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AN ANALYSIS AND SIMULATION OF AN EXPERIMENTAL SUEZ CANAL TRAFFIC CONTROL SYSTEM

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A SLAM model of Suez Canal traffic flow is reported in this paper. An experimental traffic control scheme is proposed, tested, and discussed. A method for analysis of multi-response-variable systems is discussed and illustrated.

1. INTRODUCTION

Man has long seen the economic advantages of a navigable link between the Red Sea and the Mediterranean. The first canal was built 4,000 years ago between the Nile River and Bitter Lake, which then opened onto the Gulf of Suez. Abandoned and restored several times, the canal was blocked for good in the eighth century A.D. It was not until 1859 that Ferdinand de Lesseps, a French engineer and diplomat, combined the vision, authority, financial backing, and perseverance to build another canal. The Suez Canal was opened to traffic in November 1869 under a concession terminating in 1968.

When the June 1967 war between Egypt and Israel closed the canal, it had become one of the most important waterways for international cargos. In the last full year of operation, fourteen percent of world seaborne traffic passed through the canal. The canal earnings of foreign exchange for the Egyptian government increased from the equivalent of about fifteen million dollars in 1957 to nearly two hundred million dollars by 1966 (7). The canal had become Egypt's second most important foreign exchange earner.

The canal shortened the distance between Odessa and Bombay by eighty percent compared with passage via the Cape of Good Hope, more than fifty percent between London and Persian Gulf ports, and about thirty-three percent between Rotterdam and Tokyo. Closure of the canal in June 1967 created an immediate shortage of shipping and much higher rates. A United Nations' study estimated that closure of the canal cost the world seven billion dollars from June 1967 to December 1971, and one point seven billion dollars each year thereafter (7). Some countries, largely in East Africa and Southeast Asia, lost export markets because their products could not support the higher costs.

The growth in the size of tankers was a matter of considerable concern to canal authorities because nearly three-quarters of FY 1967 traffic had been petroleum. The canal in 1975 could accommodate tankers of 60,000 deadweight tons laden and 125,000 deadweight tons in ballast (7). These dimensions would have permitted about three-quarters of the tankers in service in 1966 to use the canal; by 1975 about half of the tankers in service could use the canal; and by 1983 probably only about two-fifths were able to pass. A dredging program that was ready to start in 1967 when war closed the canal would have increased permissible draft to fifty-three feet. In 1975, Egypt arranged for a Japanese firm to start the initial work on this postponed expansion under a Japanese credit of 140 million dollars. The dredging to widen and deepen the canal was scheduled for completion in 1980, at a cost of about 720 million dollars. The canal, after the project, was able to accommodate vessels of 150,000 deadweight tons laden, and 250,000 deadweight tons in ballast, increasing the traffic potential in 1983 to three times the traffic possible without the expansion.

Since the canal has been reopened, traffic has continued to increase. This increase has resulted in long waits for ships in the canal's holding areas at Port-Said, Suez, and in Bitter Lake. The purpose of this study is to provide a transportation control system that will provide the most efficient use of the canal for passing ships and limit balking, thus maximizing through-put and attendant revenue.

2. SYSTEM STRUCTURE

The Suez Canal allows one-lane traffic flow except in the area of Bitter Lakes. Traffic is controlled with modern control systems that follow the path

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of each ship and instruct movement based on existing patterns. The structure of the canal is shown in Figure 1.

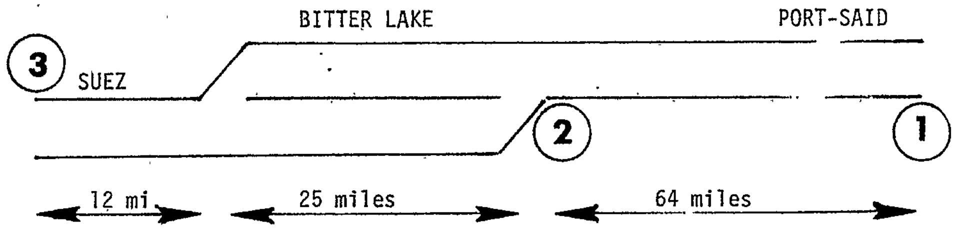

Figure 1. Schematic Diagram of Suez Canal

Currently, convoys of ships are formed at Suez and at Port-Said, are periodically input to the canal, and flow in one direction except through the two-way passage at Bitter Lake (2). The objective of the modeling effort is to demonstrate a different way to control traffic to reduce waiting time for ships at Suez and Port-Said and to reduce balking.

