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INTEROCEANIC CANAL EXCAVATION SCHEDULING VIA COMPUTER SIMULATION

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ABSTRACT

The computer simulation language GPSS/360 was used to simulate the schedule of several nuclear detonation programs for the interoceanic canal project. The effects of using different weather restriction categories due to air blast and fallout were investigated. The effect of increasing the number of emplacement and stemming crews and the effect of varying the reentry period after detonating a row charge or salvo were also studied. Detonation programs were simulated for the proposed Routes 17A and 25E.

The study demonstrates the method of using computer simulation so that a schedule and its associated constraints can be assessed for feasibility. Since many simulation runs can be made for a given set of detonation program constraints, one readily obtains an average schedule for a range of conditions. This provides a method for analyzing time-sensitive operations so that time and cost-effective operational schedules can be established.

A comparison of the simulated schedules with those that were published shows them to be similar.

INTRODUCTION

Operational schedules for nuclear detonations are established after giving consideration to many factors. The quantification and interdependence of these factors become very complex when many nuclear devices are involved. One source of variability is the time it takes to ready the devices for firing. Furthermore, there are firing time delays due to meteorological considerations (safety considerations due to air blast and fallout) which limit the available days for firing as a function of the month of the year, device yields, and geographic location of the row charges.

To understand and incorporate the scheduling variables into an operations plan for the interoceanic canal project, as well as to develop a schedule for detonations and emplacement hole construction, simulation of the emplacement and firing sequence was carried out using the General Purpose Simulation System (GPSS/360) computer language.[1] This paper discusses some of the basic assumptions of the simulation program and the results of the simulations made.

The data for an initial detonation program and a revised detonation program are shown in Table I. The table shows the number of devices which make up the salvos. For better program details and data used in the simulation, see Reference 2.

ASSUMPTIONS FOR THE SIMULATION PROGRAM

The basic excavation program to be simulated is divided into salvos, each consisting of a set of row charges which will be fired simultaneously. A number of salvos will comprise an excavation pass, and several passes may be included in the overall excavation plan. The number of devices per salvo, the number of salvos in each pass, the number of passes, and the detonation sequence of the salvos may vary from one plan to another. One basic premise, provided by the Corps of Engineers' Nuclear Cratering Group, is that drilling and casing of all emplacement holes in a pass will be accomplished prior to initiating nuclear device activities. However, hole response might be a problem; thus, a case was also simulated, for Routes 17A and 25E, wherein one performs a discrete operation of drill - case - emplace - stem - fire - then start with the drill operation again on the next salvo.

Two sets of detonation programs were simulated (see Table I).

Initial Detonation Program[3] - This consists of 25 salvos (168 devices total) for Route 17A and 23 salvos (143 devices total) for Route 25E. Schedules for two and three passes together with a discrete drill - case - emplace - stem - drill plan were simulated. The trade-off studies on the schedule for the number of passes, air blast weather, reentry period, and use of single or double crews were made for this detonation program.

Revised Detonation Program[4] - This program for Route 17A is a two-pass schedule consisting of 16 salvos for the first pass and 10 salvos for the second pass. There is a total of 248 devices. The

Salvo No.	INITIAL PROGRAM[3] Number of Devices		REVISED PROGRAM[4] Number of Devices	
	Route 17A[a]	Route 25E[b]	Route 17A[c]	Route 25E[d]
1	6	5	19	10
2	8	5	7	6
3	8	7	11	7 (Diversion Shots)
4	9	9	8 (Diversion Shots)	1
5	6	5	10	12
6	10	5	9	5
7	6	5	1	5
8	7	5	16	7
9	10	5	5	5
10	6	5	12	5
11	5	8	9	5
12	6	9	8	8
13	6	5	8	10
14	6	5	7	7
15	5	5	7	5
16	5	5	7	7
17	7	5		16
18	5	5	16	5
19	5	5	13	5
20	5	5	15	6
21	5	10	13	9
22	6	10	9	
23	7	10	3	
24	10		7	
25	9		5	
26			7	
27			14	

(Diversion Shots bracket covers salvos 1–7 for Revised Route 17A and salvos 1–4 for Revised Route 25E.)

(a) 168 devices total
(b) 143 devices total
(c) Salvos 1 - 16, first pass, 144 devices; salvos 18 - 27, second pass, 104 devices.
(d) Salvos 1 - 12, first pass, 76 devices; salvos 13 - 21, second pass, 70 devices.

TABLE I

INITIAL AND REVISED DETONATION PROGRAMS DATA first 7 salvos on the first pass are diversion shots, made up of a total of 65 devices. The program for Route 25E is also a two-pass schedule made up of 12 and 9 salvos for the first and second passes, respectively, for a total of 146 devices. The first 4 salvos are diversion shots consisting of 24 devices total. In this program, salvos are grouped into sets. For example, salvos 6 and 7 make up the first set for the first pass on Route 17A. All the salvos in a set are readied for firing continuously. Then the set waits for good firing weather. When the proper weather occurs, the salvos are detonated one after the other. A cool-off period takes place after a set of salvos is detonated. Work may also proceed on the succeeding salvos while a salvo or set of salvos is waiting for the appropriate weather to fire. Five fallout weather categories were used for Route 17A and three fallout weather categories for Route 25E. Only Category I air blast data is used.

The simulated schedules for this revised detonation program were later compared to the published schedule. [5, 6]

The devices which make up a given salvo are successively emplaced and stemmed. The emplacement crew(s) sequentially emplaces the devices that make up the salvo; the stemming crew(s) stems a particular device after it is emplaced, assuming they have completed their previous stemming. In the simulations for the initial detonation program, evacuation takes place after the last device in a salvo has been stemmed and the salvo is fired when the weather permits. The emplacement crew(s) and stemming crew(s) remain idle until the previous salvo has been fired. However, as part of the plan for the revised program, they work continuously on all the salvos which make up a set.

Two conditions have to be satisfied with regard to meteorology. These conditions can best be described by a high altitude delay function and a low altitude delay function. These functions essentially specify the percentage of days in a particular month which satisfy both meteorological conditions and thus enable the salvo to be fired. The high altitude function specifies the percentage of days it is feasible to fire with respect to air blast, whereas the low altitude function specifies the percentage of days it is possible to fire with respect to radiation fallout. The probabilities of firing may vary according to the time of the year, the device yields, and the geographic location of the salvo. The weather data used in the simulation are given in Tables II and III. Note that weather data can be given as a percentage value or as the actual number of good days for any 1 month.

