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RISK ANALYSIS OF THE M110E2 SELF-PROPELLED HOWITZER (FROM DEVELOPMENT ACCEPTANCE IN-PROCESS REVIEW TO INITIAL OPERATING CAPABILITY)

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US ARMY ARMAMENT COMMAND
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The cost and schedule risk analysis associated with the M110E2 self-propelled howitzer was performed. Uncertainties associated with the time frame between the Development Acceptance (DEVA) In-Process Review (IPR) and Initial Operating Capability (IOC) are considered. Evaluation was accomplished with the Venture Evaluation Review Technique (VERT) network analyzer. Results showed very low risk in achieving IOC within the desired time frame.

CONTENTS

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OBJECTIVE

This study was performed to assess the cost and schedule risks associated with achieving Initial Operating Capability (IOC) of the M110E2 self-propelled howitzer, using the XM188E3 propellant charge (zone 8 only) and firing the M106 Projectile. It considers the time frame between the Development Acceptance (DEVA) In-Process Review (IPR) and Initial Operating Capability.

INTRODUCTION

The 8-inch foreign artillery threat indicates superiority in both projectile lethality and range. Current technological data for the 1970-1980 time frame indicates that an improved armament program for the 8-inch howitzer M110 is the least-cost, lowest-risk and quickest approach to counter this threat. This improved armament program is being implemented in a Product Improvement Program which also contains design changes to correct reliability problems associated with the M110 family. The range of the M110 armament will be increased by the XM188E3 propellant charge and Kit 3 of the Product Improvement Proposal. It consists of the XM201 cannon assembly and a modified M116 Direct Fire Telescope designated XM139. This new configuration has been designated the M110E2.

The XM188E2, a zone 8 and 9 propelling charge, was designed to achieve the essential ballistic characteristics of the improved armament system at ranges beyond the present maximum (zone 7) range of the current M2 propelling charge. However, problems have occurred in achieving zone 9 capability and until a solution can be found, the M110E2 will be type-classified to fire at zone 8 only.

Type-Classification (TC) of the M110E2 with the M106 projectile/XM201 Cannon and XM188E3 propelling charge (zone 8) is scheduled for 3rd Qtr FY 75. The M110E2 Product Manager tasked the Systems Analysis Directorate to evaluate the risks of achieving Initial Operating Capability with the M110E2.

APPROACH

The general attitude among personnel in the M110E2 Product Manager's Office was that the achievement of IOC within one year of TC was a low risk program. We set a goal to disprove this hypothesis by surfacing significant risk areas. Our approach was to define the activities necessary to accomplish IOC and elicit expert opinion on critical events which would cause delays or cost increases and their likelihood of occurrence. There are essentially two parallel sets of activities that

must be completed to attain IOC: production and deployment of the required quantity of XM201 tubes and production of the required quantity of XM188 propelling charges to equip and support one battalion of M110E2's. To determine the required quantities of both cannons and propelling charges, the number of rounds fired (rounds/tube/day) and charge zones consumed were obtained from the P76-80 Combat Rates Study. The average life of a tube was divided into the total rounds consumed to determine the quantity of cannons required. The total rounds fired, combined with the expected percentage of XM188 to be used, determined the quantity of propelling charges required to satisfy the definition of IOC*. Based on these quantities, a critical examination was then made of necessary activities required to manufacture, test, deliver, and field the required cannon tubes and propelling charges.

METHOD OF ANALYSIS

The cost and schedule uncertainties were evaluated by combining the cost/schedule estimates of the program activities in a detailed network for analysis (VERT[1]). Experts familiar with each activity were consulted to obtain time and cost estimates in the areas of their expertise. Figure 1 shows the flow of major activities from the time of the DEVA IPR to IOC. Shown in Table 1 are the sources of information for each of these major activities.

Each source was questioned in order to uncover likely risk areas for activities within his responsibility. Particular emphasis was placed on the probability that each of the major activities could be

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* IOC will be accomplished when 12 howitzers are equipped and adequately supported to conduct the combat mission (European scenario) used to derive the P76-80 Combat Rates. This will occur when thirteen cannons are shipped to Europe, one battalion is retrofitted, and the remaining four cannons and required quantity of charges (11,000) are in the inventory. This definition of IOC does not affect the time required as these support activities do not fall upon the critical path.

