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**RISK ANALYSIS OF THE
US ARMY 155MM CANNON-LAUNCHED
GUIDED PROJECTILE PROGRAM**

MARTIN NETZLER, JR.

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DECEMBER 1974

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SUMMARY

A risk analysis was conducted on the Army 155mm CLGP program. Program cost and schedule uncertainties were examined from 1 January 1975 to initiation of full scale production. These uncertainties were analyzed by simulating the program using a network format and representing cost and schedule as random variables. Statistics were obtained using the Venture Evaluation and Review Technique (VERT) network analyzer.

The program schedule and costs are close to those obtained from the network analysis. The probability of meeting the 63 month program schedule is 47%, the cost probability of meeting the \$68M programmed cost is 30%. However, the probability of entering full scale production within ± 6 months of the 63 month schedule is 90%. There is about a 30% chance that the program cost will be between \$59M and \$63M and a 70% chance that the cost will be between \$69M and \$72M. This result is due to the absence or presence of significant technical difficulties.

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CONTENTS

	<u>Page</u>
OBJECTIVE	7
INTRODUCTION	7
APPROACH	7
NETWORK	7
DATA	8
RESULTS	8
SENSITIVITY ANALYSIS	10
DISTRIBUTION LIST	22

Next page is blank.

OBJECTIVE

The objective of this analysis was to estimate the schedule and cost risks associated with the Army 155mm Cannon-Launched Guided Projectile (CLGP) development program. The analysis considered the Army CLGP program from 1 January 1975 to initiation of full scale production.

INTRODUCTION

The initial objective of this analysis was to compare performance, schedule, and cost risks for the Army 155mm CLGP program, a combined Navy and Army program, and a 5-Inch Navy round with sabot. Lack of timely performance data and data on the Navy development program reduced this objective to the evaluation of schedule and cost uncertainties for the current Army program.

APPROACH

The Venture Evaluation and Review Technique (VERT) was used to evaluate the schedule and cost uncertainties. This network technique uses lines (arcs) to represent activities which consume cost and/or time (e.g., testing) resources, or carry information (e.g., test successfully completed). Boxes (nodes) of the network are used to represent program milestones (e.g., initiation and termination of activities, decision point). Logic features are contained in the nodes for input and output arcs (e.g., "AND" input logic requires all input arcs to be completed before the output arcs are initiated). "Monte Carlo" (MC) output logic initiates one of several output arcs (e.g., pass or fail test) according to specified probabilities. Concurrent activities were considered by constructing parallel arcs.

Once the program was structured in the network format, minimum, maximum and most likely time and cost estimates were obtained for each of the represented activities. In addition, a cost and time relationship was specified to account for cost increases due to slipped schedules.

An iteration consists of tracing the program flow by statistically sampling the cost, time, and probabilistic nodes. Several hundred iterations were used to obtain the schedule and cost data presented in this report.

NETWORK

The Life Cycle System Management Model for Major Systems (AR 1000.1) was used as the basis for the CLGP network. After a number of reviews and modifications by the CLGP Project Manager's Office (AMCPM-CAWS), the network shown in Figure 1* was derived. A description of the activities is presented in Table 1. The network is initiated at 1 January 1975 and continues to the initiation of full scale production

*All figures and tables (except Figure 2) are at back of Note.

DATA

All data were obtained from AMCPM-CAWS. Minimum, maximum, and most likely time estimates were specified for each activity. These estimates were input as a triangular distribution and illustrated in Figure 2.

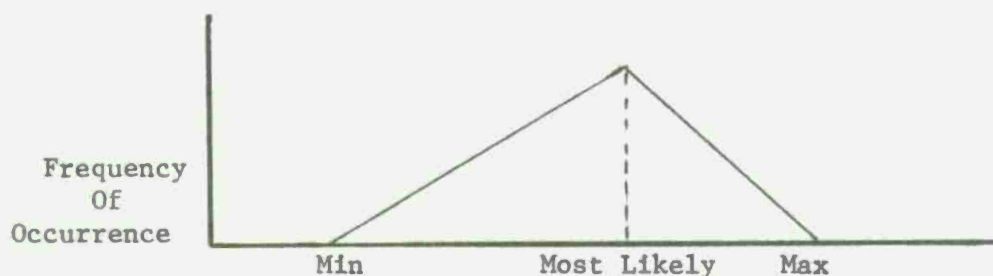


Figure 2. Triangular Distribution

Linear cost functions were considered to relate cost and schedule uncertainties.

$$\text{Cost} = a + b \cdot \text{time}$$

where

- a - Costs not dependent on time; minimum, maximum, and most likely values were estimated.
- b - Time dependent costs, estimates of the monthly dollar rate were obtained.

