up after only launch failures with those in Table III-13 for the same baseline system if premature failures are

also replaced shows that periods without satellite data from both management plans will be the same, about 4 percent of the time. If only launch failures are replaced, data from only satellites in the morning orbit would be available 7 percent of the time. Replacing premature failures as the scenarios were modeled eliminates all periods of degraded data services. Periods with dual data services from these Phase D scenarios probably would increase from 60 to 80 percent if there were three launch failures, or from 51 to 57 percent if there were four. Adding satellites to replace those that fail prematurely increases the baseline costs by almost 10 percent.

The performance figures for the 28-month system with a 14-month launch interval and replacements launched only after launch failures are listed in Table III-12. Those for the same POES system when premature failures are also replaced are listed in Table III-13.

Comparison of these two sets of figures indicates that both systems would have about the same ability to meet the minimum POES management goal: there would be no satellite data 2 to 4 percent of the time over the next 15 years. Also replacing premature failures probably eliminates all periods when data from only satellites in the morning orbit would be available. If premature failures were also replaced, dual data services would be available 70 to 74 percent of the time, rather than 40 to 54 percent if only launch failures are replaced. Costs of the 28-month system with replacements for all failures are 17 to 22 percent higher. More satellites are needed to replace the premature failures. These costs are 5 to 10 percent more than the two-satellite Phase A system without replacements.

8. Phase D Conclusions

1. Replacing all satellites that fail before their expected lifetimes in the two-satellite baseline POES system with a design life of 24 months, with a 12-month launch interval and 4-month call-up, probably would meet the minimum POES management goal of data from at least one satellite 96 percent of the time during the next 15 years. Periods when data from only satellites in the morning orbit are available would be eliminated. Concurrent services from two satellites are available 60 to 80 percent of the time. System costs are about 10 percent higher than if replacements were launched only after launch failures.

2. The POES management plan for the system with a 28-month design life, 14-month launch interval, and 4-month call-up to replace all satellites that fail before their expected lifetimes probably would result in dual data services 70 to 74 percent of

the time over the next 15 years. All periods with data from only satellites in the morning orbit would be eliminated. Long-term costs are 5 to 10 percent higher than those of the baseline 24-month two-satellite system, and 17 to 22 percent higher than if only launch failures were replaced in the 28-month system. This system management plan probably would meet the minimum POES management goal of continuous data from at least one satellite up to 98 percent of the time.

9. Phase E Analysis

In Phase E the impacts on services and costs for the two-satellite system if the on-orbit lifetimes were increased were examined. All Phase E scenarios include the plan to replace all launch or premature failures in 4 months. The first three Phase E scenarios explore the effects if the POES managers could depend on a 32-month lifetime, with a 16-month launch interval and 4-month call-up. "ISE-v-ICE" points for these 32-month scenarios are plotted as asterisks in Figure III-11.

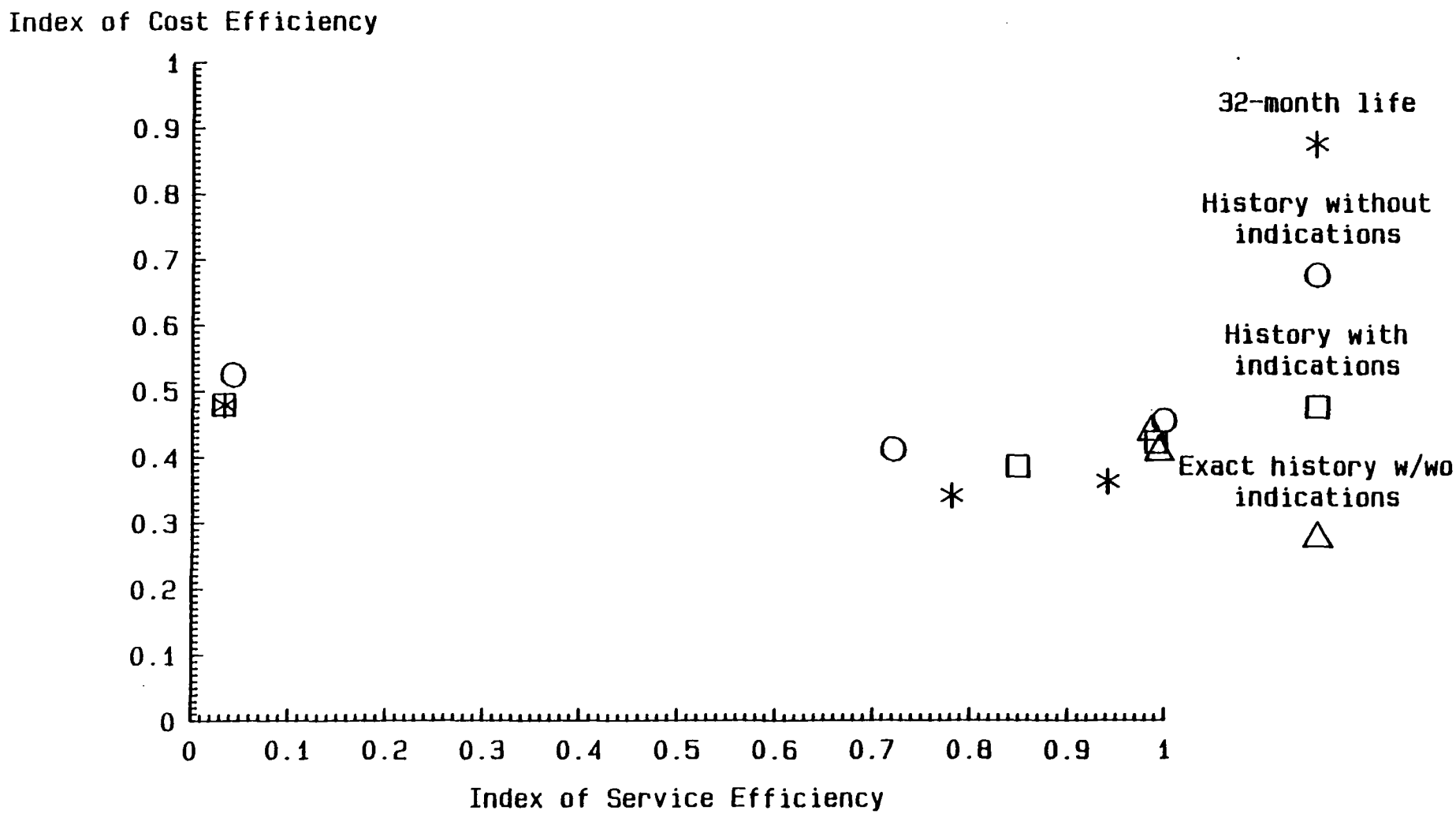
Eight scenarios were plotted that test assumptions that satellites in the future two-satellite system would follow more or less exactly the history of the satellites of the current design that have been in service since 1978.

A key feature of these POES management plans based on past history is that to take advantage of on-orbit lifetimes that extend beyond expectations, replacements would be launched only when a satellite fails or when there is convincing evidence that a failure on-orbit is imminent.

Six of these eight scenarios were modeled as if satellites would have lifetimes of 29, 41, 37, and 15 months (the history of the recent satellites that have successfully achieved orbit), with this cycle repeated over the next 15 years. Including a 15-month life for one of the satellites in this cycle automatically includes premature failures. Previous assumptions that there would be three or four launch failures were retained.

Three of these scenarios were modeled as if there would be early indications that an on-orbit failure was imminent for satellites with lifetimes of 29, 41, or 37 months. These indications would signal the need to launch a replacement in 4 months. Three scenarios were plotted as if these signals were absent and all satellites failed without advance warning. These scenarios with early indications were plotted with squares in Figure III-11, those without early indications with circles.

Figure III-11
Phase E - Two-Satellite System
"ISE-v-ICE"



32-month extended-life or POES history, w/wo early indications, 4-mo.call-up after failures

In modeling the final two scenarios in this analysis of the two-satellite POES, it was assumed that future satellites would follow exactly the history of satellites of the current design. They would have lifetimes of 29, 41, 0, 37, and 15 months, where zero represents the launch failure of NOAA B in 1980. This cycle would be repeated over the next 15 years.