[1] Moeller, G. L., VERT - A Tool to Assess Risk, Proceedings of the Eleventh US Army Operations Research Symposium, May 1972.

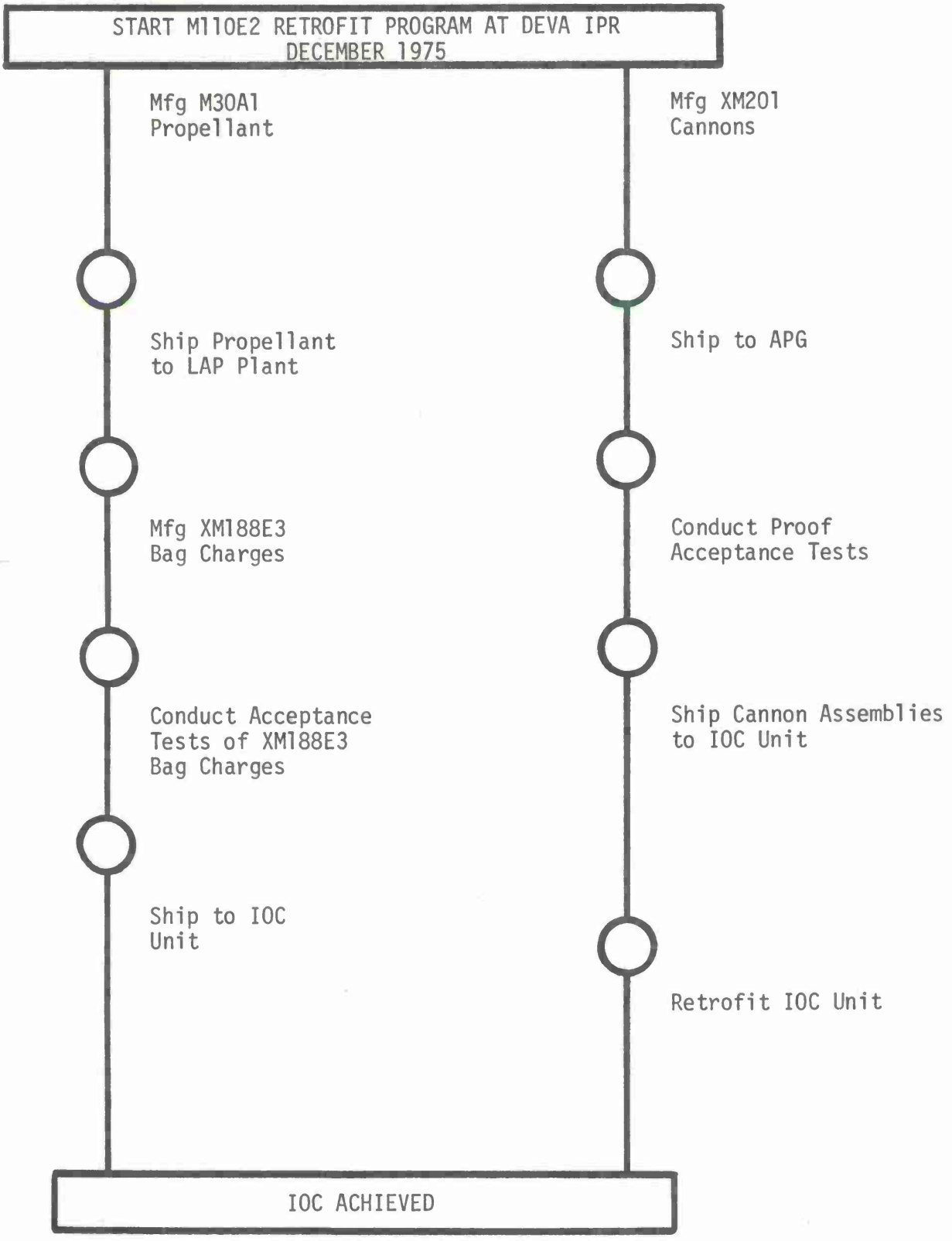

Figure 1. Flow of Major Activities

TABLE 1. SOURCES OF INFORMATION

Propellant		Cannon	
Activity	Source	Activity	Source
1. Mfg M30A1	Picatinny Arsenal Radford AAP[a]	1. Mfg Cannon	Watervliet Arsenal
2. Ship to Load, Assemble, and Pack (LAP) Plant	ARMCOM	2. Ship to APG	ARMCOM
3. Bag Mfg	Indiana AAP[a]	3. Acceptance Test	APG
4. Acceptance Test of Bag	Aberdeen Proving Ground (APG) Jefferson Proving Ground (APG)	4. Ship to IOC Unit	ARMCOM
5. Ship to IOC Unit	ARMCOM	5. Retrofit	ARMCOM Project Manager (PM) M110E2

[a] AAP = Army Ammunition Plant

completed. If an expert considered it highly unlikely that an activity could not be completed, it was assumed for this analysis that the questioned activity would be completed with 100% certainty. Otherwise, probabilities of occurrence were obtained for that activity and alternate courses of action were constructed in the event that activity failed. A characterization of activities and opinions of the experts on the likelihood of accomplishment are contained in Appendix A.

The major activities shown in Figure 1 were expanded to show the necessary interfaces and required sequence of activities within each major area. Time and cost data for each activity were obtained in the form of minimum, maximum, and most likely values.

The detailed network, associated data, and a description of each activity are contained in Appendix B.

RESULTS

The results of the network simulation show that IOC will be accomplished within 12½ to 14 months (with 90% confidence) after the DEVA IPR. The expected IOC completion time is 13½ months. These data are presented in Table 2 together with cannon and propellant activity completion times.

The results show that propellant will be delivered within 9 to 11½ months after the DEVA IPR. The expected time for completing the propellant activities is 10 months. This is about 3½ months prior to completion of the cannon activities, which indicates that the critical path for accomplishing IOC is comprised of cannon activities. This is confirmed in Table 2 which shows identical values for both the cannon activities completion and IOC.

