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A SIMULATED PORT FACILITY IN A THEATRE OF OPERATIONS

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ABSTRACT

A hypothetical port facility in a theatre of operations is modeled and coded in a special purpose simulation language, for the purpose of conducting simulation experiments on a digital computer. The experiments are conducted to investigate the resource requirements necessary for the reception, discharge, and clearance of supplies at the port. Queue lengths, waiting times, facility utilizations, temporary storage levels, and ship turn-around times are analyzed as functions of transportation and cargo handling resources, using response surface methodology. The resulting response surfaces are revealing in regard to the sensitivity of port operations to transportation resource levels and the characteristics of the port facility's load factor. Two specific conclusions of significant value are derived. First, the simulation experiments clearly show that the standard procedures for determining discharge and clearance capacities take insufficient account of the effects of variability. Second, the response surfaces for ship turn-around times and temporary storage levels indicate that an extremely steep gradient exists as a function of troop levels.

INTRODUCTION

The primary objective of this paper is to present the results of some simulation experiments designed to investigate the troop requirements necessary for the reception, discharge, and clearance of supplies at a port facility in a theatre of operations. A secondary objective is to illustrate the power of simulation in the solution of transportation and logistics problems of the type considered herein. The magnitude of logistics problems and the inadequacy of standard practice logistics manuals and tables have been obvious in both Korea and Vietnam. The complexity of the logistics planning operation in Korea has been well documented by General Garvin [2] who has vividly described the operation of Pusan Port during the Korean War.

General F. S. Besson, Jr., Commanding General of the U.S. Army Materiel Command, has recently described the nature of the logistics problem in Vietnam for the layman in a popular news magazine [1]. Periods during which inadequate supplies were available for consumption in the field as well as high theft rates have been described in the press.

A MODEL OF THE PORT

Effective port operations derive from the right combination of an adequate port facility, essential cargo handling equipment, variously trained personnel, and sufficient transportation. The commitment of these resources must provide a balanced capability to receive, discharge, and clear the port of arriving cargo.

The conceptual port considered in these experiments is pictured in Figure 1.

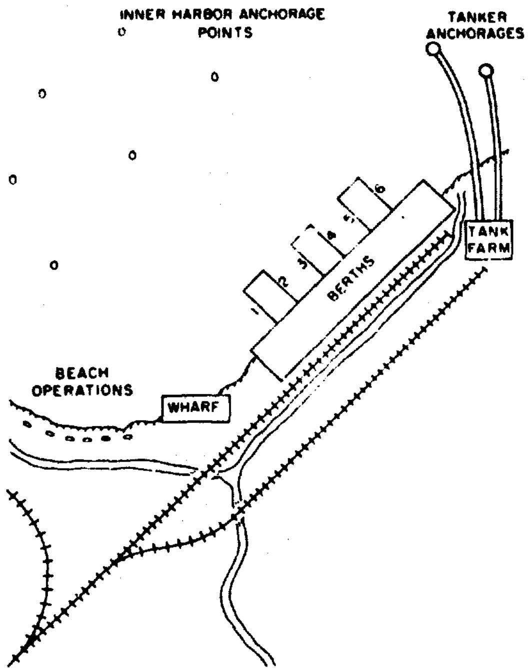

FIGURE 1. Empirical concept of port facility.

The major assumptions employed in this model are noted below:

1. The port facility was established as fixed during the timespan with which the investigation was concerned.[1] See Figure 1.

2. The dry cargo and POL (Petroleum, Oil, and Lubricant) ship interarrival times were assumed to be independent and exponentially distributed on an individual ship basis[2] with constant mean inter-arrival times.

3. No constraints were placed upon troop levels in this study; however, the existence of troop constraints can be easily considered with a slight modification to this model.

4. A constraint on available rail transportation was established at eight trains.

5. A constraint on available transportation for bulk POL was established at three medium truck companies and four trains.

[1] This is a reasonable bound for port operations in a *newly activated* theatre of operations. Certainly, port facilities will be improved at some time. An investigation of these improvements is a fruitful area for further study.

[2] Convoy arrivals of varying size could be easily simulated if such an arrival model was appropriate to the problem being studied. In this model, time between dry cargo and POL ship arrivals have the following density functions

$$\begin{array}{lll} \text{Dry Cargo:} & f(t) = \lambda_1 e^{-\lambda_1 t}; & t \geq 0 \\ & = 0; & \text{otherwise} \\ \text{POL:} & g(t) = \lambda_2 e^{-\lambda_2 t}; & t \geq 0 \\ & = 0; & \text{otherwise} \end{array}$$

6. A constraint on the temporary storage of bulk POL was established at 9800 short tons (the port's POL tank farm capacity).