To model the structure, assume traffic lights have been placed at entry points at Suez, Bitter Lake, and at Port-Said, labeled one, two, and three in Figure 1. The lights allow for a specified time interval from only one direction in the one-lane areas. When a light turns green in Port-Said, the waiting ships start and pass the light every 12 minutes, which assures the proper clearance between ships. If a ship arrives at a green light when there are no waiting ships, the ship passes through the light without delay. This situation is repeated at Suez. There is very little direct data concerning arrivals. As a result, the arrivals were assumed to be exponential and a mean was developed using figures for total ship passages in a given period. An average of .8 hour between arrivals is used. Study of the sensitivity of this variable is required (7,10).

Since the difference from Port-Said to Bitter Lake is greater (64 miles) than the distance from Suez to Bitter Lake (12 miles), it will be the "determining factor" in the traffic flow. Once the light at Port-Said is green, ships will continue to enter the Canal from both directions. The light at Suez is closed when the first ship that entered at Port-Said passes a point in the Bitter Lake, such that the flow will continue uninterrupted to Suez. The Port-Said light is turned red at the same time. Light number 2 in Figure 1 is changed to green when the last ship from Port-Said passes into Bitter Lake. Experiments with the cycle time for the lights will be discussed in a later section.

The system was modeled using the network features of the Simulation Language for Alternative Modeling (8). The network model of the traffic system is presented in Figure 2.

Its structure is quite similar to that of the classic traffic control problem discussed by Pritsker and Pegden (8:212) There are three separate processes in the system consisting of traffic flow from Port-Said and traffic flow from Suez to Bitter Lake, and information flow representing the traffic light cycle. Each of these processes is modeled by the movement of an entity through a subnetwork. Gates are used to model the traffic light system where an open gate represents a green light and a closed gate represents a red light. To insure that only one ship passes through the light at a time, a resource with a capacity of one is employed in conjunction with each gate. These resources are named Port-Said, Bitter Lake, and Suez, corresponding to LIGHT 1, LIGHT 2, and LIGHT 3, and represent the starting location before each light. The starting location is seized by each ship entity before passing through the light and then freed immediately after it passes the light. In this way, only one ship can pass through the starting location at a time.

First, consider the traffic flow from the direction of PORT-SAID. Entities representing ships are created at the CREATE node with the time between ships exponentially distributed with a mean of 0.8 hours. The time of creation of each ship entity is recorded as attribute one [ATRIB (1)]. Each entity then awaits the resource, Port-Said. The entity then proceeds to the AWAIT node where it continues if LIGHT 1 is open. Otherwise, it is delayed. The following COLCT node records values of the waiting time of the ship at the light, and the entity is then routed through one of the two emanating activities. A ship that stopped has an arrival time different from the current time, TNOW. The condition specified on the first activity is for those ships that were stopped to insure a twelve-minute delay for the ship to pass the light. The second ACTIVITY is taken if and only if the first is not taken. This ACTIVITY models the passage of moving ships that do not incur a delay. The resource PORT-SAID is then freed and the entity flows uninterrupted to the terminate node. The traffic flow for the SUEZ direction and BITTER LAKE leg is modeled in an analogous manner. The traffic light segment of the model controls the changes in the traffic lights and consists of a series of OPEN and CLOSE nodes separated by activities. As noted previously, the ship's arrival follows the exponential distribution with lambda = 0.8. The speed of ships in the canal is limited to reduce the