Additional details on the cannon schedule are provided in Table 3. These data show expected and interval (low and high) values for completion of the major cannon activities: manufacturing, testing, shipping, and retrofit. The uncertainties associated with these activities arise from the normal functioning and are not attributable to the occurrence of any major risk events. They are due to the usual uncertainties encountered in routine operation of the described activities. The risk of failing tube acceptance testing did not contribute to schedule delays as this probability is low and replacement tubes are available.

Expected costs for these activities are presented in Table 4, together with low and high values which form a 90% confidence interval. The Product Manager has not separated these activity costs from the total program budget; therefore, cost risk was not assessed.

TABLE 2. TIME FROM DEVA IPR TO IOC (Mo)

	Low (5%)	Expected	High (95%)
Total Program Completion	12.5	13.5	14.5
Completion of:			
Propellant Activities	9.3	10.2	11.7
Cannon Activities	12.5	13.5	14.5

TABLE 3. TIME FROM DEVA IPR TO CRITICAL CANNON MILESTONES (Mo)

Milestones	Low (5%)	Expected	High (95%)
Complete:			
Manufacture	9.0	9.8	10.7
Test	10.0	10.8	11.7
Ship (to overseas depot)	11.8	12.8	13.8
Retrofit	12.5	13.5	14.5

TABLE 4. TOTAL PROGRAM[a] COST ($/$\overline{M}$)

Low (5%)	Expected	High (95%)
2.8	3.0	3.1

[a] As illustrated in Figure 1.

FINDINGS

If the decision to type classify the M110E2 system with the M106 projectile at zone 8 is made at the IPR, Type Classification (TC) approval is expected within 15 days of this decision. The planned schedule is to achieve IOC 12 months after the TC date. Therefore, subtracting ½ month from the results in Table 2, IOC will be completed within 12 to 13½ months after TC, but not before. That is, the scheduled IOC is not likely to be achieved, and the expected slippage is about one month.

