AD-A009 077

REASSESSMENT OF THE ALUMINUM BOTTOM CARRIAGE FOR THE XM198 HOWITZER

Roger W. Powell, et al

Army Armament Command
Rock Island, Illinois

March 1975

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1. REPORT NUMBER: SAO Note 18	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER: AD-A009 077	
4. TITLE (and Subtitle): Reassessment of the Aluminum Bottom Carriage for the XM198 Howitzer	5. TYPE OF REPORT & PERIOD COVERED: Technical Note
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Mr. Roger W. Powell; SP4 William H. Morris	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Armament Command, Systems Analysis Office, Rock Island, IL 61201	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Armament Command, Systems Analysis Office, Rock Island, IL 61201	12. REPORT DATE: March 1975
	13. NUMBER OF PAGES: 47
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Decision Risk Analysis
XM198 155mm Howitzer, Towed
Aluminum Bottom Carriage
Steel Bottom Carriage
Parallel Development
Sensitivity Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A decision risk analysis was performed to compare the expected cost, schedule, and technical risks of the current development of a steel bottom carriage for the XM198 155mm Howitzer with those of a proposed parallel development of an aluminum version of the bottom carriage. Computerized VERT simulation networks were used to represent the time and technical risk interrelationships among the activities and decision points of the alternative programs. Expected costs were based on an approximation of the planned XM198 buy with the proportion of steel or aluminum carriages determined by alternative production change-over dates.

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A sensitivity analysis was conducted to determine the effect of a ±10 percent variation in the risks at the key decision points upon the probabilities of success and the mean-times-to-success for each option.

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INTRODUCTION

The Project Manager Office, Cannon Artillery Weapons System (AMCPM-CAWS), is considering replacement of the steel-welded bottom carriage for the XM198 155mm howitzer with a monolithic, high-strength aluminum alloy casting as a means of reducing weight and costs. When initial testing revealed design problems that could not withstand certain high stresses, an ad hoc committee was convened August 1974 to review the situation and recommend a course of action to the project manager.

DEFINITION OF PROBLEM

A decision risk analysis was performed (as requested by letter SARRI-L, Appendix A) to determine the following:

a. The expected cost and risk of continuing the current development of a steel bottom carriage; and

b. The expected cost and risk of the parallel development of a steel and an aluminum bottom carriage, and the probability of being able to introduce the aluminum version at the scheduled start of the first (July 1978) or the second (July 1979) year of full production of the XM198 howitzer.

ALTERNATIVES

Proceed with the steel bottom carriage which is scheduled to begin development testing/operational testing (DT/OT 2) in January 1975.

Redesign the casting and continue development of the aluminum bottom carriage with the intent of making a production changeover at some later time.

ASSUMPTIONS

The following assumptions were considered while performing this decision risk analysis:

a. Only two aluminum bottom carriages will be ordered with the second carriage as a backup if the first one fails during the testing.

b. A January 1975 base point was used to coordinate the resumption of the aluminum bottom carriage development and the start of DT/OT 2 for the XM198 Howitzer.

c. Because the two development programs would be out of phase, AMCPM-CAWS proposed to evaluate the aluminum bottom carriage with a rigorous durability test (15,000 rounds, effective full charge) in lieu of a complete DT/OT 2.

d. AMCPM-CAWS stipulated that a production changeover to the aluminum bottom carriage later than July 1979, the start of second year of full production, would not be beneficial.

DISCUSSION

Computerized VERT (Venture and Evaluation Review Technique) simulation networks were used to represent the time and risk inter-relationships among the activities and decision points of the alternative programs. Each simulation was subjected to 1000 iterations.

The decision points in these simulations represent scheduled procurement, testing, and review activities in the XM198 program. With each activity there is a time value to accomplish the task and/or risk of successfully achieving the task objective, i.e., complete DT/OT 2. Estimates of these times and/or risks were obtained, as indicated, from the following individuals who are knowledgeable in bottom carriage development programs.

a. Professor Thomas J. Dolan, consultant, University of Illinois, Urbana, IL.

b. Mr. H. G. Noble, Jr., - AMCPM-CAWS-TM.

c. Mr. M. E. Braddock - SARRI-LA.

d. Mr. Ralph Edelman - Frankford Arsenal, Philadelphia, PA.

e. Mr. C. R. Shaffer - SARRI-LA.

f. Mr. R. E. Seamands - SARRI-LR-W.

g. Mr. J. H. Williams - AMSAR-RDG.

h. Mr. E. Ryan - AMCPM-CAWS.

Each of these experts was asked to bracket his "most likely" estimate with a "pessimistic" and and "optimistic" one. Risk estimates were obtained from the first six experts. Time estimates came from Mssrs. Braddock, Shaffer, Williams and Ryan.

These estimates were averaged to obtain the following times and risks:

a. Time required for ordering, delivering, and machining two new aluminum bottom carriage castings was uniformly distributed from 5 to 9 months.

b. Times required for the following activities were triangularly distributed as indicated:

(1) 4.4, 6.25, and 9.4 months for the durability testing (15,000 rounds, effective full charge) of the aluminum bottom carriage.

(2) 7.25, 9.75, and 12.0 months for the DT/OT 2 of the steel bottom carriage.

(3) 2.1, 3.5, and 5.25 months for ASARC 2.[1]

(4) 5.25, 6.5, and 8.25 months for DT/OT 3.

(5) Low rate initial production was 17.8, 20.25, and 24.2 months for the steel bottom carriage and 19.25, 21.25, and 25.0 months for an aluminum bottom carriage.

(6) 1.1, 2.1, and 4.0 months for ASARC 3.

c. A 60 percent probability that an aluminum bottom carriage would successfully complete the 15,000 round, effective full charge durability test.

d. A 80 percent probability that a steel bottom carriage would successfully complete DT/OT 2.

e. A 73 percent probability that an aluminum bottom carriage would successfully complete DT/OT 3.

f. A 92 percent probability that a steel bottom carriage would successfully complete DT/OT 3.

Total and differential costs needed to complete the programs were estimated for the steel carriage and the parallel steel/aluminum carriage development options as shown in Appendix C. All costs have been updated to constant FY 75 dollars. The total costs are based on an approximation of the planned production (actual goal is classified), assuming that all carriages will either be steel or aluminum if a production changeover is made to the aluminum version in July 1978 or 1979. The test costs include the expected number of rounds that AMCPM-CAWS indicated might be expended during DT/OT 2 of the steel carriage (32,300) and the durability testing of the aluminum bottom carriage (15,000).

A sensitivity analysis was conducted to determine the effect of a $\pm$ 10 percent variation in the risks at the key decision points upon

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[1] Army Systems Acquisition Review Council.

the probabilities of success and the mean times to success for each option. This analysis was performed by systematically increasing or decreasing each risk while holding the other fixed and by changing all of the risks concurrently.

SUMMARY

The results of the analysis are shown in Table 1 and indicate a 73 percent probability of success for the steel-only option with a mean time of 36 months at an estimated total cost of \$27.8M. The parallel development option has an 80 percent probability of success with a mean time of 45 months and an estimated total cost of \$27.7M. With the parallel option, the probability of the aluminum bottom carriage being selected is 67 percent, reflecting the preference given to the aluminum carriage in the analysis. The cost estimated for the parallel effort is a maximum based on the assumption that the production changeover is not made until July 1979. For the parallel development, there is a 20 percent probability that neither a steel nor an aluminum bottom carriage will be developed as opposed to a 27 percent probability of failure for the steel-only option. While its risk is lower than that of the steel-only approach, the parallel option entails a significantly longer mean-development-time. Expected costs were estimated to be about the same for both development programs.

TABLE 1

COMPARISON OF STEEL-ONLY AND PARALLEL PROGRAMS

Development Option	Prob (Option Success)	Prob Steel Being Selected	Prob Aluminum Being Selected	Meantime (mos)	Expected Cost
Steel Only	73%	100%	NA	36	\$27.8M
Parallel Steel/ Aluminum	80%	13%	67%	45	\$27.7M

The criticality of time for both the steel and the aluminum versions of the bottom carriage is illustrated in Table 2 where the probabilities of successful development are related to the scheduled start of the first and second year of production in July of 1978 or 1979, respectively. These probabilities also indicate the risks associated with the prior committment of funds for the acquisition of the long leadtime items in October of 1976 or 1977.