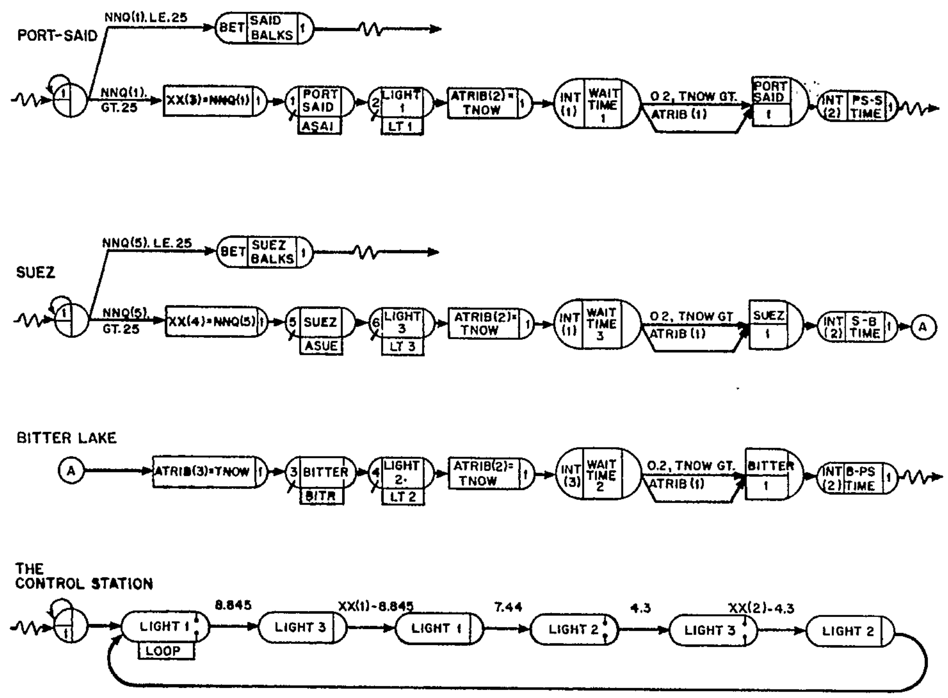

Figure 2. SLAM Network

effect of corrosion on the edges. So, the company determined an average speed of eight miles per hour in the direction of Suez to Port-Said and 8.6 miles per hour in the direction of Port-Said to Suez. From this data, the flow time may be considered virtually constant and equal to 11.74 hours from Port-Said to Suez, 4.63 hours from Suez to Bitter Lake, and 8.00 hours from Bitter Lake to Port-Said. These times are included in the model for sensitivity analysis. They may be replaced by distributions, if desired.

Balking is included in the model at Port-Said and at Suez. Very little is documented about the balking rate and the complex information feedback structure that would determine when balking occurred. To characterize the pattern and establish a mechanism in the model to investigate the problem, balking after twenty-five ships were waiting at either entrance was established. A separate study of the structure of balking for the canal is required.

3. MODEL OPERATION AND EXPERIMENTATION

The design of the experiment for the model presents a problem which is rarely addressed in the simulation literature. Measurement of the system must be established across several dimensions because of the direction changes in the network. Waiting time is incurred at three places in the system requiring three separate response variable measures, and balking is incurred at two places requiring two more response measures. Since balking data were contrived to provide a mechanism for later research, it will not be included in the analysis. A minimum linear combination of the three waiting times will be sought.

Given the minimization criteria, a structural data model can be developed using the opening cycles of the two control variables, LIGHT 1 and LIGHT 2. LIGHT 3 is not used as a control variable because the limiting link of the system is the Suez-to-Bitter Lake leg. The opening and closing of LIGHT 3 is cycled in coordination with movement from Bitter Lake to Suez by south-bound ships. The resulting data structure is shown in Figure 3.

Initial runs of the network were accomplished to establish a range for the XX(1) and XX(2) vectors that would be used for further data development and analysis. The initial runs were completed to establish an operable functional model along the lines given by Shannon (9:155-161). The objective is to determine the number of replications required to adequately characterize each variable and the number of computer runs required for analyses. The model initially was operated for 720.0 time units (one month). Results showed highly variable distributions with large standard deviations relative to the mean. The distributions had very small error estimates, however, indicating they were accurately captured with runs of the chosen length. To insure this, runs of 1440.0, 2210.01, 4420.0 time units were conducted to test the hypothesis

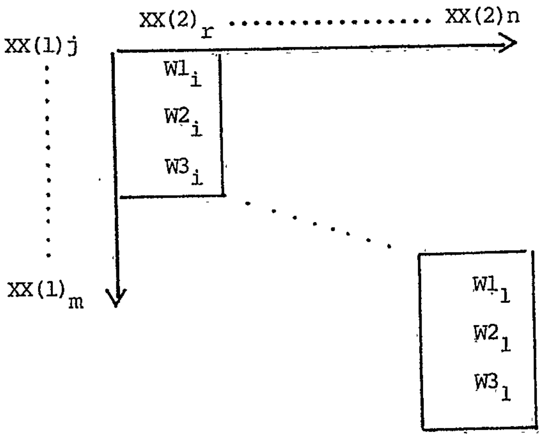

Figure 3. Data Structure

for each variable:

$$\sigma_1^2 = \sigma_2^2 = \ldots = \sigma_R^2$$

The variances of the distributions were virtually unchanged, indicating the run length of one month was adequate.