Four scenarios are clustered around Index of Service Efficiency values near 1.0000 in Figure IV-11. They are:

- Scenario II-62 - the POES history with three launch failures and no early indications of on-orbit failure (ISE 1.0000).
- Scenario II-68 - the exact POES history with early indications of on-orbit failure (ISE 0.9947).
- Scenario II-65 - the POES history with three launch failures with early indications of on-orbit failure (ISE 0.9915).
- Scenario II-67 - the exact POES history without early indications of on-orbit failure (ISE 0.9869).

The minor differences in the ISE values for these scenarios not withstanding, all four scenarios provide the best satellite services to the users of all the 121 scenarios plotted in this analysis of the POES management. Their costs are 14 to 23 percent below that of the baseline 24-month two-satellite system without replacements for any satellites that fail before their expected lifetimes.

The average ISE for the 32-month extended-life system with three or four launch failures (0.8614) indicates that services from such a system would be better than from any of the two-satellite systems examined through Phase D, but not as good as the other Phase E scenarios listed above.

Details on the performance of all eight Phase E scenarios are listed in Table III-14.

The performance of the 32-month extended-life system is about the same as that of the Phase D scenario with a 28-month design life and a 14-month launch interval. Data gaps probably would occur about 2 percent of the time. One or 2 percent of the time, data would be available only from satellites in the morning orbit. Dual data services would be available about 77 percent of the time, 5 percent more than from the 28-month system. Costs of the 32-month system are about 9 percent less than those of the 28-month system. The other forms of extended life for the two-satellite POES system discussed below would cost 10 to 19 percent less than the 32-month system.

Table III-14

Performance statistics for two-satellite systems:
32-month Life, 16-month launches, or
on-orbit lifetimes following the POES history,
with or without early indications of on-orbit failure,
all failed satellites replaced in 4 months

Scenarios with	Data Services (% of the Time)		
	Loss	From AM Satellites Only	From Both AM and PM Satellites
32 MONTH LIFE, 16 MONTH LAUNCH INTERVAL, 4-MONTH CALL-UP			
Three launch failures and three premature failures	2	1	78
Four launch failures and three premature failures	2	1	76
POES HISTORY WITHOUT EARLY INDICATIONS OF ON-ORBIT FAILURE			
Three launch failures and on-orbit life in cycle	2	8	68
Four launch failures and on orbit life in cycle	2	9	67
POES HISTORY WITH EARLY INDICATIONS OF ON-ORBIT FAILURE			
Three launch failures and on-orbit life in cycle	0	2	82
Four launch failures and on-orbit life in cycle	0	2	79
EXACT POES HISTORY			
Without early indications of on-orbit failure	1	11	67
With early indications of on-orbit failure	0	4	81

It was assumed that some scenarios would follow the history of the recent POES satellites that successfully reached orbit, have three or four launch failures, and may or may not have early indications of on-orbit failure.

The performance of the six scenarios that follow these assumptions all do well in avoiding data gaps. Early indications of failure followed by the launch of replacements would eliminate all data gaps. Without these indications, there could be no satellite data perhaps 2 percent of the time, with individual gap periods of 2 months occurring once or twice over the next 15 years. It is unlikely that satellite lifetimes would follow the models exactly as the scenarios were plotted. Chances are that a system plan based on following past history and launching satellites only after failures would eliminate all data gaps. The 4-month call-up to replace satellites that fail on-orbit or at launch is essential in meeting these performance levels.

If the future satellites in the two-satellite system were to follow exactly the history of the recent POES, with the launch failures included in the cycle, all data gaps probably would be eliminated over the next 15 years. A data gap of 1 month could occur as the scenarios were plotted if there were no early indications of on-orbit failure. Without early indications, there would be 20 months over the next 15 years when services would be available only from satellites in the morning orbit. If there were early indications, this figure would be reduced by 60 percent. Dual data services from satellites that are fully operational probably would be available 67 to 82 percent of the time.

10. Phase E Conclusions

1. The two-satellite POES can be managed to take advantage of long on-orbit lifetimes when they occur, while protecting satellite services to the users when on-orbit lifetimes are short, by launching replacements in 4 months following launch failures or when satellites on-orbit fail. Services to the users would be better if there were early indications of on-orbit failures. The lack of such early indications would not preclude high quality services to the users. The two-satellite system managed in this fashion, with or without early indications of on-orbit failure, probably would meet the minimum POES management goal of continuous data from at least one satellite 98 to 99 percent of the time. Images, soundings, and other services from satellites in both the afternoon and morning orbits probably would be available 70 to 80 percent of the time over the next 15 years.

2. The only one-satellite system that appears to meet the minimum POES management goal requires the launch of 12 satellites during the next 15 years. If the future two-satellite system

follows the recent history of the POES, 12 or 13 satellites will be required. This represents a maximum of an 8 percent increase in the long-term costs.

D. COMPARISONS BETWEEN CASE II SCENARIOS FOR THE TWO-SATELLITE SYSTEM

Fourteen of the two-satellite scenarios were chosen for further comparison and analysis.

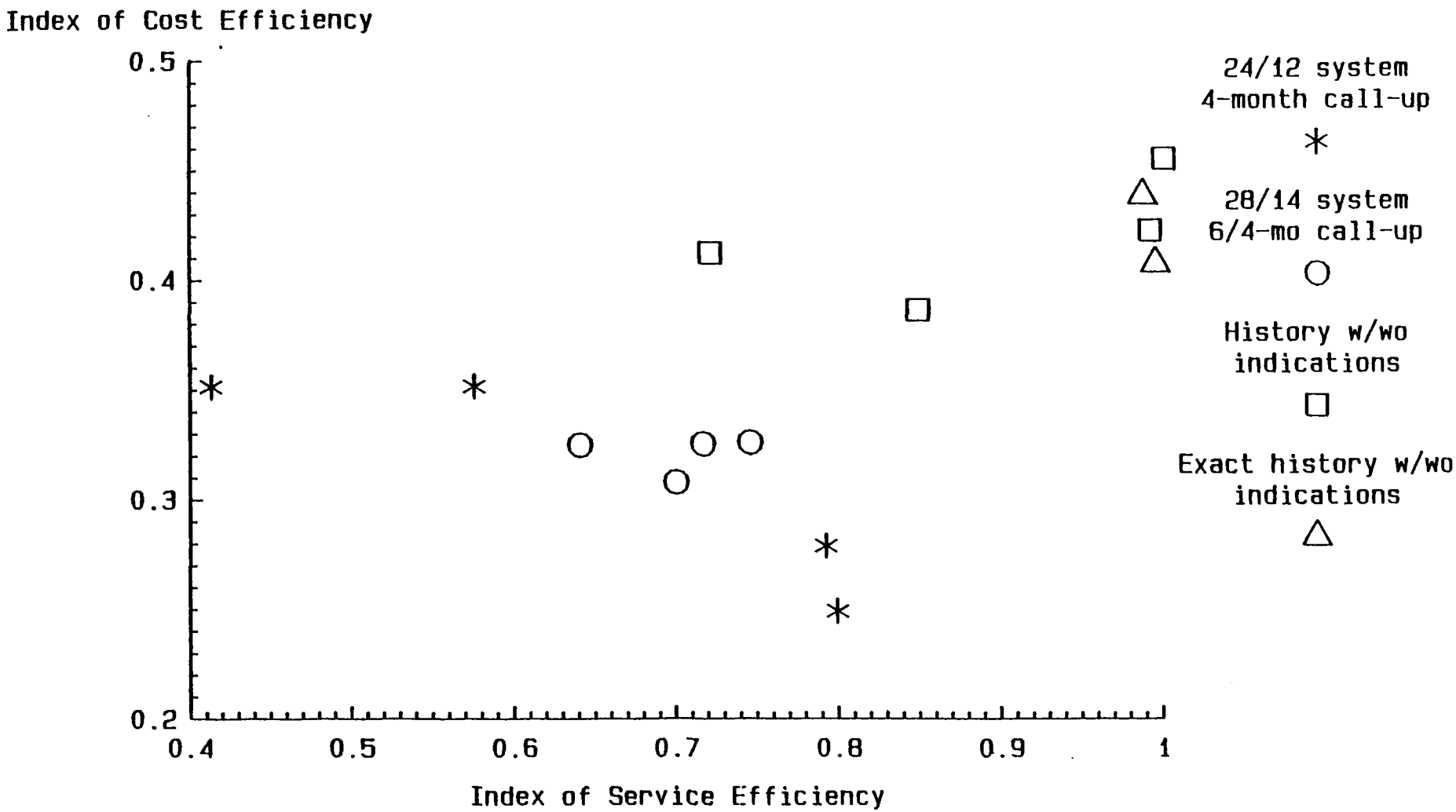
To examine the effects of replacements being launched for all satellites that fail before their design lifetimes rather than only after launch failures, four scenarios for the baseline 24-month design life system were included. Two scenarios have three assumed launch failures, two have four. One pair has replacements only for launch failures, the other replaces all satellites that fail before their design lifetimes. All these scenarios have a 12-month launch interval and a 4-month call-up schedule. "ISE-v-ICE" points for these scenarios are plotted as asterisks in Figure III-12.