TABLE 2

AVAILABILITY OF STEEL AND ALUMINUM BOTTOM CARRIAGES

Type of Bottom Carriage	Development Meantime (Months)	Probability of Being Available Jul 78	Jul 79
Steel	36	>99%	>99%
Aluminum	45	57%	92%

The development of the steel bottom carriage has approximately a 100 percent probability of being available by July 1978. With the aluminum version, however, there is only a 57 percent probability of it being available by the same time. The difference reflects the slippage that has occurred in the aluminum effort, and there is even a possibility that this carriage would not be available by July 1979 - the final deadline for a production changeover.

The results of the sensitivity analysis showed that systematically or concurrently varying the risks by $\pm$ 10 percent essentially had no effect on the mean time to success for either option. The changes that occurred represent fractional parts of a month with the most variation in the parallel program where the time spread ranged from about 44 1/2 to 45 1/2 months when all risks were changed concurrently. There were changes, however, in the probabilities of success for each option as well as the probability of steel or aluminum being selected in the parallel development. Most of these changes were minor with the biggest difference observed in the steel-only option where the average variance ranged from -8 to +14 percent (see Table D-3, Appendix D).

CONCLUSIONS

There is a high probability that the current steel bottom carriage will be available by July 1978 - the start of the first year of production.

An aluminum version of the bottom carriage would probably not be ready by July 1978, and there is a possibility that it may not be available by July 1979 - the deadline for making a production changeover to the aluminum unit.

A steel/aluminum parallel development program would have a slightly higher probability of success, but this option entails a significantly longer development time.

The expected total costs were estimated to be about the same for the parallel and steel-only development programs.

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APPENDIX A

LETTER OF INSTRUCTION

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DEPARTMENT OF THE ARMY
ROCK ISLAND ARSENAL
ROCK ISLAND, ILLINOIS 61201

10 September 1974

REPLY TO
ATTENTION OF:
SARRI-L

SUBJECT: Ad Hoc Committee for Assessment of XM198 Aluminum Bottom Carriage Design

SEE DISTRIBUTION

1. Reference:

a. Meeting of subject committee held 27 Aug 74 in the RIA Commander's Conference Room

b. Letter, 7 Aug 74, Subject: Ad Hoc Committee for Assessment of Cast Aluminum Bottom Carriage for the XM198 Howitzer.

c. Final Report of Ad Hoc Committee for Assessment of XM198 155mm Howitzer Aluminum Bottom Carriage Design.

2. Reference 1b. reconvenes this committee, with some changes in membership, and establishes general guidelines. This LOI enlarges on those guidelines and establishes more specific tasks.

3. Reference 1c. recommended a course of action to the Project Manager, Cannon Artillery Weapons Systems. That course of action was, in general, accepted and followed until fundamental errors in the aluminum bottom carriage design (causing unacceptably high stresses) were discovered. These made further testing of the existing design a waste of time. A redesign and new castings are required if work is to proceed. Additional costs and relatively long time delays inevitably would be involved. Given these events, the specific assignment of the committee is to review the situation and again recommend a course of action to the Project Manager. It is my intent to follow the same procedures we used in making our first assessment.

4. Per our discussion (ref. 1a.), four courses of action are to be considered:

a. Continue development of the aluminum bottom carriage with the intent of substituting it in the XM198 production runs at some point.

b. Continue development of the aluminum bottom carriage as a PIP for later retrofit.

c. Drop the aluminum bottom carriage work from the XM198 program, but recommend it to be considered as an approach for any future towed artillery system.

d. Drop further consideration of this design approach.

5. Cost and schedule considerations are involved in these alternatives. Production of the XM198 is scheduled to start in October 1975 and continue for three and one-half years. With respect to course of action "a", obviously there is no point in considering introduction of the aluminum bottom carriage to production later than the start of third year production, October 1977. With respect to course of action "b", obviously only an overwhelming technical advantage (e.g., a weight reduction of 500 lbs.) could justify a retrofit program. This possibility was thoroughly discussed and rejected in the initial action of this committee (ref. 1c.). The course of action is included here solely for completeness and needs no further discussion. Courses of action "c" and "d", of course, are largely judgmental at this point since they do not involve a specific design. Any recommendation of either of them, however, must be based on sound technical arguments.

6. As in our first review of this work, what is needed from each committee member is a discussion relative to his area of expertise, of the known facts and, as appropriate, their effect on the courses of action. I will integrate these sub reports into the final report, taking into account the individual recommendations, and circulate it to the committee members for their approval. Discussion of the individual areas of concern follows:

a. Risk Analysis -- (G. Moeller, AMSAR-SAL) This discussion applies only to course of action "a". The cost to be determined is the "most likely" cost (determined as was done with the last review) to (1) continue with the steel bottom carriage, or (2) to introduce the aluminum bottom carriage at the start of second year production (October 1976) or (3) to introduce it at the start of the third year production (October 1977). The probability of successfully completing the production program within cost and schedule for each of these variations is also to be determined. All cost and schedule data should be checked and updated. Data should be obtained from or coordinated with AMCPM-CAWS-PR. Inputs from the other committee members are an essential part of this analysis.

SARRI-L
SUBJECT: Ad Hoc Committee for Assessment of XM198 Aluminum Bottom Carriage Design

b. Re-evaluation of Aluminum Bottom Carriage Feasibility -- This question (and succeeding ones) are addressed to the remaining members of the committee. In particular, this question was raised by Professor Dolan. Experience with the aluminum bottom carriage since our first evaluation also needs to be taken into consideration. Your answers, of course, bear on all of the alternate courses of action. Producibility, both in the sense of attainable properties and in the probable cost (and practicality) of manufacturing/inspection procedures which will give sound castings, is at issue here. So, too, is the problem of field repair should that be necessary.

c. Development Schedule -- Allowing that a case still can be made that the aluminum bottom carriage is feasible, the most immediate question is whether a realistic development schedule for it can be matched to the XM198 schedule (see para. 6a. above). This is a primary factor in evaluating course of action "a". Given the limitations of theoretical stress analysis of as complex a structure as the aluminum bottom carriage, this question resolves into ones of how many design iterations (with testing) will be required and how long will each take.

d. Advantages to be gained -- As has been noted (ref. 1c.), the expected payoffs from this development are reduced weight and cost. Discussion at our 27 Aug 74 meeting threw both of these into doubt. It appears possible that it will prove necessary to raise the aluminum bottom carriage weight to obtain the required strength and durability. Successive design iterations, with the required testing of each, can quickly eat up expected cost savings. Elaborate inspection procedures which may be required to insure sound castings in production may have a similar effect. Without the advantages of cost and weight savings, there is little reason to go to an aluminum bottom carriage. This question bears on all of the stated courses of action.

7. Attached as inclosures are a nominal time schedule and a short discussion of desired physical properties as requested by Mr. Edelman (SARFA-PDM).

8. Mr. Marvin H. Linn, AMCPM-CAWS-TM (AVN 793-4278/6751) will continue to be the point of contact for all committee business. Requests for additional reference material should be made to him. Arrangements for the planned trip to Yuma Proving Ground to examine the aluminum bottom carriage in service there should be coordinated through him.

FOR THE COMMANDER:

Herbert H. Dobbs

HERBERT H. DOBBS
LTC, OrdC
Chairman

2 Incl
as

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  IL 61201
Professor Thomas J. Dolan, University of Illinois, Urbana, IL
  61801

CF:
PM-CAWS

NOMINAL TIME SCHEDULE

Ad Hoc Committee For Assessment of
XM198 Aluminum Bottom Carriage Design

(SECOND REVIEW)

Task Assignment	7 Aug 74
Initial Meeting (at RIA)	27 Aug 74
Preparation of Instructions and Data Package	28 Aug - 11 Sep 74
Individual Work by Committee Members	12 Sep - 11 Oct 74
Visit to YPG	to be arranged
Individual Reports to Chairman	14 Oct 74
Preparation of Final Report for Signatures	14-28 Oct 74
Circulation of Final Report for Signatures	28 Oct - 11 Nov 74
Submission of Final Report to PM-CAWS	11 Nov 74

10 September 1974

PHYSICAL PROPERTIES OF MATERIAL

FOR XM198 ALUMINUM BOTTOM CARRIAGE

This subject was discussed with C. Schaffer, SARRI-LA (AVN 793-6232), the project engineer for the XM198 development work at Rodman Laboratory. The required material strength for the XM198 aluminum bottom carriage was determined simply from weight and stiffness considerations; the former dictating maximum stress levels for minimum weight, the latter, for rigidity, setting a limit on these. That limit, with aluminum's modulus of elasticity is 15,000 psi. Allowing a safety factor of 1.2 this gives a desired minimum yield strength of 18,000 psi for a single loading cycle. From this, the minimum tensile limit should be in the neighborhood of 30,000 psi. The elongation originally specified was 3%. Fracture toughness was not specified.