Runs were conducted along each XX(1) vector from nine to twenty-one hours. A low region of the response surface was selected for further analysis. The target response surface bounds are shown in Figure 4.

XX(1) \ XX(2)	14	15	16	17	18	19	20
12	1	2	3	4	5		
13	6	7	8	9	10		
14			11	12	13	14	15
15			16	17	18	19	20
16			21	22	23	24	25

Figure 4. Response Surface Bounds

This provides twenty-five cells for analysis. If the control variables are combined to form a single policy, twenty-five policies are generated for analysis.

The dynamic behavior of the system is illustrated in Figure 5. As shown, as the lights cycle there is a slow build-up and rapid draw-down of ships at Suez and Bitter Lake. The waiting time at either location is a function of the cycles. Balking after twenty-five ships are waiting is illustrated. As previously discussed, this is included for sensitivity analysis and is not directly addressed in this study. Also, balking should be more carefully addressed. The model must include alternative routing for ships if conditions provide more beneficial routes. Work in this area should focus on the decision structure of major ship companies using the canal.

Multivariate analysis of variance (MANOVA) was chosen to test the hypothesis:

$$H_0: \underline{\mu}_1 = \underline{\mu}_2 = \ldots = \underline{\mu}_{25}$$

where is a vector of the means of the three response variables. The experimental model is:

$$\underline{Y} = \underline{A}\,\underline{\Theta}^* + \underline{\mathcal{E}}$$

where $\underline{Y}$ is the N by p data matrix, $\underline{\mathcal{E}}$ is the N by p matrix of residuals, and $\underline{A}$ is the N by m analysis of variance matrix as discussed in Finn (1:205-250). By considering each combination of XX(1) and XX(2) as a single policy, a one-way model such as this may be employed. Four replications of each policy were conducted, even though the estimate error for the mean on the pilot runs was quite small. The functional matrix shown in Figure 6 resulted.

The objective is to determine if policy has an effect on waiting time and if one policy is better than the others. As a result of multiple observations, the model is represented as:

$$\underline{Y}. = \underline{A}\,\underline{\Theta}^* + \underline{E}.$$

where $\underline{Y.}$ and $\underline{E.}$ are J by p with the rows of $\underline{E.}$ distributed normally with expectation zero. Homogeneity of variance is assumed.

The model was estimated using the <u>Statistical Package for the Social Sciences</u> (SPSS), MANOVA program (3). The Box's M statistic was used to test the homogeneity assumption. The $H_0: \sigma_R^2 = \sigma_m^2$ hypothesis was rejected. As noted by Kleijnen for the univariate model, the errors need not be normally distributed with common variance because the power of the test is not affected seriously when there are equal observations in each cell (5:302-305) and there are sufficient observations. The values of Hotelling's trace and Wilk's lambda indicate that some set of policies is different from other sets, but, because of the homogeneity assumptions, the results remain questionable. Results are shown in Figure 7. The difficulty, in any case, is discerning the set of policies that provides the best operating conditions.

There are two courses available. The first is to operate the model further to generate more data in the hope of better discerning the distributions or to use other variance reduction techniques. This method may, however, still lead to results that would violate the homogeneity assumption and may not change the data structure. The computer runs, in this case, are also expensive, which mitigates such a strategy. The second course is to perform further statistical and qualitative analysis with existing data.