These schedule and cost data are presented in Table 1 for each activity represented in the network. All costs are in FY 74 dollars.

The lack of probability of program termination is a reflection of the AMCPM-CAWS feelings that all technical problems are resolvable within the current program. However, delays due to technical failures will increase program cost and time; these increases are reflected in the results.

RESULTS

Table 2 presents a comparison between key program milestones and the expected time values obtained from the computer runs. A comparison between the programmed costs and the expected costs, obtained from the network analysis, is also presented. The expected values are observed to be close to the AMCPM-CAWS program values. The probability of meeting the 63 month program estimate is, from Figure 3, 47%; the probability of staying within the \$67.8M budget is, from Figure 4, 30%.

TABLE 2. RESULTS

<u>NODE</u>	<u>MILESTONE</u>	<u>AMCPM-CAWS SCHEDULE (MO)</u>	<u>EXPECTED^a SCHEDULE (MO)</u>	<u>AMCPM-CAWS PROGRAMMED COSTS (M)</u>	<u>EXPECTED^a COST (M)</u>
N6	ASARC/DSARC II, Sign ED	9.0	8.3		
N14	Begin DT/OT II	32.5	32.0		
N19	ASARC/DSARC IIa, Sign LRIP Contract	41.0	38.9		
N25	Begin DT/OT III	55.0	56.4		
N32	ASARC/DSARC III, Begin Full Scale Production	63.0	64.0	\$67.8	\$68.5

^aResults of network analysis

Figure 3 shows that the program will be completed within ± 6 months of the programmed schedule with 90% confidence. Analysis of Figure 4 shows that the program cost will either range between \$59M and \$63M or between \$69M and \$72M, with high probability. This dichotomy results from the presence or absence of significant technical difficulties.

SENSITIVITY ANALYSIS

Time did not permit estimating minimum and maximum values of fixed costs; only the most likely estimates were obtained. Therefore, a sensitivity analysis was conducted in which these values were input as $\pm 10\%$, and then $\pm 25\%$, deviations from the most likely value. (For example, a most likely estimate of \$10M would give rise to a minimum value of \$9M and a maximum value of \$11M, for the 10% case.) These minimum, most likely, and maximum values formed the parameters of a triangular distribution, as discussed under DATA.

The results of this analysis are presented in Table 3. Expected costs are unaffected, but the cost ranges are increased, see Figures 5 and 6. The observed increases in the probability of meeting programmed costs are due to increased probabilities of lower costs to resolve technical difficulties. Alternatively, higher costs are also observed. The increased cost range for the $\pm 10\%$ case is insignificant when compared with the base case (AMCPM-CAWS data). However, the sharp cost distinction between encountering or not encountering significant technical problems is obliterated in the $\pm 25\%$ case, see Figure 7. A maximum cost increase of about 10% of the programmed cost is observed for the worst situation (the $\pm 25\%$ case).

