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Summary

This paper discusses a simulation model which was developed to provide the National Range Division with a method for planning the National fleet of instrumented ships to support a wide variety of tests of many missile and space vehicle programs. The model simulates in a realistic way the manner and frequency with which missiles with their associated support requirements appear on a launch schedule. Then it uses the launch schedule to impose a loading upon the range ships on a simulated real-time basis. Finally the model schedules the ships against this simulated workload, and both qualitative and quantitative estimates are obtained of the future need for the given range resource.

Introduction

The purpose of this paper is to discuss a planning methodology used by the U.S. Air Force National Range Division. It is a simulation model which generates launch schedules, schedules ships against the simulated launches, and determines the amount of support that can be expected with a given ship pool. This model has been used to determine the number of instrumented ships needed in support of a forecasted global workload of launched missiles and space vehicles and more recently in a trade-off study between instrumented ships and aircraft. The trade-off study was done by Mr. M.J. Cleveland and others in the Operations Analysis Office within the Directorate of Operations Management of the National Range Division.

Discussion

In the time that I have, I will be unable to talk about each part of the simulation model in great detail, therefore, I will concentrate on how a launch schedule and different scheduling combinations of ships are produced. The model simulates launching of missiles and space vehicles by generating a feasible launch schedule. Here a feasible launch schedule means one that has a chance of occurring. After a feasible launch schedule has been determined, the ships from the instrumented ship fleet are scheduled to meet the launch workload. Scheduling combinations that have the highest probability of meeting the launch schedule are used to reduce to a minimum the number of missile and space vehicle launches that go unsupported. An unsupported launch is called a scheduling conflict, and it means that no ship can get to the required "on station position" in time to support the launch. After ship scheduling is completed, a measure of how well the ship fleet met the launch workload is obtained as the percent of launch attempts supported. Finally, the method is an iterative one, and it is repeated enough times so that sufficient statistical data are obtained for a confident estimate of the instrumented ship fleet needed to support the forecasted missile and space vehicle launches.

Let us consider a simple example so that we can get some feeling for the complexity of this problem. Assume the following:

(1) There are twenty launches needing ship support sometime during a three month planning period.

(2) There are four ships available, all except one with a different technical capability for supporting launches. We call these technical capabilities one, two, and three. Two ships have capability one, one ship has capability two, and the other ship has capability three. Also these capabilities are nested, that is, the ship with technical capability three can do its own work plus that of the ships with technical capabilities one and two; the ship with technical capability two can do its own work, plus that of the ships with technical capability one, but not that of the ship of technical capability three; and the two ships with technical capability one can only do their own work.

(3) Nine launches require a ship with technical capability one, six launches require a ship with technical capability two, and five launches require a ship with technical capability three.

(4) There are no scrubbed launches.

Ignoring the length of time that it takes for a ship to move from one "on station position" to another, there are approximately 17 million different scheduling combinations. In general for this type of problem the number of scheduling combinations, c is

$$c = (k + m + n)^r (m + n)^s n^t, \text{ where}$$

r is the number of launches requiring a ship of technical capability one;

s is the number of launches requiring a ship of technical capability two;

t is the number of launches requiring a ship of technical capability three;

k is the number of ships with technical capability one;

m is the number of ships with technical capability two; and

n is the number of ships with technical capability three.

Iterating our example 20 times could theoretically lead to investigating approximately 350 million scheduling combinations. Although there are constraints that greatly reduce this figure, it is still rather hopeless to do by hand; also the bookkeeping would get extremely involved. Therefore, we appeal to the computer to relieve us of the tedious task of examining the scheduling combinations that must be tried and to take care of our bookkeeping.

Next, one might ask what are the constraints and how are they used to reduce the number of scheduling combinations. However, before answering this I would like to describe the permutation algorithm which is the heart of the ship scheduling part of the simulation model and from which the various scheduling combinations are generated.

The permutation algorithm is quite simple. Let me explain it by the use of an example. Assume that there are four ships available for scheduling. Number these ships one, two, three, and four; and construct the permutation diagram shown in Figure 1. The diagram is constructed by first writing the four numbers in their natural order in the top row. Next, choose any number in the first row. Omit this number and write the remaining numbers in their natural order beneath it in the second row. Then, within each set of three numbers in the second row, choose any number. Omit this number and write the remaining numbers of the set beneath it in the third row. Finally, beneath each consecutive pair of numbers in the third row, write the pair of numbers in reverse order in the fourth row. This algorithm can be expanded to the general case, and it is quite easy to see what needs to be done to expand it.