Considering the experimental mechanical properties shown on the attached sheet, the specified stress levels above appear reasonable from the point of view of low cycle fatigue strength.

Encl 2

F.D. 435

CERTIFICATE OF ANALYSIS AND TESTS

CUSTOMER Commanding General
U.S. Army Weapons Command
~~Rock Island, Illinois 61201~~
Attn: AMSWE-REA-TA

DATE 22 May 1972
YOUR ORDER NO. 72-0-0150
OUR SALE ORDER NO. 231.131

DESCRIPTION OF MATERIAL	SPECIFICATIONS
1. 1 pc Bottom Carriage Structure P/N 231-0002 Heat No. A-4	KO-1 Alun
2.	
3.	
4.	
5.	

CHEMICAL ANALYSIS

SAMPLE #	C	Mn	P	S	Si	Ni	Cr	Mo	Al	V	Zn	Fe	Mg	Cu	Ti	Sn	Pb	B	W	Sb	Co	Cb
1. A-4		.28			.03				Rem			.04	.23	4.55	.25							
2.																						
3.																						
4.																						
5.																						

MECHANICAL PROPERTIES

Tensile Lbs./Sq. in.	Yield Lbs./Sq. in.	Elong. % 2in.	Reduction of area %	Hardness	Bend Test			
1. 53,600	32,000	14.0%						
2.								
3.	Mechanical Properties as shown. No analysis for AG performed.							
4.								
5.								

~~I, a Notary Public do hereby certify that this affidavit was subscribed and sworn to before me by a duly authorized agent of Northern Ordnance Division of FMC CORPORATION, on~~

19

NORTHERN ORDNANCE DIVISION OF
FMC CORPORATION
48th & Marshall St. N.E.
Minneapolis, Minnesota 55421
560-9201

We hereby certify that the foregoing data are the results of tests performed in the NORTHERN ORDNANCE LABORATORY. Northern Ordnance Division of FMC CORPORATION

By [signature]
Authorized Agent

*NOTE: This letter of instruction states that the critical dates for change-over to the aluminum bottom carriage are either the start of the second year (October 1976) or the third year (October 1977) of production. According to the XM198 milestone schedule, these dates are for the release of long leadtime items for the first and second years of full production which are scheduled to start in July of 1978 and 1979, respectively. Therefore, this analysis determined the cost and risk of meeting the July 1978 and July 1979 production dates.

APPENDIX B

SIMULATION NETWORKS AND

TERMINAL NODE HISTOGRAMS

PART 1 - Steel-Only Development

PART 2 - Parallel Steel/Aluminum Development

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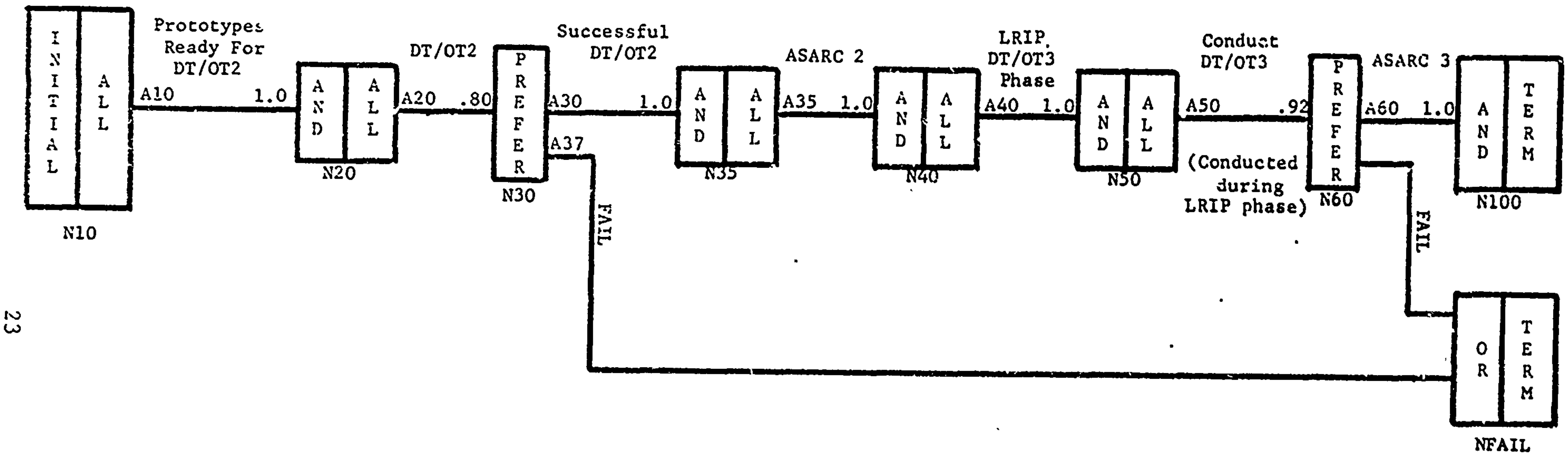


Figure B-1. Flow Diagram Simulating Current Development of the Steel Bottom Carriage for the XM198.

APPENDIX B

PART 1 - STEEL-ONLY DEVELOPMENT

(Arc and Node Descriptions for Figure B-1)

```
A10     N10      N20       1.0 XM198 PROTOTYPES READY FOR DT/OT 2
A20     N20      N30      0.80 DT/OT 2 WITH STEEL BOTTOM CARRIAGES
A20     SDTIME13.0          7.25      12.0      9.75
A30     N30      N35       1.0 SUCCESSFUL DT/OT 2
A35     N35      N40       1.0 ASARC 2
A35     SDTIME13.0          2.1       5.25      3.5
A37     N30      NFAIL     1.0 UNSUCCESSFUL DT/OT 2
A40     N40      N50       1.0 LOW RATE INITIAL PRODUCTION AND DT/OT 3
A40     SDTIME13.0          17.8      24.2      20.25
A50     N50      N60      0.92 DT/OT 3
A60     N60      N100      1.0 ASARC 3
A60     SDTIME13.0          1.1       4.0       2.1
A65     N60      NFAIL     1.0 UNSUCCESSFUL DT/OT 3
ENDARC
N10     1  2                   NETWORK INITIATOR
N20     2  2                   START DT/OT 2 IN JANUARY 1975
N30     6 -1                   BALANCE OF DT/OT 2
N30     LINKA20      A30              A37
N35     2  2                   ASARC 2 REVIEW AFTER DT/OT 2
N40     2  2                   START LRIP
N50     2  2                   START DT/OT 3
N60     6 -1                   RELIEF NODE FOR DT/OT 3 FAILURE
N60     LINKA50      A60              A65
NFAIL   4  1  -1               NETWORK FAILURE SINK
N100    2  1                   SUCCESSFUL DEVELOPMENT OF STEEL BOTTOM CARRIAGE
ENDNODE
```

XM198 CARRIAGE

Interval lower bound	Interval upper bound	PDF	CDF
7.5232 (MIN)	7.5232	0.0	0.0
7.5232	8.7170	0.169	0.169
8.7170	9.9108	0.307	0.476
9.9108	11.1046	0.236	0.712
11.1046	12.2984	0.041	0.753
12.2984	13.4922	0.0	0.753
13.4922	14.6860	0.0	0.753
14.6860	15.8798	0.0	0.753
15.8798	17.0736	0.0	0.753
17.0736	18.2674	0.0	0.753
18.2674	19.4612	0.0	0.753
19.4612	20.6550	0.0	0.753
20.6550	21.8487	0.0	0.753
21.8487	23.0425	0.0	0.753
23.0425	24.2363	0.0	0.753
24.2363	25.4301	0.0	0.753
25.4301	26.6239	0.0	0.753
26.6239	27.8177	0.0	0.753
27.8177	29.0115	0.0	0.753
29.0115	30.2052	0.004	0.757
30.2052	31.3990	0.007	0.764
31.3990	32.5928	0.049	0.813
32.5928	33.7866	0.041	0.854
33.7866	34.9804	0.079	0.933
34.9804	36.1742	0.034	0.963
36.1742	37.3680	0.019	0.985
37.3680	38.5620	0.015	1.000
38.5620	38.5620 (MAX)	0.0	0.0