In this research the results are only valid for the assumed arrival and service rates and model structure as described.

As noted, the inter-arrival times for ships were assumed to be mutually independent, exponentially distributed random variables. Dry cargo ships arrive at a mean inter-arrival time of 30 hours ($\lambda_1 = 1/30$) with a load of 5,600 short tons. POL tankers arrive at a mean inter-arrival time of 80 hours ($\lambda_2 = 1/80$) with a load of 8,400 short tons of bulk POL.

The service times (times to unload ship) were also taken to be mutually independent, exponentially distributed random variables. Mean times for various services were based upon unit capabilities as described below[4]:

1. Light Truck Company—350 short tons per day of cargo (4 tons per truck), based on 75 percent availability of vehicles and two line hauls daily.

2. Medium Truck Company—1,050 short tons per day of cargo (or POL if equipped with petroleum semi-trailers), based on 75 percent availability of vehicles and two line hauls daily.

3. Terminal Service Company—operating on a 20-hour day, two-shift basis: discharges one standard five-hatch ship and loads onto available transportation 700 short tons of cargo daily, or loads onto available transportation 840 short tons of cargo from temporary storage daily.

4. Amphibious Truck Company—transports 700 short tons of cargo daily, based on an availability of 30 vehicles carrying 3 tons per trip and making eight trips per day.

5. Railway Operation Battalion—operates and maintains the eight trains, each of which can transport 700 short tons of cargo (sufficient petroleum tankers are available to equip four trains) daily.

THE SIMULATION MODEL

The computer programs were written using GPSS III, a special-purpose simulation language provided by the IBM corporation [5, 6, 7]. The language is well suited to the study of problems which can be reasonably viewed as large-scale discrete unit flow and queuing problems. It is a special purpose computer language with its own compiler, allowing the analyst to describe the simulation model in "real world language," thereby shifting a great deal of the translation task to the computer. A GPSS III simulation model is written in terms of the program's 11 entities and their respective attributes [5]. The programmer must simply understand the functions of a set of flow-chart symbols and the rules for combining them. Once the analysis and flow diagram are completed, the program is easily written.

The general flow diagram for the model's dry cargo portion is reflected in Figure 2.

When a cargo ship arrives, it will queue before entering the inner harbor. The inner harbor is tested to determine if its content is less than 12 ships. If space is available the ship will enter the harbor and depart the queue for the inner-harbor. The ship will then test to determine if berth content is less than six (the number of berths available). Based upon the outcome of this test the entering ship will occupy either a berth or an anchorage. In each line the ships will queue and seize (occupy) the service unit(s)[3] necessary for unloading. Upon obtaining the needed service unit(s), seven duplicate "transactions" are created. Each of the duplicate transactions represents 700 tons of dry cargo, whereas the original "transaction" continues to represent the ship and the last 700 ton unit of cargo to be un-

[3] Ships with a berth need only a terminal service company. Ships with an anchorage require a terminal service company and an amphibious truck company.

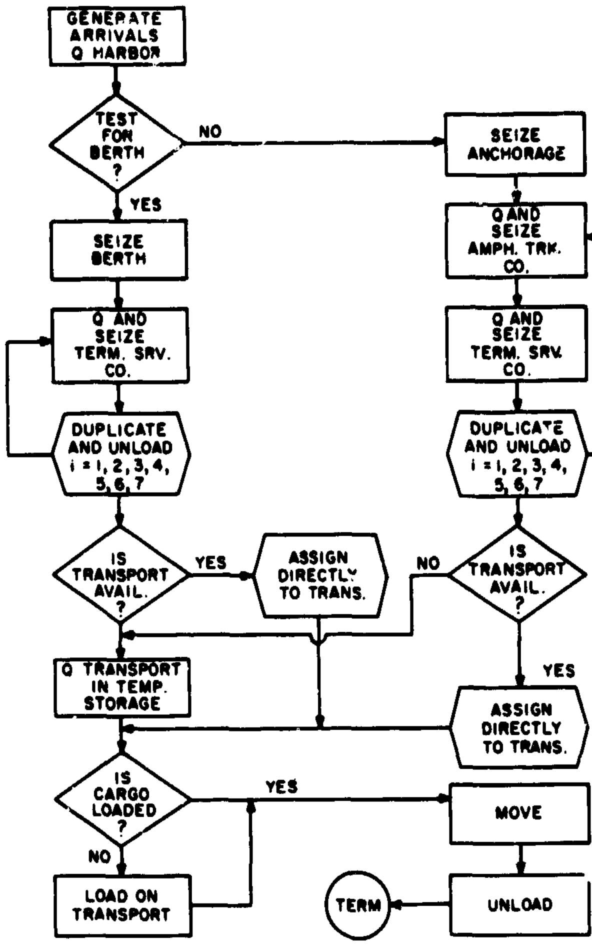

FIGURE 2. General flow diagram (dry cargo).