Now briefly here is how the permutation generator is used. For a starting point assume that we have a feasible launch schedule and that some permutation on K ships has been generated. The assignments of ships to support the launch schedule are made according to the generated permutation with the following modification: any ship that can support a launch will continue to be used as long as it can support consecutive launches. This modification increases the length of time that the next ship in the permutation will have to get to the "on station position" for the launch it will be called on to support. Hence, the probability that the next ship will be able to support is increased. When the current ship can no longer support, the model tries the next ship in the permutation. Two cases must be considered. The ship being tried can support or it cannot. If it can, then assignments are made as before. If it cannot, then the next member of the permutation is tried. As long as some ship in the permutation can support, assignments are made using the permutation cyclically. If for a particular launch no member of the permutation can support, a conflict is recorded to be resolved. Attempts to resolve the conflict are made by returning to the initial starting point, or some intermediate point, and generating another permutation. The intermediate point is a point in time within the schedule where the ship positions have no bearing upon the conflict to be resolved. The assignment procedures just described are used with the new permutation. Finally, a conflict is accepted only after all permutations have been tried, and the conflict that is accepted, in general, is the one which occurs furthest into the planning period.

Although there are more scheduling constraints that can be discussed, I feel that the remaining time will be much better used by discussing how a feasible launch schedule is generated and why we need the launch schedule.

Suppose we had a "crystal ball" and could gaze into the future and see how the actual day-to-day launch attempts would occur. Then a priori we could schedule the ships against this fixed workload and determine whether or not we had enough ships of the proper configuration to satisfy all support requirements. Thus, we could plan our inventory accordingly. This would be very nice, but we are not blessed with such a "crystal ball"; therefore, we need some way of predicting the future launch schedule. The missile scheduling part of the simulation model serves this purpose. It provides us with a way of producing launch schedules which have a chance of occurring. This is accomplished in the following manner using a forecasted missile workload, certain operating procedures that pertain to the scheduling of launch attempts, and a Monte Carlo sampling technique.

Let's assume that the simulation has already started. This implies that the missiles have been numbered, and the missiles with their associated support requirements have been entered in the computer program in a random order. Now a random number is generated. This number is entered in the cumulative distribution for the days between launch attempts to determine the minimum number of days that will elapse between the last launch attempt and the next one, which I will refer to as the current missile. Another random number is generated and is entered in the cumulative distribution of attempts per launch to determine whether or not the current missile will be launched on the first attempt. If it is not launched on the first attempt, then the random number further determines how many attempts will be needed before the current missile will be launched.

If the current missile is scrubbed, it is put in a "scrub queue". Missiles that are in the scrub queue get preferential treatment for getting back on the launch schedule. This process is quite involved, and I don't want to go into it here. However, I do want to mention a couple of scheduling constraints that are used in the model. When missiles are put back on the schedule, the minimum reschedule and minimum turn-around times are satisfied. The minimum reschedule time is the minimum time that must elapse before a scrubbed missile can be rescheduled for another launch attempt, and the minimum turn-around time is the minimum time that must elapse between the launch of a missile of any given type and the first launch attempt of the next missile of the same type. If either of these constraints are violated, the current missile will be ignored and the next one waiting to get on the launch schedule will be considered.

Besides the two distributions that I have already discussed there are four other distributions that are used. All of these are used in a manner similar to the two that I have already discussed therefore I will not talk about them. However, I do want to point out that all of the distributions in the model were constructed from empirical data, and only one of them follows a well known distribution. That one is the days between launch attempts distribution which is a Poisson distribution.

In closing I will just state some other pertinent features of the simulation model and show you a sample of the input data and the output data. First, the features are:

(1) Different classes of missiles can be handled, such as missiles that are required to be launched during a launch window and missiles that are required to be launched in salvos. Also different types of missiles can be handled.

(2) Different launch densities during the same planning period can be considered.

(3) Different reschedule times and turn-around times can be used.

(4) Missile launches having different priorities for ship support can be considered. Wherever possible the model will accept a conflict of lesser priority.

(5) Multiple ship support can be given to any missile requiring it.

(6) A ship can be held on station for as long as it is needed.

(7) In the case that the primary ship cannot support a launch, another ship can be considered.

(8) Three ports can be made available for each ship for routine maintenance and upkeep. Also dry docking can be considered.

(9) A variety of ships may be used.

(10) A history of ship usage is maintained.

Finally, a sample of the input data is given in Figures 2 and 3, and a sample of the output data is given in Figure 4.