Four scenarios were chosen for a two-satellite system with a design life of 28 months to make the same tests about replacing only launch failures rather than all satellites that fail before 28 months. There was a 14-month launch interval, and replacements were launched in 4 months. Data points for these scenarios are plotted as circles in Figure III-12.

Four extended-life scenarios based on future satellites following the history of the recent POES system were chosen. They have three or four launch failures over the next 15 years. All satellites that fail on launch or on-orbit were replaced in 4 months. Early indications that on-orbit failure is imminent may or may not have been present in these scenarios. "ISE-v-ICE" points for these scenarios that have no fixed launch schedule are plotted as squares in Figure III-12.

Two extended-life scenarios based on future POES satellites following exactly the history of the recent POES, including launch failures and on-orbit lifetimes as they occur in the cycle, were selected. One scenario was modeled as if early indications of on-orbit failure were present, the other as if they were not. Replacements would be launched in 4 months. These scenarios are plotted as triangles in Figure III-12.

Figure III-12
Selected Two-Satellite Scenarios
"ISE-v-ICE"



Sixteen of the best two-satellite scenarios

Thirty-five of the Case II scenarios were eliminated from this comparison. The scenarios were modeled only to establish the baseline for services and costs of satellites that fail prematurely or on launch and are not replaced in a two-satellite system of given characteristics. There were 24 of these scenarios in Phase A, six in Phase B, two in Phase C, and three in Phase D. Since the performance of all these scenarios fell far short of meeting the minimum POES management goal of providing data from at least one satellite at all times, these 35 scenarios were eliminated from further consideration.

Three of the extended-life two-satellite scenarios were for a system that cannot be implemented until improvements are made in on-orbit reliability. As discussed in the Phase E analysis, the services from this 32-month system were not as good as those from other extended-life management plans in any event, and its costs were higher. These scenarios, therefore, were not plotted in Figure III-12.

Examination of Figure III-12 reveals that four of the scenarios have Index of Service Efficiency values near or at the maximum possible in this analysis of the POES management system. The average Index of Cost Efficiency value for these four scenarios is 0.4307, higher than any other two-satellite management plan examined. Their average cost is relatively low, compared to other two-satellite systems. They produce the largest amount on data services, resulting in the most efficient use of expended funds of all the two-satellite systems.

Two of these scenarios, plotted with triangles, are for extended-life management plans that follow exactly the recent history of the POES system. The other two scenarios, plotted with squares, are also extended-life management plans. They are based on the recent POES history and three assumed launch failures. The other two scenarios plotted with squares are plotted near the center of the chart. They have four assumed launch failures. Basic assumptions in all six of these extended-life scenarios were modeled with and without early indications of on-orbit failure.

The conclusions drawn from these six extended-life POES management scenarios are:

- Performance, as it is measured by the Index of Service Efficiency, is relatively insensitive to assumptions about early indications that an on-orbit failure is imminent.

- Performance measures are more sensitive to assumptions about the number of launch failures. The average ISE if there were three launch failures is 0.9958, or 0.7954 if there were four, for a difference of 25 percent.

- Examination of the performance data about these extended-life two-satellite scenarios in Table III-15 shows that differences in services to the users are not as great as these ISE values would seem to indicate. None of the four scenarios with ISE values near 1.0000 would produce data gaps more than 2 percent of the time over the next 15 years. There would be no data lost if early indications of on-orbit failure were present. Degraded data from scenarios with either three or four assumed launch failures decrease from about 9 to 2 percent if there are early indications. There is no statistically significant difference in the percentage of the time that dual data services would be available.

The four scenarios shown as circles near the center of the chart are for a two-satellite system with a 28-month design life. The launch interval is 14 months. Replacements are launched 4 months after launch failures or premature failures on-orbit. These scenarios have a poorer performance than those with an extended life. The average ISE value is 0.7010. They cost more, resulting in an average ICE value of 0.3206.

Scenarios in the 24-month life baseline system with a 12-month launch interval are plotted as asterisks. Replacements are launched in 4 months. Two of these points located near the center of Figure III-12 show the service if both launch and premature failures are replaced. Their service is good (average ISE of 0.7957), but their high costs reduce the ICE to the lowest of all these two-satellite scenarios (average ICE of 0.2639). The two asterisks near the left side of the chart are for the same two-satellite system if only launch failures are replaced. Replacing premature failures increases the average ISE from 0.4943 to 0.7447, indicating a substantial improvement in the services to the users. As a consequence of launching more satellites, the average ICE decreases from 0.3514 to 0.2639.

It can be concluded that:

1. The optimum management plan for the two-satellite POES system is one designed to take advantage of long on-orbit lifetimes when they occur, while protecting services to the users when on-orbit lifetimes are short. Satellites are launched on a 4-month call-up schedule only upon the failure of a satellite on-orbit, or after any launch failure.

2. Extended-life systems managed in this way probably will meet the minimum POES management goal of providing data from at least one satellite at all times. In addition, data from only satellites in the morning orbit will be available no more than 2 to 11 percent of the time over the next 15 years, depending on the number of launch failures that occur and the presence or absence of early indications of impending on-orbit failure.

3. The cost of this two-satellite extended-life management plan is from 68 to 90 percent of that of the baseline two-satellite system with a 24-month life without replacement launches.

4. The two-satellite management plan with a 28-month design life, 14-month launch interval and 4-month call-up meets the minimum POES management goal 98 percent of the time. Services from only satellites in the morning orbit probably would be available up to 3 percent of the time, and from satellites in both the morning and afternoon orbits about 70 percent of the time over the next 15 years. Costs of this system would be 5 to 11 percent more than the baseline two-satellite system.

5. Adding replacements for satellites that fail on launch or prematurely on-orbit in the planning for the baseline 24-month system makes available satellite data services 96 percent of the time. It eliminates all periods when only degraded data are available. Dual satellite data services probably would be available about 80 percent of the time over the next 15 years. Costs are 21 percent higher than the baseline system without replacements.

6. If only launch failures are replaced in 4 months in the 24-month baseline system, there would be no satellite data 4 percent of the time. Only degraded data probably would be available 7 percent of the planning period. Between 50 and 60 percent of the time, dual satellite data services would be available. Costs are 11 percent more than those of the baseline system without replacements, and 9 percent less than if the premature failures were also replaced.

E. COMPARISONS BETWEEN ONE-SATELLITE AND TWO-SATELLITE POES MANAGEMENT PLANS

In this section of the analysis of the POES management, three topics are examined:

- Call-up schedules - impacts on services and costs if call-up schedules when replacing satellites that fail were longer or shorter.

- Extending on-orbit lifetimes - improving satellite reliability to permit POES system managers to plan on on-orbit lifetimes being as long as 32 months.

- Optimum system management plans - selection of one-satellite and two-satellite management plans that will provide the best services to the users at the lowest long-term cost.

1. Call-up Schedules - Analysis

Table III-15 shows system performance with longer or shorter call-up schedules. As the figures in this table show, in either the one-satellite or the two-satellite systems, the longer call-up schedules increase by about 50 percent periods without satellite data. This translates into increasing by about 8 months the periods when no satellite data would be available, on average as the scenarios were plotted. In some one-satellite scenarios, the 4-month call-up eliminated all data gaps, but the 9-month call-up left data voids of 10 to 20 months.