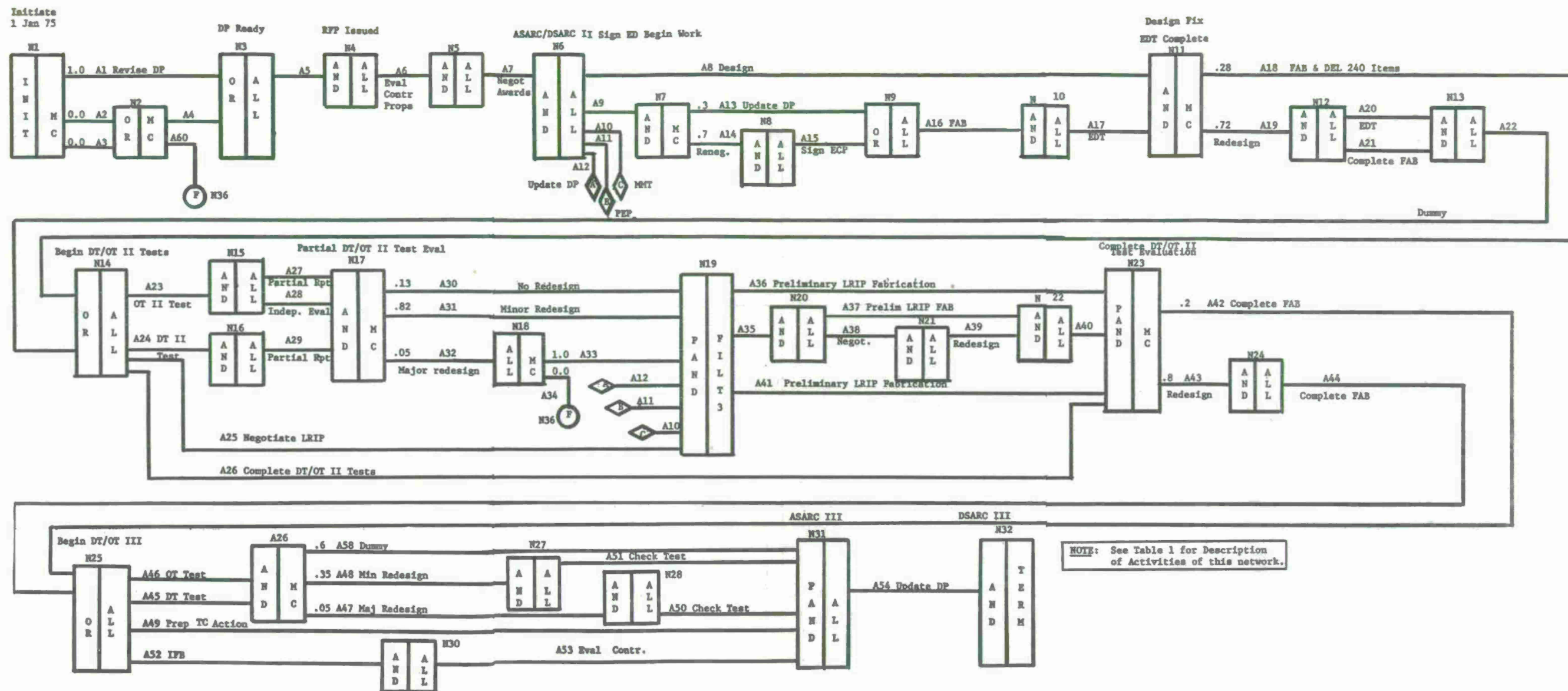


Figure 1

Network of Army 155mm Cannon-Launched
Guided Projectile Program - From 1 January 75
to Initiation of Full Scale Production.