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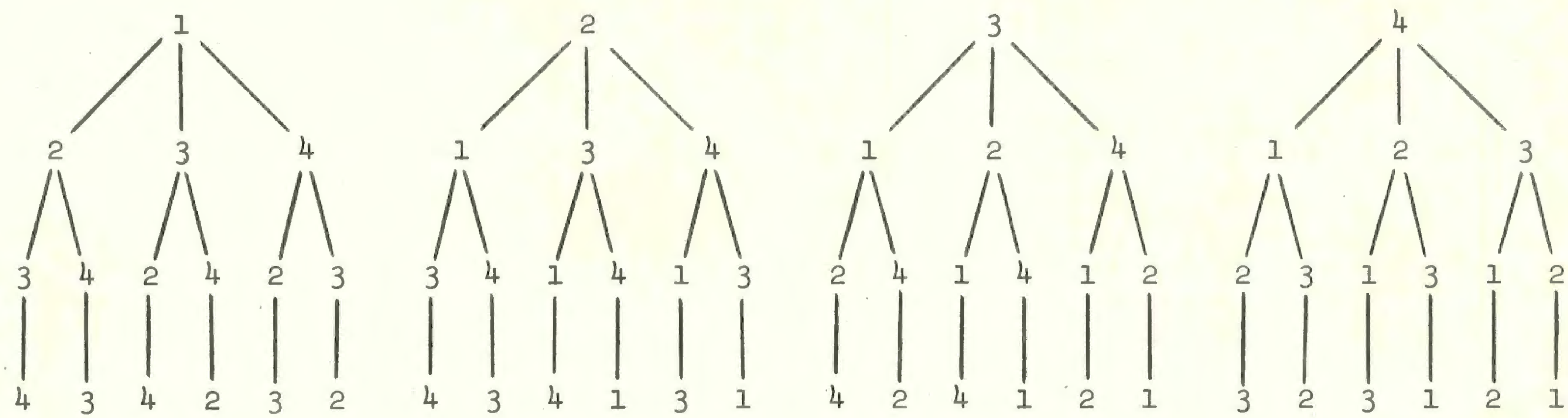

FIGURE 1. Permutation Diagram

Total No. of Regular Missiles	1st Day of 2nd Division of Period	1st Day of 3rd Division of Period	Scrub Factor for Regular Missiles	Scrub Factor for Salvos
9	32	62	1.00	1.15

No. Missiles in 1st Period	No. Missiles in 2nd Period	No. Missiles in 3rd Period	No. Days in 1st Period	No. Days in 2nd Period	No. Days in 3rd Period
3	3	3	22	22	21

Priority for Ship Support	Days Held on Station After Launch	Minimum Reschedule Time	Launch Window
2	0	1	0
2	0	1	0
2	0	1	1025
.	.	.	.
.	.	.	.
.	.	.	.

Missile	Support Area 1	Support Area 2	Tech Cap. Needed in Area 1	Tech. Cap. Needed in Area 2	Missile Type	Turn-Around Time
1	7	0	3520	0	1	4
5	5	0	-2020	0	6	18
10	15	17	3520	-4040	13	15
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.

Attempts per Launch Distribution for Regular Missiles	Attempts per Launch Distribution for Salvos
1000	900
	950
	1000

FIGURE 2. Input Data Sample for Missile Scheduler

On Station Position	Port
1	31
2	31
3	31
.	.
.	.
.	.

Mileage Table

Location-Location	Travel Time
3101	1
3102	3
3103	3
.	.
.	.
.	.

Ship	Home Port	Drydock Schedule	Speed Factor	Present Position	Tech. Capa-bility	Maint. Con-straints	Alter-nate Ports
1	31	0	1.00	31	20	6005	3536
2	31	0	1.00	31	20	6005	3536
3	31	0	1.00	37	35	6005	3637
4	31	0	1.00	36	40	6005	3637

FIGURE 3. Input Data Sample for Ship Scheduler

This is for Home Port 31

Attempt-Missile	Launch Day	Support Area	Technical Capability Needed in Support Area	Priority	Support Ship
1005	9	5	-2020	2	1
1010	10	15	3520	2	3
1010	10	17	-4040	2	4
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
1001	48	7	3520	2	2
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.

Number of Missile Launch Attempts	Number of Times Ships Called on to Support	Number of Conflicts	Percent of Launch Attempts Supported
11	14	0	100

Summary of Ship Usage

Launch Attempts Supported by Ship 1	Launch Attempts Supported by Ship 2	Launch Attempts Supported by Ship 3	Launch Attempts Supported by Ship 4
3	6	3	2

FIGURE 4. Output Data Sample