All these constraints are followed by the simulation. What it does most uniquely is display the schedule based on the basic operations needed for each device for each salvo and sample the fallout and air blast weather probability of firing.

MAIN COMPUTATIONAL BLOCKS OF THE SIMULATION PROGRAM

Block 1: Specify the case description, devices per salvo, salvo firing sequence, fallout weather, and air blast weather.

Category / Month	FALLOUT					AIR BLAST		
	Route 17A			Route 25E		Routes 17A and 25E, All Salvos		
	Salvos 1 - 9	Salvos 10 - 19	Salvos 20 - 25	Salvo 7	All Others	I	I - VI	I - VII
June	71	58	9.7	10	35	0	19	100
February	71	64	10.7	21	47	33	21	100
March	29	29	3.2	59	71	0	23	100
April	40	40	10	26	36	15	37	100
May	39	32	6.5	10	16	43	58	100
June	4	0	6.7*	0	0	14	70	100
July	10	6.5	3.2	22	26	10	52	100
August	14	3.2	3.2	16	19	44	58	100
September	7	6.7	3.7*	3.3	3.2	44	50	100
October	19*	19*	22.8*	3.2	6.5	20	29	100
November	53	50	23.4	20	23	19	50	100
December	42	39	19.3	26	52	18	52	100

Note: Fallout pattern is to the south unless asterisked, in which case half of those periods have patterns to the north.

TABLE II

FREQUENCY OF ACCEPTABLE FALLOUT AND AIR BLAST WEATHER (IN PERCENT) - INITIAL DETONATION PROGRAM

Category / Month	ROUTE 17A					ROUTE 25E		
	B	C	D	E	E	A	B	C
January	22	19	18	3	0	16	10	3
February	20	22	18	3	1	18	12	7
March	9	12	9	1	0	17	21	17
April	12	19	12	3	2	13	10	7
May	12	10	10	2	2	7	6	5
June	1	0	0	0	0	1	1	1
July	3	3	2	1	1	8	7	6
August	4	2	1	1	0	7	7	7
September	1	1	1	1	1	2	2	2
October	5	5	5	3	2	2	2	1
November	17	17	16	7	5	7	7	6
December	13	14	12	7	5	16	14	9

For Route 17A:
- Category B: Salvos 8-10, 18-20
- Category C: Salvos 4-7
- Category D: Salvos 1, 11-13, 21-24
- Category E: Salvos 2, 3, 14-16
- Category F: Salvo 25

For Route 25E:
- Category A: Salvos 2, 4
- Category D: Salvos 1, 3, 5, 6, 8-10, 12-14 16-21
- Category C: Salvos 7, 11, 15

Air blast data for initial and revised detonation programs are identical.

TABLE III

AVERAGE FALLOUT DATA (GOOD DAYS PER MONTH)
REVISED DETONATION PROGRAM

Block 2: Specify the starting time, reentry time, and salvos to be fired.

Block 3: Compute the number of devices per salvo and the number of salvos in a set.

Block 4: Stem, emplace, and ready the devices which make up a salvo or a set of salvos.

Block 5: Fire the salvo, or the salvos in a set, if weather permits.

Block 6: Repeat Blocks 3, 4, and 5 for other salvos or sets of salvos in the detonation plan.

Block 7: Output information.

Block 1 is used to specify several "functions" needed for the simulation. These are:

a. The number of devices per salvo for each salvo.

b. The salvo firing sequence for the case under consideration.

c. Fallout delay weather.

d. Air blast delay weather.

Because of the different device yields and the geographic location of the salvos, several fallout delay weather functions are defined. Air blast weather is defined in terms of severe restriction (Category I), modest restriction (Category I-VI), and no restriction (Category VII).

The starting time for the operation is specified in Block 2, together with the total number of devices to be fired. This starting time is a calendar time in hours. The salvos are then operated one by one, using the number of devices in each salvo and the salvo sequence. The number of devices to be emplaced and stemmed is determined in Block 3 for each salvo under consideration. Block 4 gives the emplacement and stemming sequence. The simulator advances the clock corresponding to the time it takes to perform every operation. It is noted at this point that when one performs an intermittent drill - case - emplace - stem - fire - drill operation, a program change is made between Blocks 3 and 4 to take into account the drilling operation.

Block 5 indicates the firing sequence. The salvo is fired only if the weather satisfies the radiation fallout and air blast effect criteria. One can thus investigate the effect of different weather restrictions on the schedule by changing the fallout and air blast weather delay functions in Block 1. In Block 5, the time of operation and the salvo type and number are utilized to specify the appropriate fallout and air blast weather delay functions.

Block 6 tests whether the last salvo fired was the last salvo in the pass; if not, the next salvo in the sequence is considered and the process repeated.

After the last salvo has been fired, the simulation permits a printout of the statistics on the simulation time, delay times, utilization of the crews, total number of devices, and total number of salvos. This is done in Block 7.

AVERAGING THE INFORMATION

To permit obtaining the schedule from the simulation, time is printed out immediately after firing the salvo. Ten simulation trials for each case were made and the results were averaged out. A plot of the results leads to a graph of the mean, maximum, and minimum time to accomplish a pass for a given set of constraints. Such a graph is shown in Figure 1. Note the large changes in the slope of the curves caused by drastic changes in the meteorological data which applies to the individual salvos. Note also the elongation of the time to accomplish the detonation of one salvo during the bad weather months.

For the rest of the results discussed in this paper, only the mean will be used.

SIMULATION BASED ON THE INITIAL DETONATION PROGRAM

For this set of simulations, the emplacement and stemming crews stop working after a salvo is ready and is waiting to be detonated. Work does not proceed on the next salvo until after the previous salvo has been fired and until after a specified reentry period has elapsed. Start time is October 1 for Route 17A and November 1 for Route 25E. This was done to take advantage of the good weather months for firing.

The first set of simulations was used to investigate the time it takes to accomplish the first pass out of a two-pass and out of a three-pass schedule. The results are shown in Figure 2. Note the almost linear behavior at the beginning. There is more variability during the bad weather months. Category (I-VI) air blast data was used in Figure 2.