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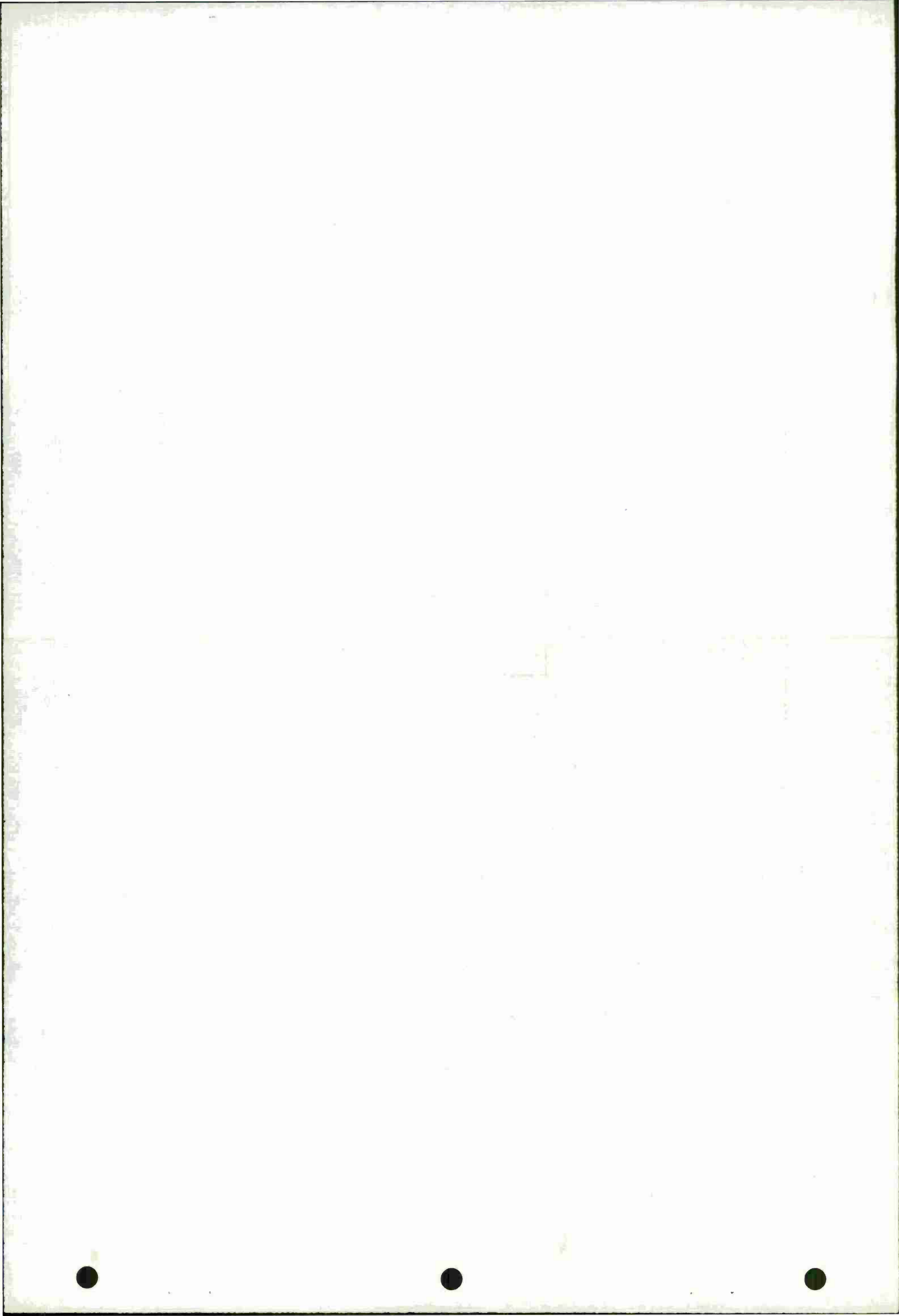


TABLE 1. DESCRIPTION OF ACTIVITIES FOR NETWORK (FIGURE 1)

Activity No.	Description of Activity	MC	Time (MOs) (t)			Cost Function
			Min	Max	ML	
1	If Alternative #1 is selected, the DP may be revised to reflect special DSARC		1	2	1.5	47900t
2	If Alternative #2 is selected, some redesign of Army gyro and optics					
3	If Alternative #3 is selected, revalidate the COEA and design adaptation kit					
4	Revise DP if Alternative #2 or #3 is selected	.80	1	2	1.5	47900t
60	Fail	.20	0	0	0	-----
5	Prepare and issue RFP for ED contract		0	1	0.5	47900t
6	Contractor prepare proposals and government evaluate		4	5	4	47900t+110,000
7	Negotiate awards with all likely winners; obtain concurrences		1	3	2	47900t
8	Contractor design		10	18	15	200,000t
9	Dummy					
10	Conduct MMT effort - (Not an R&D task - PEMA funded)		14	23	18	200,000t
11	Conduct PEP; to be completed at signing of LRIP		12	16	14	9,535,400
12	Update DP before ASARC/DSARC II		1	2	1.5	47900t
13	Update DP, sign contract, and reflect ASARC/DSARC II decisions	.30	.5	1.5	1	47900t
14	Renegotiate contract changes by ECP	.70	1	2	1	47900t
15	Update DP, sign contract, and reflect ASARC/DSARC II decisions		.25	.75	.50	47900t+25000
16	Contractor fabricate hardware		3	4	3	6,156,000
17	Conduct EDT		4.5	7	5	2,616,000