The key events in this program are initiation of the cannon and propellant activities. The propellant activities are scheduled to begin at TC. A one month delay can be tolerated without affecting IOC; a slippage beyond one month will delay IOC. Cannon activities at Watervliet are expected to commence 30 days after TC action. Any delay will cause an equal slippage in the results presented in Table 1. The major risk in initiating these activities is the timely commitment of funds.

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APPENDIX A

CHARACTERIZATION OF MAJOR ACTIVITIES

XM201 CANNON

The cannon activities required to complete IOC can be summarized as follows:

1. Manufacture (machine) tube forgings
2. Test the assembled cannon
3. Deliver tested cannons to IOC units
4. Retrofit cannon in field

Manufacture.

Watervliet Arsenal will manufacture the tube on the same equipment presently used to manufacture the current 175mm and 8-inch tubes. Fifty forgings are on hand at Watervliet and 224 forgings have already been produced by National Forge and are ready to be delivered. Specifications for metallurgical properties for these forgings are very similar to most other tubes previously manufactured at Watervliet. Past history indicates that rejection of forgings because of incorrect properties is very unlikely. In simple terms, the actual manufacturing consists of straightening the forging, turning concentric spots on the outside diameter, lathe-boring the inside dimensions, turning the outside diameter, and x-raying the tube (Magnaglo). The last two are repeated until the required dimensions are obtained.

Thirty-three XM201 prototypes have already been manufactured and successfully tested. Additionally, 1600 175mm tubes have been processed on the same line and no failures have occurred (both the XM201 and 175mm tube require the same machining techniques). No new techniques or unproven manufacturing processes are required to produce the XM201 cannon. Watervliet plans to start manufacturing tubes in February 1976 with an expected delivery of five per month starting in July. Production will gradually increase until the tubes reach a production rate of 40-50/month in 1978. Watervliet indicates that they have not received any funding to machine the tubes. Funds have been provided for tooling only. The Product Manager will have to insure that funds are made available by February or the production schedule could slip.

After the tubes are machined, they are attached to the breech, thereby forming the XM201 Cannon assembly. There are 240 breech mechanisms presently available at Watervliet; therefore, breech mechanisms are not expected to cause delay. After the cannons are assembled, they are prepared for shipment by oiling and plugging the bore, priming the outside surfaces, and wrapping the breech mechanism in barrier material. When two cannons are prepared, they are mounted on wooden skids, strapped down on trucks and shipped to Aberdeen Proving Ground (APG) for proof-testing.

Testing.

Production Acceptance Test of the finished cannons is to be conducted at Aberdeen Proving Ground and is based on established Acceptance Test Procedures. The testing procedure involves three distinct steps: prefiring inspection, proof-firing, and post-firing inspection. Aberdeen's usual procedure is to proof-fire 6-8 cannons at one time since this constitutes approximately one day's firing. As the cannons arrive, they are unpacked, inspected, and prepared for firing. This pre-firing inspection requires about 2 days to be completed for each cannon. When 6 to 8 cannons have been prepared for firing, the actual proof-firing is scheduled.

Proof-firing consists of firing one inert M106 projectile at zone 9 through each cannon. This firing insures the integrity of the cannon. After firing, the cannons are cleaned and inspected again. Approximately 2 days are required to conduct the post-firing inspection and repacking of each cannon. The entire testing procedure consumes between 35 and 50 man-hours for each cannon.

Aside from a catastrophic failure during firing, other possible reasons to reject a cannon include: cracks discovered during inspection, dimensions out of tolerance, oversize tubes, and chrome plating defects. If the cannon passes inspection, it is prepared for shipment by fastening it to the original shipping skid. If the cannon does not pass inspection, it is prepared for shipping and sent back to Watervliet for further inspection and/or rework. Past records indicate that about 1 out of every 300 cannons does not pass inspection. Based on this information, there is approximately a 5% chance of one cannon failure out of the first 16 and .1% chance of two failures in the first 16 cannons.