The first step in pursuing the latter strategy was to plot the variables for waiting time at Port-Said and Bitter Lake. The results are shown in Figures 8 and 9. The response surfaces are generally flat and increase only slightly from a given low point. One could conclude that the points are most likely statistically the same over large portions of the surface. The problem now is how to

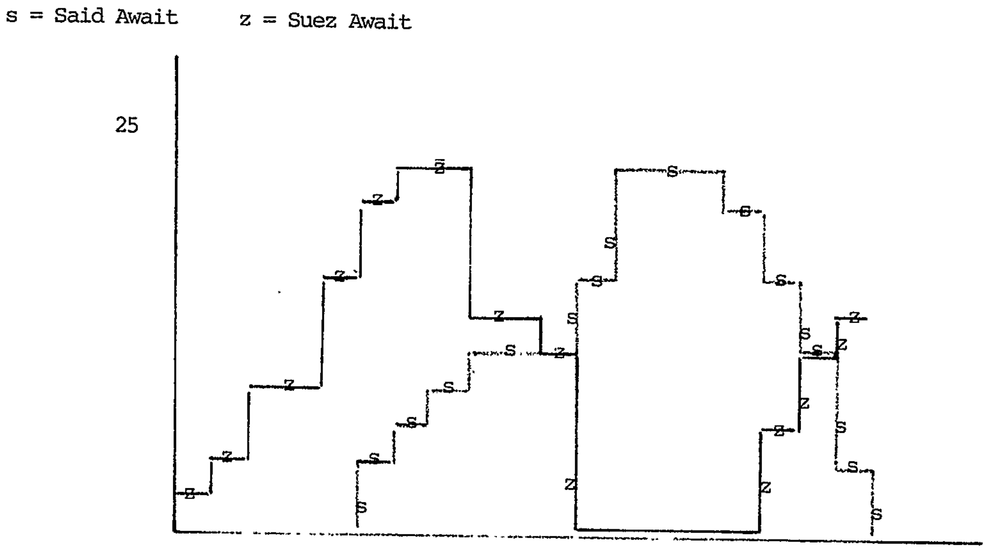

Figure 5. System Behavior over Time

	Policy 1 25
Observations	Var 1_i
1	Var 2_i
⋮	Var 3_i
4	

Figure 6. Functional Matrix

Test	Value	Approx F	Sig Off
Pillas	.99982	137953.	0
Hotellings	5669.34	137953.	0
Wilks	.00018	136953.	0
Roys	.99982	137953.	0

Figure 7. Multivariate Tests of Significant ($s=1$, $m=\frac{1}{2}$, $n=35\frac{1}{2}$)

identify policies which are, in fact, statistically the same.