Table III-15

Performance statistics if call-up schedules were longer or shorter in one-satellite and two-satellite systems

Scenarios with	Data Services (% of the Time)		
	Loss	From AM Satellites Only	From Both AM and PM Satellites
24-MONTH LIFE, 12- OR 18-MONTH LAUNCH INTERVALS			
9-month call-up one-satellite system	10/15	N/A	N/A
6-month call-up two satellite system	7	7	47 to 57
4-month call-up one-satellite system	7/9	N/A	
two-satellite system	4	7	51 to 60
28-MONTH LIFE, 14- OR 20-MONTH LAUNCH INTERVAL			
9-month call-up one-satellite system	6/11	N/A	N/A
6-month call-up two-satellite system	4	1 to 9	40 to 52
4-month call-up one-satellite system	4/7	N/A	N/A
two-satellite system	2	7 to 10	50 to 54
three premature failures	2	1	74

In some scenarios, the shorter call-up schedule required that an additional satellite be launched during the 15 years. This additional satellite would increase the cost of the one-satellite

systems by about 8 percent when this situation occurs. The two-satellite systems require more satellites to begin with, so adding one more increases long-term costs by 5 to 6 percent.

2. Call-up Schedules - Conclusions

1. The 4-month schedule for call-ups (versus a 9-month schedule for one-satellite systems or a 6-month schedule for two-satellite systems) reduces periods when there would be no satellite data. On average, the number of months without data would be reduced by eight. In some one-satellite scenarios, the 4-month call-up eliminates all data gaps, but the 9-month call-up leaves data voids 6 to 11 percent of the time. In the two-satellite system, periods when dual data services are available increase by 3 to 12 percent.

2. The shorter call-up schedule increases the long-term costs by 8 percent in the one-satellite system, and by 5 to 6 percent in the two-satellite system, because an additional satellite is needed in some, but not all, scenarios.

3. Extending On-Orbit Lifetimes - Analysis

The only one-satellite management plan that meets minimum POES management goals has an assumed design life of 28 months. If this lifetime were increased to 32 months, the system probably would still meet this goal. Costs would decrease by 8 percent, translating into savings of about $100 million over the 15-year planning period.

The 32-month design lifetime plan in the two-satellite system with a regular launch schedule of 16 months did not appear to be as cost effective as the extended-life scenarios based on replacing on-orbit satellites only when there were failures. The cost reductions in the two-satellite system if the satellites lasted 4 months longer than they do now cannot be measured in the same way. Examination of these extended-life scenarios in Volume 3, Appendix A, reveals that if satellites in those scenarios based on the future systems following the recent POES history were to last 4 months longer than this history would indicate, one or perhaps two satellites would no longer be needed. There would be a cost avoidance of 6 to 8 percent.

4. Extending On-Orbit Lifetimes - Conclusions

1. If on-orbit reliability were improved enough to permit POES program managers to depend in their planning on extending

on-orbit lifetimes by 4 months, data services probably would not be degraded in either system configuration. Costs to build and launch satellites over the next 15 years might be reduced by up to $100 million. In this analysis, no attempt was made to determine the cost of making improvements in sensor systems or spacecraft components needed to assure that satellites would consistently last 4 months longer.

5. Optimum System Management Plans - Analysis

There are several ways to measure and compare the relative performance and costs of the different approaches in which the POES can be managed in the future. The Index of Service Efficiency versus the Index of Cost Efficiency ("ISE-v-ICE") was used in previous discussions, as were individual performance statistics and costs measured as a percentage of the cost of the baseline systems for the one-satellite and two-satellite configurations.

Figures III-13 and III-14, prepared for the one-satellite and two-satellite systems, respectively, use the simplest of performance measures. The percentage of time over the next 15 years when data from at least one satellite will be available is plotted against the cost of a given scenario as a percentage of the cost of a baseline system management plan. For these two charts, the base cost chosen was that of the one-satellite system, as this system has been proposed in recent budget submissions to the Congress, without replacements for satellites that fail.

Figure III-13 shows that two pairs of scenarios probably would meet the minimum POES management goal 100 percent of the time, as these scenarios were plotted in Volume 3, Appendix A. These scenarios are:

- Scenarios I-41 and I-42 for the one-satellite system with a 28-month design life, 20-month launch interval; two or three assumed launch failures and two assumed premature failures on-orbit over the next 15 years; and with these failed satellites replaced on a 4-month call-up schedule.

- Scenarios I-44 and I-45 for a system with a 32-month extended lifetime, a 16-month launch interval, and failures and replacements as specified above for the 28-month lifetime system plan.

Costs for these two pairs of scenarios (a pair is needed to model scenarios with either two or three launch failures in a one-satellite system) are from 3 percent below to 5 percent above the cost of the base system as it has been defined.

Three other pairs of scenarios are for one-satellite POES management plans with design lifetimes of 24 or 28 months and launch

Figure III-13
Comparison of One-Satellite Scenarios
Cost Versus Meeting the POES Management Goal

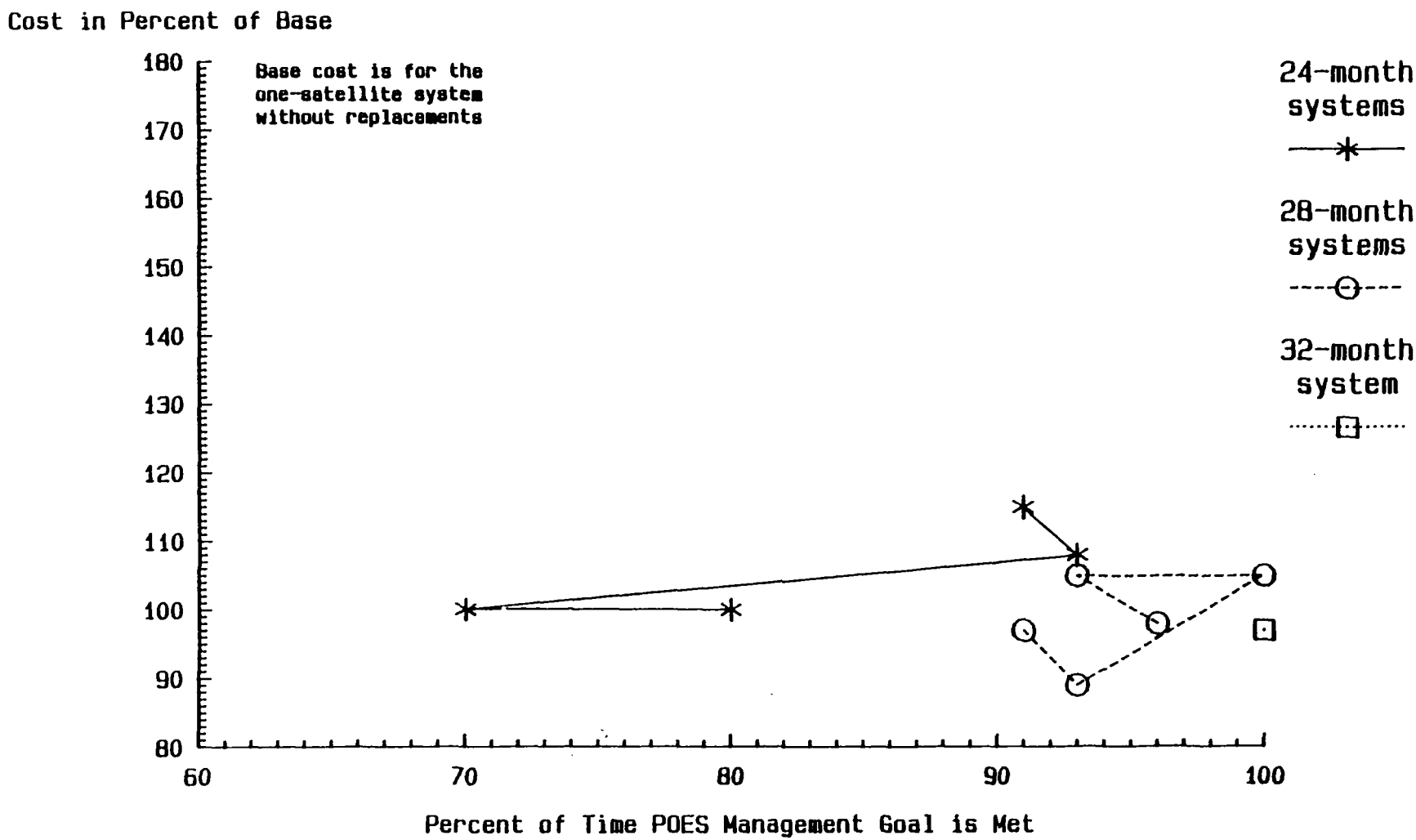
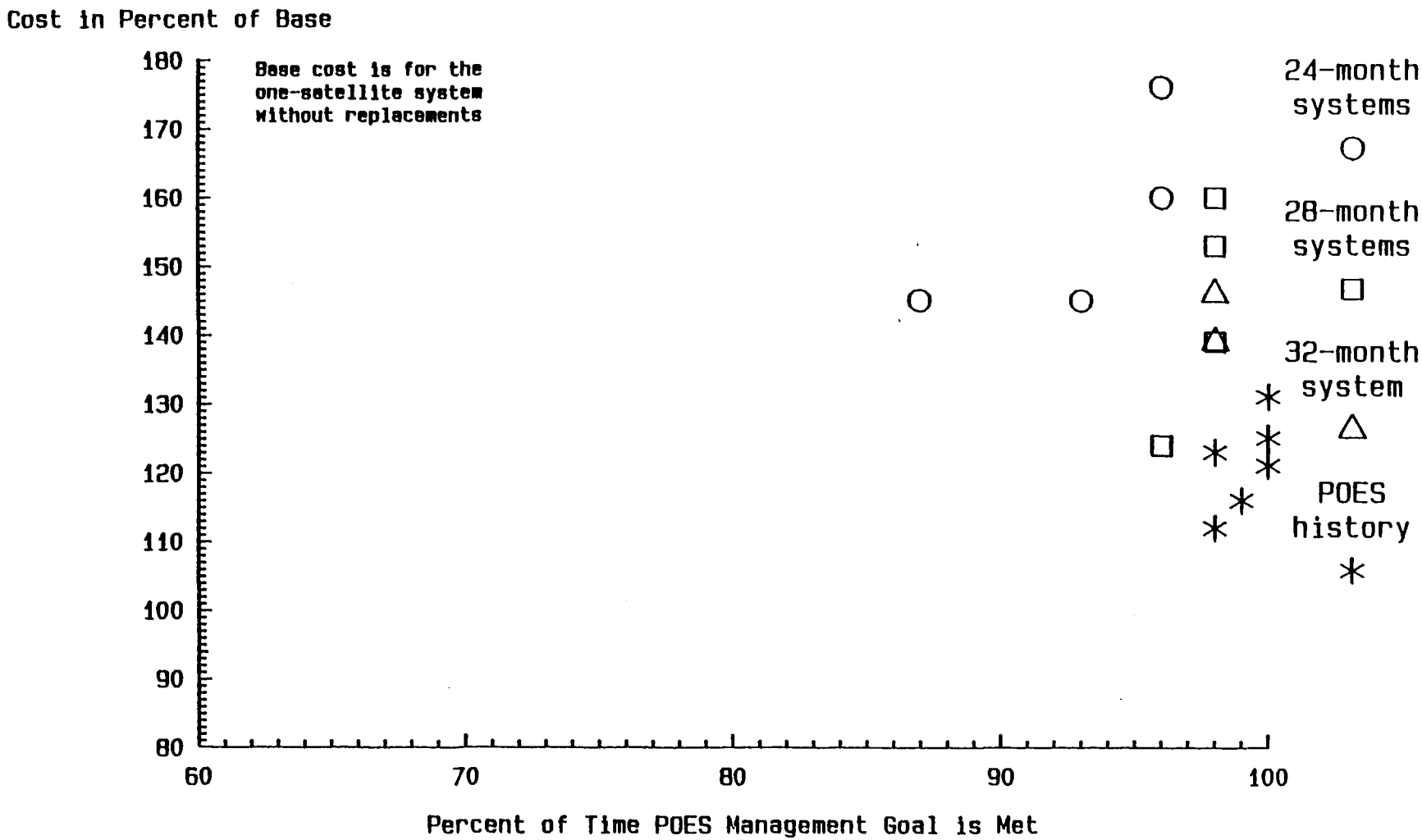