Figure 3 shows the large changes in time to accomplish the first pass out of three-pass schedule for both routes using different degrees of weather restriction due to air blast. It is clear that changing air blast restriction from no restriction (Category I-VII), medium restriction (Category I-VI) and maximum restriction (Category I) varies the schedule tremendously. For example, for Route 17A the first pass is seen to take 4.6, 7.4, and 12 months, respectively, for the different air blast restriction categories.

Figure 4 shows the effect of doubling the emplacement and stemming crews. This does not induce a major change in the schedule; in fact, the savings correspond to no more than 1 month for each pass. However, the cost trade-off studies that were made[2] show that double crews are advantageous; hence, double crews were used in the simulations for the revised detonation program.

Figure 5 shows the effect of varying from 1 day to 1 week the reentry time after detonating each salvo. Again, it is seen that reentry time does not have a very significant effect on the schedule.

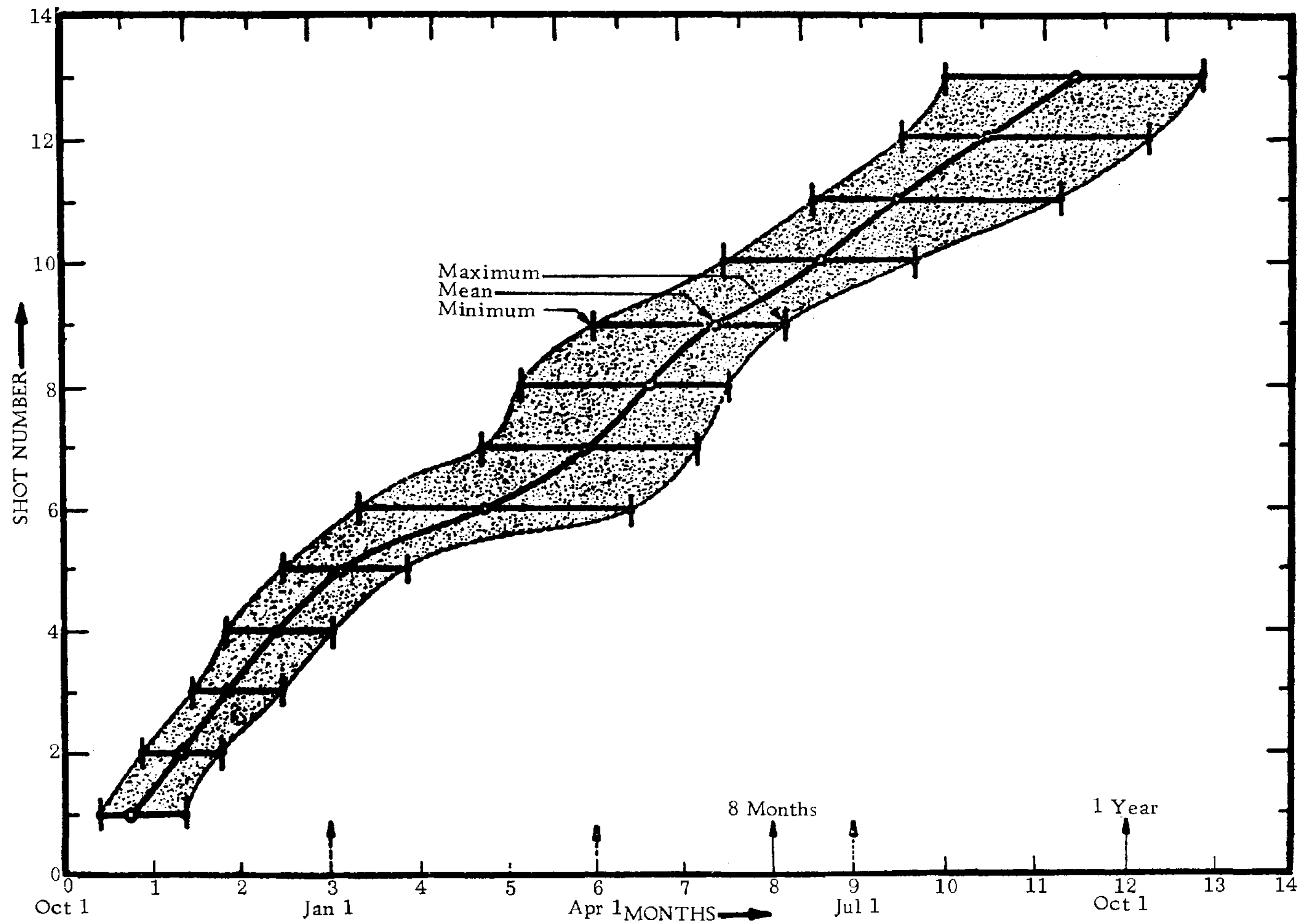

FIGURE 1

A TYPICAL SIMULATED SCHEDULE

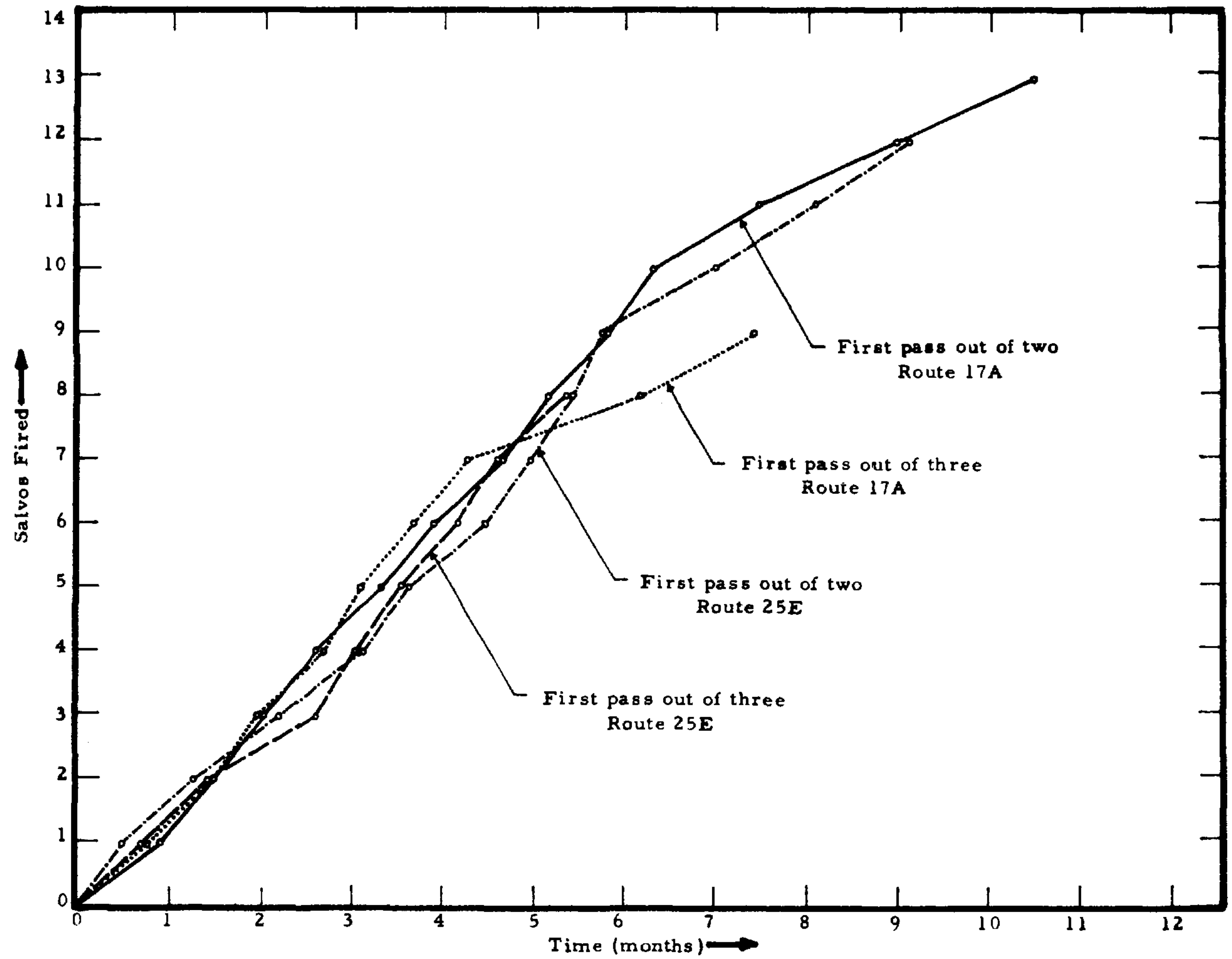

FIGURE 2

AVERAGE SCHEDULES OF VARIOUS PASSES
INITIAL DETONATION PROGRAM

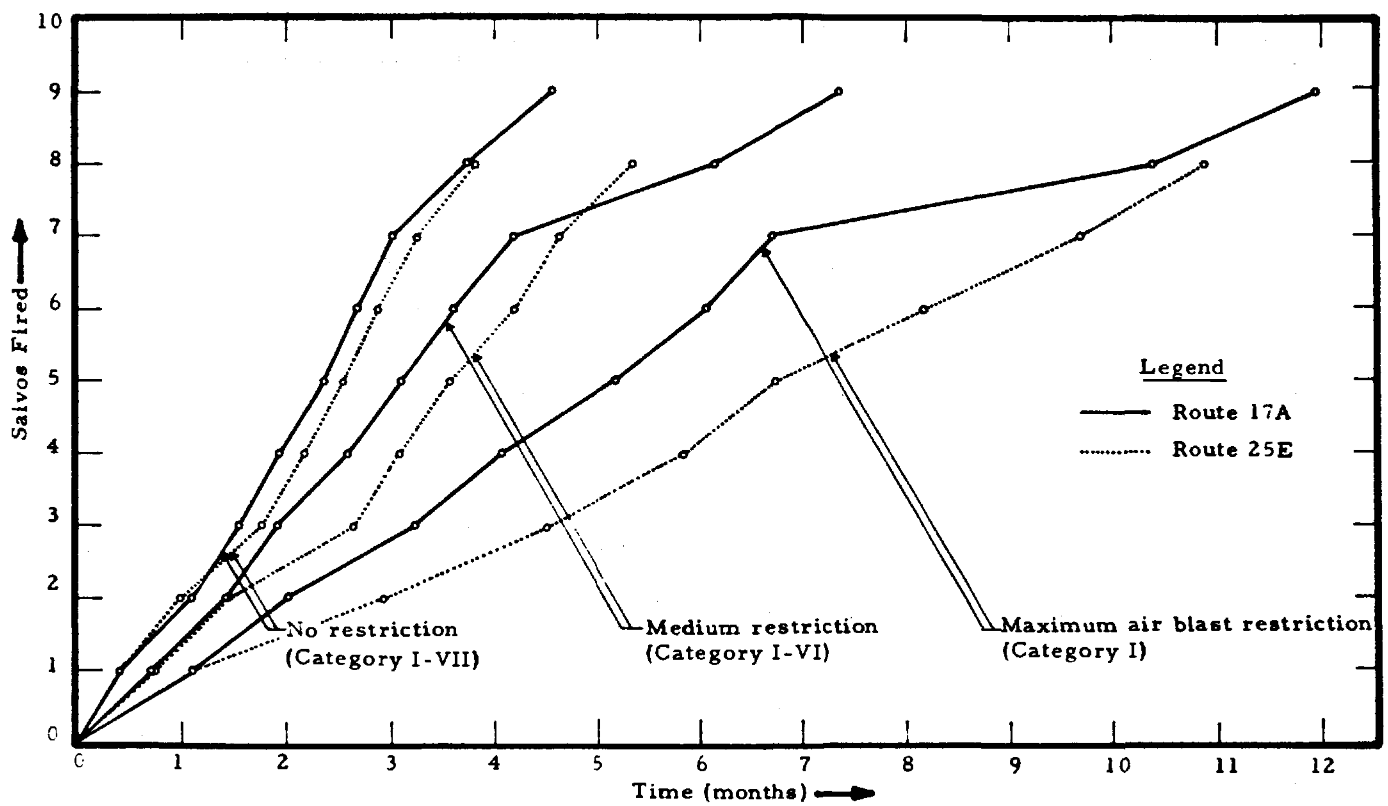

FIGURE 3

AVERAGE SCHEDULES SHOWING THE EFFECT OF AIR BLAST RESTRICTION
INITIAL DETONATION PROGRAM

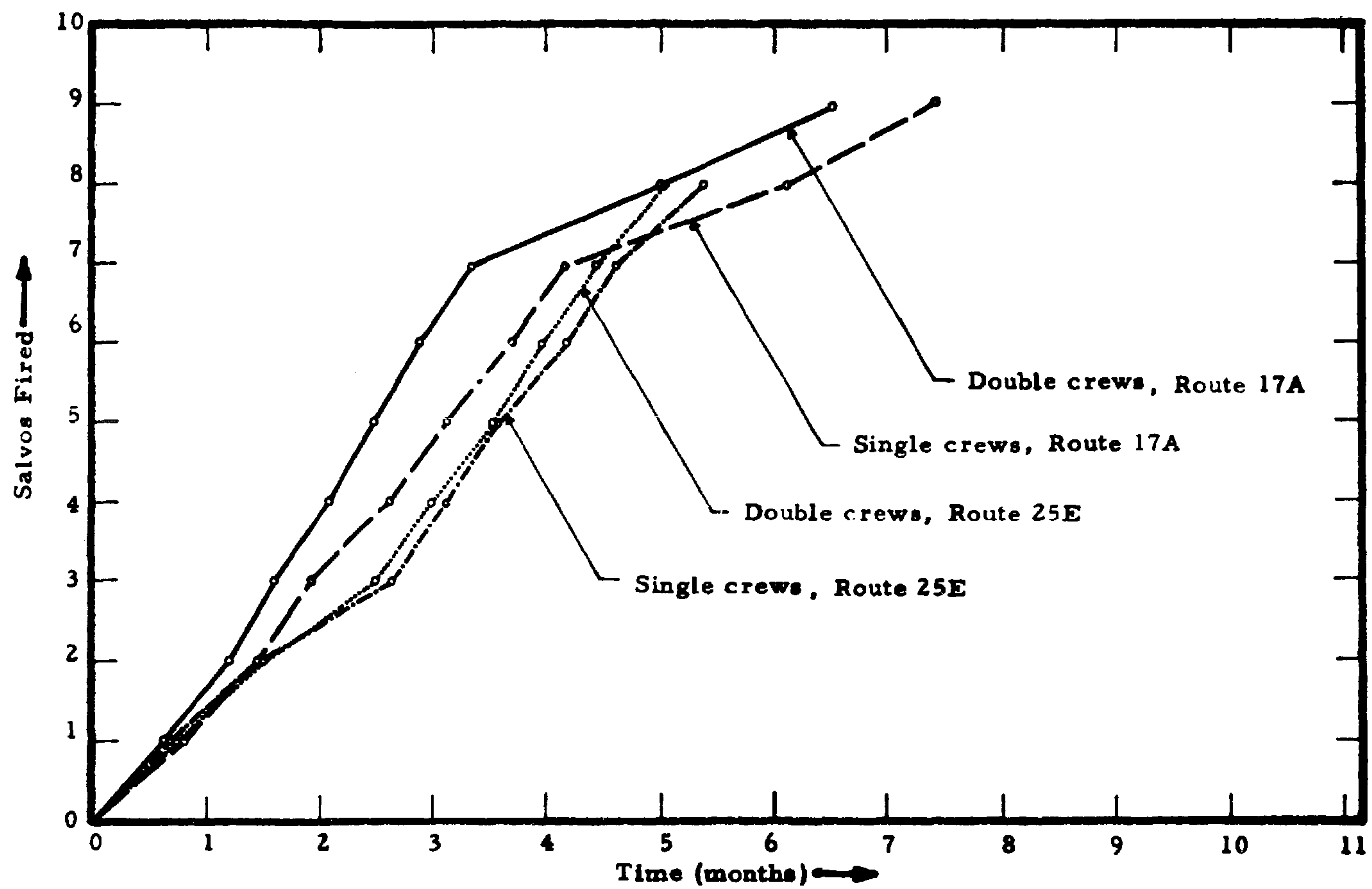

FIGURE 4

AVERAGE SCHEDULES SHOWING THE EFFECT OF DOUBLING CREWS
INITIAL DETONATION PROGRAM

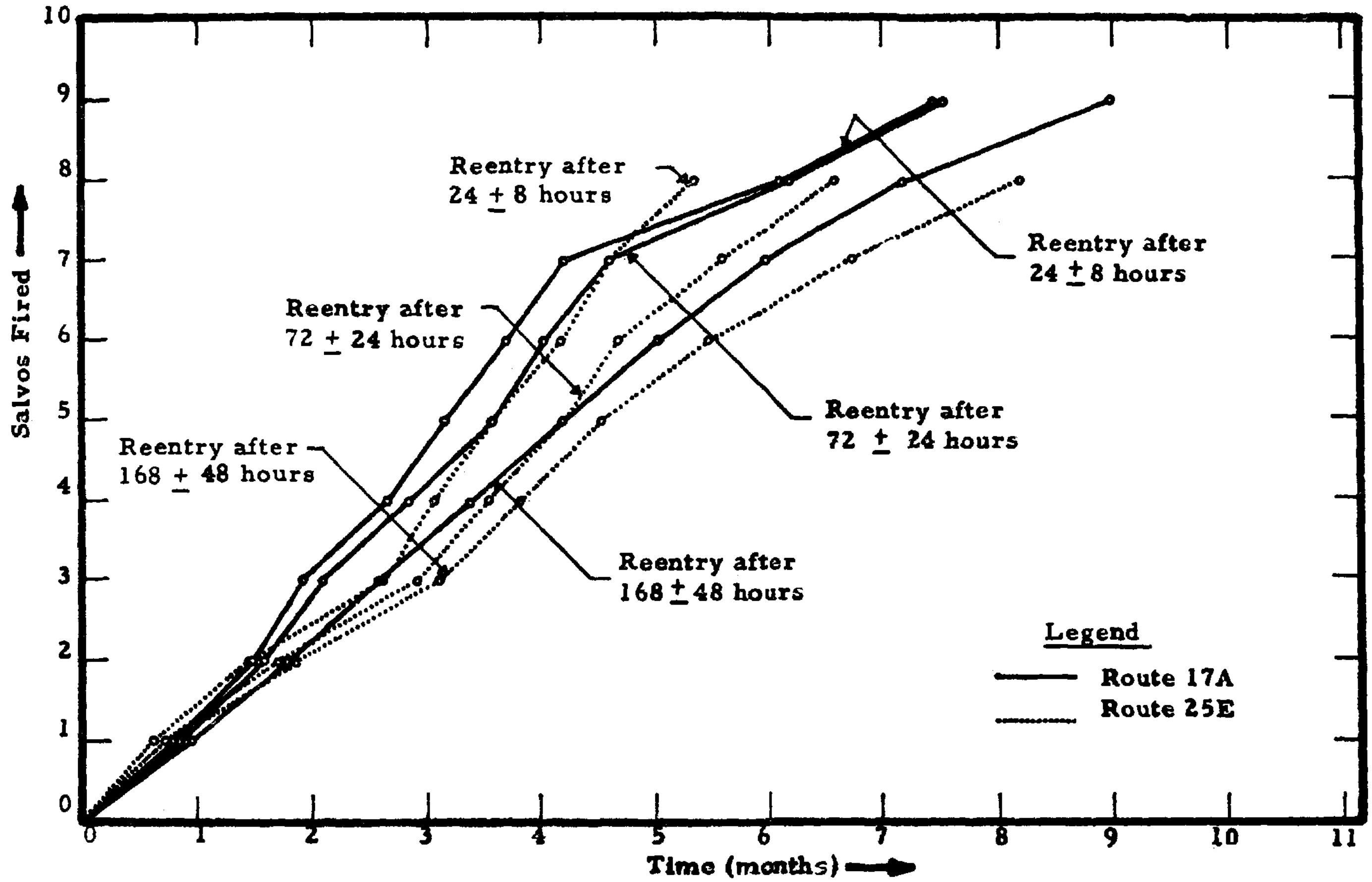

FIGURE 5

AVERAGE SCHEDULES SHOWING THE EFFECT OF REENTRY TIME
INITIAL DETONATION PROGRAM

Concern over the response of the holes was expressed while a salvo is detonated; therefore, a simulation was also made for the case of the intermittent drill - case - emplace - stem - fire - drill operations. The results are shown in Figure 6. It takes 49 and 44 months for Routes 17A and 25E, respectively. The general slope of the curve is almost constant. This is because the 1 month allocated to drilling and casing for each salvo tends to average out any variations in the weather delays.