TECOM assigns a project number to each test when a request is made. The request usually contains the rate at which cannons are expected, and APG generally arranges their schedule accordingly. Aberdeen's standing policy is to never let any scheduled testing slip more than one month. Aberdeen has been notified of the required testing via the pre-IPR for Type Classification; however, no request has been sent to TECOM because funds have not yet been made available. The Product Manager will have to insure that funds are available and a testing schedule is established prior to the delivery of cannons from Watervliet; otherwise, testing could be delayed.

Transportation.

When APG completes proof-testing the cannons, they are shipped by truck (two per truck) to a US port where they will await shipment. The amount of time the cannons are delayed at the dock will depend upon ship availability, loading time, loading space, and possible weather conditions. The number of cannons loaded on one ship may vary. Several ships could be used to transport the 13 cannons. Transit time to reach Europe is estimated as 12 days but weather delays, availability of port space, dock labor shortage, or strikes could increase the transit time. The probability of the cannons not reaching Europe is considered very low. Once the ships are docked in Europe, the cannons will be unloaded and placed either on rail cars or trucks depending upon availability of each and then transported to the IOC unit. Retrofit will begin at the discretion of the IOC unit.

Retrofit Cannon.

Once the XM201 cannon arrives at the IOC units, the Direct Support (DS) Maintenance units can begin changing cannon assemblies. A draft Modification Work Order (MWO) will accompany the cannons. No maintenance teams from ARMCOM will be sent to Germany to participate in the retrofit. The procedure will be no different from that now used to change cannons and the DS unit has experienced personnel to make the changes. The procedures for changing cannons is well defined and no problems are foreseen. Should some accident occur, one spare cannon assembly will be on hand.

PROPELLANT

The following activities are required to provide XM188E3 charges to the IOC units:

1. Manufacture Propellant (M30A1)
2. Conduct Acceptance Tests - Propellant M30A1
3. Ship Propellant to LAP Plant
4. Manufacture Base Charges - XM188E3
5. Conduct Acceptance Tests
6. Deliver to IOC Unit.

Manufacture Propellant.

M30A1 propellant will be manufactured by Radford Army Ammunition Plant at the rate of 1.2M lbs per month. The first product lot of 1.2M lbs is scheduled for completion on 1 April 1976 followed by acceptance and

delivery to the LAP plant on 1 May 1976. Occasional Production Engineering lots have been made since 1974 and no pilot samples appear necessary before the next production run of M30A1. Picatinny Arsenal has specified the formulation based on the acceptance test of a sample taken from the 15,000 lb pilot lot. The risk associated with this activity is considered low because Radford has had sufficient experience in manufacturing M30A1 propellant. Ignoring a major incident, there is no reason to doubt that the propellant of correct specifications will be produced in the required quantities at the required time.

Conduct Acceptance Tests - Propellant M30A1.

A sample of propellant taken by Picatinny from the 15,000 lbs pilot lot quantity produced by Radford was tested by APG. Data obtained was then used by Picatinny to specify the charge weight. No further testing, other than normal quality control, will be performed with the propellant unless a serious error occurs during charge acceptance tests.

Ship Propellant to Load, Assemble, and Pack (LAP) Plant.

As production quantities of propellant are accepted and packed-out at Radford, they are shipped to Indiana Army Ammunition Plant, a LAP plant. Shipment is accomplished by commercial truck or piggyback trailer. Time variability in obtaining shipment mode could cause a delay.

Manufacture Bag Charges.

Propellant from Radford is used to produce charges at Indiana. The expected production rate is 8,000 to 11,000 charges per month. The first year buy will be 91,000 XM188E3 charges and the first month production is earmarked for the IOC unit. Inability to perform according to specifications appears to be the only risk associated with this activity. Production is expected to begin in June 1976, if shipping containers are available and in July 1976, if no containers are available.

Conduct Acceptance Test.

Upon completion of an XM188E3 lot, a sample is selected and sent to JPG/APG where its performance is compared to Technical Data Package (TDP) specifications. Previous experience indicates the first lot chance of rejection is 10%. If a test shows propellant charges do not meet specifications completely, a waiver may be issued, or the lot may be reblended. In case of the waiver, the charge weight is adjusted to insure that chamber pressure is not exceeded while achieving the desired muzzle velocity. The chance of this occurrence is less than 5%. If a lot is rejected, about one month delay could occur while awaiting a new lot.