Figure III-14
Comparison of Two-Satellite Scenarios
Cost Versus Meeting the POES Management Goal



intervals of 18, 20, and 22 months. These scenarios would result in data being available 90 percent or more of the time. Their average costs are about the same as those of the baseline one-satellite system.

Figure III-14 shows that almost all of these two-satellite management plans would provide data from at least one satellite more than 90 percent of the time. Twelve of the scenarios probably would meet the minimum POES management goal 98 percent of the time, or more, as the scenarios were plotted in Volume 3, Appendix A, and are likely to meet this goal 100 percent of the time during the next 15 years. The average cost for these 12 pairs of scenarios is 34 percent more than the base cost for the one-satellite system.

The two scenarios with the lowest costs are extended-life plans based on following recent POES history. Their costs are 12 to 30 percent higher than the base.

Using the percentage of time that satellite data would be available is a restricted measure of performance in determining the optimum management plan for the future POES system. In Figures III-15 and III-16 the same cost measure used in the last two charts was retained, but the Index of Service Efficiency was substituted as the other measurement. Here the data points are more disbursed, an indication that there are substantial differences in the quality of data services provided to the users. The ISE values for the one-satellite system range from 0.1515 to 0.6610, those for the two-satellite system from 0.4361 to 1.0000, with the averages being 0.5057 and 0.7627, respectively. This spread of ISE values indicates that, while there is some overlap, the quality of services is better from the two-satellite systems.

While these data are illuminating, the choice of the optimum management plan remains obscure as the data have been compiled and presented thus far.

The future one-satellite or two-satellite POES system may not behave precisely as the launch failures and on-orbit lifetimes have been modeled. The analysis of probabilities, reported in Volume 3, Appendix C, makes it probable that in the long term, satellites will behave in the way they have been modeled. As with any short-term predictions based on probability statistics, chances are good that individual sequences of events in any scenario may well differ from those plotted.

Projections of detailed service levels from the various management plans must, therefore, be considered approximations, rather than finite predictions of exactly what will happen at all times in the next 15 years. With this fact in mind, all the scenarios

Figure III-15
Comparison of One-Satellite Scenarios
Cost Versus Index of Service Efficiency

