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Analysis of System Reliability as a Capital Investment

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ANALYSIS OF SYSTEM RELIABILITY AS A CAPITAL INVESTMENT

BY

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ABSTRACT

This report, "Analysis of System Reliability as a Capital Investment", is an analysis of radar system reliability of two similar tracking radar systems as a capital investment. It describes the two tracking radar systems and calculates the mission failure rates based upon field failure data. Additionally, an analysis of a simulation program written in FORTRAN is performed which treats system reliability as a capital investment based on 335 electronic systems that were fabricated with a reliability program versus 564 electronic systems fabricated without a reliability program. The data from the two tracking radar systems, one with a reliability program and the other without, is incorporated in the computer program to verify the conclusions of the author of the computer simulation program.

Harold Klee

Director of Research Report

ACKNOWLEDGEMENT

I would like to acknowledge the encouragement and support of my family during the preparation of this report. This report is dedicated to my wife and daughters, Carolyn, Vicki, Donna and Denise whose unwavering love and understanding were instrumental in the completion of the research for this report.

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CHAPTER I

INTRODUCTION

Performance of electronic and mechanical equipment is a grave concern of commercial as well as military customers. Failure or unscheduled down time can be costly. Equipment bought or leased on a contract basis is expected to do the specified job any time the job is required, and "the probability that no failure will occur in a given time interval of operation of a device or equipment is termed its reliability."[1]

Equipment reliability can evoke a comical overtone such as the case of the national television presidential candidate debate in 1977 when the voice communication system failed and the candidates stood and looked at each other and the audience for several minutes. Also, equipment reliability can denote a deadly overtone. An example is the L1011 aircraft that crashed into a Southern Florida swamp in 1972 while a member of the crew was trying to localize a failure in the landing mechanism. Another example of equipment reliability is the costly loss of an atomic

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[1]Igor Bazovsky, Reliability Theory and Practice (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1961), p. 6.

submarine and its crew which in 1963 failed to surface and sank to the bottom of the Atlantic Ocean.

Since the Korean War, quantitative reliability has become widely used and measured by applying statistical methods. Government and commercial industry has placed a strong emphasis on equipment reliability. The Department of Defense contracts for equipment specify reliability compliance with the DOD specification MIL-STD-785A.[2] MIL-STD-785A defines the specifications that a reliability program must contain for systems and equipment development and production.[3] These specifications are:

1. The contractor must establish and maintain an effective reliability program to permit the most economical achievement of overall program objectives.

2. The mission responsive reliability requirements and objectives must be specified contractually.

3. The minimum acceptable hardware reliability requirements must be demonstrated by means of tests and analyses.

4. The proposed program plan must describe how the reliability program is to be conducted.

System reliability treated as a capital investment is

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[2]Bertram L. Amstadter, Reliability Mathematics Fundamentals; Practices; Procedures (New York: McGraw-Hill Book Co., 1971), pp. 1-3.

[3]U. S., Department of Defense, Reliability Program for Systems and Equipment Development and Production MIL-STD-785A, (Washington, D.C.: Government Printing Office, 28 March 1969), pp. 1-9.

the subject of a report by Anthony Coppola entitled "Reliaability as a Capital Investment" in the Proceedings 1974 Annual Reliability and Maintainability Symposium. Capital investment is defined as an expenditure of funds in the expectation of a worthwhile return. The treatment in his report demonstrates that a total reliability program is a good investment by comparing the operational costs of 564 avionics electronic systems procured with minimum reliability with the operational costs of 335 avionics electronic systems procured with a total reliability program.

Objective Of The Study

The objective of this study is to demonstrate the accuracy of the Coppola report and verify his conclusions in order to apply the simulation method to a pair of radar systems.

Statement Of The Problem

The problem of this study is to apply the simulation technique to a pair of radar systems which have reliability histories similar to the Coppola examples to verify his conclusions that reliability is a good capital investment.

Radar Background Criteria

The pair of radar systems employed for cost and reliability data are the Mod 3 Radio Guidance System, Mod 3 RGS, located at Cape Canaveral Air Force Station, Florida and the Mod 3 General Electric Radio Tracking System, Mod 3 GERTS, located at Vandenberg Air Force Base, California. Mod 3 RGS and Mod 3 GERTS have a tracking radar operating in conjunction with launch vehicle guidance equipment and a guidance computer. The guidance computers are different and are not included in the reliability assessment. Mod 3 RGS has a total reliability program and Mod 3 GERTS has a minimal reliability program based on data through 1976.

The tracking radar mission requirement is to supply accurate position information consisting of launch vehicle range, azimuth and elevation to the guidance computer and to transmit guidance commands to the launch vehicle during the guidance portion of the launch vehicle trajectory. Guidance commands consist of pitch and yaw steering and discrete relay closure commands. The guidance portion of the launch vehicle trajectory consists of the first six minutes after lift-off. Failure rates of the two systems are calculated based on a mission failure. A mission failure is classified as a failure that could prevent the equipment from meeting mission requirements during an actual missile flight.

CHAPTER II

RELIABILITY CONCEPTS

The concept of reliability is centuries old. Sailors and fishermen have been concerned about the design and seaworthiness of their sea craft for thousands of years. Kings and knights of the Middle Ages were apprehensive about the design, performance, and effectiveness of their armor and weapons. However, the science of reliability engineering is a relative new field that grew out of the failure problems associated with complex military service equipment during World War II and the Korean War. Reliability measures equipment or device performance based on mathematical probability theory and statistical methods.[5] The widely accepted definition of reliability is "the probability that a device will operate adequately for a given period of time in its intended application."[6] Reliability can be predicted and measured based on the failure rate history of a device. Failure rate of a device usually falls into three categories which are early failures, random failures, and end-of-life failures. Each of these has a particular identity. Early failures are those which occur when a

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[5] Bazovsky, Reliability Theory and Practice, pp. 274-286.

[6] Amstadter, Reliability Mathematics, p. 1.

device is new and undergoing debugging. Random failures are those which occur during the useful life of a device. Random failures of a device that has completed a thorough debugging phase usually exhibit a constant failure rate or relatively constant failure rate during the useful life of the device. End-of-life failures are failures which occur due to the wear out or ageing of a device. If a failure distribution or histogram of failures versus time were plotted on a new piece of electronic equipment that was repaired as it failed, early failures would indicate a high failure frequency that decreases approximately exponentially to a relatively constant failure frequency over a period of time, then the failure frequency would begin increasing approximately exponentially indicating that the end-of-life or wear out of the equipment is being reached. The contour of the histogram would be shaped like a standard bathtub which is commonly referred to as the "bathtub curve" in engineering reliability.[7]

One of the forerunners of engineering reliability is the work performed in the early years of the rail transportation industry concerning ball and roller bearings. Extensive records on failure rate histories were maintained in order to improve the reliability of ball and roller bear-

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[7]A. K. S. Jardine, Maintenance, Replacement, and Reliability (New York: John Wiley and Sons, 1973), pp. 1-9.

ings. Another forerunner of engineering reliability is the probability calculations performed on multiengine aircraft between World War I and World War II.[8] Considerable effort was expended in calculating and predicting the probability of flight survival of aircraft with two engines if one engine failed and three or four engine aircraft if one or more engines failed. Information was gained that was valuable concerning "the relative amount of engine overhaul maintenance for aircraft of different types of configurations."[9]

In 1952, the exponential failure distribution became the most popular distribution used in reliability work. Its popular use is based on the fact that it uses simple addition of failure rates for reliability calculations. Design data can be compiled using a simple format.[10]

The system failure rate of n units operating in series so the system fails if any unit fails is equal to the sum of the individual unit failure rates.

$$\lambda_{ss} = \sum_{i=1}^{n} \lambda_i$$

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[8]Bazovsky, <u>Reliability Theory and Practice</u>, p. 2.

[9]<u>Ibid</u>., p. 274.

[10]Richard E. Barlow and Frank Proschan, <u>Mathematical Theory of Reliability</u> (New York: John Wiley and Sons, 1965), pp. 1-5.

The system mean time between failure (MTBF) is equal to the inverse of system failure rate.

$$MTBF = \frac{1}{\lambda_{ss}}$$

System reliability for repairable systems which are operating in the useful life portion of the bath-tub curve is defined with the following formula.[11]

$$R_{ss}(t) = e^{-\lambda_{ss} t}$$

The Department of Defense reliability document MIL-HDBK-217B specifies that Air Force electronic systems will be assessed by using the exponential failure distribution for calculation of failure rates and reliability computing.

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[11] Amstadter, Reliability Mathematics, pp. 32-35.

CHAPTER III

SYSTEM DESCRIPTION

The Mod III Radio Guidance System is composed of a Mod III Track Radar, Guidance Computer, and Airborne Beacon Set. Launch vehicle position information consisting of range, azimuth, and elevation is supplied to the Guidance Computer by the Mod III Track Radar at a 2 pps rate. A flag line is also supplied to the computer to indicate that the radar is tracking in the monopulse mode. For acquiring a target, Mod III Track uses a conical scan mode of tracking and a monopulse mode for normal tracking of a target. The radar operates in the X band frequency range at a nominal pulse recurrence frequency of 300 with a message train of 14 pulses in conjuction with an Airborne Beacon Set which is aboard a launch vehicle. Contained within the 14 pulse message train is pitch and yaw steering and discrete relay closure commands which are determined by the Guidance Computer, decoded by the Airborne Beacon Set and supplied to the vehicle auto pilot system. For range information, the Airborne Beacon Set transmits an RF pulse to the Mod III Track Radar. The beacon transmitted RF pulse is triggered by the fourteenth pulse in the message train. Mod III Track also utilizes the beacon return pulse for pointing the antenna and azimuth and elevation information is derived based on antenna position. Baldwin encoders, mounted on the antenna in the azimuth and elevation plane, derive the azimuth and elevation angle information.

For Go-No Go checks prior to entering a test with a launch vehicle, Mod III Track utilizes a boresight tower test transmitter antenna which is triggered by the Track transmitted fourteenth pulse. To check out Mod III Track, an automatic test sequence is utilized which checks the angle encoders, angle tracking, range tracking, acquisition, message data validity, and track mode sequence switching.

A Flight Data Recording System is used to monitor Mod III Radio Guidance operation. The equipment provides facilities for recording data obtained from the position tracking radar during checkout operations or tests and during the flight of a launch vehicle. The data is used for the following purposes:

1. Preflight monitoring of the guidance system during checkout or test as an aid in the determination of guidance system status.
2. Inflight monitoring of the guidance system to check its performance and observe any radical or abnormal departure of the launch vehicle from its programmed trajectory.
3. Postflight evaluation of the guidance system to

determine such factors as: programming errors; operating errors; equipment failures; inaccuracies and/or inadequacies; and ease of operation.

Documentation and classification of all repairs and failures on units comprising the Mod III Track Radar are provided for through use of an Inspection and Consumption Report (I & CR) form. Provision for vendor or internal laboratory analysis is made as required.

Mod III RGS Tracking Radar is comprised of 18,753 components in 33 units. A discription of the system functional operation is enclosed in Appendix A. System failure rate is 0.0011057 and the calculations are included in Appendix A. The cost of the system is $21,417,000.

The Mod III GERTS Tracking Radar is comprised of 16,953 components in 31 units. It does not have an extended range tracker or a redundant transmitter. The system failure rate is 0.0018416 based on limited available data. The cost of the system is $12,620,000.

The MTBF of the RGS Tracking Radar is 904 hours between failures compared to 543 for the GERTS Tracking Radar.

CHAPTER IV

RELIABILITY PROGRAM AS CAPITAL INVESTMENT

A reliability program is a capital investment with the return on the investment based on benefits due to reduced maintenance costs. A capital investment is an investment of funds with the expectation of incurring a greater return. Five commonly used methods of evaluating a capital investment are:

1. Computation of return on investment: Percent of investment returned each year of investment.
2. Payback period: Time required to recoup investment at zero discounting.
3. Ratio of benefit to cost: Total return divided by amount of investment.
4. Net return: Total return less cost of investment.
5. Discounted benefit/cost ratio and discounted net return: Return reduced by a preset amount usually compounded yearly.

In his study, Coppola used number 3 above and computed the return on investment for each reliability case and used actual field failure data from three comparable avionic systems as inputs to a computer simulation model. The model uses standard economic analysis procedures to compute the return in reduced maintenance costs of a system procurred with a complete reliability program as a basis for comparing with another system which was procured without any or little reliability activity. Included in the program is a model to compute the cost of a complete reliability program. Costs of the reliability program were based on a thorough and complete reliability effort including the following program elements.

1. Screening of all microcircuits to MIL-STD-883, Class B.
2. Screening of all semiconductors to JAN "TX" specifications.
3. A burn-in of 100 hours of all critical assemblies (e.g., power supplies, etc.).
4. Performance of reliability allocations, predictions and design review activity.
5. A 5000 hour reliability evaluation test.
6. A formal reliability demonstration to test plan III of MIL-STD-781B, Test Level F.
7. A 50 hour burn-in of each system produced.
8. A failure analysis of each failure encountered during the above tests.

In developing the computer program, the definition for return on investment(ROI) was designated as annual return divided by the investment cost, and annual return was defined to be the savings in maintenance costs due to the application of a reliability program. The investment cost includes the cost of performing each reliability program element, the labor overhead charges and the increase in G and A(general and administrative overhead) and profit that is caused by the use of a reliability program.

$$ROI = \frac{NC_1}{C_2\ (1 + k_1)(1 + k_2)}$$

Where N = number of failures avoided each year because of the reliability program

C_1 = cost to repair a failure

C_2 = cost of the reliability program including labor overhead.

k_1 = G & A overhead.

k_2 = fee or profit.

The factors of the above equations were expanded into 34 variables and a computer program computes ROI from these variables. In a sensitivity analysis, return on investment was iterated with each one of the 34 variables doubled one at a time and the results compared to the original ROI.

Case 1 in Coppola's simulation consisted of 564 systems with 13,553 parts per system and Case 3 consisted of 335 systems with 11,545 parts per system. Case 1 had little or no reliability effort compared with Case 3 which had a thorough reliability program.