loaded. The model easily identifies the nature of each transaction by the assignment of appropriate parameter values [5, 6]. The transaction which represents both the ship and cargo is unloaded last.

If transportation is available, the cargo is unloaded from the ship to the transport means, and it is moved to the depot area and unloaded. If transportation is not available, the cargo is unloaded into temporary storage, where it must queue for transportation and a *terminal service company*. When both service units are available the cargo must be loaded, moved to the depot area, and unloaded. As can be seen, the availability of transportation at the time of a ship's unloading is a highly desirable state of successful port operation.

The POL portion is somewhat different in structure from the dry cargo portion. The general flow diagram for POL is reflected in Figure 3. When a tanker arrives it will queue before a POL anchorage and test to determine if its contents are less than two (the inner harbor's POL tanker capacity). On an affirmative to this test the tanker will depart the anchorage queue and seize (occupy) an anchorage. Upon seizure of the anchorage facility, 11 duplicate transactions are created. Of these duplicate transactions, the original one continues to represent the tanker and the last 700 tons of bulk POL to be discharged. Due to the lesser complexity of the POL portion, as compared to the dry cargo portion, separate event chains are created for each type transaction. The duplicate transactions are simply given a preemptive priority which insures that all duplicate transactions are discharged from a tanker prior to

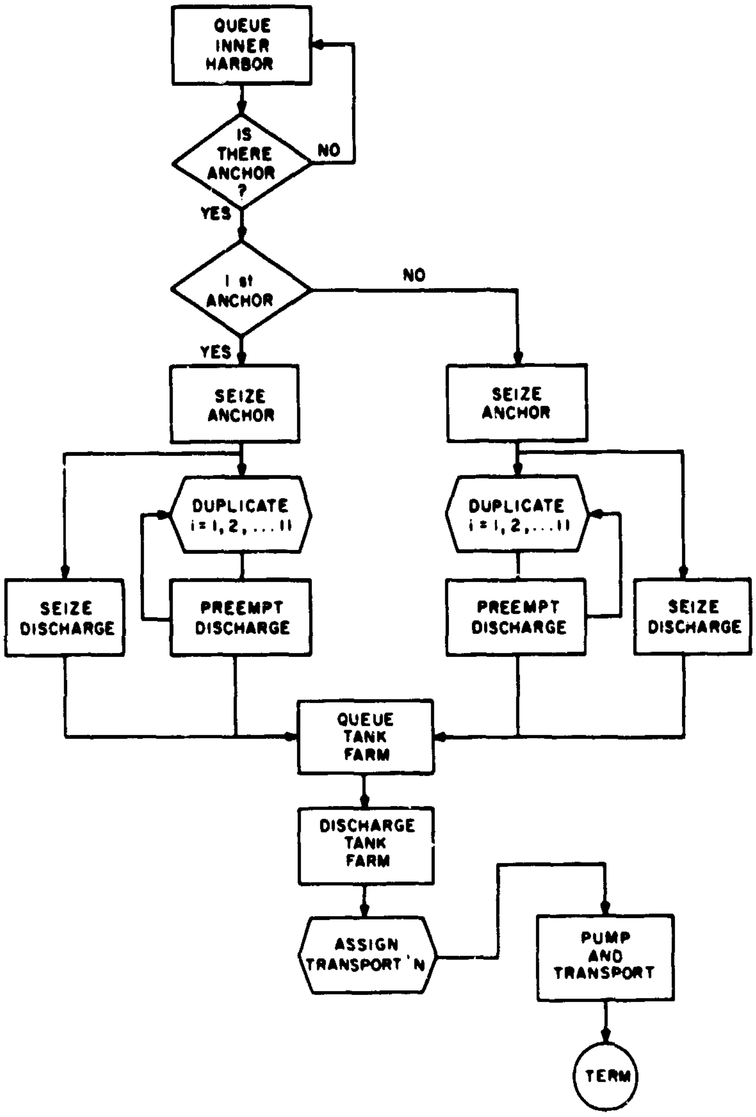

FIGURE 3. General flow diagram (POL).