NO. OBS. = 267 MEAN = 15.6486 STD. DEV. = 10.6694 COEF. OF VARIATION = 0.68

25

NETWORK TIME FOR NODE N100

XM198 CARRIAGE

Lower	Upper	PDF	CDF
	31.5374	0.0 (MIN)	0.0 (MIN)
31.5374	31.9214	0.003	0.003
31.9214	32.3054	0.001	0.004
32.3054	32.6894	0.011	0.015
32.6894	33.0734	0.008	0.023
33.0734	33.4574	0.023	0.046
33.4574	33.8414	0.029	0.075
33.8414	34.2254	0.037	0.112
34.2254	34.6093	0.053	0.165
34.6093	34.9933	0.060	0.225
34.9933	35.3773	0.078	0.303
35.3773	35.7613	0.072	0.375
35.7613	36.1453	0.083	0.458
36.1453	36.5293	0.102	0.561
36.5293	36.9133	0.068	0.629
36.9133	37.2973	0.064	0.693
37.2973	37.6812	0.059	0.752
37.6812	38.0652	0.048	0.799
38.0652	38.4492	0.048	0.847
38.4492	38.8332	0.038	0.885
38.8332	39.2172	0.037	0.922
39.2172	39.6012	0.026	0.948
39.6012	39.9852	0.030	0.978
39.9852	40.3692	0.010	0.988
40.3692	40.7531	0.001	0.989
40.7531	41.1371	0.004	0.993
41.1371	41.5212	0.007	1.000
41.5212	41.5212	0.0 (MAX)	0.0 (MAX)

NO. OBS. = 733 MEAN = 36.4108 STD. DEV. = 1.8325 COEF. OF VARIATION = 0.05

NETWORK TIME FOR THE COMPOSITE TERMINAL NODE

XM198 CARRIAGE

Cell lower limit	Cell upper limit	PDF	CDF
MIN	7.5232	0.0	0.0
7.5232	8.8308	0.050	0.050
8.8308	10.1384	0.094	0.144
10.1384	11.4460	0.050	0.194
11.4460	12.7537	0.007	0.201
12.7537	14.0613	0.0	0.201
14.0613	15.3689	0.0	0.201
15.3689	16.6765	0.0	0.201
16.6765	17.9841	0.0	0.201
17.9841	19.2917	0.0	0.201
19.2917	20.5993	0.0	0.201
20.5993	21.9069	0.0	0.201
21.9069	23.2145	0.0	0.201
23.2145	24.5221	0.0	0.201
24.5221	25.8297	0.0	0.201
25.8297	27.1373	0.0	0.201
27.1373	28.4449	0.0	0.201
28.4449	29.7525	0.001	0.202
29.7525	31.0601	0.001	0.203
31.0601	32.3677	0.017	0.220
32.3677	33.6753	0.050	0.270
33.6753	34.9829	0.143	0.413
34.9829	36.2905	0.207	0.620
36.2905	37.5981	0.190	0.810
37.5981	38.9057	0.111	0.921
38.9057	40.2133	0.066	0.987
40.2133	41.5212	0.013	1.000
41.5212	MAX	0.0	0.0

NO. OBS. = 1000 MEAN = 30.8669 STD. DEV. = 10.8267 COEF. OF VARIATION = 0.35

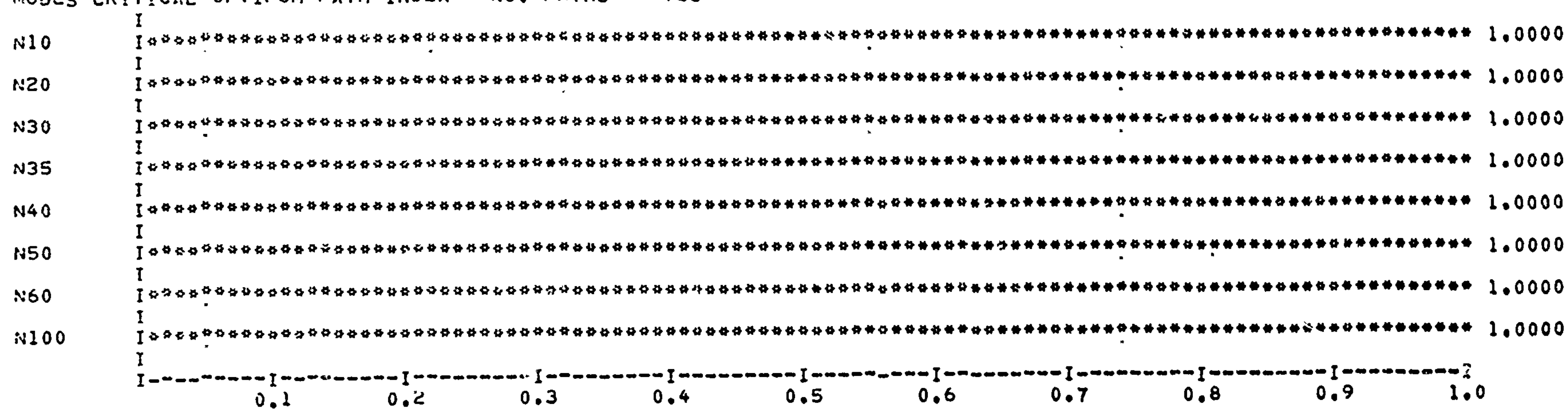
```
OPTIMUM TERMINAL NODE INDEX - NO. ITERATIONS = 1000
             I
NFAIL        I*************************------------------------------------------------------------------------- 0.2670
             I
N100         I*************************************************************************------------------------- 0.7330
             I
             I---------I---------I---------I---------I---------I---------I---------I---------I---------I---------I
                      0.1       0.2       0.3       0.4       0.5       0.6       0.7       0.8       0.9       1.0

CRITICAL-OPTIMUM PATHS TERMINATING IN THE FOLLOWING NODES HAVE BEEN EXCLUDED FROM THE CRITICAL-OPTIMUM PATH ANALYSIS


             NFAIL
```

```
ARCS CRITICAL-OPTIMUM PATH INDEX - NO. PATHS =  733
        I
A10     I**************************************************************************************************** 1.0000
        I
A20     I**************************************************************************************************** 1.0000
        I
A30     I**************************************************************************************************** 1.0000
        I
A35     I**************************************************************************************************** 1.0000
        I
A40     I**************************************************************************************************** 1.0000
        I
A50     I**************************************************************************************************** 1.0000
        I
A60     I**************************************************************************************************** 1.0000
        I
        I---------I---------I---------I---------I---------I---------I---------I---------I---------I---------I
                 0.1       0.2       0.3       0.4       0.5       0.6       0.7       0.8       0.9       1.0
```

NODES CRITICAL-OPTIMUM PATH INDEX - NO. PATHS = 733



APPENDIX B (CON'T)