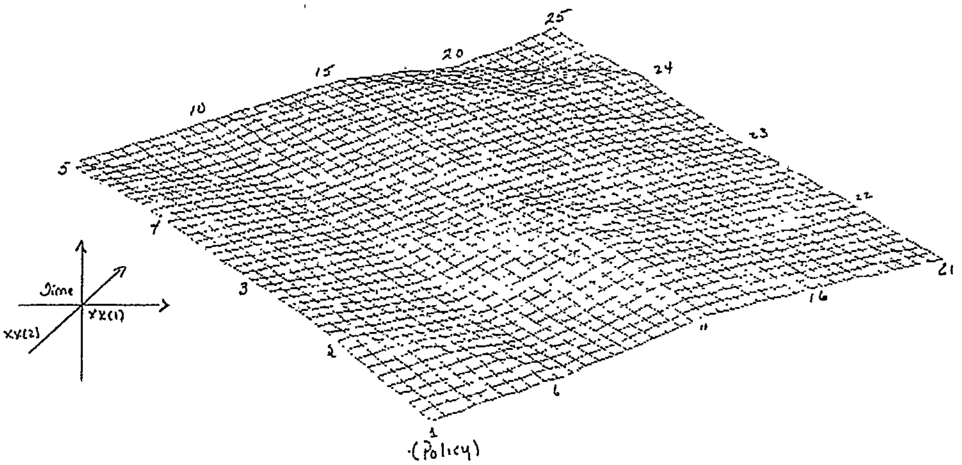

Figure 8. Port-Said Waiting Time Response Surface

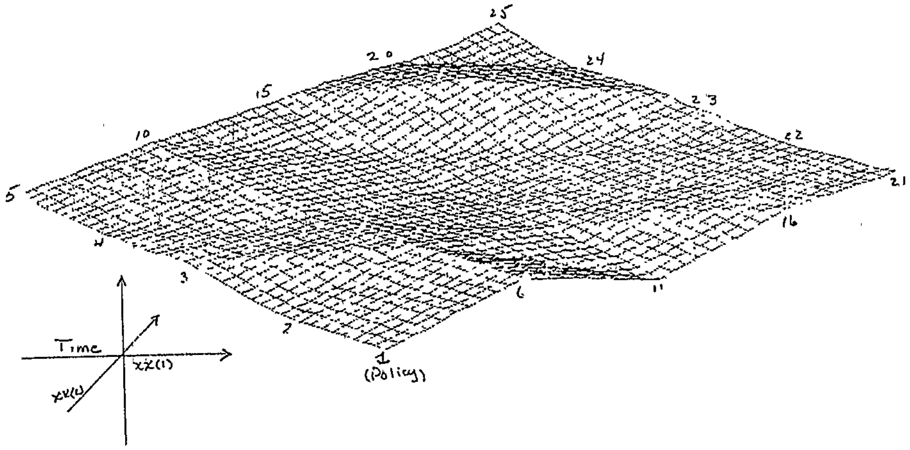

Figure 9. Bitter Lake Waiting Time Response Surface

A factor analysis of the data was accomplished to identify which vectors had common factor variance and to create a set of factor scores that could be used for further analysis. To establish the structure, the SPSS factor analysis program was operated with the default eigenvalue (λ) set to one. The results are shown in Figure 10. The only significant factor using $\lambda = 1$ is the first factor, which indicated 57 percent of the total variation in the data can be explained by the first factor. Since factor two has an eigenvalue close to one, it also will be included. The factor matrix is shown in Figure 11. The question is, of course, what are the two factors? As shown, there is strong commonality or common variation, in both Suez and Bitter Lake waiting time, indicating these variables are strong contributors to factor 1. The same is true for Suez waiting time for factor two. Given this, we will continue to focus on the two variables believed to be the most important to the process.

Factor	Eigenvalue	Pct	Cum Pct
1	1.73285	57.8	57.8
2	.98902	33.0	90.7
3	.27813	9.3	100.0

Figure 10. Factor Analysis Results

	Factor 1	Factor 2	Commonality
Port-Said waiting	-.92720	.01499	.85967
Bitter Lake waiting	.85775	.91859	.73574
Suez waiting	.37070	-.38078	.13742

Figure 11. Factor Matrix

The factor scores for the variables for each policy are used to create a linear composite that may be used for further analysis (6:6-72). Using this composite variable, a one-way ANOVA was performed using Duncan's Multiple Ranges method of a'posteriori contrast. The test produces ranges that allow grouping homogeneous subsets of policies. Results are shown in Figure 12 for the two subsets with minimum values for the composite variable.

To interpret the results, refer to Figures 8 and 9. The lowest areas of surfaces can be related to the first subset of policies from Duncan's test. Policies 5, 4, 10, 15 and 14 are grouped and are lowest. One can see these policies occur in the lower areas of the response surfaces. The area of the policy is labeled in each figure. These policies are reviewed in Figure 13 and would be recommended if this traffic control system were implemented.

The discussion presents a method to approach multivariate response problems. Each problem, of course, has unique properties that require selection of different multivariate techniques. The main point is that a system need not be restricted to one response measure across several factors or levels.

4. SUMMARY AND CONCLUSIONS

A proposed traffic control system for the Suez Canal has been presented in this paper. Its structure was tested, using a multivariate statistical approach. What remains is to compare this system to the existing control system. Work in this area has been started (4). The objective will be to compare revenue under the current system to that of the proposed system.

Subset 1

Group	Grp 5	Grp 4	Grp 10	Grp 15	Grp 14
Mean	-1.5076	-1.1922	-1.1581	-1.0759	-1.0659

Subset 2

Group	Grp 4	Grp 10	Grp 15	Grp 14	Grp 25	Grp 13
Mean	-1.1922	-1.1581	-1.0759	-1.0659	-.7989	-.6751

Figure 12. Results of Duncan's Multiple Ranges Test

	Green Time		Ships Passing	
Policy	Light 1	Light 2	Light 1	Light 2
5	12	18	736	871
4	12	17	720	858
10	13	18	716	823
15	14	20	724	854
14	14	19	731	831

Figure 13. Lowest Waiting Time Policies

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