CHAPTER V

REVIEW OF LITERATURE

Reliability program costs for current military and commercial electronic equipment range from 7 to 30 percent of the contract price for high reliability equipment. In the early 1950's, before a reliability program for military equipment was mandatory, the yearly cost of maintaining and repairing some equipment exceeded the contract price of the equipment. Consequently many studies have been performed to show that a reliability program is a good investment of capital for electronic equipment. The most common method of measuring the worth of a capital investment is to compute the return on investment of the capital outlay. This is the method used in a study by Coppola (1974).

Black and Proschan (1959) used models to minimize shortages subject to cost restraint with demand probability density for spares assumed a priori. In another model, they maximized system reliability with optimal allocation of spares subject to a linear restraint with the demand for spares depending on actual field failures with known probability failure distributions. The models used were nonlinear functions and were solved by a nonlinear programming method for maximizing a nonlinear function subject to linear restraints.

Everett (1963) showed that the LaGrange multiplier method of solving constrained maximum problems can be applied to any type of problem if the constraints can be represented as bounds. The method does not guarantee a solution but if one is found, it is an optimum solution. He states that "the method has good potential for solving problems of optimal allocation of a number of resources to a number of independent ventures where the total payoff is the sum of the payoffs that accrue from each venture."

Federowicz and Mazumda (1968) developed a geometric programming model to determine the cost of achieving a predicted reliability level assuming the allocation of redundant elements is optimal. The model design can be used with linear and nonlinear constraints and random failures.

In a study of the SST aircraft system concept edited by English, Howard (1968) measures the return on investment by using the discounted cash flow method which is based on the time value of money or compound rates of return.[12] The Civil Aeronautics Board calculates return on investment as a straight line depreciation method using a

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[12]J. Morely English, Cost-Effectiveness The Economic Evaluation of Engineered Systems (New York: John Wiley and Sons, 1968), p. 177.

10 or 15 year life period. The time value of money is not considered. It does not assume that a dollar now is worth more than in the future.[13]

Thorne and Carlson (1970) treat profit on an investment as income generated minus expenses and show that return on investment has many variations.[14] Payout time is the time required to recoup the initial investment. Payout time with interest applies an interest charge on the fixed investment remaining or applies an interest charge on the working capital and fixed capital. It is more common to use payout time without interest than payout time with interest. The return on original investment is the ratio of average annual cash flow to the original investment. A variation of this is the return on average investment in which the divisor is the average outstanding investment and it depends on the depreciation schedule used. The discounted cash flow, interest rate of return method, profitability index, internal rate of return or investor's method adjust cash flows over the life of a project to a fixed point in time using compound interest. The fixed point in

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[13] Ibid., p. 202.

[14] F. C. Jelen, Cost and Optimization Engineering (New York: McGraw-Hill Book Co., 1970), pp. 85-88.

time used is the original investment time. The venture worth or incremental present worth method uses discounting at a fixed rate and depends on life of the project.

Thuesen, Fabrycky and Thuesen (1977) show that an investment is described by cash receipts and disbursements anticipated if the investment is undertaken.[15] Present worth is an amount at the present that is equal to investment cash flow at a given interest rate. The payback or payout period is the length of time to recover the initial cost of an investment. Prospective value is a recently developed basis that measures investment desirability considering that the rate representing a minimum desirable return is greater than the rate money can be invested.

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[15] H. G. Thuesen, W. J. Fabrycky, and G. J. Thuesen, Engineering Economy (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1977), pp. 135-156.

CHAPTER VI

SIMULATION PROGRAM AND RELIABILITY ANALYSIS

When Coppola's simulation program was transcribed to program coding sheets for card punching, three errors were identified in the typing format.

1. Entry 0940 reads CABI=G+H

   Correct reading is CABI=G*H

2. Entry 1210 reads PRINT: 75 , CM,CL,CT,SS

   Correct reading is PRINT 75,CM,CL,CT,SS

3. Entry 1310 reads 50 FORMAT(3X,2F(12,0,F8.3,F8.3))

   Correct reading is 50 FORMAT(3X,2F(12.0,F8.3,F8.3))

After the above corrections were made, the program was then run on FTU computer link. The job failed because the FTU computer link would not accept the PRINT statements as written in entries 0760, 0820, 1200, 1230, 1260, 1290, and 1320. Further investigation revealed that these print statements would be accepted on a Honeywell 635 computer system. In order to run the program on the FTU computer link, the PRINT statements were changed to a PRINT and FORMAT statement. The corrected simulation program was successfully run using Coppola data and the data print out verifies his results. The simulation run is included in this report as Appendix B.

Coppola's corrected computer program was used to perform an analysis of Mod 3 reliability as a capital investment. The results of this computer run are included in Appendix C. Case I used the data from the Mod 3 GERTS and case 3 used the data from the Mod 3 RGS. Case 2 values were not changed for this computer run. The field failure rates of GERTS and RGS were divided by the number of parts in each system to put the values of V(1) and V(6) in the same units of measure as used by Coppola, failures per part hour. The following list shows which variables and values were changed to run the computer program for Mod 3 comparisons.

VARIABLE	NAME	OLD VALUE	NEW VALUE
V(1)	FR W/O REL	6.5×10^{-6}	10.86×10^{-8}
V(2)	No. Parts	13553	16953
V(3)	No. Systems	564	1
V(4)	Op Hrs/Mo	45.5	120
V(6)	FR W Rel	1.7×10^{-6}	5.9×10^{-8}
V(2)	(Case 3)	11545	18753
V(3)	(Case 3)	335	1

The descriptions of the 3 cases used in this computer run are summarized in Table I.

TABLE I - DESCRIPTION OF CASE STUDIES

CASE	PARTS/SYSTEM	TOTAL SYSTEMS	COST/SYSTEM
I	16,953	1	$12,620,000
II	3,293	325	35,000
III	18,753	1	21,417,000

Table II presents the results of ROI analysis where the cost of reliability does not consider spares savings.

TABLE II - RESULTS OF ROI WITHOUT SPARES SAVINGS

CASE	CR	ROI(1)
I	$2,323,314	0.00013
II	5,114,711	0.004
III	2,420,308	0.00014

The above results do not reflect the same results that Coppola obtained with his systems. Case I does not show a higher ROI than Case III. Moreover, the Case II results are considerably different from what he obtained in his computer simulation.

Table III presents the results of ROI analysis where the cost of reliability is reduced by spares savings.

TABLE III - RESULTS OF ROI WITH SPARES SAVINGS

CASE	CR	ROI(2)
I	$2,323,037	0.00013
II	5,101079	0.00400
III	2,419,756	0.00014

In Table III above the CR entries are slightly different from those in Table II; however, the percentages for ROI(2) are the same as those for ROI(1). This is not the type of results that Coppola obtained with his simulation using hundreds of systems. Again, Case II does not reflect the results that Coppola obtained.

Table IV indicates the analysis of reliability as a capital investment where spares savings are not considered. Benefit/Cost is the ROI multiplied by the expected number of years of service. The expected number of years of service was chosen as ten years, the same value Coppola used in his simulation study. The Discounted B/C(benefit/cost) ratio is obtained by multiplying ROI by a present worth factor. The present worth factor is obtained from Table IV in the Coppola report and is based on discount rate of ten percent compounded annually. The net return is computed by multiplying the Benefit/Cost by capital investment cost and then subtracting the capital investment cost. Discounted net return(Discounted NR) is then computed by multiplying the

Discounted B/C by the investment cost then subtracting the investment cost.

TABLE IV - ANALYSIS OF RELIABILITY AS A CAPITAL INVESTMENT WITHOUT SPARES SAVINGS

MEASURE	CASE I	CASE II	CASE III
ROI(%)	0.013	0.4	0.014
Payback(years)	7,675	268	7,228
Benefit/Cost	0.13	4	0.14
Discounted B/C	0.0008	0.025	0.0009
Net Return($X10^6)	-2.02	15.34	-2.08
Discounted NR ($X10^6)	-2.32	-4.99	-2.40

The results in Table IV do not reflect the same results as Coppola obtained. Payback in years in Table IV for Case I is greater than Case III, which is opposite from Coppola's results. Also, the Net Return and Discounted NR for both Case I and III are negative values; and another interesting point is that the number of years for payback is in the thousands.

Table V shows the analysis of reliability as a capital investment with spares savings subtracted from investment cost. These results are very close to the results in Table IV above which are considerably different from the results Coppola obtained in his analysis.

TABLE V - ANALYSIS OF RELIABILITY AS A CAPITAL INVESTMENT WITH SPARES SAVINGS

MEASURE	CASE I	CASE II	CASE III
ROI(%)	0.013	0.4	0.014
Payback(years)	7674	267	7226
Benefit/Cost	0.13	4	0.14
Discounted B/C	0.0008	0.025	0.0009
Net Return($ $X10^6$)	-2.02	15.30	-2.08
Discounted NR ($ $X10^6$)	-2.32	-4.97	-2.42

Coppola's results show that the Net Return and Discounted NR are greater when spares savings are subtracted from investment cost. In Table IV and V above there is no change in these values.

The sensitivity analysis results in Appendix C compare favorably with those in Appendix B which uses Coppola data in the simulation.