Although the results are not shown here, simulations were carried out to determine the probability of being able to fire a salvo when the wind is blowing to the north on Route 17A. It was found that there is a 92 percent chance of firing one salvo and a 67 percent chance of firing a second salvo. Note that one or two salvos less to fire decreases to a large degree the time to accomplish a pass.

EVALUATION OF FINAL SCHEDULE BASED ON THE REVISED DETONATION PROGRAM USING SIMULATION TECHNIQUES

Data and Assumptions

Final schedules were published for both Route 17A[5] and Route 25E,[6] and these were evaluated using the simulation techniques discussed earlier. These schedules were based on the revised detonation program and with a different set of constraints. The two major constraints consist of:

a. The use of Category I only for air blast restriction.

b. The device emplacement activities for subsequent salvos were permitted while waiting for suitable firing weather for the earlier salvo or sets of salvos.

Basically, the revised program consists of a two-pass schedule for both routes. The salvos are arranged into sets. Table IV shows the grouping of salvos into sets, plus the data that goes with them. For example, Salvos 6 and 7 make up the first set of salvos for the first pass on Route 17A. A set of salvos is continuously readied for firing; and once ready, the set waits for favorable weather to fire as a whole. As soon as the weather is favorable, the salvos in the set are detonated one after the other with just 10 hours interval between salvos. On the first pass for both routes, work stops while a set of salvos is awaiting favorable detonation weather. However, on the second pass for both routes, work is allowed to continue on subsequent sets of salvos while other salvos are waiting for favorable detonation weather. The reentry delay periods were taken from the published schedules. Five fallout categories were used for Route 17A and three for Route 25E. Only Category I air blast data was used since this was indicated in References 5 and 6 to be essential.

Discussion of the Results

The simulated schedule for the revised detonation program for Route 17A is shown in Figure 7; for Route 25E it is shown in Figure 8.