PART 2 - PARALLEL STEEL/ALUMINUM DEVELOPMENT

```
A10     N10       N20      1.0 ORDER, DELIVER & MACHINE TWO ALUMINUM CARRIAGES
A10     SDTIME12.0          5.0       9.0
A20     N20       N30      1.0 DURABILITY TEST OF 1ST ALUMINUM CARRIAGE
A20     SDTIME13.0          4.4       9.4       6.25
A30     N30       N35      1.0 SUCCESSFUL DURABILITY TEST OF 1ST ALUMINUM CARRIAGE
A30     MC     1.60
A32     N35       N40      1.0 ASARC 2 OF 1ST ALUMINUM CARRIAGE
A32     SDTIME13.0          2.1       5.25      3.5
A35     N30       N60      1.0 FAILURE PATH FOR 1ST ALUMINUM CARRIAGE
A35     MC     1.40
A40     N40       N50      1.0 LRIP AND DT/OT 3 OF 1ST ALUMINUM CARRIAGE
A40     SDTIME13.0          19.25     25.50     21.25
A50     N50       N90      1.0 ASARC 3 AFTER SUCCESSFUL DT/OT 3 OF 1ST ALUMINUM
A50     MC     1.73
A50     SDTIME13.0          1.1       4.0       2.1
A51     N50       N60      1.0 UNSUCCESSFUL DT/OT 3 FOR 1ST ALUMINUM CARRIAGE
A51     MC     1.27
A52     N60       N65      1.0 DURABILITY TEST OF 2ND ALUMINUM CARRIAGE
A52     SDTIME13.0          4.4       9.4       6.25
A58     N65       N70      1.0 ASARC 2 OF 2ND ALUMINUM CARRIAGE
A58     MC     1.60
A58     SDTIME13.0          2.1       5.25      3.5
A54     N65       NFAIL    1.0 UNSUCCESSFUL DURABILITY TEST OF 2ND ALUMINUM CARR.
A54     MC     1.40
```

```
A53     N70      N80       1.0 LRIP AND DT/OT 3 OF 2ND ALUMINUM CARRIAGE
A53     SDTIME13.0          19.25     25.50     21.25
A55     N80      N90       1.0 ASARC 3 AFTER SUCCESSFUL DT/OT 3 OF 2ND ALUMINUM
A55     MC    1.73
A55     SDTIME13.0          1.1       4.0       2.1
A56     N80      NFAIL     1.0 UNSUCCESSFUL DT/OT 3 FOR 2ND ALUMINUM CARRIAGE
A56     MC    1.27
A60     N90      N100      1.0 SUCCESSFUL DEVELOPMENT OF ALUMINUM BOTTOM CARRIAGE
A70     N100     N200      1.0 TRANSITION TO FULL PRODUCTION OF ALUMINUM CARRIAGE
A100    N10      N15       1.0 DT/OT 2 OF STEEL BOTTOM CARRIAGES
A100    SDTIME13.0          7.25      12.0      9.75
A115    N15      N20       1.0 FAILURE PATH FOR DT/OT 2 OF STEEL CARRIAGE
A115    MC    1.20
A110    N15      N22       1.0 ASARC 2 FOR STEEL CARRIAGE
A110    MC    1.80
A110    SDTIME13.0          2.1       5.25      3.5
A116    N22      N25       1.0 LRIP AND DT/OT 3 FOR STEEL CARRIAGE
A116    SDTIME13.0          17.8      24.2      20.25
A117    N25      N40       1.0 FAILURE IN STEEL EMPHASIZES ALUMINUM DEVELOPMENT
A117    MC    1.04
A118    N25      N60       1.0 FAILURE IN STEEL EMPHASIZES ALUMINUM DEVELOPMENT
A118    MC    1.04
A120    N25      N100      1.0 ASARC 3 FOR STEEL BOTTOM CARRIAGE
A120    MC    1.92
A120    SDTIME13.0          1.1       4.0       2.1
A130    N100     N200      1.0 TRANSITION TO FULL PRODUCTION OF STEEL CARRIAGE
ESCAPE  N100     NFAIL     1.0 ESCAPE ARC
ENDARC
N10     1  2                   JANUARY 1975 BASE POINT
N15     2  3                   END OF DT/OT 2 FOR STEEL CARRIAGE
N20     4  2                   ALUMINUM BOTTOM CARRIAGES READY FOR DURABILITY TEST
N22     2  2                   INITIATE LRIP AND DT/OT 3 FOR STEEL
N25     2  3                   FINISH LRIP AND DT/OT 3 OF STEEL CARRIAGE
N30     2  3                   FINISH DURABILITY TEST OF 1ST ALUMINUM CARRIAGE
N35     2  2                   ASARC 2 REVIEW OF SUCCESSFUL ALUMINUM CARRIAGE
N40     4  2                   INITIATE LRIP AND DT/OT 3 OF 1ST ALUMINUM CARRIAGE
N50     2  3                   ASARC 2 OF SUCCESSFUL ALUMINUM CARRIAGE
N60     4  2                   START DURABILITY TEST OF 2ND ALUMINUM CARRIAGE
N65     2  3                   INITIATE ASARC 2 REVIEW
N70     2  2                   INITIATE LRIP AND DT/OT 3 OF 2ND ALUMINUM CARRIAGE
N80     2  3                   ASARC 3 OF SUCCESSFUL ALUMINUM CARRIAGE
N90     4  2                   SUCCESSFUL DEVELOPMENT OF ALUMINUM BOTTOM CARRIAGE
N100    6  1                   PREFERENCE GIVEN TO ALUMINUM DEVELOPMENT
N100    LINKA60      A70      A120    A130          ESCAPE
NFAIL   4  1                   FAILURE NODE FOR PARALLEL DEVELOPMENT PROGRAM
N200    4  1                   SUCCESS NODE FOR EITHER STEEL OR ALUMINUM CARRIAGE
ENDNODE
```

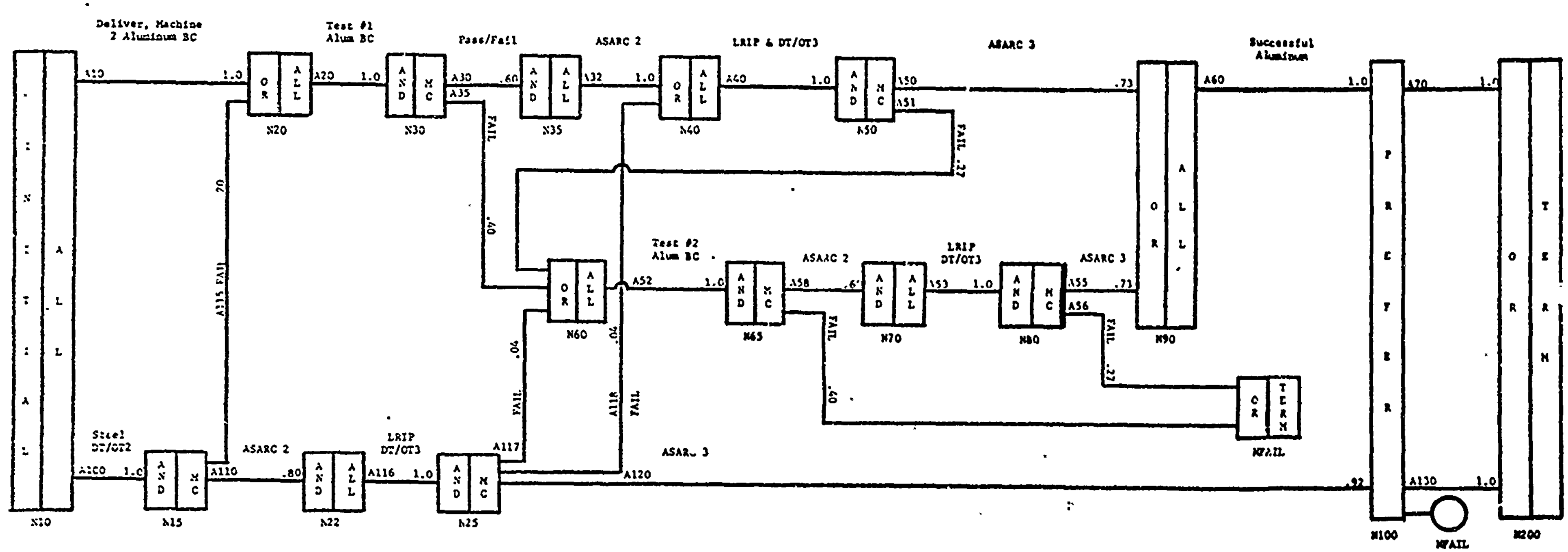


Figure B-2. Flow Diagram Simulating Proposed Parallel Steel/Aluminum Development

NETWORK TIME FOR NODE NFAIL

XM198 CARRIAGE

Time	PDF	CDF
15.5106 (MIN)	0.0	0.0
15.5106	0.085	0.085
17.7197	0.229	0.313
19.9286	0.308	0.622
22.1376	0.134	0.756
24.3466	0.005	0.761
26.5556	0.0	0.761
28.7646	0.0	0.761
30.9736	0.0	0.761
33.1826	0.0	0.761
35.3916	0.0	0.761
37.6006	0.015	0.776
39.8096	0.020	0.796
42.0186	0.035	0.831
44.2276	0.090	0.920
46.4366	0.040	0.960
48.6456	0.005	0.965
50.8546	0.0	0.965
53.0636	0.0	0.965
55.2726	0.0	0.965
57.4816	0.0	0.965
59.6906	0.0	0.965
61.8996	0.0	0.965
64.1086	0.0	0.965
66.3176	0.0	0.965
68.5266	0.010	0.975
70.7356	0.025	1.000
72.9450	0.0	0.0
72.9450 (MAX)		