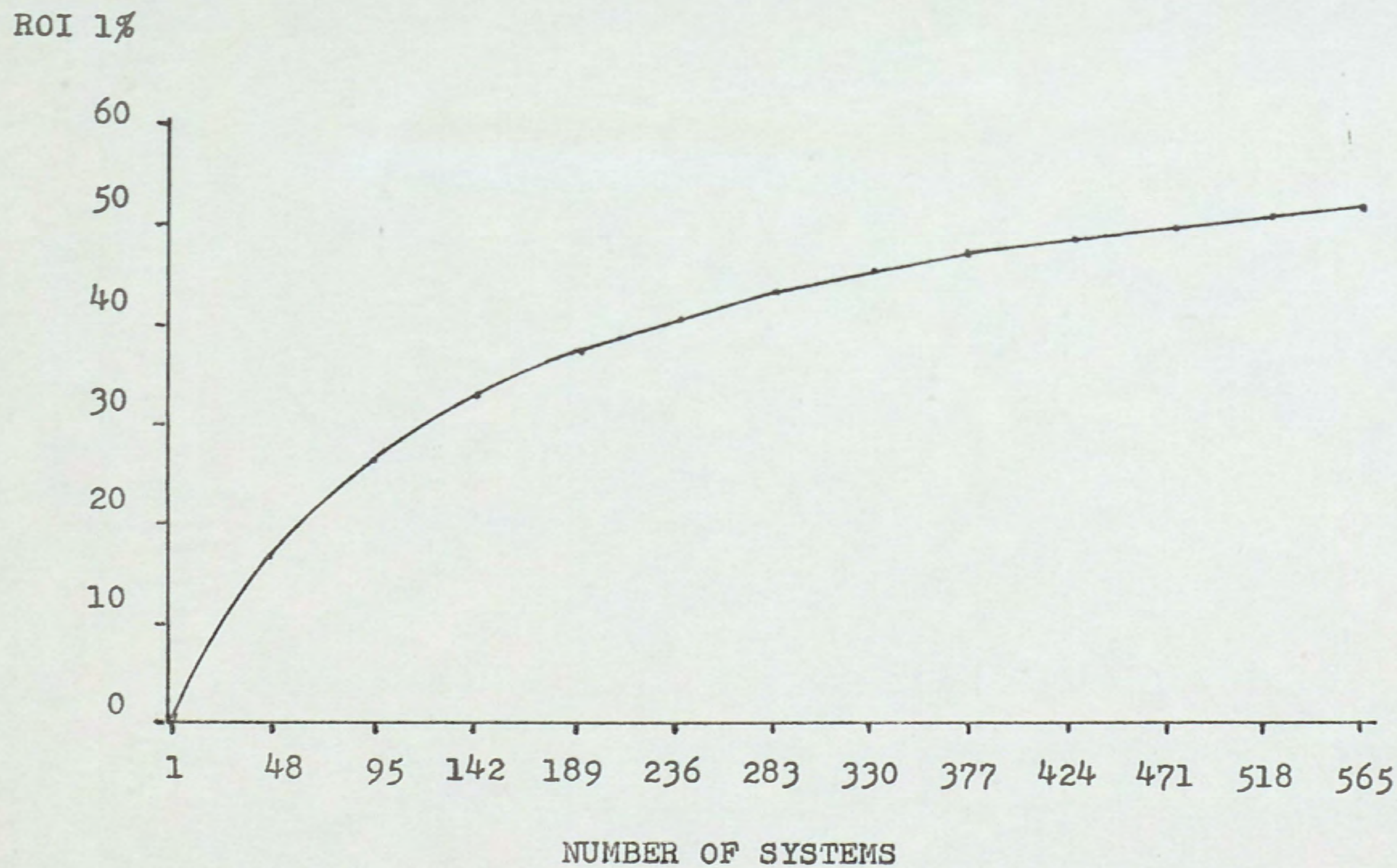
CHAPTER VII

ANALYSIS OF SYSTEM SIMULATION

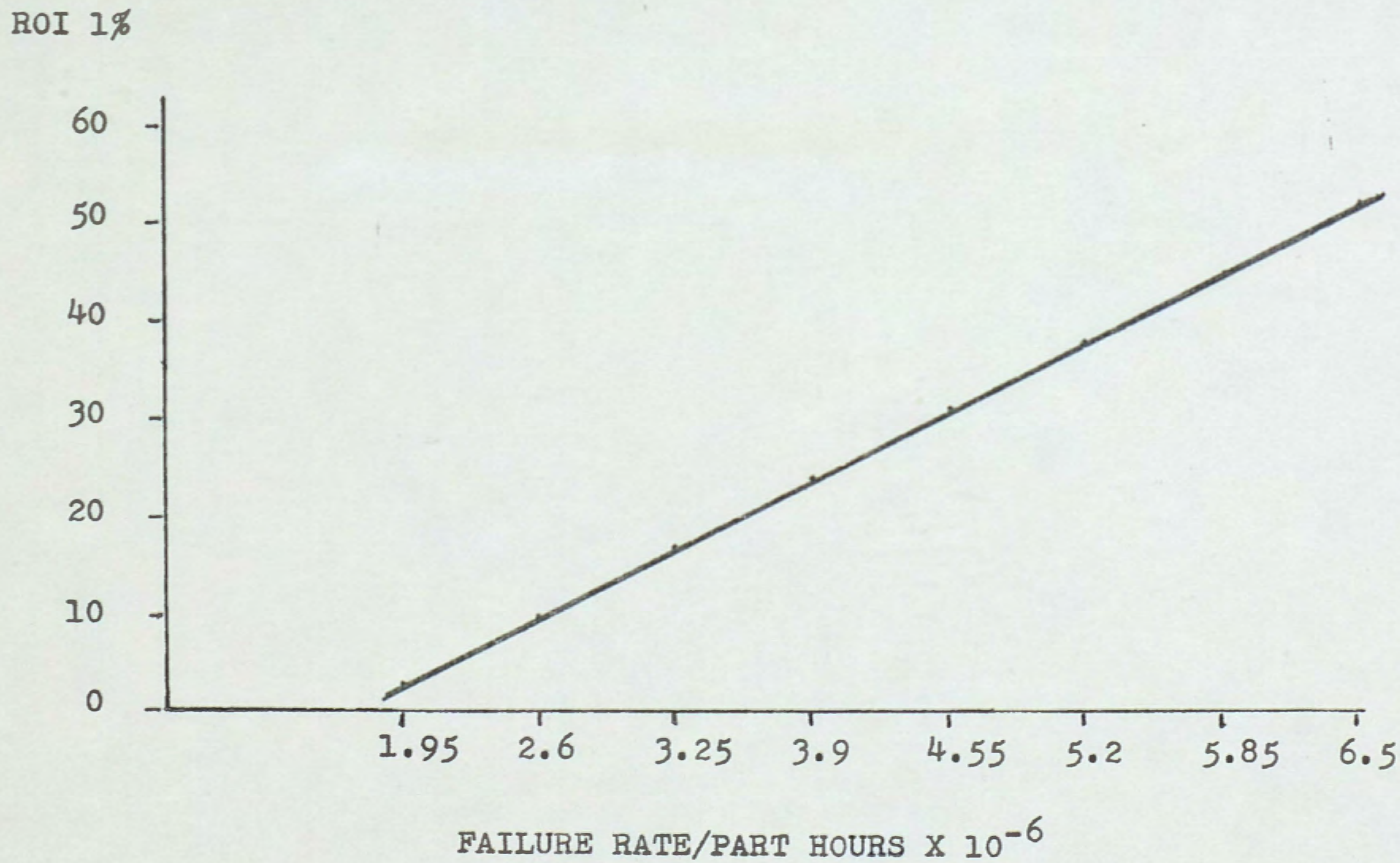
In the computer simulation run using the Mod 3 Track data as inputs, the return on investment(ROI) for Case I and Case 3 is opposite to the results Coppola obtained in his simulation. In order to investigate the effect the number of systems has on the return on investment, a computer simulation run was made using Coppola data and varying the number of systems from 1 to 565 in steps of 47. The print out of the results of this computer run is shown in Appendix D. Graph 1 illustrates the change in ROI 1 as the number of systems is varied and shows the number of systems versus ROI 1 is a hyperbolic type relationship.

The relationship between failure rate and ROI 1 was investigated by making a computer run with Coppola data and varying the failure rate from $0.325X10^{-6}$ to $6.825X10^{-6}$ in steps of $0.325X10^{-6}$. The print out of the results of this computer run is included in Appendix E. Graph 2 shows system failure rate versus ROI 1 as the Coppola data system failure rate without reliability approaches the system failure rate with reliability. The graph illustrates that this relationship is linear.

Cost of Reliability(CR) for Case 2 in the Mod 3 simulation run is considerably different from CR in the Coppola simulation run. The reason for the difference is that the failure rate for Case 3 is used to calculate CR in each computer simulation and V(6), failure rate with reliability, is $5.9X10^{-6}$ in Coppola data inputs and $1.7X10^{-8}$ for Mod 3 data inputs in the simulation runs.



GRAPH 1 - SYSTEMS VERSUS ROI 1



GRAPH 2 - FAILURE RATE VERSUS ROI 1

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The objective of this study was to demonstrate the accuracy of the Coppola report and verify his conclusions in order to apply the simulation method to a pair of radar systems.

The problem of this study was to apply the simulation technique to a pair of radar systems which have reliability histories similar to the Coppola examples to verify his conclusions that reliability is a good capital investment.

The results of this study show that the Coppola simulation program was verified by running the program on the FTU computer link. The computer print out data verified the accuracy of the Coppola report data, and based on his data and simulation technique, his conclusions were also verified.

When the simulation technique was applied to a pair of radar systems, the Coppola conclusions were not verified. Two reasons for this are documented in Appendix D and E as follows:

1. The simulation program is sensitive to the number

of systems used as input data which is illustrated with Graph 1 in Chapter VII.

2. The simulation is sensitive to the difference between the failure rates which is illustrated in Graph 2 in Chapter VII.

Recommendations

Based on the findings, observations, and analyses of this study the following recommendations are submitted for the reader's consideration:

1. No further sensitivity analysis is required.
2. Capital should be invested in a reliability program as a contract item when electronic equipment is procured.

APPENDIX A

SYSTEM FUNCTIONAL CONFIGURATION

For reliability purposes, Mod III Track is subdivided into specific cabinets or cabinet groupings which have relatively independent operational and failure effect characteristics. The following listings show the units and a discription of the operational characteristics of the equipment. Failure rate calculations are included.

UNITS 1 and 2, TRACK TRANSMITTER

These two units are identical; either unit may be selected as the prime unit at the option of the Track Console Operator. The transmitter accepts coded 14-pulse message groups from the Encoder, Unit 6. The pulses are transformed into 60kw, X-band, RF pulses by a tunable magnetron power oscillator in the main transmitter. Two levels of radiated power are used during normal operation of the transmitter. Radiation is at lower power until the missile has traveled 12 miles when power changeover is controlled by two micro switches on the range servo gear train.

Transmitter Junction Box, Unit 3 (consisting of terminal boards, ledex switch, toggle switches and cabling) provides interconnections between the two Transmitters, Track

Console and Recorder. A failure in this unit shall be assessed to the unit affected, Unit 1 or 2.

UNIT 4, TRACK CONSOLE

The Track Console is primarily used to monitor the condition of the position tracking radar equipment. It is also used as a maintenance device to isolate troubles in a unit, equipment or assembly.

The operation of the Track Console consists of those procedures which must be performed to turn on and adjust the subsystem units and to verify operational status. The latter includes: the monitoring of the controls and indicators for proper position and display; the automatic equipment checkout; and the manual checkout and calibration required to bring the equipment to the standby condition.

UNIT 5, RANGE DATA

The timing pulse generator panels contained in Unit 5 generate the basic timing pulse sequence for the position tracking radar equipment. This unit also contains the range tracking servo which provides the pulse transmitted to return pulse time from which range is derived.

UNIT X5, EXTENDED RANGE DATA

Unit X5 is part of the Extended Range Tracker group which includes Cabinet X6 and X62. The group is an electronic range gate system that provides space launch guidance capabilities beyond the 800-mile-plus limitations of the mechanical data unit in Cabinet 5.

UNIT 6, ENCODER

Timing pulses generated in Unit 5 are used to generate the sequence of pulses designated the ABC pulse repetition frequency. These pulses occur at a rate of approximately 300 Hertz and each pulse initiates transmission of a specific message to the missile.

UNIT X6, EXTENDED RANGE ENCOCER

Unit X6, part of the Extended Range Tracker group, provides the timing for Unit X5.

UNIT 7, ANGLE DATA

Unit 7 contains the angle data handling equipment and part of the range data handling equipment. The latter computes the range of the missile in flight and generates fine and coarse tracking gates which switch on the receiver for reception of the video returns. The angle data handling equipment extracts azimuth and elevation data from angle encoders on the antenna. These encoders derive this data from the physical position of the antenna.

UNIT 8, POWER DISTRIBUTION

Unit 8 controls the distribution of power to all the units of the position tracking equipment. A failure occurring in this unit is assessed with respect to the cabinet or function of the position tracking equipment effected by the malfunction. For example, a failure to circuit breaker number 1 which controls the load to the radome air conditioner would not be assessed as a failure against primary mission objectives since the absence of air conditioning in the radome for the short period that the missile is controlled in flight is considered noncritical. Circuit breaker number 8, however, which controls power flow to the receiver, would be assessed in-line criticality in case of failure.

UNIT 9, CHECKOUT TRANSMITTER

The Checkout Transmitter, Unit 9, is used to simulate beacon response during manual or automatic checkout of the position tracking radar equipment. The maximum power output of the Checkout Transmitter is 1 watt. The power output may be adjusted by a motor driven attenuator controlled by a switch on the Track Console, Unit 4. A coaxial switch couples the output to the boresight tower or to a test horn located between the two monopulse reflectors in the radome.

This transmitter is used to perform system calibration, verification and operation tests. It is not essential to fulfillment of primary mission objectives and, therefore, its failures cannot be included in the assessment of Mod III Track reliability.

UNIT 10, TRANSLATOR

The Translator houses automatic checkout control equipment circuits which simulate the missile decoder and pulse beacon and test message comparator circuits. The purpose of the equipment is to perform an automatic or manual checkout of the position tracking radar equipment on a

Go/No Go basis during countdown or standby. Automatic checkout is accomplished by a series of 13 discrete tests. Although the Translator is a piece of checkout equipment, it does not contribute any in-line functions.

UNIT 11, ANTENNA MOUNT

The Antenna Mount consists primarily of: a conical acquisition antenna; two monopulse reflectors; antenna elevation drive motor; antenna azimuth drive motor; two angle data encoders; mount junction boxes; a camera and the antenna mount proper.

UNIT 12, RF EQUIPMENT

Unit 12 is one part of the receiver group which is a three-channel radar receiver system incorporating the receiver principles of conical scan acquisition and monopulse tracking. The conical scan acquisition mode is used to acquire the missile whereas the monopulse tracking mode provides tracking data after the missile has been acquired.

During monopulse tracking, the nominal 300 pps beacon replies received by the two horns of the monopulse antenna are coupled through waveguides to a magic T comparator. The signals are added, subtracted, phase shifted and finally converted to a 30 mega Hertz IF signal in waveguide mixers and passed through separate monopulse preamplifiers to Receiver Unit 13.

UNIT 13, RECEIVER

The 30 MHz IF signals from the monopulse preamplifiers in Unit 12 are routed through coaxial cables to the monopulse main IF amplifier unit in Unit 13. The separately preamplified signals are routed through separate IF amplifier stages for further amplification before detection.

UNIT 14, RADOME

Unit 14, Radome, is positioned by the Radome servo which is slaved to the antenna azimuth servo in normal operation.

UNIT 15, AZIMUTH MOTOR GENERATOR

Unit 15 provides further amplification of the dc drive signal from the main servo amplifier and in turn supplies power for the motor that drives the antenna in azimuth. The failure of the antenna to be driven in azimuth would cause loss of azimuth data. Therefor, Unit 15 is an In-line item.

UNIT 16, ELEVATION MOTOR GENERATOR

This unit functions in the same manner as Unit 15, except it supplies power for the antenna elevation motors. It also is an In-line item.

UNIT 17, RADOME MOTOR GENERATOR

This unit functions in the same manner as Unit 15, except it supplies power for the motor moving the radome in the azimuth plane. If the radome does not move in the direction of the missile, then the antenna radiation will be obstructed. Consequently, this is an In-line unit.

UNIT 18, GYRO MOTOR GENERATOR

The Gyro Motor Generator provides the excitation for the azimuth and elevation gyros. The gyros and the associated precession amplifiers provide velocity feedback signals. Therefore, it is an In-line unit.

UNIT 19, RADOME AIR CONDITIONER

The entire radome is air conditioned to protect the equipment against dust and changes in temperature. However, lack of air conditioning in the Radome for the short period of a launch vehicle flight is not considered to be critical. Therefore, the unit is regarded as not In-line.

UNIT 20, SERVO CABINET

Unit 20 processes Azimuth, Elevation and Radome error signals and applies error correction signals to the Azimuth, Elevation, and Radome motor-generators (Units 15, 16, and 17) which provide the driving signals for the antenna and radome.

UNIT 21, MOTOR FIELD SUPPLY

The azimuth motor field supply provides 100 volts dc for the field windings of the azimuth drive motor. Loss of this supply would be critical; therefore, Unit 21 is an In-line unit.

UNIT 34, ANTENNA AND BORESIGHT ASSEMBLY

This is checkout equipment used during countdown and other checkout procedures, but not used during the liftoff and flight phases of a mission. Therefore, this equipment is classified as not In-line.

UNIT 29, OPTICAL TRACKER

The Optical Tracker is pointed toward the missile dur-flight by the Optical Tracker Operator (via visual contact). It generates electrical signals corresponding to the azimuth and elevation of the missile. The signals can be manually selected by the Track Console Operator to drive the antenna servo system for acquisition, or reacquisition in case of a failure in the designate mode of operation. For failure assessment purposes, it is classified as not In-line.

UNIT 30, WAVEGUIDE AND CABLE ASSEMBLY

The majority of the waveguide and cables are In-line; however, each is assessed according to the classification of the function it performs.

UNIT 31, TRACK JUNCTION BOX

The majority of Unit 31 is In-line; however, the functions affected by failures in this unit are the basis upon which a failure is assessed.

UNIT 37, VOLTAGE REGULATOR

Unit 37 is a commercial regulator for critical power and classified as In-line.

UNIT 33, RECORDER NO. 1

Unit 33 serves the same as Unit 32.