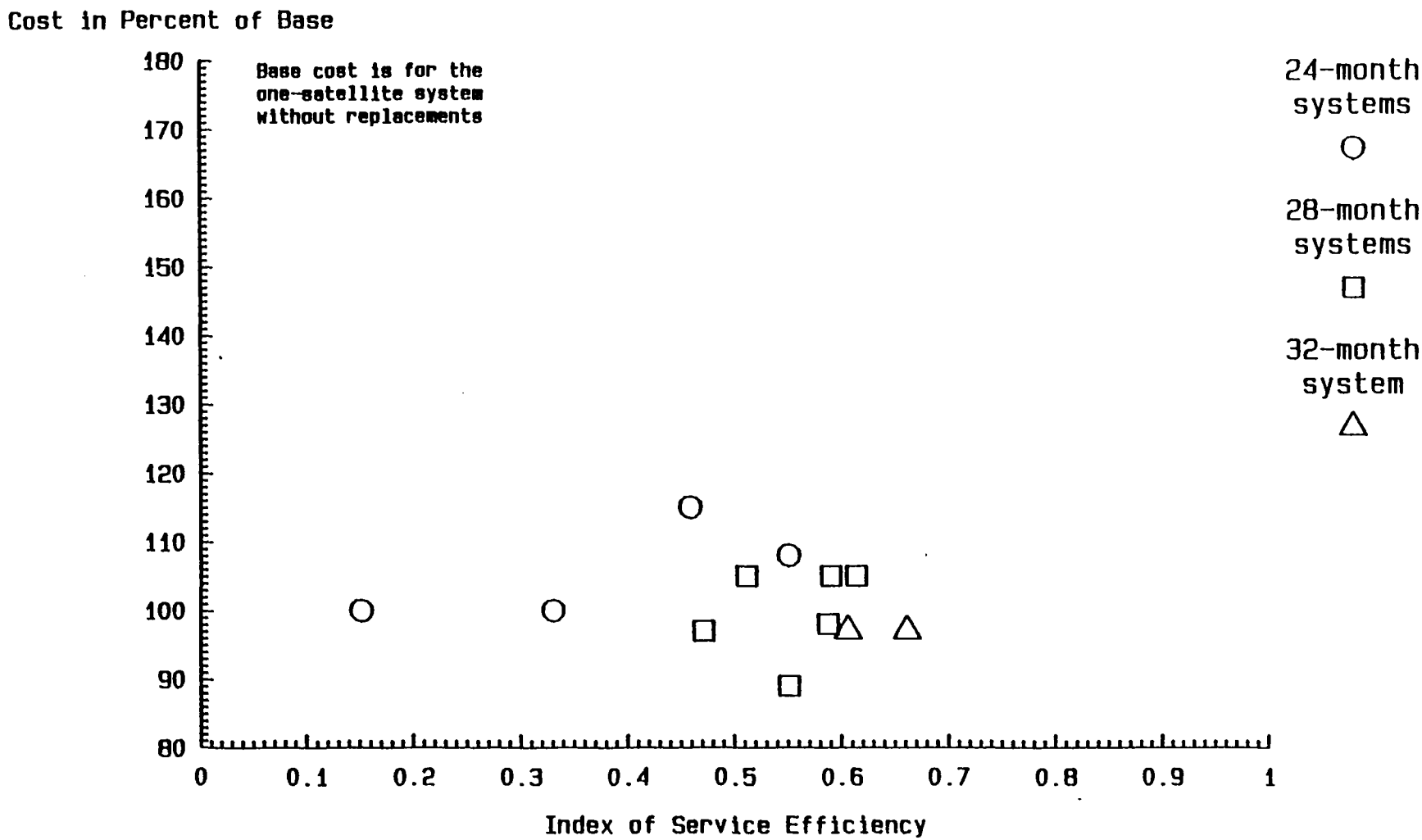
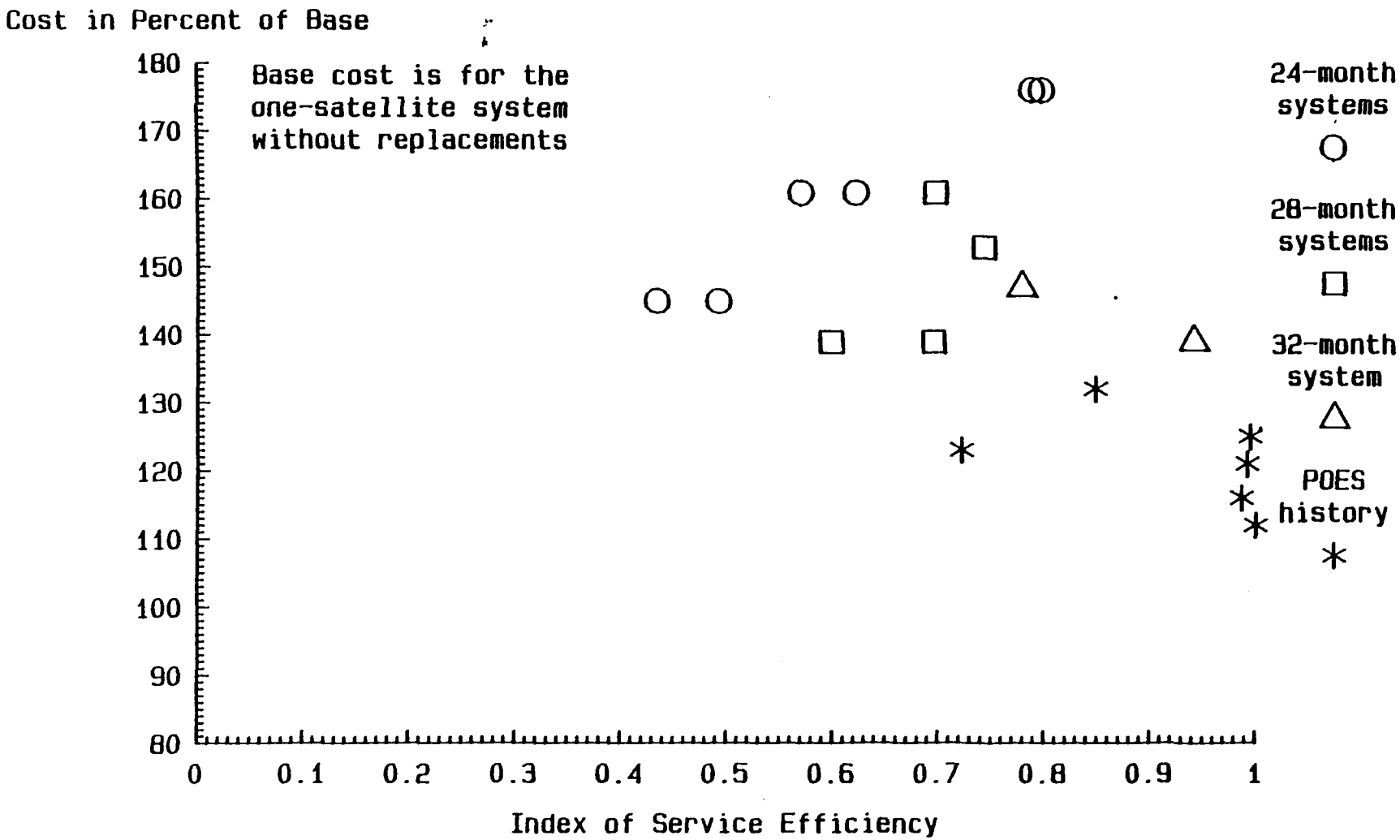


Figure III-16
Comparison of Two-Satellite Scenarios
Cost Versus Index of Service Efficiency



that were plotted on the last four charts were reexamined. It was decided that those scenarios that are modeled as if they would provide data from one satellite at least 95 percent of the time are probably about equal in their ability to meet the minimum POES management goal all the time.

There are six scenarios in the one-satellite system that met this criterion. Two were for the 32-month extended-life management plan that cannot be implemented until needed changes are made in the sensor systems and the spacecraft. These changes may take several years to accomplish. These 32-month life systems were eliminated from further consideration at this point. Fourteen two-satellite systems were expected to meet this 95 percent criterion.

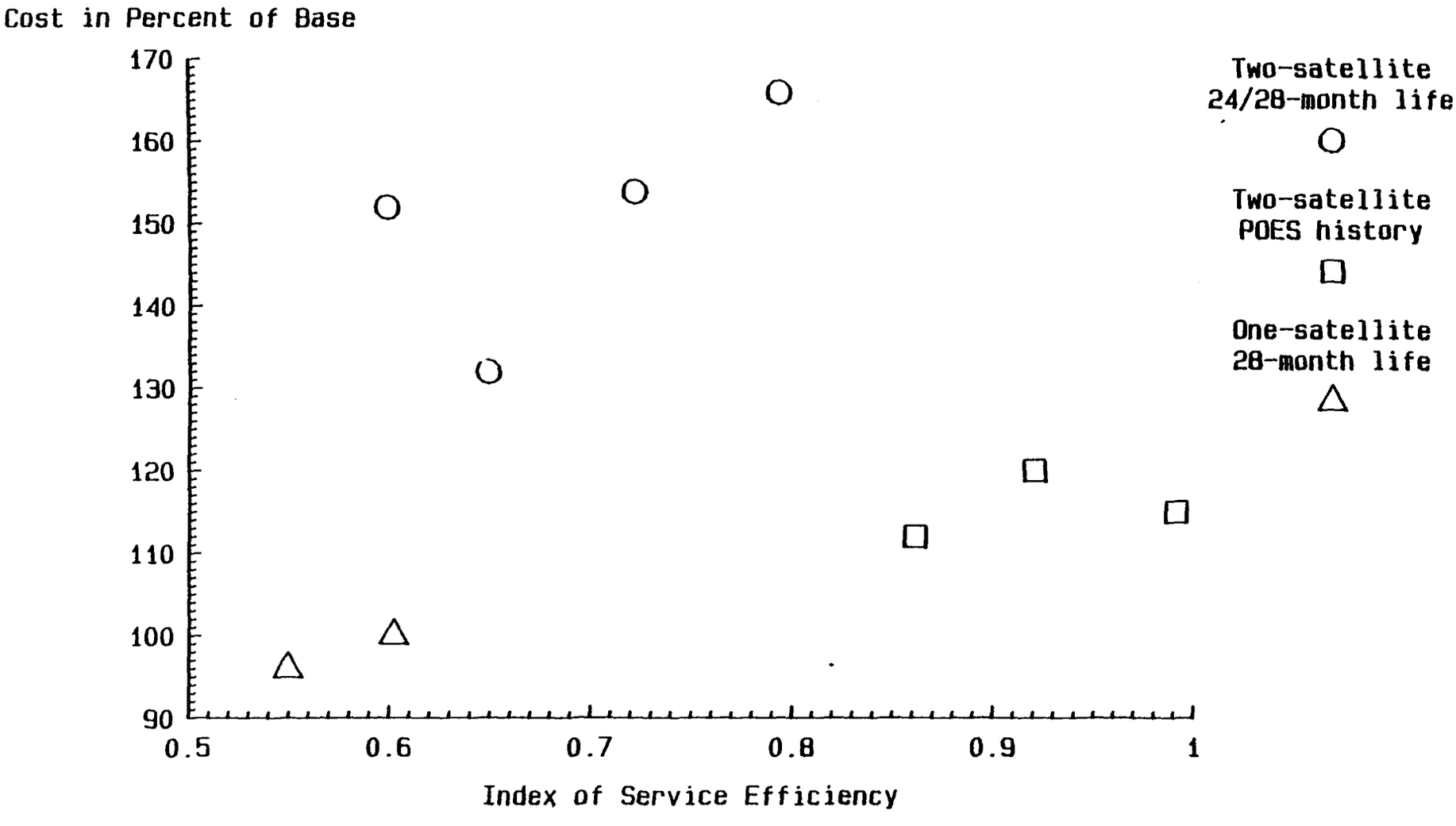
In a one-satellite system, it is almost equally probable that there will be either two or three launch failures over the next 15 years. This being the case, those scenarios in a pair with two or three such failures were not kept separate. Their performances and costs were combined and averaged. Thus, for any management plan for a given design lifetime, launch interval, and other characteristics, there is only one data point plotted in Figure III-17. The same was done for scenarios in a two-satellite system that is likely to suffer either three or four launch failures.