NO. OBS. = 201 MEAN = 27.0641 STD. DEV. = 13.0995 COEF. OF VARIATION = 0.48

NETWORK TIME FOR NODE N200

XM198 CARRIAGE

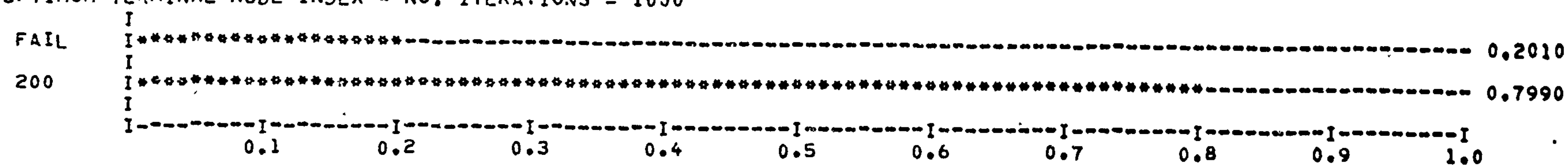
Upper limit	PDF	Upper limit	CDF
32.7403	MIN 0.0	32.7403	MIN 0.0
32.7403	0.021	32.7403	0.021
34.6710	0.070	34.6710	0.091
36.6017	0.083	36.6017	0.174
38.5323	0.165	38.5323	0.339
40.4630	0.161	40.4630	0.501
42.3937	0.134	42.3937	0.635
44.3244	0.073	44.3244	0.707
46.2551	0.098	46.2551	0.805
48.1858	0.063	48.1858	0.867
50.1165	0.038	50.1165	0.905
52.0472	0.010	52.0472	0.915
53.9779	0.001	53.9779	0.916
55.9086	0.0	55.9086	0.916
57.8393	0.0	57.8393	0.916
59.7700	0.0	59.7700	0.916
61.7007	0.0	61.7007	0.916
63.6314	0.0	63.6314	0.916
65.5621	0.0	65.5621	0.916
67.4928	0.004	67.4928	0.920
69.4235	0.014	69.4235	0.934
71.3542	0.013	71.3542	0.946
73.2849	0.023	73.2849	0.969
75.2155	0.014	75.2155	0.982
77.1462	0.013	77.1462	0.995
79.0769	0.004	79.0769	0.999
81.0076	0.001	81.0076	1.000
82.9384	0.0 MAX	82.9384	0.0 MAX
82.9384		82.9384	

NO. OBS. = 799 MEAN = 45.0551 STD. DEV. = 9.8831 COEF. OF VARIATION = 0.22

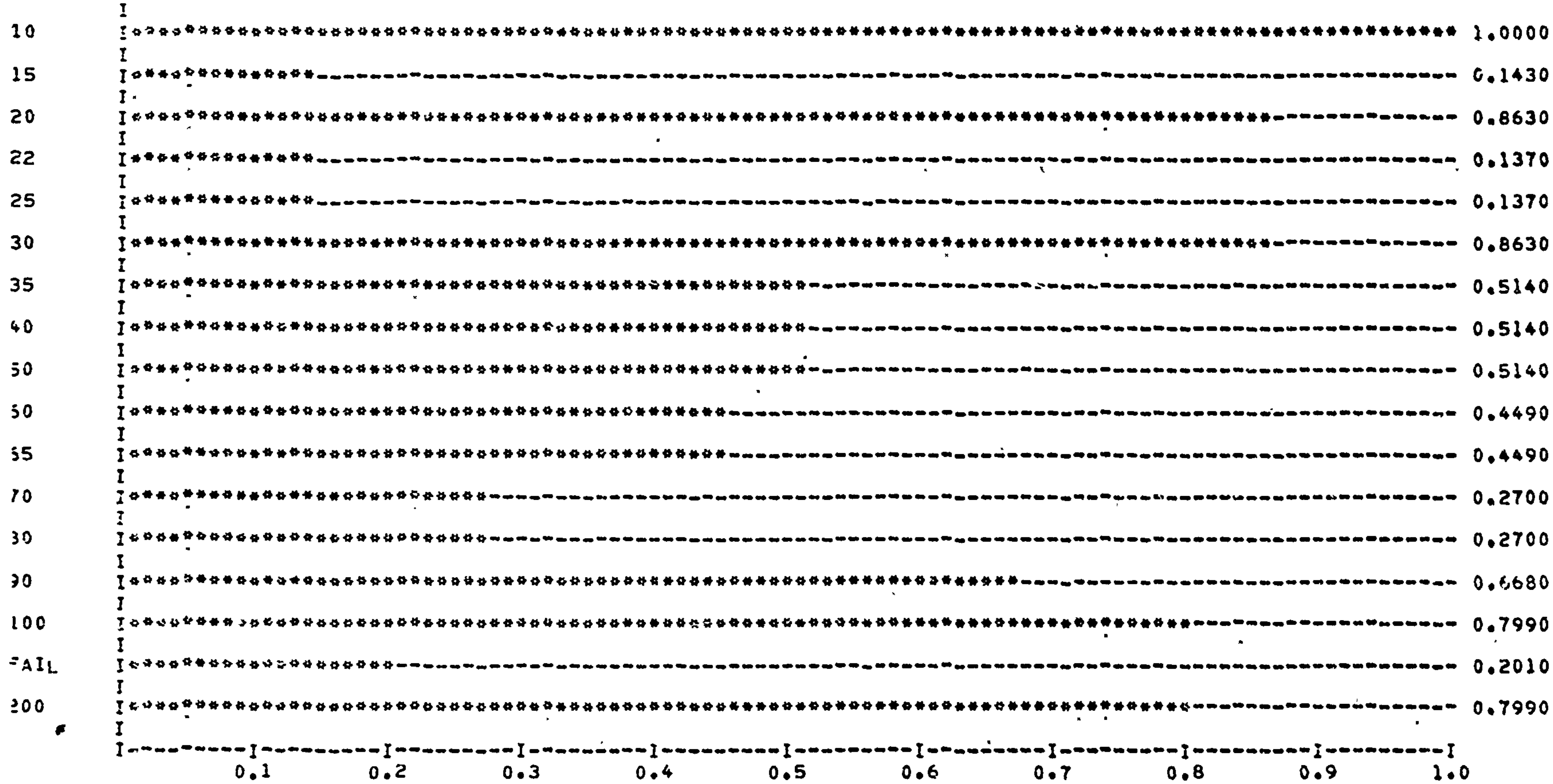
```
                                   NETWORK TIME FOR THE COMPOSITE TERMINAL NODE
   XM198 CARRIAGE
          PDF  0.05 0.10 0.15 0.20 0.25                  CDF  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
15.5106 I----I----I----I----I----I MIN          15.5106 I----I----I----I----I----I----I----I----I----I----I MIN
        I                          0.0                  I                                                    0.0
15.5106 I                                       15.5106 I
        I**                        0.022                I*                                                   0.022
18.1040 I                                       18.1040 I
        I******                    0.065                I****                                                0.087
20.6974 I                                       20.6974 I
        I*****                     0.058                I*******                                             0.145
23.2907 I                                       23.2907 I
        I                          0.007                I********                                            0.152
25.8841 I                                       25.8841 I
        I                          0.001                I********                                            0.153
28.4775 I                                       28.4775 I
        I                          0.0                  I********                                            0.153
31.0708 I                                       31.0708 I
        I                          0.008                I********                                            0.161
33.6642 I                                       33.6642 I
        I*****                     0.056                I***********                                         0.217
36.2576 I                                       36.2576 I
        I*********                 0.094                I****************                                    0.311
38.8510 I                                       38.8510 I
        I******************        0.185                I************************                            0.496
41.4443 I                                       41.4443 I
        I****************          0.163                I*********************************                   0.659
44.0377 I                                       44.0377 I
        I***********               0.112                I***************************************             0.771
46.6311 I                                       46.6311 I
        I*********                 0.098                I*******************************************         0.869
49.2244 I                                       49.2244 I
        I****                      0.045                I**********************************************      0.914
51.8178 I                                       51.8178 I
        I*                         0.012                I**********************************************      0.926
54.4112 I                                       54.4112 I
        I                          0.0                  I**********************************************      0.926
57.0045 I                                       57.0045 I
        I                          0.0                  I**********************************************      0.926
59.5979 I                                       59.5979 I
        I                          0.0                  I**********************************************      0.926
62.1913 I                                       62.1913 I
        I                          0.0                  I**********************************************      0.926
64.7846 I                                       64.7846 I
        I                          0.0                  I**********************************************      0.926
67.3780 I                                       67.3780 I
        I                          0.006                I***********************************************     0.932
69.9714 I                                       69.9714 I
        I**                        0.020                I************************************************    0.952
72.5647 I                                       72.5647 I
        I**                        0.022                I*************************************************   0.974
75.1581 I                                       75.1581 I
        I*                         0.015                I*************************************************   0.989
77.7515 I                                       77.7515 I
        I*                         0.010                I**************************************************0.999
80.3448 I                                       80.3448 I
        I                          0.001                I**************************************************1.000
82.9384 I                                       82.9384 I
        I                          0.0                  I                                                    0.0
82.9384 I                          MAX          82.9384 I                                                    MAX

        NO. OBS. = 1000   MEAN =        41.4386   STD. DEV. =        12.8220   COEF. OF VARIATION =  0.31
```