UNIT 38, FOUNDATION JUNCTION BOX

Most of Unit 38 is In-line; however, each failure in the Junction Box is assessed on the basis of the classification of the function that the cable or item in the Junction Box performs.

UNIT 39, RECORDER NO. 3

Unit 39 serves the same function as Unit 32.

UNIT 50, TEST EQUIPMENT SERIES

The Test Equipment Series is composed of a Range and Timing Simulation, Autosequence Tester, Command Simulator and Receiver Simulator Console. Since this is checkout equipment, it is not In-line.

UNIT 62, EXTENDED RANGE CONSOLE

Unit 62 is an operating console for Units X5 and X6.

UNIT 32, RECORDER NO. 2

Unit 32 is an 8-channel Sanborn Recorder that provides analog data as a check on system performance. The recorder measures eight of the Track parameter for quick-look purposes during the flight phase. Since this equipment performs a monitoring function, it is classified as not In-line for the purposes of failure assessment.

SYSTEM FAILURE RATE CALCULATIONS

The Mod III RGS Track system failure rate is calculated by summing the failure rates of the individual unit cabinets. To calculate a cabinet failure rate, the cumulative number of failures in a cabinet is divided by the cumulative hours of operation of the cabinet.

UNIT	NAME	HOURS	FAILURES	FAILURE RATE
1	Transmitter	3010	1	.0003322
5	Range Data	26072	1	.0000384
6	Encoder	26073	4	.0001534
7	Angle Data	26066	3	.0001151
11	Antenna Mount	25639	5	.0001950
12	RF Equipment	25773	1	.0000388
13	Receiver	25773	6	.0002328
	System Total			.0011057

APPENDIX B

COMPUTER PROGRAM WITH COPPOLA DATA

```
//FORTRVW   JOB (1718,01,$$$$,FTU),'WILLIAMS',CLASS=D                              JOB 445
***JOBPARM CPU=8,ID=7
// EXEC FTGICLG,LIBS='FTU.SS.IRLINK'
//FORT.SYSIN DD *
//GO.SYSIN DD *

***LTODS***  STEP FORT       PROCSTEP              DDNAME SYSPRINT

 FORTRAN IV G1  RELEASE 2.0                MAIN                 DATE = 78141

                    C     INITIAL STATEMENTS
  0001                    DIMENSION V(34)
  0002                    V(1)=6.5/10**6
                    C     FLD FR W/O REL PROG
  0003                    V(2)=13553
                    C     NO PARTS
  0004                    V(3)=564
                    C     NO SYSTEMS
  0005                    V(4)=45.5
                    C     OP HRS/MO (35 FH*1.3)
  0006                    V(5)=250
                    C     COST PER FAILURE
  0007                    V(6)=1.7/10**6
                    C     FLD FR W REL PROG
  0008                    V(7)=2
                    C     COST OF SCREENS/PART
  0009                    V(8)=0.1
                    C     MAT OH
  0010                    V(9)=10
                    C     ENG $/HR
  0011                    V(10)=2.2
                    C     ENG OH FACTOR
  0012                    V(11)=2
                    C     ENG MH/PART FOR REL EFFORT
  0013                    V(12)=7
                    C     QC $/HR
  0014                    V(13)=2.5
                    C     FACTORY OH FACTOR
  0015                    V(14)=1.3
                    C     ADDITIONAL QC MH/PT DUE TO REL PROG
  0016                    V(15)=0.00087
```

```
              C      SPECIAL ASSM/PART
0017                 V(16)=100
              C      BURN-IN HOURS/SPECIAL ASSM
0018                 V(17)=5
              C      $/HR TECHNICIAN
0019                 V(18)=100
              C      PARTS/SPECIAL ASSM
0020                 V(19)=24
              C      ENG HRS/FAIL (REL,PARTS,FAIL ANAL)
0021                 V(20)=5000
              C      RET HRS
0022                 V(21)=7
              C      FR IN ASSM BI&RET/FLD FR
0023                 V(22)=2
              C      SPEC MTBF/FLD MTBF
0024                 V(23)=10.8
              C      TEST HRS IN MULTS OF SPEC MTBF
***LTOP***

FORTRAN IV G1  RELEASE 2.0              MAIN                DATE = 78141

0025                 V(24)=50
              C      SYSTEM BI HRS/EA
0026                 V(25)=3
              C      SYSTEM BI FR/FLD FR
0027                 V(26)=0.15
              C      G&A
0028                 V(27)=0.1
              C      FEE
0029                 V(28)=0.1
              C      LRU NRTS
0030                 V(29)=2
              C      DEPOT TURN AROUND IN MOS
0031                 V(30)=11000
              C      $/SPARE LRU
0032                 V(31)=300
              C      $/SPARE MODULE
0033                 V(32)=0.05
              C      HRS ASSN BI/DAY
0034                 V(34)=2
              C      CALENDAR TIME/RET & ROT"ON" TIME
0035                 V(33)=0.23
              C      NO SEMICONDUCTORS/TOTAL PARTS
```

```
      DO 16 L=1,3
      IF(L-2)23,14,13
   13 V(2)=3293
      V(3)=325
      V(30)=8000
      V(33)=0.27
      PRINT 22
   22 FORMAT(7H CASE 2/)
      GO TO 23
   14 V(2)=11545
      V(3)=335
      V(30)=22000
      V(33)=0.36
      PRINT 33
   33 FORMAT(7H CASE 3/)
   23 CONTINUE
      DO 15 N=1,35
      IF(N-1)20,20,10
   10 V(N-1)=V(N-1)*2
   20 CONTINUE
      CO=V(1)*V(2)*V(3)*V(4)*12*V(5)
      CN=V(6)*V(2)*V(3)*V(4)*12*V(5)
      CM=V(2)*V(3)*V(7)*(1+V(8))*V(33)
      CL=V(9)*V(10)*V(11)*V(2)+V(12)*V(13)*V(14)*V(2)
      G=V(2)*V(3)*V(15)*V(16)
      H=V(32)*V(17)*V(13)+V(6)*V(21)*V(18)*V(9)*V(10)*V(19)
*LTOP***

FORTRAN IV G1  RELEASE 2.0              MAIN                DATE = 78141

      CABI=G*H
      AX=V(17)*V(13)*V(34)+V(6)*V(21)*V(2)*V(9)*V(10)*V(19)
      CRET=V(20)*AX
      AA=1/(V(6)*V(2))*V(22)*V(23)
      AB=V(17)*V(13)*V(34)+V(6)*V(9)*V(10)*V(19)*V(2)
      CRQT=AA*AB
      CSHI=V(3)*V(24)*(V(17)*V(13)+V(9)*V(10)*V(19)*V(6)*V(25)*V(2))
      C1=CABI+CRET+CRQT+CSHI
      CR=(CM+CL+CT)*(1+V(26))*(1+V(27))
      SO=V(1)*V(2)*V(3)*V(4)*V(28)*V(29)
      SO2=V(1)*V(2)*V(3)*V(4)*(1-V(28))*V(29)
      SN=V(6)*V(2)*V(3)*V(4)*V(28)*V(29)
```

```
      SN2=V(6)*V(2)*V(3)*V(4)*(1-V(28))*V(29)
      SS=V(30)*(SO-SN)+V(31)*(SO2-SN2)
      CI=CR-SS
      ROI1=(CO-CN)/CR
      ROI2=(CO-CN)/CI
      YP1=1/ROI1
      YP2=1/ROI2
      IF(N-1)30,30,40
   30 CRB=CR
      CIB=CI
      ROI1B=ROI1
      YP1B=YP1
      ROI2B=ROI2
      YP2B=YP2
      PRINT 44
   44 FORMAT(45H     CM                CL              CT                SS/)
      PRINT 75,CM,CL,CT,SS
   75 FORMAT(1X,4(F12.1,1X))
      PRINT 66
   66 FORMAT(19H     CO                CN/)
      PRINT 76,CO,CN
   76 FORMAT(1X,2(F12.1,1X))
      PRINT 88
   88 FORMAT(47H     CABI              CRET            CRQT              CSBI/)
      PRINT 77,CABI,CRET,CRQT,CSBI
   77 FORMAT(1X,4(F12.1))
      PRINT 99
   99 FORMAT(59H       CR              ROI1      YP1         CI          ROI2
     1YP2/)
      PRINT 50,CR,ROI1,YP1,CI,ROI2,YP2
   50 FORMAT(3X,2(F12.0,F8.3,F8.3))
      PRINT 11
   11 FORMAT(34H  RESULTS OF DOUBLING ONE VARIABLE/)
      GO TO 15
   40 CONTINUE
      K=N-1
**LTOP***
```

FORTRAN IV G1 RELEASE 2.0 MAIN DATE = 78141

```
      PRINT 55,K,CR,ROI1,YP1,CI,ROI2,YP2
   55 FORMAT(1X,I2,2(F12.0,F8.3,F8.3))
      A=CR/CRB
      B=ROI1/ROI1B
      C=YP1/YP1B
      D=CI/CIB
      E=ROI2/ROI2B
      F=YP2/YP2B
      PRINT 65,A,B,C,D,E,F
   65 FORMAT(1X,5HRATIO.3(F8.3),6X,3(F8.3))
      V(N-1)=V(N-1)/2
   15 CONTINUE
   16 CONTINUE
      STOP
      END
***LTOP***

 FORTRAN IV G1  RELEASE 2.0              MAIN                 DATE = 78141

   *OPTIONS IN EFFECT*  NOTERM,NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
   *OPTIONS IN EFFECT*  NAME = MAIN     , LINECNT =        50
   *STATISTICS*    SOURCE STATEMENTS =       123,PROGRAM SIZE =      2990
   *STATISTICS*  NO DIAGNOSTICS GENERATED

***LTODS***  STEP LKED      PROCSTEP             DDNAME SYSPRINT

 F88-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED LIST,LET
          DEFAULT OPTION(S) USED -  SIZE=(116736,34816)
****GO        DOES NOT EXIST BUT HAS BEEN ADDED TO DATA SET


***LTODS***  STEP GO        PROCSTEP             DDNAME FT06F001

   CM             CL            CT            SS

   3867805.0      904662.3     2800773.0     4574224.0
   CO             CN

   6782039.0      1773763.0
   CABI           CRET          CROT          CSBI

    833479.9      550780.7      34842.2    1381671.0
```

	CR	ROI1	YP1	CI	ROI2	YP2
	9580140.	0.523	1.913	5105916.	1.000	1.000

RESULTS OF DOUBLING ONE VARIABLE

	CR	ROI1	YP1	CI	ROI2	YP2
1	9580140.	1.231	0.813	-1188345.	-9.922	-0.101
RATIO	1.000	2.354	0.425	-0.237	-9.917	-0.101
2	18497328.	0.542	1.847	9348881.	1.071	0.933
RATIO	1.931	1.036	0.965	1.868	1.071	0.934
3	17275072.	0.580	1.725	8126625.	1.233	0.811
RATIO	1.803	1.109	0.902	1.623	1.232	0.812
4	9580140.	1.046	0.956	431693.	23.203	0.043
RATIO	1.000	2.000	0.500	0.086	23.192	0.043
5	9580140.	1.046	0.956	5005916.	2.001	0.500
RATIO	1.000	2.000	0.500	1.000	2.000	0.500
6	11934399.	0.271	3.690	8980212.	0.360	2.776
RATIO	1.246	0.518	1.929	1.794	0.360	2.778
7	14472913.	0.346	2.890	9898689.	0.506	1.976
RATIO	1.511	0.662	1.511	1.977	0.506	1.977
8	10024938.	0.500	2.002	5450714.	0.919	1.088
RATIO	1.046	0.956	1.046	1.089	0.918	1.089
9	12718009.	0.394	2.539	8143785.	0.615	1.626
RATIO	1.328	0.753	1.328	1.627	0.615	1.627
10	12718009.	0.394	2.539	8143785.	0.615	1.626
RATIO	1.328	0.753	1.328	1.627	0.615	1.627
11	10334497.	0.485	2.063	5760273.	0.869	1.150
RATIO	1.079	0.927	1.079	1.151	0.869	1.151
12	9970178.	0.502	1.991	5395954.	0.928	1.077
RATIO	1.041	0.961	1.041	1.078	0.928	1.078
13	11129642.	0.450	2.222	6555418.	0.764	1.309
RATIO	1.162	0.861	1.162	1.310	0.764	1.310
14	9970178.	0.502	1.991	5395954.	0.928	1.077
RATIO	1.041	0.961	1.041	1.078	0.928	1.078
15	10634490.	0.471	2.123	6060266.	0.826	1.210
RATIO	1.110	0.901	1.110	1.211	0.826	1.211
16	10634489.	0.471	2.123	6060265.	0.826	1.210
RATIO	1.110	0.901	1.110	1.211	0.826	1.211
17	10739603.	0.466	2.144	6165379.	0.812	1.231
RATIO	1.121	0.892	1.121	1.232	0.812	1.232
18	10108712.	0.495	2.018	5534488.	0.905	1.105
RATIO	1.055	0.948	1.055	1.106	0.904	1.106

```
19     11963652.     0.419     2.339       7389428.     0.678     1.475
RATIO     1.249     0.801     1.249           1.476     0.677     1.476
20     10276875.     0.487     2.052       5702651.     0.878     1.139
RATIO     1.073     0.932     1.073           1.139     0.878     1.139
21     10647324.     0.470     2.126       6073100.     0.825     1.213
RATIO     1.111     0.900     1.111           1.213     0.824     1.213
22      9624215.     0.520     1.922       5049991.     0.992     1.008
RATIO     1.005     0.995     1.005           1.009     0.991     1.009
23      9624215.     0.520     1.922       5049991.     0.992     1.008
RATIO     1.005     0.995     1.005           1.009     0.991     1.009
24     11327953.     0.442     2.262       6753729.     0.742     1.349
RATIO     1.182     0.846     1.182           1.349     0.741     1.349
25     10882040.     0.460     2.173       6307816.     0.794     1.259
RATIO     1.136     0.880     1.136           1.260     0.794     1.260
26     10829720.     0.462     2.162       6255496.     0.801     1.249
RATIO     1.130     0.885     1.130           1.250     0.800     1.250
27     10451065.     0.479     2.087       5876841.     0.852     1.173
RATIO     1.091     0.917     1.091           1.174     0.852     1.174
28      9580140.     0.523     1.913       1433347.     3.494     0.286
RATIO     1.000     1.000     1.000           0.286     3.492     0.286
29      9580140.     0.523     1.913        431693.    11.601     0.086
RATIO     1.000     1.000     1.000           0.086    11.596     0.086
30      9580140.     0.523     1.913       1333181.     3.757     0.266
RATIO     1.000     1.000     1.000           0.266     3.755     0.266
31      9580140.     0.523     1.913       4104427.     1.220     0.820
RATIO     1.000     1.000     1.000           0.820     1.220     0.820
32     10105918.     0.496     2.018       5531694.     0.905     1.105
RATIO     1.055     0.948     1.055           1.105     0.905     1.105
33     14472909.     0.346     2.890       9898685.     0.506     1.976
RATIO     1.511     0.662     1.511           1.977     0.506     1.977
34      9767912.     0.513     1.950       5193686.     0.964     1.037
RATIO     1.020     0.981     1.020           1.038     0.964     1.038
CASE 3

   CM              CL             CT               SS

   3063117.0        770628.4      1678435.0        4172707.0
   CO              CN

   3431502.0        897470.2
   CABI            CRET           CROT             CSBI

    421715.4       487697.2        38918.6      730104.3
    CR             ROI1      YP1          CI           ROI2        YP2
```