Nine alternate POES management plans remained, seven two-satellite systems and two one-satellite systems. In plotting Figure III-17, the base cost against which all others are compared was changed to the lowest cost of any of the management plans that appeared to have a high probability of providing satellite data at all times. This lowest cost system was the one-satellite system with a 28-month design life, 20-month launch interval, and satellites launched in 4 months to replace any that fail on launch or before their design on-orbit lifetimes.

The one-satellite POES management plans are plotted as triangles in Figure III-17. The one with the lowest cost (about 96 percent of the base cost) is for the system with a 28-month design life, 20-month launch interval, and replacements launched only after launch failures. This plan is more likely than any other POES management plan considered here to have periods in which there were no satellite data. While it has been included in this group of management plans that <u>could</u> provide data at all times, data gaps are likely to occur 4 to 8 percent of the time as the scenarios were plotted in Volume 3, Appendix A. The other one-satellite system management plan (the baseline system in this comparison) is almost certain to produce data all the time.

The four two-satellite scenarios plotted with circles in Figure III-17 are for 24- or 28-month design lifetimes. Their costs are

Figure III-17
Comparison of Case I and Case II Scenarios
Cost Versus Index Of Service Efficiency



The base cost is that of the only one-satellite system to meet POES management goals

high, from 32 to 66 percent more than the base cost. The values of their Index of Service Efficiency are lower than the other two-satellite management plans, showing that the quality and quantity of data services they provide are lower.

The three two-satellite management plans plotted with squares on the right side of the chart have the lowest cost of all two-satellite system plans. As a group, they are from 12 to 20 percent more expensive than the base one-satellite system. Their services to the users are of the highest quality and quantity, as the ISE measures such things. These management plans are based on assuming that the future satellites will follow more or less exactly the recent history of the POES system.

The probability is very high that most, if not all, of these two-satellite management plans based on future events following those that have occurred in the past would meet the POES management goal of providing satellite data services 100 percent of the time over the next 15 years. As a bonus, there probably would be soundings, images and other data services from satellites in both the morning and afternoon orbits 70 to 90 percent of the time. It is not certain which of these three versions of this form of extended-life service in the two-satellite system are most likely to occur in the future. The events described in one of these three plans would cost 2 percent more than the one-satellite system described above. This particular series of events is as likely to occur as are the events in the system which costs 25 percent more than the base.

6. Optimum System Management Plans - Conclusions

1. The optimum one-satellite management plan probably will meet the minimum POES management goal of providing data service from at least one satellite at all times over the next 15 years. It is the only one-satellite management plan devised that is almost certain to do so. This system plan is based on a satellite design life of 28 months, a 20-month launch interval, and replacements in 4 months for all satellites that fail on launch or before the end of their design on-orbit lifetimes. It has the lowest cost of any POES management plan that would meet the minimum performance goal.

2. The optimum management plan for the two-satellite POES system is the one in which satellites are launched only to replace those that fail to achieve orbit, or when on-orbit satellites cease to provide useful images and soundings. This permits taking advantage of long on-orbit lifetimes when they occur, while protecting data services to the users when on-orbit lifetimes are short. A 4-month call-up is mandatory if this

system is to perform acceptably. This system management plan would almost certainly provide some data services 100 percent of the time over the next 15 years. As a bonus, images, soundings, and other satellite services from fully operational satellites in both morning and afternoon orbits probably would be available 70 to 90 percent of the time. This system would cost as little as 2 percent more than the optimum one-satellite system to as much as 25 percent more.

7. Test of the Optimum Management Plans

A test was devised to determine how well those POES management plans found to be the optimum for the one-satellite and two-satellite systems would perform if conditions were worse than considered probable over the next 15 years. NOAA may introduce a new series of satellites of a different design, and the launch vehicle used in the future initially may be less reliable than those used in the past. In this test, the following assumptions were made:

- The last three satellites of the current design now being procured (NOAA K, L, and M) would have on-orbit lifetimes of 29, 33, and 41 months, consistent with the past performance of satellites in this series.

- Satellites following these three would be of a new design, and would experience "infant mortality" problems until malfunctioning components were improved.

- After "infant mortality" problems were solved, starting with the fourth satellite in the series, satellites of the new design were assumed to have on-orbit lifetimes that follow the history of POES satellites of the present design (i.e., lifetimes of 29, 41, 0, 37, and 15 months), with this cycle repeated until the end of the 15-year period.

- All future satellites would be launched with the TITAN II expendable launch vehicle (ELV), which initially would not have the same reliability as previous ELVs, resulting in launch failures on the second and fifth attempts, with subsequent launch failures occurring as determined in the life-cycle history mentioned above.

All scenarios following this sequence of successes and failures were plotted assuming a 4-month call-up of replacements after

failures. As in previous modeling, scenarios were plotted as if early indications of on-orbit failure were present or absent for all satellites that fail after their nominal design lifetimes of 24 months. Scenarios for the one-satellite system are shown in Figures III-18 and III-19; those for the two-satellite system are in Figures III-20 and III-21.

Both the one-satellite and two-satellite optimum management plans handled this tough combination of failures rather well, as shown in Table III-16.

Table III-16

Performance of the optimum management plans for the one-satellite and two-satellite POES systems under extreme conditions

POES management plans with and without early indications of on-orbit failure	Satellites Required	Services Available (% Time)			
		Data Voids	AM Data Only	PM Data Only	Dual Data
One-satellite system					
Without indications	12	3	N/A	97	N/A
With indications	12	3	N/A	97	N/A
Two-satellite system					
Without indications	16	2	13	22	63
With indications	16	0	11	16	73

In the one-satellite system, with or without early indications of on-orbit failure, there would be two periods when there were no satellite data: one of 4 months and one of 2 months, as shown in Figures III-18 and III-19. These gap periods between months 68 and 92 were the result of the "infant mortality" conditions assumed for satellites of the new design.

The two-satellite optimum plan based on launching satellites only after failures protected services reasonably well. As the scenarios were modeled, without early indications (Figure III-20) the 4-month gap between months 57 and 61 was the result of the short lifetime of the second satellite of the new design to be orbited. There were no data voids if it is assumed that early indications of on-orbit failure were present (Figure III-21).