Deliver to IOC Unit.

The charges are processed through the pipeline as follows: (1) LAP plant to the US port, (2) US port to European port, (3) European port to depot, and (4) depot to IOC unit.

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APPENDIX B

VERT NETWORK AND DATA

This appendix contains a summary of the activities described in Appendix A and the data used to evaluate the network depicted in Figure B-1. Table B-1 contains the data used as input for the VERT computer program which was used to assess the program uncertainty.

Activities A1 through A11 represent the manufacturing of the gun tubes. The cost of 17 cannons is charged to the program. The proof acceptance testing will be done in 3 separate lots of 8, 6, and 8 gun tubes, respectively. In addition, the time to build the first 2 cannons (activity A1) includes the total production lead time between the DEVA IPR and the delivery of the first cannon.

Activities A12 through A22 represent the shipping of the cannons from Watervliet Arsenal to Aberdeen Proving Ground. The shipping will occur by truck, and each truck will transport 2 cannons. Time and costs associated with the shipping have been included using the same reasoning as for the manufacturing.

Activities A23 through A33 show the time required to prepare the cannons for proof acceptance testing at Aberdeen Proving Ground. The gun tubes will be prepared as they arrive in pairs at Aberdeen Proving Ground. No cost is associated with these activities because the testing cost (activities A34 through A36) will include the total Aberdeen Proving Ground charges.

Activities A34, A35, and A36 represent the testing of three lots of 8, 6, and 8 gun tubes, respectively. The testing cost of the first 2 lots is fully charged to IOC, but only the cost of 3 cannons of the last lot is considered. This is consistent with the description of activities A1 through A11.

Activities A34 through A39 represent the post-firing inspection of the 3 test lots. A total of 17 guns must be inspected prior to IOC. No cost is charged because the testing cost (activities A34 through A36) includes the total Aberdeen Proving Ground charges.

Activities A40 and A41 represent the possible outcomes of the proof acceptance testing. A40 has a 94.7% chance of occurring, in which case all of the 17 gun tubes have been accepted, and the network continues with no time delay or additional cost caused by tube rejection. A41 has a 5.3% chance of occurring, in which case one or more of the 17 gun

tubes have been rejected. The network continues after adding the cost of one additional tube FOB Aberdeen Proving Ground. No additional time is charged to IOC because of tube(s) rejection, since the probability of more than one tube rejection is exceedingly small, and Aberdeen Proving Ground will have sufficient cannons on hand to make-up the loss of one with no delay.

Activities A42 and A43 account for the time and cost to ship a total of 13 guns from Aberdeen Proving Ground to the US port. The first 8 cannons will be shipped when testing of first test lot has been completed; the last 5 will be shipped when the 2nd lot is completed.

Activities A44 and A45 represent the shipping of 13 gun tubes from the US port to the European port and from the European port to the European depot, respectively.

Activity A46 represents the retrofitting of twelve M110's with the new cannon.

Activities S1 and S2 are signals to indicate that proof acceptance test of a lot has been completed and the facilities at Aberdeen Proving Ground are ready to begin testing on the next lot.

Activity B1 represents the manufacturing of the propellant and includes the lead time between the DEVA IPR and the beginning of production.

Activity B2 represents the shipping of the propellant from Radford Army Ammunition Plant to the Load, Assemble, and Pack (LAP) Plant.

Activity B3 represents the manufacturing of 11,000 bag charges at the LAP Plant. The time considered includes 40 days lead time between the arrival of the propellant and the beginning of production.

Activity B4 represents the ballistic test of the bag charges.

Activities B5 and B6 are the possible outcomes of the ballistic test. B5 has a 90% chance of occurring, in which case the bag charges have been accepted, and the network continues with no time delay or additional cost. B6 has a 10% chance of occurring, in which case the LAP Plant must wait for a new lot of propellant. This last activity includes the cost of shipping between the LAP Plant and Radford, and the cost of performing the ballistic test on the new lot.