that transaction which represents the last 700 tons of POL and the tanker itself. All units of POL at an anchorage will queue at the tank farm and test to determine if its contents are less than 14 (tank farm capacity in 700 ton units of bulk POL). With an affirmative result to this test, each 700 ton unit of POL seizes a discharge facility and is pumped into the tank farm with duplicate transactions preceding first. When the last 700-ton unit of POL is discharged, it will cause the release of the anchorage. Each POL unit in the tank farm queues to seize a transportation unit capable of hauling bulk POL. Upon seizure of the transport means, the POL is loaded, transported to the depot area, and unloaded.

EXPERIMENTAL DESIGN

The number of terminal service companies and transportation companies required to support the daily input were computed, as prescribed in FM 101-10-1, *Staff Officers' Field Manual* [3] to be seven terminal service companies, four light truck companies, two medium truck companies, and two trains to handle the expected daily input of dry cargo. Additionally, it was determined that three medium truck companies and one train would be required to handle the expected daily input of bulk POL. An initial simulation run was made on this basis with a small margin of allowance for variability of arrivals and service rates. Eight terminal service companies and 13 transportation units (4 light truck, 5 medium truck, and 4 trains) were utilized with this first run. The results reflected that the system could not realize a steady state as the inner-harbor queues for cargo ships and POL tankers grew without bound. This result was anticipated, and simulation was conducted at these levels to determine the time required to saturate the system and demonstrate the fallibility of the prescribed procedures for determining discharge and clearance capacities.

Based on the results of the intial simulation, a two-factor experiment was designed as follows:

Number of Transportation Units	Number of Terminal Service Companies					
	14	13	12	11	10	9
31	A-2	B-2	C-2	D-2	E-2	F-2
33	A-2	B-3	C-2	D-3	E-3	

RESULTS

The significant results are reflected in Tables 1 through 5 which show for each experiment (treatment), mean queue lengths, mean waiting times, mean waiting times given a wait $E(w|w > 0)$, major facility utilizations, and aggregate ship and tanker turn-around times, respectively. The most striking aspect of these results is the high sensitivity of the system to the number of transportation units provided.

Based on the information reflected in Tables 1 through 5, experiments A-2 and A-3 are given no further consideration due to the small realization from the additional terminal service company as compared to experiments B-2 and B-3. Experiments D-2, E-2, E-3, and F-2 are given no further consideration due to each presenting queue(s) of importance which are growing without bound indicating instability of the system.

TABLE 1. *Queue Lengths of Importance*

Experiments	Mean contents				
	Outer harbor	POL anchorage	Temperature storage	Loading temperature storage	Total storage
A-2	0.00	0.29	0.00	0.00	0.00
A-3	0.00	0.15	0.08	0.03	0.11
B-2	0.00	0.27	0.04	0.04	0.08
B-3	0.02	0.07	0.01	0.00	0.01
C-2	0.01	0.07	0.06	0.63	0.69
C-3	0.01	0.18	0.06	0.52	0.58
D-2	3.45	19.14	29.44	15.00	44.44
D-3	0.00	0.12	0.00	0.00	0.00
E-2	0.00	29.70	54.31	15.64	69.95
E-3	0.00	3.22	5.81	6.97	12.78
F-2	18.86	18.51	37.10	17.10	54.20

TABLE 2. *Waiting Times of Importance*

Experiments	Meantime/transaction				
	Outer harbor	POL anchorage	Temperature storage	Loading temperature storage	Total storage
A-2	0.00	16.66	0.00	0.00	0.00
A-3	0.00	16.47	2.39	0.79	3.28
B-2	0.00	21.04	0.89	0.86	1.75
B-3	0.48	6.33	0.66	0.00	0.00
C-2	0.24	6.41	1.40	13.79	15.19
C-3	0.21	10.64	1.58	12.77	14.35
D-2	94.52	873.72	115.63	60.00	175.63
D-3	0.00	9.29	0.00	0.00	0.00
E-2	0.00	1969.71	236.09	75.50	311.59
E-3	0.00	189.82	41.77	50.13	91.90
F-2	465.54	1588.14	184.07	90.04	274.11