TABLE 1 (Cont'd)

Activity No.	Description of Activity	MC	Time (MOs) (t)			Cost Function
			Min	Max	ML	
18	Fabricate OT/DT II hardware without redesign and deliver (240 rds for day one, 124 second month and 85 third month)	.28	6	8	7	24,900,000
19	Redesign and fabricate	.72	2	5	3.5	200,000t+6,156,000
20	Conduct EDT		1	3	2	2,616,000
21	Fabricate OT/DT II hardware if redesign carried out and deliver		4	9	7	24,900,000
22	Dummy					
23	Conduct partial OT II tests to meet needs of DSARC IIa		2	4	3	280,000
24	Conduct partial DT II tests to meet needs of DSARC IIa		4	8	6	568,000
25	Negotiate LRIP		2.5	4	3	47,900t
26	Complete remaining DT/OT II tests		11	14	12	1,719,000
27	Evaluate partial OT II test and prepare test report		1	2	1	47,900t
28	Evaluate partial OT II tests independently and prepare test report (OTEA will perform subject to TRADOC concurrence)		2	4	2	47,900t
29	Evaluate partial DT II tests and prepare test report		1	2	1	47,900t
30	Dummy signal	.13	0	0	0	0
31	Signal to allow signing of LRIP and perform redesign by ECP	.82	0	0	0	0
32	Major redesign and test after DT/OT II test report	.05	8	13	11	200,000t+2,567,000
33	Dummy signal		0	0	0	0
34	Fail		0	0	0	0
35	Dummy					
36	Preliminary fabrication of DT/OT III hardware		9	13	11	1,102,400

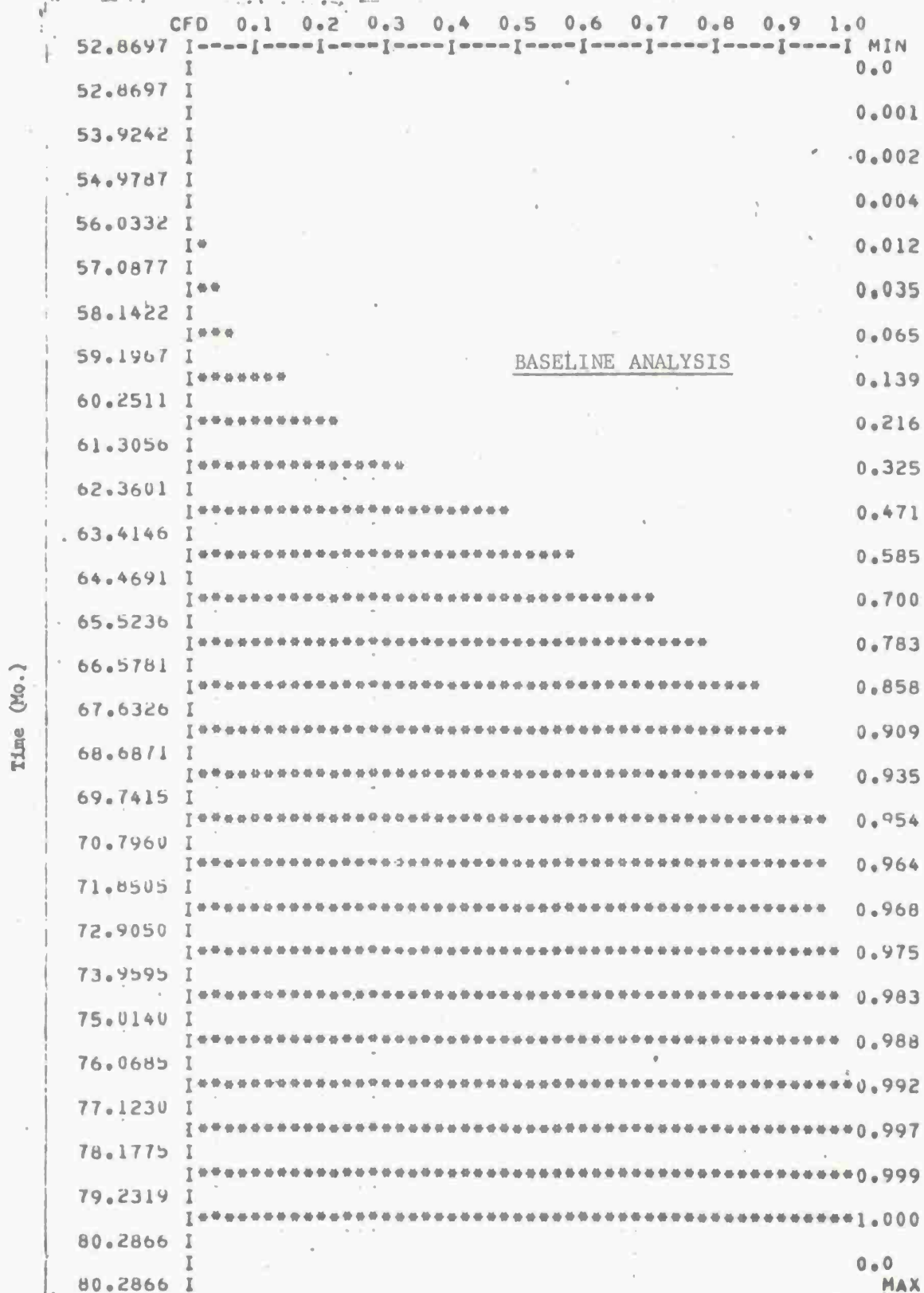
TABLE 1 (Cont'd)