Activities B7, B8, and B9 represent the shipping of 11,000 bag charges from the LAP Plant to the US port, from the US port to the European port, and from the European port to the European depot, respectively.

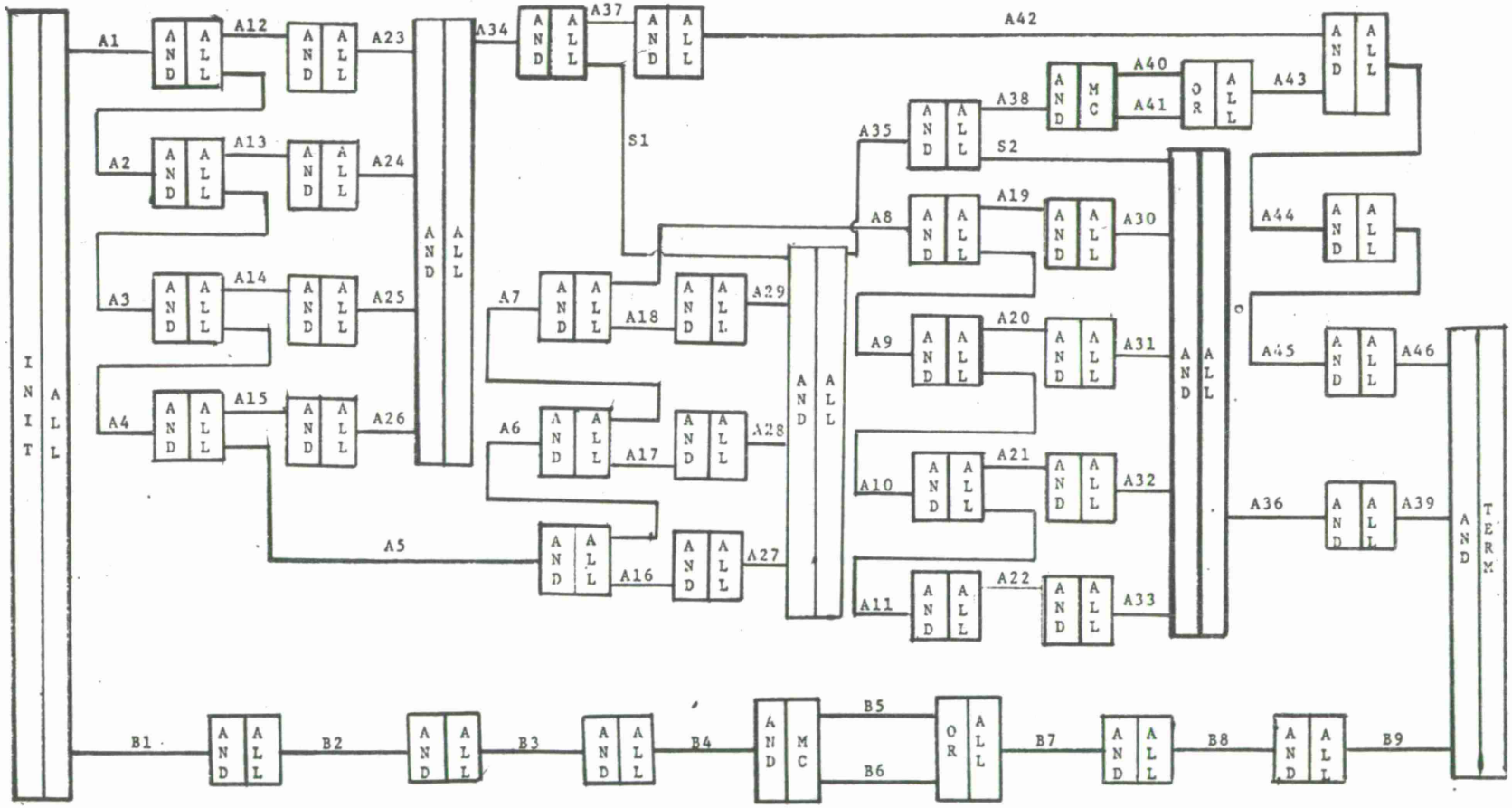

Figure B-1. VERT Network

TABLE B-1. DATA AND DESCRIPTION OF ACTIVITIES

ACTIVITY NO	TIME (DAYS)			COST ($)			DESCRIPTION
	MIN	MAX	ML	MIN	MAX	ML	
A1	187	259	207	94,230	109,613	104,690	Manufacture 2 Gun Tubes
A2	11	15	12				
A3							
A4							
A5							
A6							
A7							
A8							
A9				47,115	54,806	52,345	
A10				0	0	0	
A11				0	0	0	
A12	7	21	14	620	1,075	920	Ship 2 Gun Tubes from Watervliet to APG
A13							
A14							
A15							
A16							
A17							
A18							
A19							
A20				310	537	460	
A21				0	0	0	
A22				0	0	0	
A23	0	0	0	3	5	4	Prepare 2 Gun Tubes for Proof Testing

TABLE B-1. DATA AND DESCRIPTION OF ACTIVITIES (CONT)

ACTIVITY NO	TIME (DAYS)			COST ($)			DESCRIPTION
	MIN	MAX	ML	MIN	MAX	ML	
A24	0	0	0	3	5	4	Prepare 2 Gun Tubes for Proof Testing
A25							
A26							
A27							
A28							
A29							
A30							
A31							
A32							
A33							
A34	1	2	1	8,000	9,600	8,800	Test 8 Gun Tubes
A35	1	2	1	6,000	7,200	6,600	Test 6 Gun Tubes
A36	1	2	1	3,000	3,600	3,300	Test 8 Gun Tubes
A37	12	20	16	0	0	0	Conduct Post-Firing Inspection of 8 Gun Tubes
A38	9	15	12				Conduct Post-Firing Inspection of 6 Gun Tubes
A39	4	8	6				Conduct Post-Firing Inspection of 8 Gun Tubes