	6972900.	0.363	2.752	2800193.	0.905	1.105

RESULTS OF DOUBLING ONE VARIABLE

1	6972900.	0.356	1.169	-2850348.	-2.093	-0.478
RATIO	1.000	2.354	0.425	-1.018	-2.313	-0.432
2	13456180.	0.377	2.655	5110764.	0.992	1.008
RATIO	1.930	1.036	0.965	1.825	1.096	0.913
3	12304787.	0.412	2.428	3959371.	1.280	0.781
RATIO	1.765	1.133	0.882	1.414	1.414	0.707
4	6972900.	0.727	1.376	-1372509.	-3.693	-0.271
RATIO	1.000	2.000	0.500	-0.490	-4.080	-0.245
5	6972900.	0.727	1.376	2800193.	1.810	0.553
RATIO	1.000	2.000	0.500	1.000	2.000	0.500
6	8340472.	0.196	5.095	5645599.	0.290	3.450
RATIO	1.196	0.540	1.852	2.016	0.320	3.122
7	10847737.	0.234	4.281	6675030.	0.380	2.634
RATIO	1.556	0.643	1.556	2.384	0.420	2.384
8	7325161.	0.346	2.891	3152454.	0.804	1.244
RATIO	1.051	0.952	1.051	1.126	0.888	1.126
9	9014897.	0.281	3.558	4842190.	0.523	1.911
RATIO	1.293	0.773	1.293	1.729	0.578	1.729
10	9014897.	0.281	3.558	4842190.	0.523	1.911
RATIO	1.293	0.773	1.293	1.729	0.578	1.729
11	7615495.	0.333	3.005	3442788.	0.736	1.359
RATIO	1.092	0.916	1.092	1.229	0.813	1.229
12	7305152.	0.347	2.883	3132445.	0.809	1.236
RATIO	1.048	0.955	1.048	1.119	0.894	1.119
13	8028967.	0.316	3.168	3856260.	0.657	1.522
RATIO	1.151	0.868	1.151	1.377	0.726	1.377
14	7305152.	0.347	2.883	3132445.	0.809	1.236
RATIO	1.048	0.955	1.048	1.119	0.894	1.119
15	7506368.	0.338	2.962	3333661.	0.760	1.316
RATIO	1.077	0.929	1.077	1.191	0.840	1.191
16	7506369.	0.338	2.962	3333662.	0.760	1.316
RATIO	1.077	0.929	1.077	1.191	0.840	1.191
17	7696716.	0.329	3.037	3524009.	0.719	1.391
RATIO	1.104	0.906	1.104	1.258	0.795	1.258
18	7240341.	0.350	2.857	3067634.	0.826	1.211
RATIO	1.038	0.963	1.038	1.096	0.913	1.096

```
19       8372303.   0.303    3.304      4199596.    0.603    1.657
RATIO     1.201     0.833    1.201          1.500    0.667    1.500
20       7589836.   0.334    2.995      3417129.    0.742    1.345
RATIO     1.038     0.919    1.088          1.220    0.819    1.220
21       7699153.   0.329    3.038      3526446.    0.719    1.392
RATIO     1.104     0.906    1.104          1.259    0.794    1.259
22       7022133.   0.361    2.771      2849426.    0.889    1.124
RATIO     1.007     0.993    1.007          1.018    0.983    1.018
23       7022133.   0.361    2.771      2849426.    0.889    1.124
RATIO     1.007     0.993    1.007          1.018    0.983    1.018
24       7696482.   0.321    3.116      3723775.    0.681    1.470
RATIO     1.132     0.883    1.132          1.330    0.752    1.330
25       7631623.   0.332    3.012      3458916.    0.733    1.365
RATIO     1.094     0.914    1.094          1.235    0.810    1.235
26       7862407.   0.321    3.111      3709700.    0.683    1.464
RATIO     1.130     0.885    1.130          1.325    0.755    1.325
27       7606803.   0.333    3.002      3434096.    0.738    1.355
RATIO     1.091     0.917    1.091          1.226    0.815    1.226
28       6972900.   0.363    2.752      -865703.   -2.927   -0.342
RATIO     1.000     1.000    1.000         -6.309   -3.235   -0.309
29       6972900.   0.363    2.752     -1372509.   -1.846   -0.542
RATIO     1.000     1.000    1.000         -0.490   -2.040   -0.490
30       6972900.   0.363    2.752      -916390.   -2.765   -0.362
RATIO     1.000     1.000    1.000         -0.327   -3.056   -0.327
31       6972900.   0.363    2.752      2344067.    1.081    0.925
RATIO     1.000     1.000    1.000          0.837    1.195    0.837
32       7238927.   0.350    2.857      3066220.    0.826    1.210
RATIO     1.038     0.963    1.038          1.095    0.913    1.095
33      10847742.   0.234    4.281      6675035.    0.380    2.634
RATIO     1.556     0.643    1.556          2.384    0.420    2.384
34       7165830.   0.354    2.828      2993123.    0.847    1.181
RATIO     1.028     0.973    1.028          1.069    0.936    1.069
CASE 2

   CM               CL              CT                SS

   635713.1         219807.6       800234.5         500197.1
   CO               CN

   949556.4         248345.2
   CABI             CRET           CRQT              CSBI

   116695.9         228452.7       107866.1      347219.7
   CR               ROI1       YP1         C1          ROI2       YP2
```

	2094527.	0.335	2.987	1594329.	0.440	2.274

RESULTS OF DOUBLING ONE VARIABLE

1	2094527.	0.788	1.269	916980.	1.800	0.555
RATIO	1.000	2.354	0.425	0.575	4.093	0.244
2	3576516.	0.392	2.550	2576121.	0.544	1.837
RATIO	1.708	1.171	0.854	1.616	1.238	0.808
3	3485556.	0.402	2.485	2485161.	0.564	1.772
RATIO	1.664	1.202	0.832	1.559	1.283	0.779
4	2094527.	0.670	1.494	1094132.	1.282	0.780
RATIO	1.000	2.000	0.500	0.686	2.914	0.343
5	2094527.	0.670	1.494	1594329.	0.880	1.137
RATIO	1.000	2.000	0.500	1.000	2.000	0.500
6	2420667.	0.187	5.345	2097623.	0.216	4.632
RATIO	1.156	0.559	1.789	1.316	0.491	2.037
7	2898703.	0.242	4.134	2398505.	0.292	3.421
RATIO	1.334	0.723	1.384	1.504	0.665	1.504
8	2167634.	0.323	3.091	1667436.	0.421	2.378
RATIO	1.035	0.966	1.035	1.046	0.956	1.046
9	2679395.	0.262	3.821	2179197.	0.322	3.108
RATIO	1.279	0.782	1.279	1.367	0.732	1.367
10	2679395.	0.262	3.821	2179197.	0.322	3.108
RATIO	1.279	0.782	1.279	1.367	0.732	1.367
11	2277816.	0.308	3.248	1777618.	0.394	2.535
RATIO	1.088	0.920	1.088	1.115	0.897	1.115
12	2189294.	0.320	3.122	1689096.	0.415	2.409
RATIO	1.045	0.957	1.045	1.059	0.944	1.059
13	2800011.	0.250	3.993	2299813.	0.305	3.280
RATIO	1.337	0.748	1.337	1.442	0.693	1.442
14	2189294.	0.320	3.122	1689096.	0.415	2.409
RATIO	1.045	0.957	1.045	1.059	0.944	1.059
15	2242147.	0.313	3.198	1741949	0.403	2.484
RATIO	1.070	0.934	1.070	1.093	0.915	1.093
16	2242147.	0.313	3.198	1741949.	0.403	2.484
RATIO	1.070	0.934	1.070	1.093	0.915	1.093
17	2705242.	0.259	3.858	2205904.	0.318	3.145
RATIO	1.292	0.774	1.292	1.383	0.723	1.383
18	2168532.	0.323	3.093	1668334.	0.420	2.379
RATIO	1.035	0.966	1.035	1.046	0.956	1.046

19	2496106.	0.281	3.560	1995908.	0.351	2.846
RATIO	1.192	0.839	1.192	1.252	0.799	1.252
20	2383519.	0.294	3.399	1883321.	0.372	2.686
RATIO	1.138	0.879	1.138	1.181	0.847	1.181
21	2299400.	0.305	3.279	1799202.	0.390	2.566
RATIO	1.098	0.911	1.098	1.129	0.886	1.128
22	2230978.	0.314	3.182	1730780.	0.405	2.468
RATIO	1.065	0.939	1.065	1.086	0.921	1.086
23	2230978.	0.314	3.182	1730780.	0.405	2.468
RATIO	1.065	0.939	1.065	1.086	0.921	1.086
24	2533759.	0.277	3.613	2033561.	0.345	2.900
RATIO	1.210	0.827	1.210	1.275	0.784	1.275
25	2276806.	0.308	3.247	1776608.	0.395	2.534
RATIO	1.087	0.920	1.087	1.114	0.897	1.114
26	2367725.	0.296	3.377	1867528.	0.375	2.663
RATIO	1.130	0.885	1.130	1.171	0.854	1.171
27	2284940.	0.307	3.259	1784742.	0.393	2.545
RATIO	1.091	0.917	1.091	1.119	0.893	1.119
28	2094527.	0.335	2.987	1234374.	0.568	1.760
RATIO	1.000	1.000	1.000	0.774	1.292	0.774
29	2094527.	0.335	2.987	1094132.	0.641	1.560
RATIO	1.000	1.000	1.000	0.686	1.457	0.686
30	2094527.	0.335	2.987	1220350.	0.575	1.740
RATIO	1.000	1.000	1.000	0.765	1.306	0.765
31	2094527.	0.335	2.987	1468112.	0.478	2.094
RATIO	1.000	1.000	1.000	0.921	1.086	0.921
32	2168141.	0.323	3.092	1667943.	0.420	2.379
RATIO	1.035	0.966	1.035	1.046	0.956	1.046
33	2898703.	0.242	4.134	2398505.	0.292	3.421
RATIO	1.384	0.723	1.384	1.504	0.665	1.504
34	2374675.	0.295	3.387	1874477.	0.374	2.673
RATIO	1.134	0.882	1.134	1.176	0.851	1.176