Activity No.	Description of Activity	MC	Time (MOs) (t)			Cost Function
			Min	Max	ML	
37	Preliminary fabrication of DT/OT III hardware		9	13	11	1,102,400
38	Negotiate ECP for minor change		2.5	4	3	47,900t
39	Redesign-minor (to account for cost)		1	3	2	200,000t+1,300,000
40	Dummy Signal					
41	Preliminary fabrication of 350 items (LRIP)		9	13	11	1,102,400
42	Complete fabrication	.2	3	5	4	2,576,000
43	Redesign based DT/OT II results	.8	1	3	2	200,000t
44	Complete fabrication		3	5	4	2,576,000
45	Conduct DT III tests, evaluate, and present test report		4	8	6	47,900t+971,000
46	Conduct OT III tests, evaluate, and present test report		3	4	3	47,900t+508,000
47	Major redesign and rebuild	.05	2	4	3	200,000t
48	Minor redesign/rebuild	.35	1	3	2	200,000t
49	Update DP, prepare TC action	.60	1	2	1.5	47,900t
50	Check test after major rebuild		1	2	1	47,900t
51	Check test after minor rebuild		1	2	1	47,900t
58	Dummy signal					
52	Prepare and issue 2 step IFB for FSP		2.5	3.5	3.0	47,900t
53	ASARC III, government evaluate contractor prepared proposals and select a winner		2.5	4.0	3.0	47,900t
54	DSARC III, update DP, TDP, finalize documentation, sign FSP and begin FSP		.5	1.5	1.0	47,900t

TABLE 3. COST RESULTS ($\bar{M}$)

	AMCPM-CAWS DATA	FIXED COSTS SENSITIVITY ANALYSIS	
AMCPM-CAWS Programmed Costs	\$67.8	$\pm 10\%$	$\pm 25\%$
Expected Program Costs ^a	\$68.5	\$68.5	\$68.5
Probability of Meeting Programmed Costs	.30	.33	.42
0 - 30% cost ^a Probability Interval	\$59-\$63	\$59-\$64	\$57-\$65
30 - 100% cost ^a Probability Interval	\$69-\$72	\$68-\$73	\$65-\$77