A40	0	0	0	0	0	0	Probability is 0.947 that no Gun Tubes are rejected during Proof-Testing
A41	0	0	0	48,425	56,543	53,905	Probability is 0.053 that 1 or more Gun Tubes are rejected during Proof-Testing
A42	10	30	20	2,480	4,296	3,680	Ship 8 Gun Tubes from APG to US Port
A43	10	30	20	1,550	2,685	2,300	Ship 5 Gun Tubes from APG to US Port
A44	12	35	28	8,000	10,000	8,400	Ship 13 Gun Tubes from US Port to Europe Port

TABLE B-1. DATA AND DESCRIPTION OF ACTIVITIES (CONT)

ACTIVITY NO	TIME (DAYS)			COST ($)			DESCRIPTION
	MIN	MAX	ML	MIN	MAX	ML	
A45	3	21	15	400	700	600	Ship 13 Gun Tubes from Europe Port to Europe Depot
A46	14	28	21	0	0	0	Retrofit 12 M110's at DS/GS Level
S1	-	-	-	-	-	-	Signal - A VERT Requirement
S2	-	-	-	-	-	-	Signal - A VERT Requirement
B1	90	135	105	550,000	611,000	586,000	Produce Propellant
B2	10	30	20	25,000	43,000	35,700	Ship Propellant to LAP Plant
B3	85	115	100	1,128,000	1,457,000	1,370,000	Manufacture Bag Charges
B4	7	21	14	5,000	15,000	10,000	Test Bag Charges
B5	0	0	0	0	0	0	Probability is 0.90 that the Bag Charges will be accepted or Pass on Waiver
B6	45	60	50	55,000	101,000	83,000	Probability is 0.10 that the Bag Charges will be rejected
B7	10	30	20	25,000	43,000	36,700	Ship Bag Charges from LAP Plant to US Port
B8	12	35	28	49,000	61,000	51,000	Ship Bag Charges from US Port to Europe Port
B9	3	21	15	2,500	4,300	3,700	Ship Bag Charges from Europe Port to Europe Depot

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