APPENDIX C

COMPUTER PROGRAM WITH MOD III TRACK RADAR DATA

```
//FORTRVW  JOB (1718,01,$$$$,FTU),'WILLIAMS',CLASS=D                  JOB 471
***JOBPARM CPU=8,IO=7
// EXEC FTG1CLG,LIB5='FTU.SS.IRLINK'
//FORT.SYSIN DD *
//GO.SYSIN DD *

***LTODS***  STEP FORT        PROCSTEP           DDNAME SYSPRINT

  FORTRAN IV G1  RELEASE 2.0                    MAIN            DATE = 78141

                      C       INITIAL STATEMENTS
  0001                        DIMENSION V(34)
  0002                        V(1)=10.86/10**6
                      C       FLD FR W/O REL PROG
  0003                        V(2)=16953
                      C       NO PARTS
  0004                        V(3)=1
                      C       NO SYSTEMS
  0005                        V(4)=120
                      C       OP HRS/MO (35 FH*1.3)
  0006                        V(5)=250
                      C       COST PER FAILURE
  0007                        V(6)=5.9/10**8
                      C       FLD FR W REL PROG
  0008                        V(7)=2
                      C       COST OF SCREENS/PART
  0009                        V(8)=0.1
                      C       MAT OH
  0010                        V(9)=10
                      C       ENG $/HR
  0011                        V(10)=2.2
                      C       ENG OH FACTOR
  0012                        V(11)=2
                      C       ENG MH/PART FOR REL EFFORT
  0013                        V(12)=7
                      C       QC $/HR
  0014                        V(13)=2.5
                      C       FACTORY OH FACTOR
  0015                        V(14)=1.3
                      C       ADDITIONAL QC MH/PT DUE TO REL PROG
  0016                        V(15)=0.00087
```

```
                C      SPECIAL ASSM/PART
0017                   V(16)=100
                C      BURN-IN HOURS/SPECIAL ASSM
0018                   V(17)=5
                C      $/HR TECHNICIAN
0019                   V(18)=100
                C      PARTS/SPECIAL ASSM
0020                   V(19)=24
                C      ENG HRS/FAIL (REL.PARTS.FAIL ANAL)
0021                   V(20)=5000
                C      RET HRS
0022                   V(21)=7
                C      FR IN ASSM BI&RET/FLD FR
0023                   V(22)=2
                C      SPEC MTBF/FLD MTBF
0024                   V(23)=10.8
                C      TEST HRS IN MULTS OF SPEC MTBF
***LTOP***
FORTRAN IV G1  RELEASE 2.0              MAIN                 DATE = 78141
0025                   V(24)=50
                C      SYSTEM BI HRS/EA
0026                   V(25)=3
                C      SYSTEM BI FR/FLD FR
0027                   V(26)=0.15
                C      G&A
0028                   V(27)=0.1
                C      FEE
0029                   V(28)=0.1
                C      LRU NRTS
0030                   V(29)=2
                C      DEPOT TURN AROUND IN MOS
0031                   V(30)=11000
                C      $/SPARE LRU
0032                   V(31)=300
                C      $/SPARE MODULE
0033                   V(32)=0.05
                C      HRS ASSN BI/DAY
0034                   V(34)=2
                C      CALENDAR TIME/RET & RQT"ON" TIME
0035                   V(33)=0.23
                C      NO SEMICONDUCTORS/TOTAL PARTS
```

```
      DO 16 L=1,3
      IF(L-2)23,14,13
   13 V(2)=3293
      V(3)=325
      V(30)=8000
      V(33)=0.27
      PRINT 22
   22 FORMAT(7H CASE 2/)
      GO TO 23
   14 V(2)=18753
      V(3)=1
      V(30)=22000
      V(33)=0.36
      PRINT 33
   33 FORMAT(7H CASE 3/)
   23 CONTINUE
      DO 15 N=1,35
      IF(N-1)20,20,10
   10 V(N-1)=V(N-1)*2
   20 CONTINUE
      CO=V(1)*V(2)*V(3)*V(4)*12*V(5)
      CN=V(6)*V(2)*V(3)*V(4)*12*V(5)
      CM=V(2)*V(3)*V(7)*(1+V(8))*V(33)
      CL=V(9)*V(10)*V(11)*V(2)+V(12)*V(13)*V(14)*V(2)
      G=V(2)*V(3)*V(15)*V(16)
      H=V(32)*V(17)*V(13)+V(6)*V(21)*V(18)*V(9)*V(10)*V(19)
*LIOP***

FORTRAN IV G1  RELEASE 2.0              MAIN              DATE = 78141

      CABI=G*H
      AX=V(17)*V(13)*V(34)+V(6)*V(21)*V(2)*V(9)*V(10)*V(19)
      CRET=V(20)*AX
      AA=1/(V(6)*V(2))*V(22)*V(23)
      AB=V(17)*V(13)*V(34)+V(6)*V(9)*V(10)*V(19)*V(2)
      CROT=AA*AB
      CSBI=V(3)*V(24)*(V(17)*V(13)+V(9)*V(10)*V(19)*V(6)*V(25)*V(2))
      CT=CABI+CRET+CROT+CSBI
      CR=(CM+CL+CT)*(1+V(26))*(1+V(27))
      SO=V(1)*V(2)*V(3)*V(4)*V(28)*V(29)
      SO2=V(1)*V(2)*V(3)*V(4)*(1-V(28))*V(29)
      SN=V(6)*V(2)*V(3)*V(4)*V(28)*V(29)
```

```
      SN2=V(6)*V(2)*V(3)*V(4)*(1-V(28))*V(29)
      SS=V(30)*(S0-SN)+V(31)*(S02-SN2)
      CI=CR-SS
      ROI1=(CO-CN)/CR
      ROI2=(CO-CN)/CI
      YP1=1/ROI1
      YP2=1/ROI2
      IF(N-1)30,30,40
   30 CRB=CR
      CIP=CI
      ROI1B=ROI1
      YP1B=YP1
      ROI2B=ROI2
      YP2B=YP2
      PRINT 44
   44 FORMAT(45H    CM              CL              CT              SS/)
      PRINT 75,CM,CL,CT,SS
   75 FORMAT(1X,4(F12.1,1X))
      PRINT 66
   66 FORMAT(19H    CO              CN/)
      PRINT 76,CO,CN
   76 FORMAT(1X,2(F12.1,1X))
      PRINT 88
   88 FORMAT(47H    CABI            CRET            CRQT            CSBI/)
      PRINT 77,CABI,CRET,CRQT,CSBI
   77 FORMAT(1X,4(F12.1))
      PRINT 99
  990FORMAT(59H      CR             ROI1      YP1         CI           ROI2
     1YP2/)
      PRINT 50,CR,ROI1,YP1,CI,ROI2,YP2
   50 FORMAT(3X,2(F12.0,F8.3,F6.3))
      PRINT 11
   11 FORMAT(34H  RESULTS OF DOUBLING ONE VARIABLE/)
      GO TO 15
   40 CONTINUE
      K=N-1
**LTOP***
```

FORTRAN IV G1 RELEASE 2.0 MAIN DATE = 78141

```
      PRINT 55,K,CP,ROI1,YP1,CI,ROI2,YP2
   55 FORMAT(1X,I2,2(F12.0,F8.3,F8.3))
      A=CR/CRB
      B=ROI1/ROI1B
      C=YP1/YP1B
      D=CI/CIB
      E=ROI2/ROI2B
      F=YP2/YP2B
      PRINT 65,A,B,C,D,E,F
   65 FORMAT(1X,5HRATIO.3(F8.3),6X,3(F8.3))
      V(N-1)=V(N-1)/2
   15 CONTINUE
   16 CONTINUE
      STOP
      END
***LTOP***

 FORTRAN IV G1  RELEASE 2.0               MAIN                DATE = 78141

   *OPTIONS IN EFFECT*  NOTERM,NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
   *OPTIONS IN EFFECT*  NAME = MAIN     , LINECNT =        50
   *STATISTICS*    SOURCE STATEMENTS =        123,PROGRAM SIZE =      3006
   *STATISTICS*  NO DIAGNOSTICS GENERATED

***LTODS***  STEP LKED     PROCSTEP           DDNAME SYSPRINT

 F88-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED LIST,LET
          DEFAULT OPTION(S) USED -   SIZE=(116736,34816)
****GO          DOES NOT EXIST BUT HAS BEEN ADDED TO DATA SET


***LTODS***  STEP GO       PROCSTEP           DDNAME FT06F001

  CM            CL            CT            SS

 CO 8578.2      1131612.0     696424.1      276.5
                CN
 CABI 662.8     CRET 360.1    CROT          CSBI

     954.0      143484.1      551281.9      704.2
```

```
    CR              ROI1      YP1         CI           ROI2       YP2

     2323314.   0.0007674.980     2323037.    0.0007674.066
 RESULTS OF DOUBLING ONE VARIABLE

  1    2323314.   0.0002406.315     2322432.    0.0002405.402
 RATIO   1.000   3.190    0.314          1.000   3.190    0.313
  2    3448868.   0.0005696.602     3448315.    0.0005695.687
 RATIO   1.484   1.347    0.742          1.484   1.347    0.742
  3    2336262.   0.0003858.879     2335709.    0.0003857.964
 RATIO   1.006   1.989    0.503          1.005   1.989    0.503
  4    2323314.   0.0003837.492     2322761.    0.0003836.580
 RATIO   1.000   2.000    0.500          1.000   2.000    0.500
  5    2323314.   0.0003837.492     2323037.    0.0003837.036
 RATIO   1.000   2.000    0.500          1.000   2.000    0.500
  6    2005366.  -0.000********     2005418.   -0.000********
 RATIO   0.863  -0.220   -4.554          0.863  -0.220   -4.555
  7    2334165.   0.0007710.820     2333888.    0.0007709.906
 RATIO   1.005   0.995    1.005          1.005   0.995    1.005
  8    2324300.   0.0007678.230     2324023.    0.0007677.316
 RATIO   1.000   1.000    1.000          1.000   1.000    1.000
  9    3304865.   0.000********     3304588.    0.000********
 RATIO   1.422   0.703    1.422          1.423   0.703    1.423
 10    3304865.   0.000********     3304588.    0.000********
 RATIO   1.422   0.703    1.422          1.423   0.703    1.423
 11    3266914.   0.000********     3266637.    0.000********
 RATIO   1.406   0.711    1.406          1.406   0.711    1.406
 12    2811199.   0.0009286.684     2810922.    0.0009285.770
 RATIO   1.210   0.826    1.210          1.210   0.826    1.210
 13    3654223.   0.000********     3653946.    0.000********
 RATIO   1.573   0.636    1.573          1.573   0.636    1.573
 14    2811199.   0.0009286.684     2810922.    0.0009285.770
 RATIO   1.210   0.826    1.210          1.210   0.826    1.210
 15    2324520.   0.0007678.957     2324243.    0.0007678.043
 RATIO   1.001   0.999    1.001          1.001   0.999    1.001
 16    2324520.   0.0007678.957     2324243.    0.0007678.043
 RATIO   1.001   0.999    1.001          1.001   0.999    1.001
 17    3166338.   0.000********     3166061.    0.000********
 RATIO   1.363   0.734    1.363          1.363   0.734    1.363
 18    2323354.   0.0007675.105     2323077.    0.0007674.191
 RATIO   1.000   1.000    1.000          1.000   1.000    1.000
```

```
19       2361264.    0.0007800.340       2360987.     0.0007799.426
RATIO      1.016    0.984     1.016           1.016     0.984    1.016
20       2504820.    0.0008274.570       2504543.     0.0008273.656
RATIO      1.078    0.928     1.078           1.078     0.928    1.078
21       2346736.    0.0007752.348       2346459.     0.0007751.434
RATIO      1.010    0.990     1.010           1.010     0.990    1.010
22       3020685.    0.0009978.711       3020408.     0.0009977.797
RATIO      1.300    0.769     1.300           1.300     0.769    1.300
23       3020684.    0.0009978.707       3020407.     0.0009977.793
RATIO      1.300    0.769     1.300           1.300     0.769    1.300
24       2324204.    0.0007677.914       2323927.     0.0007677.000
RATIO      1.000    1.000     1.000           1.000     1.000    1.000
25       2323414.    0.0007675.305       2323137.     0.0007674.391
RATIO      1.000    1.000     1.000           1.000     1.000    1.000
26       2626354.    0.0008676.055       2626077.     0.0008675.141
RATIO      1.130    0.885     1.130           1.130     0.885    1.130
27       2534525.    0.0008372.699       2534248.     0.0008371.785
RATIO      1.091    0.917     1.091           1.091     0.917    1.091
28       2323314.    0.0007674.973       2322821.     0.0007673.344
RATIO      1.000    1.000     1.000           1.000     1.000    1.000
29       2323314.    0.0007674.973       2322761.     0.0007673.148
RATIO      1.000    1.000     1.000           1.000     1.000    1.000
30       2323314.    0.0007674.973       2322815.     0.0007673.324
RATIO      1.000    1.000     1.000           1.000     1.000    1.000
31       2323314.    0.0007674.973       2322983.     0.0007673.679
RATIO      1.000    1.000     1.000           1.000     1.000    1.000
32       2324479.    0.0007678.824       2324202.     0.0007677.906
RATIO      1.001    0.999     1.001           1.001     0.999    1.000
33       2334165.    0.0007710.820       2333888.     0.0007709.906
RATIO      1.005    0.995     1.005           1.005     0.995    1.005
34       3164382.    0.000********       3164105.     0.000********
RATIO      1.362    0.734     1.362           1.362     0.734    1.362
CASE 3

   CM               CL              CT                SS

   CO 14852.4       1251762.0       646676.6          551.4
                    CN

   CABI 733.2       CRET 398.3      CRQT              CSRI

   CR 1055.3        145446.7        499462.0          712.6
                    ROI1      YP1        CI           ROI2       YP2
```

```
          2420308.   0.0007227.957      2419756.     0.0007226.309
RESULTS OF DOUBLING ONE VARIABLE

 1        2420308.   0.0002266.162      2418549.     0.0002264.516
RATIO       1.000    3.190    0.314        1.000      3.191    0.313
 2        3741198.   0.0005586.301      3740085.     0.0005584.656
RATIO       1.546    1.294    0.773        1.546      1.294    0.773
 3        2441333.   0.0003645.376      2440230.     0.0003643.727
RATIO       1.009    1.983    0.504        1.008      1.983    0.504
 4        2420308.   0.0003613.981      2419205.     0.0003612.334
RATIO       1.000    2.000    0.500        1.000      2.000    0.500
 5        2420308.   0.0003613.981      2419756.     0.0003613.157
RATIO       1.000    2.000    0.500        1.000      2.000    0.500
 6        2137634.  -0.000########      2137738.    -0.000########
RATIO       0.883   -0.215   -4.660        0.883     -0.215   -4.662
 7        2439096.   0.0007284.066      2438544.     0.0007282.418
RATIO       1.008    0.992    1.008        1.008      0.992    1.008
 8        2422017.   0.0007233.062      2421465.     0.0007231.414
RATIO       1.001    0.999    1.001        1.001      0.999    1.001
 9        3504547.   0.000########      3503995.     0.000########
RATIO       1.448    0.691    1.448        1.448      0.691    1.448
10        3504547.   0.000########      3503995.     0.000########
RATIO       1.448    0.691    1.448        1.448      0.691    1.448
11        3464097.   0.000########      3463545.     0.000########
RATIO       1.431    0.699    1.431        1.431      0.699    1.431
12        2959996.   0.0008839.672      2959444.     0.0008838.023
RATIO       1.223    0.818    1.223        1.223      0.818    1.223
13        3737593.   0.000########      3737041.     0.000########
RATIO       1.544    0.648    1.544        1.544      0.648    1.544
14        2959996.   0.0008839.672      2959444.     0.0008838.023
RATIO       1.223    0.818    1.223        1.223      0.818    1.223
15        2421644.   0.0007231.949      2421092.     0.0007230.301
RATIO       1.001    0.999    1.001        1.001      0.999    1.001
16        2421644.   0.0007231.949      2421092.     0.0007230.301
RATIO       1.001    0.999    1.001        1.001      0.999    1.001
17        3197906.   0.0009550.164      3197354.     0.0009548.516
RATIO       1.321    0.757    1.321        1.321      0.757    1.321
18        2420355.   0.0007228.098      2419803.     0.0007226.449
RATIO       1.000    1.000    1.000        1.000      1.000    1.000
```

```
19      2460758.   0.0007348.758      2460206.     0.0007347.109
RATIO    1.017    0.984    1.017            1.017    0.984    1.017
20      2604299.   0.0007777.426      2603747.     0.0007775.777
RATIO    1.076    0.929    1.076            1.076    0.929    1.076
21      2446219.   0.0007305.340      2445667.     0.0007303.691
RATIO    1.011    0.989    1.011            1.011    0.989    1.011
22      3052127.   0.0009114.812      3051575.     0.0009113.164
RATIO    1.261    0.793    1.261            1.261    0.793    1.261
23      3052127.   0.0009114.812      3051575.     0.0009113.164
RATIO    1.261    0.793    1.261            1.261    0.793    1.261
24      2421210.   0.0007230.652      2420659.     0.0007229.004
RATIO    1.000    1.000    1.000            1.000    1.000    1.000
25      2420420.   0.0007228.293      2419868.     0.0007226.645
RATIO    1.000    1.000    1.000            1.000    1.000    1.000
26      2736001.   0.0008170.739      2735449.     0.0008169.090
RATIO    1.130    0.885    1.130            1.130    0.885    1.130
27      2640337.   0.0007885.051      2639785.     0.0007883.402
RATIO    1.091    0.917    1.091            1.091    0.917    1.091
28      2420308.   0.0007227.957      2419272.     0.0007224.867
RATIO    1.000    1.000    1.000            1.000    1.000    1.000
29      2420308.   0.0007227.957      2419205.     0.0007224.664
RATIO    1.000    1.000    1.000            1.000    1.000    1.000
30      2420308.   0.0007227.957      2419265.     0.0007224.844
RATIO    1.000    1.000    1.000            1.000    1.000    1.000
31      2420308.   0.0007227.957      2419696.     0.0007226.133
RATIO    1.000    1.000    1.000            1.000    1.000    1.000
32      2421599.   0.0007231.816      2421047.     0.0007230.164
RATIO    1.001    0.999    1.001            1.001    0.999    1.001
33      2439096.   0.0007284.066      2438544.     0.0007282.418
RATIO    1.008    0.992    1.008            1.008    0.992    1.008
34      3195826.   0.0009543.949      3195274.     0.0009542.301
RATIO    1.320    0.757    1.320            1.320    0.757    1.320
CASE 2

   CM             CL           CT            SS

   635713.1       219807.6     3187734.0      13631.8
   CO             CN

   41841.5        22731.5
   CABI           CRET         CRQT          CSBI

   60223.8        128590.4     2790795.0     208125.9
    CR            ROI1      YP1       CI         ROI2        YP2
```