^aResults of network analysis



MEAN = 64.0

Figure 3. Time Distribution From Jan 75 to Full Production - 155mm CLGP

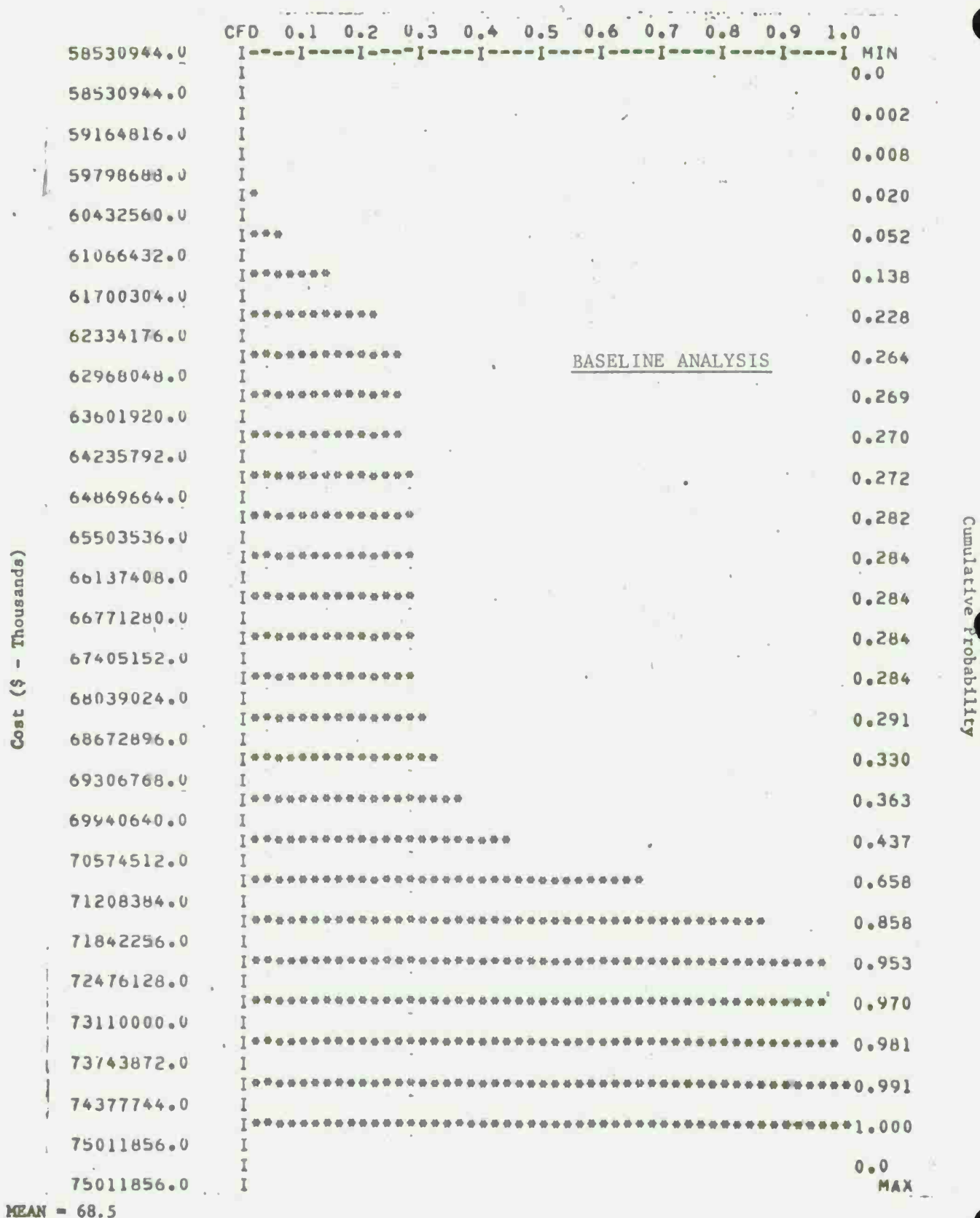


Figure 4. Cost Distribution From Jan 75 to Full Production - 155mm CLGP

COST (\$ - MILLIONS)