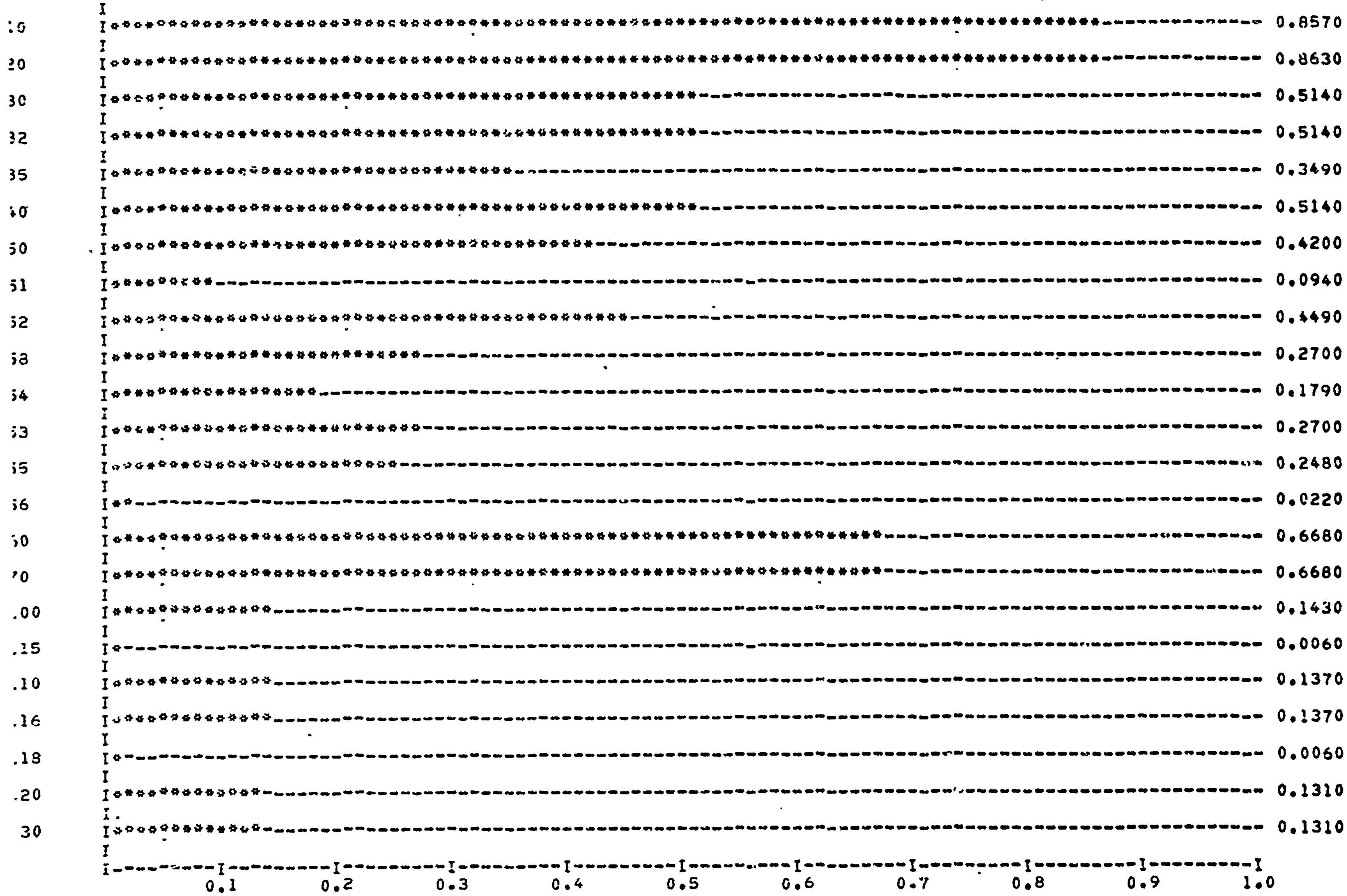
OPTIMUM TERMINAL NODE INDEX - NO. ITERATIONS = 1000



ODES CRITICAL-OPTIMUM PATH INDEX - NO. PATHS = 1000



ARCS CRITICAL-OPTIMUM PATH INDEX - NO. PATHS = 1000



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APPENDIX C

COST ANALYSIS

The expected cost for the steel-only and parallel steel/aluminum development options were estimated as indicated in Figure C-1. These costs are based on an approximation of the planned buy (actual goal is classified) assuming that all bottom carriages will either be steel or a production mix of steel and aluminum carriages. The proportions were determined by assuming that the production changeover to the aluminum version would be made in July of 1978 or 1979. AMCPM-CAWS stipulated that this changeover should not be made later than July 1979, the start of the second year of production.

An inflation factor of 1.16 was used to update the redevelopment ($4,500,000) and extra test costs ($1,700,000) from the previous study to constant FY 75 dollars.[1] Test and ammunition costs were then incorporated to represent the 32,300 rounds expected to be fired during the DT/OT 2 of the steel bottom carriage, and the additional 3000 rounds needed for the 15,000-round durability testing of the aluminum version (the extra test costs originally included only 12,000 rounds).

Since the redevelopment cost is an expense occurred only if there is a failure, this cost was adjusted to reflect the probability of failure for each program: 20 percent for the parallel and 27 percent for the steel-only.

The expected cost for the parallel option ranged from $27.0M to $27.7M depending on whether the proposed changeover to the less expensive aluminum version was made in 1978 or 1979. Expected cost for the steel-only option was about $27.8M. The risk for the parallel option is lower but the effort entails a longer mean development time with the result that the production changeover to the aluminum version could not be made by July 1978.

Figure C-2 is a "breakeven" plot of the cost relationship between the parallel steel/aluminum and steel-only development options. It indicates a "breakeven" point between the respective development costs if about 350 aluminum units were produced.

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[1] Moeller, Gerald L., Assessment of the XM198 Bottom Carriage. Plans and Analysis Directorate, US Army Weapons Command, March 1973, p. 27.

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The equations used to calculate the expected total cost of each development option is as follows:

<u>Steel-only</u>

$$ETC = NS(UCS) + (CPF)\ (NOR) + (RDT)\ (1.0 - PPF)$$

<u>Parallel Steel/Aluminum</u>

$$ETC = NS(UCS) + NA(UCA) + (CPF)\ (NOR) \div (RDT)\ (1.0 - PPF) + TCA$$

Where:

ETC = Expected total cost of program
NS = Assumed total buy of steel carriages
NA = Assumed total buy of aluminum carriages
UCS = Unit cost of steel bottom carriage
UCA = Unit cost of aluminum bottom carriage
CPF = Cost per firing
NOR = Number of rounds (DT/OT 2 for steel, extra durability rounds for aluminum)
RDT = Redevelopment and testing cost if current design fails
TCA = Extra test cost for aluminum carriage development
PPF = Probability of program failure - (1.0 - .73) for steel-only (1.0 - .80) for parallel steel/aluminum

TABLE C-1

COST ANALYSIS

EXPECTED BUY

Production Dates for Changeover to Aluminum Bottom Carriage	July 78	July 79
Number of aluminum units manufactured =	528	410
Number of steel units manufactured =	442	560
Total number of units	970	970

PROBABILITY OF PROGRAM FAILURE

(1.0 - .80) for parallel development
(1.0 - .73) for steel-only development

COST INPUTS

Cost per Unit

Steel carriage = 1.16 x $17,770 = $20,532
Aluminum carriage = 1.16 x $12,807 = $14,856

Cost per firing (test and ammunition) = $200
Expected rounds for DT/OT 2 = 32,300
Extra rounds for aluminum durability test = 3,000
Redevelopment and testing cost if current design fails = 1.16 x $4,500,000 = $5,220,000
Extra test cost for aluminum carriage development = 1.16 x $1,700,000 = $1,970,000

COST ANALYSIS

Parallel Steel/Aluminum Development

Total Cost Assuming July 78 Changeover from Steel to Aluminum Bottom Carriage

528 ($14,856) + 442 ($20,532) + $200 (35,300) + $5,220,000
(1.0 - .80) + $1,970,000 = $26,993,112

Total Cost Assuming July 79 Changeover from Steel to Aluminum Bottom Carriage

410 ($14,856) + 560 ($20,532) + $200 (35,300) + $5,220,000
(1.0 - .80) + $1,970,000 = $27,662,880

TABLE C-1 (Cont'd)

Differential

Jul 79 Changeover Total Cost	=	$27,662,880
Jul 78 Changeover Total Cost	=	$26,993,112
Difference	=	$ 669,768