5114711. 0.004 267.646 5101079. 0.004 266.933

RESULTS OF DOUBLING ONE VARIABLE

1	5114711.	0.012	83.915	5071232.	0.012	83.201
RATIO	1.000	3.190	0.314	0.994	3.208	0.312
2	4526032.	0.008	118.421	4498768.	0.008	117.708
RATIO	0.885	2.250	0.442	0.882	2.268	0.441
3	6253349.	0.006	163.746	6231035.	0.006	163.033
RATIO	1.224	1.635	0.612	1.222	1.637	0.611
4	5114711.	0.007	133.824	5087447.	0.008	133.110
RATIO	1.000	2.000	0.500	0.997	2.005	0.499
5	5114711.	0.007	133.823	5101079.	0.007	133.467
RATIO	1.000	2.000	0.500	1.000	2.000	0.500
6	3370183.	-0.001	-930.577	3372766.	-0.001	-931.290
RATIO	0.659	-0.288	-3.477	0.661	-0.287	-3.489
7	5918837.	0.003	309.728	5905255.	0.003	309.015
RATIO	1.157	0.864	1.157	1.158	0.864	1.158
8	5187819.	0.004	271.472	5174187.	0.004	270.759
RATIO	1.014	0.986	1.014	1.014	0.986	1.014
9	5325862.	0.004	278.696	5312230.	0.004	277.982
RATIO	1.041	0.960	1.041	1.041	0.960	1.041
10	5325862.	0.004	278.696	5312230.	0.004	277.982
RATIO	1.041	0.960	1.041	1.041	0.960	1.041
11	5297999.	0.004	277.238	5284367.	0.004	276.524
RATIO	1.036	0.965	1.036	1.036	0.965	1.036
12	5209479.	0.004	272.605	5195847.	0.004	271.892
RATIO	1.019	0.982	1.019	1.019	0.982	1.019
13	9214100.	0.002	482.163	9200468.	0.002	481.449
RATIO	1.801	0.555	1.801	1.804	0.554	1.804
14	5209479.	0.004	272.605	5195847.	0.004	271.892
RATIO	1.019	0.982	1.019	1.019	0.982	1.019
15	5190895.	0.004	271.633	5177263.	0.004	270.920
RATIO	1.015	0.985	1.015	1.015	0.985	1.015
16	5190895.	0.004	271.633	5177263.	0.004	270.920
RATIO	1.015	0.985	1.015	1.015	0.985	1.015
17	9119330.	0.002	477.203	9105698.	0.002	476.490
RATIO	1.783	0.561	1.783	1.785	0.560	1.785
18	5117279.	0.004	267.781	5103647.	0.004	267.068
RATIO	1.001	0.999	1.001	1.001	0.999	1.001

19	5142574.	0.004	269.194	5128942.	0.004	268.391
RATIO	1.005	0.995	1.005	1.005	0.995	1.005
20	5277378.	0.004	276.159	5263746.	0.004	275.445
RATIO	1.032	0.969	1.032	1.032	0.969	1.032
21	5121820.	0.004	268.019	5108188.	0.004	267.305
RATIO	1.001	0.999	1.001	1.001	0.999	1.001
22	8645067.	0.002	452.386	8631435.	0.002	451.672
RATIO	1.690	0.592	1.690	1.692	0.591	1.692
23	8645067.	0.002	452.386	8631435.	0.002	451.672
RATIO	1.690	0.592	1.690	1.692	0.591	1.692
24	5377990.	0.004	281.424	5364358.	0.004	280.710
RATIO	1.051	0.951	1.051	1.052	0.951	1.052
25	5121037.	0.004	267.978	5107405.	0.004	267.264
RATIO	1.001	0.999	1.001	1.001	0.999	1.001
26	5781846.	0.003	302.557	5768214.	0.003	301.844
RATIO	1.130	0.885	1.130	1.131	0.884	1.131
27	5579687.	0.003	291.978	5566055.	0.003	291.265
RATIO	1.091	0.917	1.091	1.091	0.916	1.091
28	5114711.	0.004	267.646	5091269.	0.004	266.420
RATIO	1.000	1.000	1.000	0.998	1.002	0.998
29	5114711.	0.004	267.646	5087447.	0.004	266.220
RATIO	1.000	1.000	1.000	0.997	1.003	0.997
30	5114711.	0.004	267.646	5090887.	0.004	266.400
RATIO	1.000	1.000	1.000	0.998	1.002	0.998
31	5114711.	0.004	267.646	5097639.	0.004	266.753
RATIO	1.000	1.000	1.000	0.999	1.001	0.999
32	5188325.	0.004	271.499	5174693.	0.004	270.785
RATIO	1.014	0.986	1.014	1.014	0.986	1.014
33	5918887.	0.003	309.728	5905255.	0.003	309.015
RATIO	1.157	0.864	1.157	1.158	0.864	1.158
34	8788764.	0.002	459.905	8775132.	0.002	459.192
RATIO	1.718	0.582	1.718	1.720	0.581	1.720

APPENDIX D

NUMBER OF SYSTEMS VERSUS ROI 1

```
*LTODS***   STEP FORT       PROCSTEP             DDNAME SYSPRINT

FORTRAN IV G1  RELEASE 2.0                 MAIN                 DATE = 78199

                  C       INITIAL STATEMENTS
 0001                     DIMENSION V(34)
 0002                     V(1)=6.5/10**6
                  C       FLD FR W/O REL PROG
 0003                     V(2)=13553
                  C       NO PARTS
 0004                     V(3)=564
                  C       NO SYSTEMS
 0005                     V(4)=45.5
                  C       OP HRS/40 (35 FH*1.3)
 0006                     V(5)=250
                  C       COST PER FAILURE
 0007                     V(6)=1.7/10**6
                  C       FLD FR W REL PROG
 0008                     V(7)=2
                  C       COST OF SCREENS/PART
 0009                     V(8)=0.1
                  C       MAT OH
 0010                     V(9)=10
                  C       ENG $/HR
 0011                     V(10)=2.2
                  C       ENG OH FACTOR
 0012                     V(11)=2
                  C       ENG MH/PART FOR REL EFFORT
 0013                     V(12)=7
                  C       QC $/HR
 0014                     V(13)=2.5
                  C       FACTORY OH FACTOR
 0015                     V(14)=1.3
                  C       ADDITIONAL QC MH/PT DUE TO REL PROG
 0016                     V(15)=0.00087
                  C       SPECIAL ASSM/PART
 0017                     V(16)=100
                  C       BURN-IN HOURS/SPECIAL ASSM
 0018                     V(17)=5
                  C       $/HR TECHNICIAN
 0019                     V(18)=100
                  C       PARTS/SPECIAL ASSM
 0020                     V(19)=24
                  C       ENG HRS/FAIL (REL,PARTS,FAIL ANAL)
```

```
0021              V(20)=5000
           C      RET HRS
0022              V(21)=7
           C      FR IN ASSM BI&RET/FLD FR
0023              V(22)=2
           C      SPEC MTBF/FLD MT:F
0024              V(23)=10.A
           C      TEST HRS IN MULTS OF SPEC MTBF
*LTOP***

FORTRAN IV G1  RELEASE 2.0              MAIN                DATE = 78199

0025              V(24)=50
           C      SYSTEM BI HRS/EA
0026              V(25)=3
           C      SYSTEM BI FR/FLD FR
0027              V(26)=0.15
           C      GAA
0028              V(27)=0.1
           C      FEF
0029              V(28)=0.1
           C      LRU NRTS
0030              V(29)=2
           C      DEPOT TURN AROUND IN MOS
0031              V(30)=11000
           C      $/SPARE LRU
0032              V(31)=300
           C      $/SPARE MODULE
0033              V(32)=0.05
           C      HRS ASSM BI/DAY
0034              V(34)=2
           C      CALENDAR TIME/RET & RQT"ON" TIME
0035              V(33)=0.23
           C      NO SEMICONDUCTORS/TOTAL PARTS
0036              DO 16 N=1,14
0037              V(3)=564
0038              V(3)=(V(3)+1)-((N-1)*47)
0039              SYS=V(3)
0040              CO=V(1)*V(2)*V(3)*V(4)*12*V(5)
0041              CN=V(6)*V(2)*V(3)*V(4)*12*V(5)
0042              CM=V(2)*V(3)*V(7)*(1+V(8))*V(33)
0043              CL=V(9)*V(10)*V(11)*V(2)+V(12)*V(13)*V(14)*V(2)
0044              G=V(2)*V(3)*V(15)*V(16)
0045              H=V(32)*V(17)*V(13)+V(6)*V(21)*V(18)*V(9)*V(10)*V(19)
0046              CAH1=G*H
0047              AX=V(17)*V(13)*V(34)+V(6)*V(21)*V(2)*V(9)*V(10)*V(19)
0048              CRET=V(20)*AX
```

```
      AA=1/(V(6)*V(2))*V(22)*V(23)
      AB=V(17)*V(13)*V(34)+V(6)*V(9)*V(10)*V(19)*V(2)
      CROT=AA*AB
      CSRI=V(3)*V(24)*(V(17)*V(13)+V(9)*V(10)*V(19)*V(6)*V(25)*V(2))
      CT=CARI+CRLT+CROT+CSRI
      CR=(CM+CL+CT)*(1+V(26))*(1+V(27))
      SO=V(1)*V(2)*V(3)*V(4)*V(28)*V(29)
      SO2=V(1)*V(2)*V(3)*V(4)*(1-V(28))*V(29)
      SN=V(6)*V(2)*V(3)*V(4)*V(28)*V(29)
      SN2=V(6)*V(2)*V(3)*V(4)*(1-V(28))*V(29)
      SS=V(30)*(SO-SN)+V(31)*(SO2-SN2)
      CI=CR-SS
      ROI1=(CO-CN)/CR
*LTOP***

FORTRAN IV G1  RELEASE 2.0                MAIN                DATE = 78199

      ROI2=(CO-CN)/CI
      YP1=1/ROI1
      YP2=1/ROI2
      PRINT 99
   990FORMAT(71H                CR             ROI1     YP1       CI          ROI2
     1YP2            SYS/)
      K=N-1
      PRINT 55,K,CR,ROI1,YP1,CI,ROI2,YP2,SYS
   55 FORMAT(1X,I2,2(F12.0,F8.3,F8.3),6X,1(F8.3))
   40 CONTINUE
      V(3)=(V(3)-1)+((N-1)*47)
   16 CONTINUE
      STOP
      END
*LTOP***

FORTRAN IV G1  RELEASE 2.0                MAIN                DATE = 78199

  *OPTIONS IN EFFECT*  NOTERM,NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
  *OPTIONS IN EFFECT*  NAME = MAIN    , LINECNT =      50

  *STATISTICS*    SOURCE STATEMENTS =      74,PROGRAM SIZE =     2006
  *STATISTICS*  NO DIAGNOSTICS GENERATED

*LTODS***  STEP LKED     PROCSTEP         DDNAME SYSPRINT
```