Figure III-18

Test of the Optimum One-Satellite POES Management Plan
with a Nominal 28-Month Design Life and 20-Month
Launch Interval and Replacement Launches
4 Months After Failures,
Without Early Indications of On-Orbit Failure

```
-----------------------------------------------------------------------------------------------
MONTHS   10        20        30        40        50        60        70        80        90        100       110
         |         |         |         |         |         |         |         |         |         |         |
1                           29
Sssssssssssssssssssssssssssss]  (NOAA K)
                   20
2               (2) 0  (NOAA L)
                      24                                       65
3                  (3) Ssssssssssssssssssssssssssssssssssssssssss]  (NOAA M)
                                          44  48
4                                     (4) Ssss]  (New satellite design - failure after 4-months)
                                              48  52
5                                            (5) 0
                                                      56          68
6                                                (6) Sssssssssssss] (12 months)
                                                                     72                90
7                                                                (7) Sssssssssssssssssss] (18-months)
                                                                                         92              (110)
8                                                                                    (8) Sssssssssssssssssss
-----------------------------------------------------------------------------------------------
MONTHS                 110       120       130       140       150       160       170       180
                       |         |         |         |         |         |         |         |
                                  121
8 continued            sssssssssss] (29 months)
                         112                                      153
9                    (9) Ssssssssssssssssssssssssssssssssssssssssss] (41 months)
                                           132
10                                    (10) 0
                                               136                                173
11                                        (11) Ssssssssssssssssssssssssssssssssssssss] (37 months)
                                                                             166        (180)
12                                                                      (11) Sssssssssssssss  ] 181  (15 months)
-----------------------------------------------------------------------------------------------
```

LEGEND

S = Launch of a satellite in a one-satellite system
O = Launch failure
] - Failure on-orbit

Figure III-19

Test of the Optimum One-Satellite POES Management Plan
with a Nominal 28-Month Design Life and 20-Month
Launch Interval and Replacement Launches
4 Months After Failures,
With Early Indications of On-Orbit Failure

```
------------------------------------------------------------------------------------------------
MONTHS   10        20        30        40        50        60        70        80        90        100       110
         !         !         !         !         !         !         !         !         !         !         !
1                      25  29
Sssssssssssssssssssssssss]sss]  (NOAA K)
                   20
2               (2) 0  (NOAA L)
                       24                                      61  65
3                  (3) Sssssssssssssssssssssssssssssssssssssssss]sss]  (NOAA M)
                                        44  48
4                                   (4) Ssss]  (New satellite design - failure after 4-months)
                                            48  52
5                                          (5) 0
                                                     56          68
6                                               (6) Ssssssssssss] (12-months)
                                                                     72                 90
7                                                               (7) Ssssssssssssssssss] (18-months)
                                                                                          92              (110)
8                                                                                     (8) Sssssssssssssssssss
------------------------------------------------------------------------------------------------
MONTHS             110       120       130       140       150       160       170       180
                   !         !         !         !         !         !         !         !
                        117 121
8 continued        sssssss]sss] (29 months)
                    112                                  149 153
9                 (9) Sssssssssssssssssssssssssssssssssssssss]sss] (41 months)
                                        132
10                                 (10) 0
                                            136                              179 173
11                                     (11) Sssssssssssssssssssssssssssssssssss]sss] (37 months)
                                                                        166           (180)
12                                                                 (11) Sssssssssssssss  ] 181  (15 months)
------------------------------------------------------------------------------------------------
```

Note: "New satellite design" is underlined in the original.

LEGEND

S = Launch of a satellite in a one-satellite system
O = Launch failure
] = Failure on-orbit; when there are two symbols, the first indicates that failure is imminent

Figure III-20

Test of the Optimum Two-Satellite POES Management Plan if Satellites are Launched in 4 Months Only After a Failure, Without Early Indications of On-Orbit Failure

```
MONTHS   10        20        30        40        50        60        70        80        90       100       110
         |         |         |         |         |         |         |         |         |         |         |
1                            29
Pppppppppppppppppppppppppp]  (NOAA K - 29 months)
           12
2      (2) 0  (NOAA L)
              16                                    57
3          (3) Aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa]  (NOAA M - 41 months)
                                33  37      45                          74
4                           (4) Pppp] (New Satellite design - failure after 4 months)
                                         41
5                                  (5) 0
                                            45          57
6                                      (6) Pppppppppppp] (12 months)
                                                   61                79
7                                                (7) Pppppppppppppppppp] (18 months)
                                                       65                          94
8                                                  (8) Aaaaaaaaaaaaaaaaaaaaaaaaaaaaa] (29 months)
                                                                     83                        (110)
9                                                                (9) Pppppppppppppppppppppppppppp
                                                                                     98
10                                                                            (10) 0
                                                                                          102    (110)
11                                                                                  (11) Aaaaaaaaa
```

```
MONTHS            110       120       130       140       150       160       170       180
                   |         |         |         |         |         |         |         |
                                 124
9 continued        ppppppppppppp]  (41 months)
                                          139
11 continued       aaaaaaaaaaaaaaaaaaaaaaaaaaaa]  (37 months)
                                   128           143
12                            (12) Pppppppppppppp] (15 months)
                                                 143                         172
13                                          (13) Aaaaaaaaaaaaaaaaaaaaaaaaaaaaa] (29 months)
                                                    147                           (180)
14                                                (14) Pppppppppppppppppppppppppppppppp ] 188 (41 months)
                                                                                   176
15                                                                            (15) 0
                                                                                        180
16                                                                                 (16) A ] 217 (37 months)
```

LEGEND

P = Launch of a satellite into the afternoon orbit
A = Launch of a satellite into the morning orbit
O = Launch failure
] = Satellite failure

Figure III-21

Test of the Optimum Two-Satellite POES Management Plan if Satellites are Launched in 4 Months Only After a Failure, Without Early Indications of On-Orbit Failure

```
-------------------------------------------------------------------------------------------
MONTHS  10       20       30       40       50       60       70       80       90      100      110
         |        |        |        |        |        |        |        |        |        |        |
1                      25  29
Ppppppppppppppppppppppppplppp]  (NOAA K - 29 months)
           12
2      (2) 0  (NOAA L)
              16                                  53  57
3          (3) Aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaalaaa]  (NOAA M - 41 months)
                          29  33
4                     (4) Pppp] (New Satellite design - failure after 4 months)
                                  37
5                            (5) 0
                                      41          53
6                                (6) Ppppppppppppl (12 months)
                                                   57                75
7                                              (7) Pppppppppppppppppp] (18 months)
                                                       61                        86  90
8                                                  (8) Aaaaaaaaaaaaaaaaaaaaaaaaalaaa] (29 months)
                                                                            79              (110)
9                                                                 (9) Ppppppppppppppppppppppppppppppp
                                                                               90
10                                                                        (10) 0
                                                                                   94       (110)
11                                                                            (11) Aaaaaaaaaaaaaaaa
-------------------------------------------------------------------------------------------
MONTHS           110      120      130      140      150      160      170      180
                  |        |        |        |        |        |        |        |
                      116 120
9 continued       pppppplppp]  (41 months)
                                127 131
11 continued      aaaaaaaaaaaaaaaaalaaa]  (37 months)
                           120           135
12                    (12) Ppppppppppppppp] (15 months)
                                   131                     156 160
13                            (13) Aaaaaaaaaaaaaaaaaaaaaaaaalaaa] (29 months)
                                          139                              176 180
14                                   (14) Ppppppppppppppppppppppppppppppppppppplppp]  (41 months)
                                                                160
15                                                         (15) 0
                                                                      164         (180)
16                                                              (16) Aaaaaaaaaaaaaaaa ] 201 (37 months)
-------------------------------------------------------------------------------------------
```

LEGEND

P = Launch of a satellite into the afternoon orbit
A = Launch of a satellite into the morning orbit
O = Launch failure
] = Satellite failure

Data would be available from satellites in the preferred early afternoon orbit 85 to 89 percent of the time, with data from satellites in both orbits available 63 to 73 percent of the time over the 15-year period.

The one-satellite system required the launch of 12 satellites, the same number as in the earlier modeling of the 28-month "optimum" management plan. The two-satellite system required the launch of 16 satellites. Earlier modeling of the same two-satellite management plan with replacements launched only when there were failures also required 16 satellites when the same number of launch failures (four) were assumed during the 15-year period.

It can be concluded from this test that the optimum management plans for the future POES system in either the one-satellite or two-satellite configurations are sound, and will provide reasonably reliable services to the National Weather Service and the rest of the user community, even under the most extreme conditions of launch and premature failures that the POES system is likely to encounter over the next 15 years.

Any degradation in services to the users due to these extreme conditions and, perhaps more importantly, any increases in long-term costs are directly attributable to the risks encountered in introducing a satellite of a new design into a long-term operational service, or to the risks associated with using an expendable launch vehicle of unproven reliability.