Steel-Only Development

Number of Units	=	970
Cost per Unit	=	$20,532
Cost per firing (test and ammunition)	=	$200
Number of expected rounds for DT/OT 2	=	32,300
Redevelopment and testing cost if current design fails	=	$5,220,000

Total Cost

Total Cost = 970 ($20,532) + $200 (32,300) + $5,220,000 (1.0 - .73)

= $27,785,440

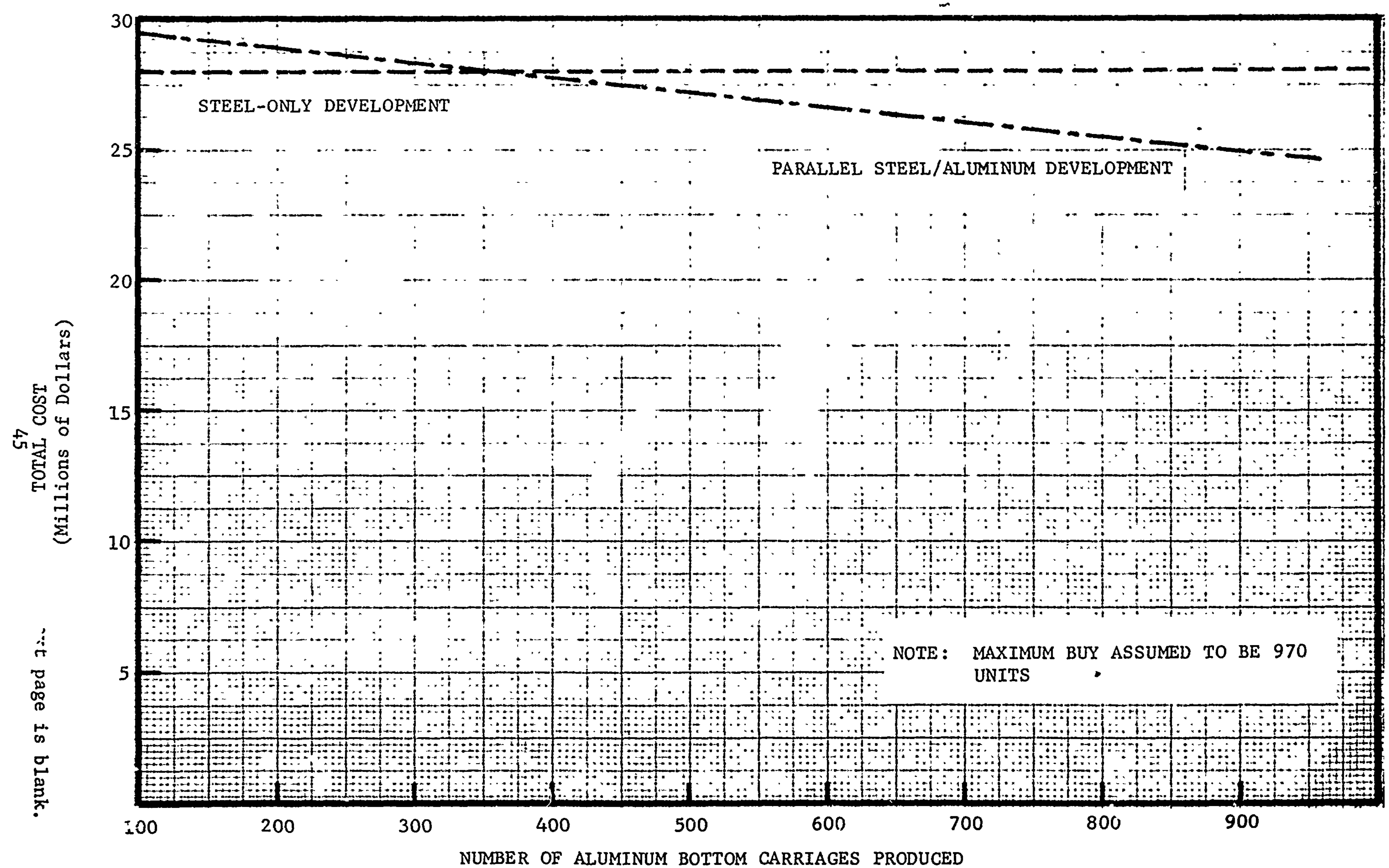

Figure C-2. Cost relationship of steel-only and parallel steel/aluminum development of bottom carriage for XM198.

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Appendix D

SENSITIVITY ANALYSIS

The mean estimates of risk for the key decision points were subjected to a sensitivity analysis to determine the effect of variations on the probability of success and the mean time to success. This analysis was performed two ways:

a. Systematically increasing or decreasing each risk by ± 10 percent while holding the other risks fixed.

b. Concurrently increasing or decreasing all of the risks by ± 10 percent.

The results are summarized in Tables D-1 and D-2.

Decreasing each risk systematically had the overall effect of

- Increasing the probability of success for each development option

- Decreasing the probability of steel being selected in the parallel development option except when the risk represented the DT/OT 2 or DT/OT 3 testing of the steel bottom carriage

- Increasing the probability of aluminum being selected in the parallel development option

Increasing each risk had the opposite effect except again when the operation involved the DT/OT 2 or DT/OT 3 testing of the steel bottom carriage in the parallel development program.

Concurrently decreasing or increasing all risks made the biggest change in the probability of success for each development option and the chance of selecting the aluminum bottom carriage in the parallel effort. The steel-only development program was the most sensitive to changes in the risks.

Changing the risks essentially had no effect on the mean time to success for either option. The changes represent fractional parts of a month with the most variation occurring in the parallel program where the time spread ranged from about 44 1/2 to 45 1/2 months when all risks were changed concurrently.

Table D-3 shows the average change caused by a ± 10 percent variation in the estimated risks for each program.

TABLE D-1

Results of Systematic and Concurrent ± 10 Percent

Variation in Estimated Risks for Parallel

Steel/Aluminum Development Option

Decision Point	Estimated Probability of Success in Base Case (%)	Effect of ± 10% Variation in Risks on Indicated Probabilities and Mean Time to Success							
		Prob of Success for Option (%) (79.9)*		Prob of Steel being Selected (%) (13.1)*		Prob of Aluminum being Selected (%) (66.8)*		Mean Time to Success (Months) (45.06)*	
		+10%	-10%	+10%	-10%	+10%	-10%	+10%	-10%
Durability Test 1st Aluminum Carriage	60	83.9	78.8	12.0	12.5	71.9	66.3	44.93	44.85
2nd Aluminum Carriage		82.1	75.0	12.4	12.8	69.7	62.2	45.32	44.63
DT/OT 2 Steel	80	79.2	78.0	14,1	10.4	65.1	67.6	44.89	45.83
DT/OT 3 1st Aluminum Carriage	73	80.1	78.6	10.1	13.9	70.0	64.7	44.72	45.64
2nd Aluminum Carriage		80.0	78.7	11.0	15.0	69.0	63.7	45.46	44.23
DT/OT 3 Steel	92	82.4	77.8	13.6	11.6	68.8	66.2	44.91	45.51
All Risks Changed Concurrently		88.6	68.7	10.7	12.6	77.9	56.1	44.52	45.51

* For comparative purposes, figures in parenthesis represent results obtained with the base case analysis.

TABLE D-2

Results of Systematic and Concurrent ± 10 Percent

Variation in Estimated Risks for

Steel-Only Development Option

Decision Point	Estimated Probability of Success in Base Case (%)	Effect of ± 10% Variation in Risks on Probability and Mean Time to Success			
		Prob of Success for Option (%)		Mean Time to Success (Months)	
		+ 10%	-10%	+10%	-10%
DT/OT 2	80	81.7	67.6	36.40	36.52
DT/OT 3	92	82.0	67.7	36.45	36.41
All Risks Changed Concurrently		87.4	62.3	36.44	36.46

NOTE: For comparative purposes, results obtained with the base case analysis were a 73.3% probability of success for option with a mean time to success of 36.41 months.

TABLE D-3

Average Change in Probabilities Caused

by ± 10% Variation in Risks

Development Option	Average Change in Probability (%)			
	Systematic Change		Concurrent Change	
	Increase	Decrease	Increase	Decrease
PARALLEL PROGRAM				
Probability of Success for Option	1.7	2.6	3.0	4.2
Probability of Steel Being Selected	6.9	3.0	8.5	3.2
Probability of Aluminum being Selected	3.4	2.5	5.3	4.4
STEEL-ONLY PROGRAM				
Probability of Success for Option	11.6	7.7	14.2	10.1