	CR	ROI1	YP1	CI	ROI2	YP2	SYS
0	9593785. CR	0.523 ROI1	1.912 YP1	5011450. CI	1.001 ROI2	0.999 YP2	565.000 SYS
1	6952541. CR	0.514 ROI1	1.946 YP1	4751392. CI	0.968 ROI2	1.033 YP2	518.000 SYS
2	8311296. CR	0.503 ROI1	1.987 YP1	4491335. CI	0.931 ROI2	1.074 YP2	471.000 SYS
3	7670051. CR	0.491 ROI1	2.037 YP1	4231274. CI	0.690 ROI2	1.124 YP2	424.000 SYS
4	7028808. CR	0.476 ROI1	2.100 YP1	3971216. CI	0.843 ROI2	1.186 YP2	377.000 SYS
5	6387562. CR	0.459 ROI1	2.180 YP1	3711155. CI	0.790 ROI2	1.266 YP2	330.000 SYS
6	5746316. CR	0.437 ROI1	2.287 YP1	3451096. CI	0.728 ROI2	1.373 YP2	283.000 SYS
7	5105074. CR	0.411 ROI1	2.436 YP1	3191039. CI	0.657 ROI2	1.523 YP2	236.000 SYS
8	4463828. CR	0.376 ROI1	2.660 YP1	2930979. CI	0.573 ROI2	1.746 YP2	189.000 SYS
9	3822584. CR	0.330 ROI1	3.032 YP1	2670918. CI	0.472 ROI2	2.118 YP2	142.000 SYS
10	3181340. CR	0.265 ROI1	3.771 YP1	2410858. CI	0.350 ROI2	2.858 YP2	95.000 SYS
11	2540095. CR	0.168 ROI1	5.959 YP1	2150799. CI	0.198 ROI2	5.046 YP2	48.000 SYS
12	1898850. CR	0.005 ROI1	213.837 YP1	1890739. CI	0.005 ROI2	212.923 YP2	1.000 SYS
13	1257607.	-0.325	-3.079	1630681.	-0.250	-3.992	-46.000

APPENDIX E

FAILURE RATE VERSUS ROI 1

```
*LTODS***   STEP FORT      PROCSTEP           DDNAME SYSPRINT

FORTRAN IV G1  RELEASE 2.0             MAIN               DATE = 78199

                   C      INITIAL STATEMENTS
 0001                     DIMENSION V(34)
 0002                     V(1)=6.5/10**6
                   C      FLD FR W/O REL PROG
 0003                     V(2)=13553
                   C      NO PARTS
 0004                     V(3)=564
                   C      NO SYSTEMS
 0005                     V(4)=45.5
                   C      OP HRS/MO (35 FH*1.3)
 0006                     V(5)=250
                   C      COST PER FAILURE
 0007                     V(6)=1.7/10**6
                   C      FLD FR W REL PROG
 0008                     V(7)=2
                   C      COST OF SCREENS/PART
 0009                     V(8)=0.1
                   C      MAT OH
 0010                     V(9)=10
                   C      ENG $/HR
 0011                     V(10)=2.2
                   C      ENG OH FACTOR
 0012                     V(11)=2
                   C      ENG MH/PART FOR REL EFFORT
 0013                     V(12)=7
                   C      QC $/HR
 0014                     V(13)=2.5
                   C      FACTORY OH FACTOR
 0015                     V(14)=1.3
                   C      ADDITIONAL QC MH/PT DUE TO REL PROG
 0016                     V(15)=0.00087
                   C      SPECIAL ASSM/PART
 0017                     V(16)=100
                   C      BURN-IN HOURS/SPECIAL ASSM
 0018                     V(17)=5
                   C      $/HR TECHNICIAN
 0019                     V(18)=100
                   C      PARTS/SPECIAL ASSM
 0020                     V(19)=24
                   C      ENG HRS/FAIL (REL,PARTS,FAIL ANAL)
```

```
0021                V(20)=5000
              C     RET HRS
0022                V(21)=7
              C     FR IN ASSM BI&RET/FLD FR
0023                V(22)=2
              C     SPEC MTBF/FLD MTBF
0024                V(23)=16.8
              C     TEST HRS IN MULTS OF SPEC MTBF
*LTOP***

FORTRAN IV G1  RELEASE 2.0            MAIN                DATE = 78199

0025                V(24)=50
              C     SYSTEM BI HRS/EA
0026                V(25)=3
              C     SYSTEM BI FR/FLD FR
0027                V(26)=0.15
              C     G&A
0028                V(27)=0.1
              C     FEE
0029                V(28)=0.1
              C     LRU KRTS
0030                V(29)=2
              C     DEPOT TURN AROUND IN MOS
0031                V(30)=11000
              C     $/SPARE LRU
0032                V(31)=300
              C     $/SPARE MODULE
0033                V(32)=0.05
              C     HRS ASSM BI/DAY
0034                V(34)=2
              C     CALENDAR TIME/RET & RQT"ON" TIME
0035                V(33)=0.23
              C     NO SEMICONDUCTORS/TOTAL PARTS
0036                DO 16 N=1,21
0037                V(1)=6.5/10**6
0038                V(1)=V(1)*N/20
0039                FR=V(1)
0040                CO=V(1)*V(2)*V(3)*V(4)*12*V(5)
0041                CM=V(6)*V(2)*V(3)*V(4)*12*V(5)
0042                CH=V(2)*V(3)*V(7)*(1+V(8))*V(33)
0043                CL=V(9)*V(10)*V(11)*V(2)+V(12)*V(13)*V(14)*V(2)
0044                G=V(2)*V(3)*V(15)*V(16)
0045                H=V(32)*V(17)*V(13)+V(6)*V(21)*V(18)*V(9)*V(10)*V(19)
0046                CABI=G*H
0047                AX=V(17)*V(13)*V(34)+V(6)*V(21)*V(2)*V(9)*V(10)*V(19)
0048                CRET=V(20)*AX
```

```
0049            AA=1/(V(6)*V(2))*V(22)*V(23)
0050            AB=V(17)*V(13)*V(34)+V(6)*V(9)*V(10)*V(19)*V(2)
0051            CRQI=AA*AB
0052            CSMI=V(3)*V(24)*(V(17)*V(13)+V(9)*V(10)*V(19)*V(6)*V(25)*V(2))
0053            CI=CAMI+CRMI+CRQI+CSMI
0054            CR=(CM+CL+CT)*(1+V(26))*(1+V(27))
0055            SO=V(1)*V(2)*V(3)*V(4)*V(28)*V(29)
0056            SO2=V(1)*V(2)*V(3)*V(4)*(1-V(28))*V(29)
0057            SN=V(6)*V(2)*V(3)*V(4)*V(28)*V(29)
0058            SN2=V(6)*V(2)*V(3)*V(4)*(1-V(28))*V(29)
0059            SS=V(30)*(SO-SN)+V(31)*(SO2-SN2)
0060            CI=CR-SS
0061            ROI1=(CO-CN)/CR
*LIOP***

FORTRAN IV G1  RELEASE 2.0                MAIN                 DATE = 78199

0062            ROI2=(CO-CN)/CI
0063            YP1=1/ROI1
0064            YP2=1/ROI2
0065            PRINT 99
0066        990FORMAT(71H        CR              ROI1      YP1       CI          ROI2
               1YP2          FR/)
0067            K=N-1
0068            PRINT 55,K,CR,ROI1,YP1,CI,ROI2,YP2,FR
0069         55 FORMAT(1X,I2,2(F12.0,F8.3,F8.3),6X,1(F12.9))
0070         40 CONTINUE
0071            V(1)=V(1)*20/N
0072         16 CONTINUE
0073            STOP
0074            END
*LIOP***

FORTRAN IV G1  RELEASE 2.0                MAIN                 DATE = 78199

  *OPTIONS IN EFFECT*  NOTERM,NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
  *OPTIONS IN EFFECT*  NAME = MAIN    , LINECNT =       50


  *STATISTICS*    SOURCE STATEMENTS =        74,PROGRAM SIZE =     2020
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
***LTODS***  STEP LKED      PROCSTEP              DDNAME SYSPRINT

 F88-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED LIST,LET
         DEFAULT OPTION(S) USED -  SIZE=(116736,34816)
****GO           DOES NOT EXIST BUT HAS BEEN ADDED TO DATA SET


***LTODS***  STEP GO        PROCSTEP              DDNAME FT06F001

      CR              ROI1      YP1        CI            ROI2       YP2              FR

  0      9580140.   -0.150   -6.678     10890464.   -0.132   -7.591          0.000000325
      CR              ROI1      YP1        CI            ROI2       YP2              FR
  1      9580140.   -0.114   -8.745     10580751.   -0.104   -9.658          0.000000650
      CR              ROI1      YP1        CI            ROI2       YP2              FR
  2      9580140.   -0.079  -12.664     10271038.   -0.074  -13.578          0.000000975
      CR              ROI1      YP1        CI            ROI2       YP2              FR
  3      9580140.   -0.044  -22.954      9961325.   -0.042  -23.868          0.000001300
      CR              ROI1      YP1        CI            ROI2       YP2              FR
  4      9580140.   -0.008-122.422      9651613.   -0.008-123.335          0.000001625
      CR              ROI1      YP1        CI            ROI2       YP2              FR
  5      9580140.    0.027   36.727      9341899.    0.028   35.814          0.000001950
      CR              ROI1      YP1        CI            ROI2       YP2              FR
  6      9580140.    0.063   15.968      9032186.    0.066   15.055          0.000002275
      CR              ROI1      YP1        CI            ROI2       YP2              FR
  7      9580140.    0.098   10.202      8722473.    0.108    9.289          0.000002600
      CR              ROI1      YP1        CI            ROI2       YP2              FR
  8      9580140.    0.133    7.495      8412761.    0.152    6.582          0.000002925
      CR              ROI1      YP1        CI            ROI2       YP2              FR
  9      9580140.    0.169    5.924      8103048.    0.200    5.010          0.000003250
      CR              ROI1      YP1        CI            ROI2       YP2              FR
 10      9580140.    0.204    4.897      7793334.    0.251    3.984          0.000003575
      CR              ROI1      YP1        CI            ROI2       YP2              FR
```

11	9580140.	0.240	4.174	7483622.	0.307	3.260	0.000003900
	CR	ROI1	YP1	CI	ROI2	YP2	FR
12	9580140.	0.275	3.636	7173911.	0.367	2.723	0.000004225
	CR	ROI1	YP1	CI	ROI2	YP2	FR
13	9580140.	0.310	3.222	6864196.	0.433	2.308	0.000004550
	CR	ROI1	YP1	CI	ROI2	YP2	FR
14	9580140.	0.346	2.892	6554481.	0.505	1.979	0.000004875
	CR	ROI1	YP1	CI	ROI2	YP2	FR
15	9580140.	0.381	2.623	6244769.	0.585	1.710	0.000005200
	CR	ROI1	YP1	CI	ROI2	YP2	FR
16	9580140.	0.417	2.400	5935058.	0.673	1.487	0.000005525
	CR	ROI1	YP1	CI	ROI2	YP2	FR
17	9580140.	0.452	2.212	5625343.	0.770	1.299	0.000005850
	CR	ROI1	YP1	CI	ROI2	YP2	FR
18	9580140.	0.487	2.052	5315631.	0.878	1.138	0.000006175
	CR	ROI1	YP1	CI	ROI2	YP2	FR
19	9580140.	0.523	1.913	5005916.	1.000	1.000	0.000006500
	CR	ROI1	YP1	CI	ROI2	YP2	FR
20	9580140.	0.558	1.792	4696205.	1.139	0.878	0.000006825

BIBLIOGRAPHY

Books

Amstadter, Bertram L. Reliability Mathematics: Fundamentals; Practices; Procedures. New York: McGraw-Hill Book Co., 1971.

Barish, Norman N. Economic Analysis For Engineering And Managerial Decision-Making. New York: McGraw-Hill Book Co., 1962.

Barlow, Richard E., and Proschan, Frank. Mathematical Theory of Reliability. New York: John Wiley and Sons, 1965.

Bazovsky, Igor. Reliability Theory and Practice. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1961.

Durling, Allen. Computational Techniques. New York: Intext Educational Publishers, 1974.

English, J. Morely. Cost-Effectiveness The Economic Evaluation of Engineered Systems. New York: John Wiley and Sons, 1968.

Forrester, Jay W. Industrial Dynamics. Cambridge, Mass.: The M.I.T. Press, 1977.

Goldman, A. S., and Slattery, T. B. Maintainability: A Major Element of System Effectiveness. New York: John Wiley and Sons, 1964.

Hull, T. E. Introduction to Computing. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1966.

Jardine, A. K. S. Maintenance, Replacement, and Reliability. New York: John Wiley and Sons, 1973.

Jelen, F. C. Cost and Optimization Engineering. New York: McGraw-Hill Book Co., 1970.

Thuesen, H. G., Fabrycky, W. J., and Thuesen, G. J. Engineering Economy. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1977.

Tocher, K. D. The Art of Simulation. London, England: The English Universities Press Ltd., 1967.

Documents and Publications

ETRO Reliability Instruction #07.02.06.00. Cape Canaveral, Fla.: General Electric Co., 1974.

Preliminary Technical Manual, Function Manual, Missile Position Tracking Radar Set An/GRQ-2. Syracuse, N. Y.: General Electric Co., 1959.

U.S. Department of Defense. Reliability Program for Systems and Equipment Development and Production MIL-STD-785A. Washington, D. C.: Government Printing Office, 28 March 1969.

Black, Guy and Proschan, Frank, "On Optimal Redundacy," Operations Research-The Journal of the Operations Research Society of America, 7 (1959). pp. 581-588.

Coppola, Anthony, "Reliability As A Capital Investment," Institute of Electrical and Electronics Engineers Proceedings 1974 Annual Reliability and Maintainability Symposium, (Jan. 1974). pp. 349-357.

Everett, III, Hugh, "Generalized LaGrange Multiplier Method for Solving Problems of Optimum Allocation of Resources," Operations Research-The Journal of the Operations Research Society of America, 11 (1963). pp. 399-417.

Federowicz, A. J. and Mazumda, M., "Use of Geometric Programming to Maximize Reliability Achieved by Redundacy," Operations Research-The Journal of the Operations Research Society of America, 16 (1968). pp. 948-954.