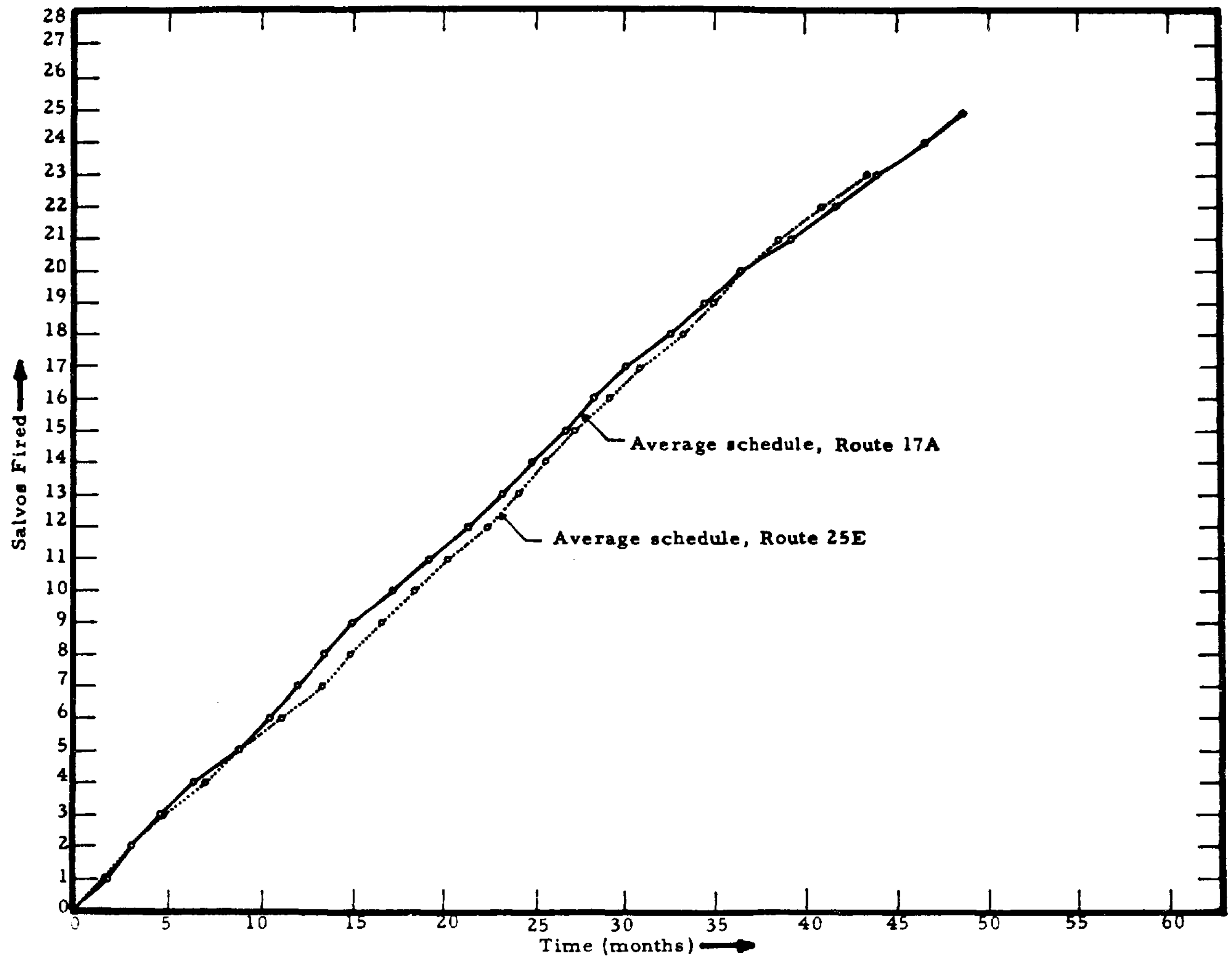

FIGURE 6

AVERAGE SCHEDULE FOR INTERMITTENT DRILL - READY - FIRE SEQUENCE
INITIAL DETONATION PROGRAM

Pass No.	Salvo Set	ROUTE 17A		ROUTE 25E	
		Salvos	Reentry Time	Salvos	Reentry Time
1	1	6, 7	4 days	2	(a)
	2	2, 3	5 weeks	1, 3	6 weeks
	3	1, 4, 5	4.5 weeks	5, 6, 7, 8, 14	5 weeks
	4	8, 9, 10	11 weeks	9, 12	
	5	11-16			
2	1	18, 19, 20	(b)	13-16	(c)
	2	21-27	(b)	17-21	(c)

(a) Salvos 2, 1, and 3 are continuously prepared so that Salvos 1 and 3 are readied while Salvo 2 waits for detonation.
(b) Salvos 18-27 are continuously prepared.
(c) Salvos 13-21 are continuously prepared.

TABLE IV

SETS OF SALVOS, REVISED DETONATION PROGRAM

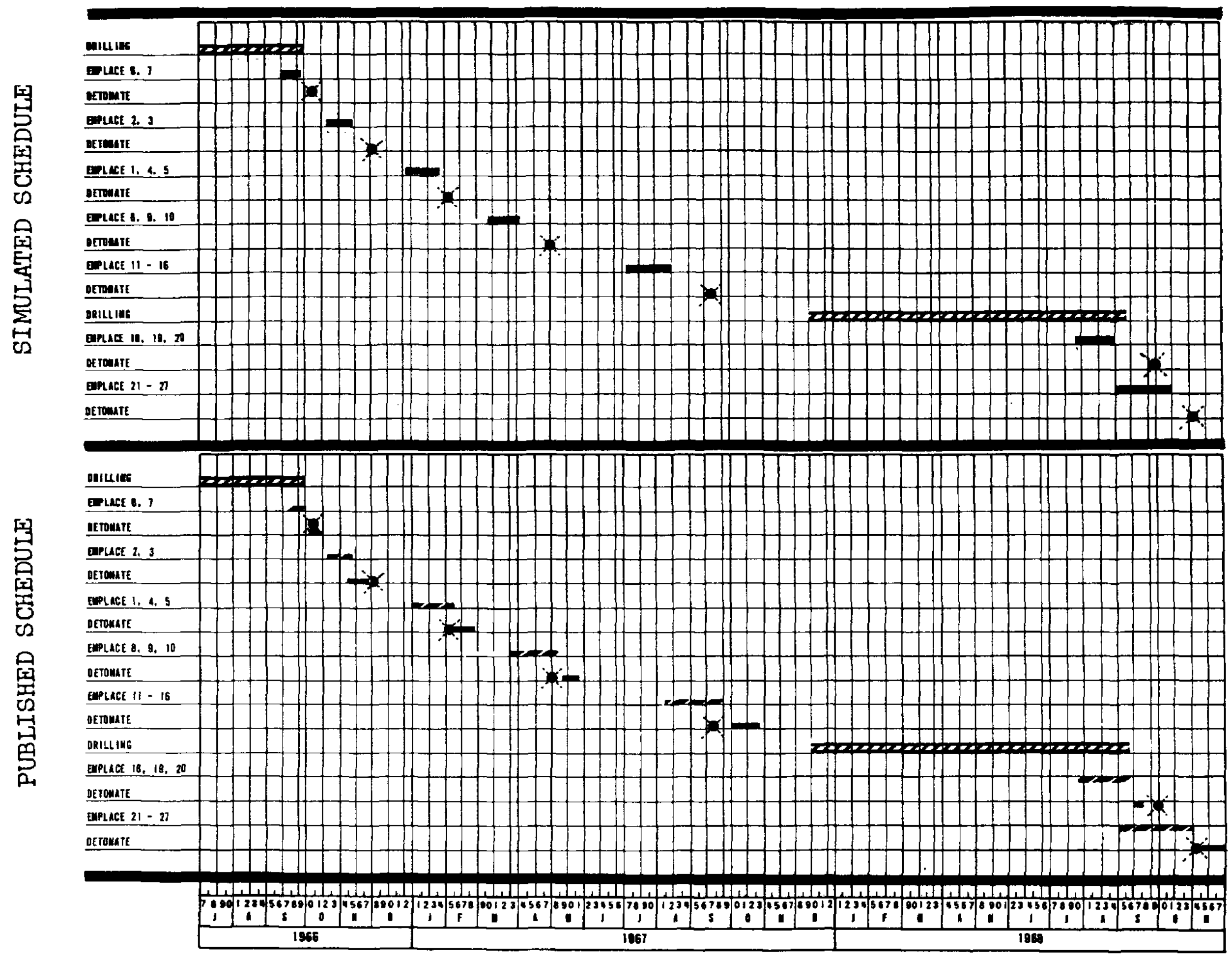

FIGURE 7

SIMULATED VERSUS PUBLISHED SCHEDULE, ROUTE 17A
REVISED DETONATION PROGRAM
Denotes Simulated Detonation Time