	CFD	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	
57199936.0	I	---	I	---	I	---	I	---	I	---	I	MIN
	I											0.0
57199936.0	I											0.002
57970512.0	I											0.006
58741088.0	I											0.017
59511664.0	I*											0.047
60282240.0	I**											0.096
	I											0.144
61052816.0	I*****											0.195
61823392.0	I*****											0.243
62593968.0	I*****											0.265
63364544.0	I*****											0.273
64135120.0	I*****											0.278
64905696.0	I*****											0.282
65676272.0	I*****											0.288
66446848.0	I*****											0.300
67217424.0	I*****											0.329
67988000.0	I*****											0.405
68758576.0	I*****											0.513
69529152.0	I*****											0.646
70299728.0	I*****											0.794
71070304.0	I*****											0.889
71840880.0	I*****											0.944
72611456.0	I*****											0.978
73382032.0	I*****											0.987
74152608.0	I*****											0.994
74923184.0	I*****											0.999
75693760.0	I*****											1.000
76464336.0	I*****											0.0
77235296.0	I*****											MAX
77235296.0	I*****											

SENSITIVITY ANALYSIS

± 10% Random Variation About
Fixed Costs
(Triangular Distribution)

MEAN = 68.4

Figure 5. Cost Distribution From Jan 75 to Full Production - 155mm CLGP

	CFD	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	
	I	I	I	I	I	I	I	I	I	I	I	MIN
53793712.0	I											0.0
53793712.0	I											0.002
54831200.0	I											0.004
55868688.0	I											0.016
56906176.0	I*											0.025
57943664.0	I											0.056
58981152.0	I***											0.089
60018640.0	I****											0.111
61056128.0	I*****											0.138
62093616.0	I*****											0.170
63131104.0	I*****											0.220
64168592.0	I*****											0.259
65206080.0	I*****											0.308
66243568.0	I*****											0.357
67281056.0	I*****											0.4
68318544.0	I*****											0.501
69356032.0	I*****											0.587
70393520.0	I*****											0.679
71431008.0	I*****											0.780
72468496.0	I*****											0.845
73505984.0	I*****											0.907
74543472.0	I*****											0.938
75580960.0	I*****											0.974
76618448.0	I*****											0.989
77655936.0	I*****											0.998
78693424.0	I*****											0.999
79730912.0	I*****											1.000
80768416.0	I											0.0
81768416.0	I											

SENSITIVITY ANALYSIS

± 25% Random Variation About
Fixed Costs
(Triangular Distribution)

MEAN = 68.5

Figure 6. Cost Distribution From Jan 75 to Full Production - 155mm CLGP

COST (\$ - MILLIONS)

RFD 0.05 0.10 0.15 0.20 0.25

53793712.0	I----	I-----I-----I-----I-----I-----I	MIN
	I		0.0
53793712.0	I		
	I		0.002
54831200.0	I		
	I		0.002
55868688.0	I		
	I*		0.012
56906176.0	J		
	I		0.009
57943664.0	I		
	I***		0.031
58981152.0	I		
	I***		0.033
60018640.0	I		
	I**		0.022
61056128.0	I		
	I**		0.027
62093616.0	I		
	I***		0.032
63131104.0	J		
	I*****		0.050
64168592.0	I		
	I***		0.039
65206080.0	I		
	I****		0.049
66243568.0	I		
	I****		0.049
67291056.0	I		
	I*****		0.065
68318544.0	I		
	I*****		0.079
69356032.0	I		
	I*****		0.086
70393520.0	I		
	J*****		0.092
71431008.0	J		
	I*****		0.101
72468496.0	I		
	I*****		0.065
73505984.0	I		
	I*****		0.062
74543472.0	I		
	I***		0.031
75580960.0	I		
	I***		0.036
76618448.0	I		
	I*		0.015
77655936.0	I		
	J		
78693424.0	I		
	I		
79730912.0	I		
	I		
80768416.0	I		
	I		
80768416.0	I		

DENSITY

SENSITIVITY ANALYSIS

± 25% Random Variation About
Fixed Costs
(Triangular Distribution)

MAX

MEAN = 68.5

Figure 7. Cost Density From Jan 75 to Full Production - 155mm CLGP

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