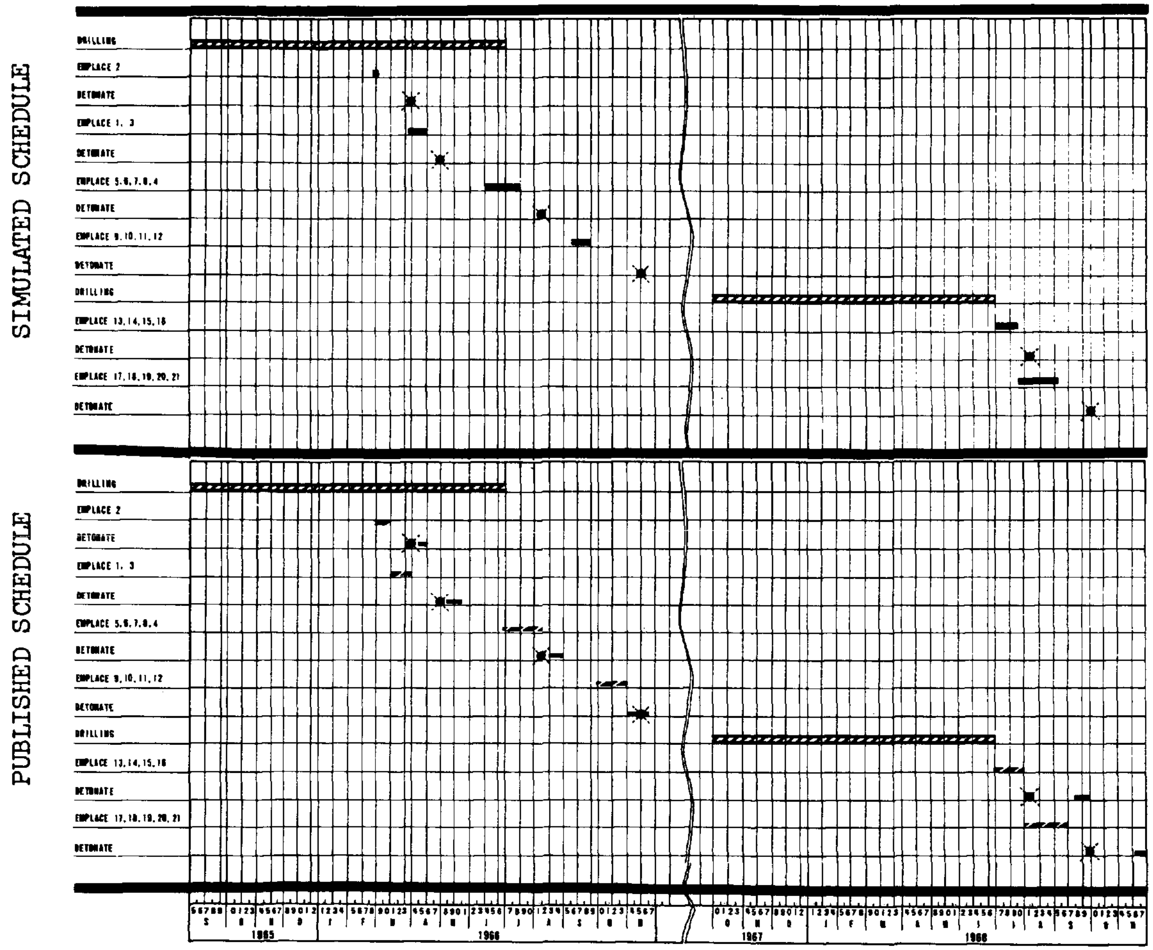

FIGURE 8

SIMULATED VERSUS PUBLISHED SCHEDULE, ROUTE 25E
REVISED DETONATION PROGRAM
✱ Denotes Simulated Detonation Time

Figure 7 shows that the first pass for Route 17A takes 52 weeks to complete, exclusive of the time it takes to drill the holes. The second pass is seen to take 14.5 weeks, again exclusive of the drilling period.

Figure 8 shows that the first pass for Route 25E takes 37 weeks, and the second pass requires 13.7 weeks.

Comparison of Simulated Schedule Versus Published Schedule

It must be emphasized at this point that the only data used from the published detonation program were:

a. The reentry period after each set of salvos.

b. The detonation sequence and grouping of salvos into sets.

Everything else in the simulation comprises an independent assessment of the schedule. Therefore, it is interesting to compare the schedules as published with those from the simulation. These comparisons are also shown in Figures 7 and 8. The ends of the detonation times, as given by the simulation and the published schedule, have been superimposed. Note that there is a high degree of similarity in the results.

CONCLUSIONS AND RECOMMENDATIONS

Computer simulation techniques using the GPSS/360 language have been used to evaluate and assess several schedules for the interoceanic canal project. The assessment of the schedule for a huge project like the proposed sea level canal is very difficult due to the many factors involved in the operations. For example, the effect of the weather, which is random in nature, can be accounted for by simulation techniques using the frequency data of good days for firing. This assessment was made easily by using simulation techniques. A typical assessment for a schedule consists of ten simulation trials taking a total of 90 seconds of computer time on an IBM 360/50 machine.

Several schedules were simulated based on data for the different detonation programs for Routes 17A and 25E. Simulation games were played by varying specific parameters like the detonation sequence, the number of emplacement and stemming crews, air blast restriction, fallout data, and the reentry period after each row charge detonation. The results of the simulation were also used to evaluate several schemes from a cost point of view. For example, based on these trade-off studies,[2] it was found that double emplacement and stemming crews should be used; this conclusion led to the use of double crews in simulating the revised detonation program. A comparison of the schedules using simulation techniques with those which were made independently and published shows them to be similar.

It is clear that the simulation method is an effective, concise, and easy way to assess or establish a schedule for the interoceanic canal project, or other complex projects. The use of this technique is recommended.

REFERENCES

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2. Computer Simulation of Nuclear Operations for the Sea Level Canal, HN-20-213, prepared for the U. S. Atomic Energy Commission, Nevada Operations Office, by Holmes & Narver, Inc., November 1969.

3. Preliminary Detonation Program, LRL Interim Assessment, June 1969.

4. Letter from G. J. Ferber, Environmental Science Services Administration, to R. S. Holmes, Nuclear Cratering Group, dated August 28, 1969.

5. Letter from A. W. Klement, Jr., U. S. Atomic Energy Commission, Nevada Operations Office, to T. J. McCarvill, et al., dated September 4, 1969.

6. Letter (NCG-IC) from R. S. Holmes, Nuclear Cratering Group, to A. W. Klement, Jr., U. S. Atomic Energy Commission, Nevada Operations Office, dated September 11, 1969.