TABLE 3. *Waiting Times (w/w > 0) of Importance*

Experiments	Meantime/transaction Q				
	Outer harbor	POL anchorage	Temperature storage	Loading temperature storage	Total storage
A-2	0.00	37.63	0.00	0.00	0.00
A-3	0.00	31.40	8.79	5.00	13.79
B-2	0.00	50.50	3.27	10.00	13.27
B-3	8.50	28.50	3.80	0.00	3.80
C-2	11.00	28.20	4.70	24.61	29.31
C-3	6.00	27.09	4.54	25.17	29.71
D-2	109.39	953.15	128.70	62.94	151.64
D-3	0.00	28.89	0.00	0.00	[illegible]
E-2	0.00	1969.71	243.64	77.51	[illegible]
E-3	0.00	285.16	54.98	54.63	109.61
F-2	498.09	1704.34	191.36	93.97	[illegible]

TABLE 4. *Major Facility Utilization (Storages)*

Experiments	Fraction of time utilized						Time (hours)	
	Inner harbor	Berth space	POL storage	Term. service company	Transportation	POL anchor	Harbor turn around	POL harbor turn around
A-2	[illegible]	[illegible]	0.7470	0.1189	0.7661	0.7494	168.54	81.71
A-3	[illegible]	[illegible]	0.3706	0.3581	0.5925	0.4625	169.77	66.57
B-2	[illegible]	[illegible]	0.4737	0.4514	0.7177	0.5011	169.15	73.04
B-3	[illegible]	[illegible]	0.2707	0.5867	0.8278	0.3254	193.62	55.70
C-2	0.5738	0.7938	0.3152	0.5069	0.6852	0.3816	194.86	63.00
C-3	0.5962	0.7508	0.5522	0.5095	0.7540	0.6457	189.14	72.83
D-2	0.9068	0.9938	0.9121	0.7333	0.9989	0.8244	301.28	465.60
D-3	0.5141	0.8214	0.3135	0.4127	0.6087	0.4138	179.43	61.89
E-2	1.0000	1.0000	0.9994	0.6667	0.9394	1.0000	390.75	1215.60
E-3	0.6650	0.8436	0.7841	0.6046	0.9021	0.7758	216.43	115.33
F-2	0.9946	0.9968	0.9897	0.5996	0.9382	0.9680	417.31	1044.30

TABLE 5. *Aggregate Ship Turn-Around*

Experiments	Time (hours)	
	Dry goods	POL products
A-2	168.54	98.37
A-3	169.77	77.04
B-2	169.15	94.08
B-3	194.10	62.03
C-2	195.10	69.41
C-3	189.35	83.47
D-3	395.80	1339.32
D-3	179.43	71.18
E-2	390.75	3285.31
E-3	216.43	305.15
F-2	882.85	2632.44

ANALYSIS OF RESULTS

Of those experiments retained there is little basis for making a choice among them as to the optimal operating policy. Queue lengths and ship turn-around times are acceptable in each case. Of the results portrayed, the points on the three response surfaces (Figures 4–6) are the most revealing. In each case the response surface appears to be relatively uniform when the system is not saturated: however, as saturation of the port's facilities is approached, a significant warp appears in each apparent response surface. The gradient, which each surface displays, indicates that the system is considerably more sensitive to the transportation unit level than it is to the level of terminal service companies. In a qualitative sense, it would appear prudent to select the higher transportation level and to then

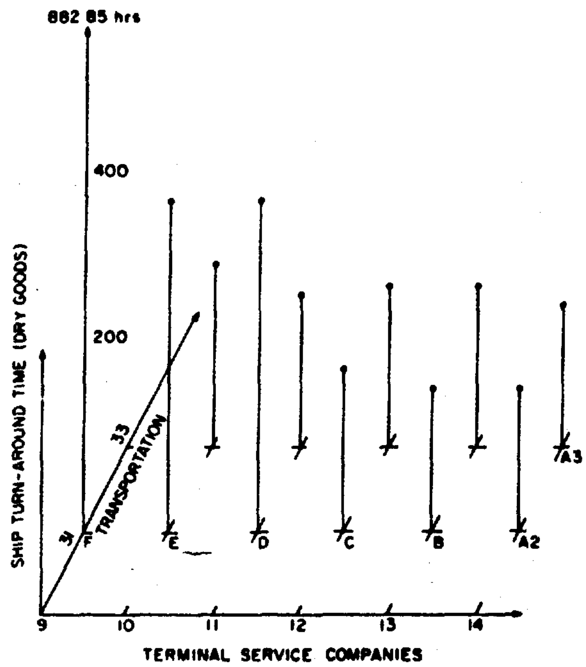

FIGURE 4. Response surface points, cargo ship turn-around.

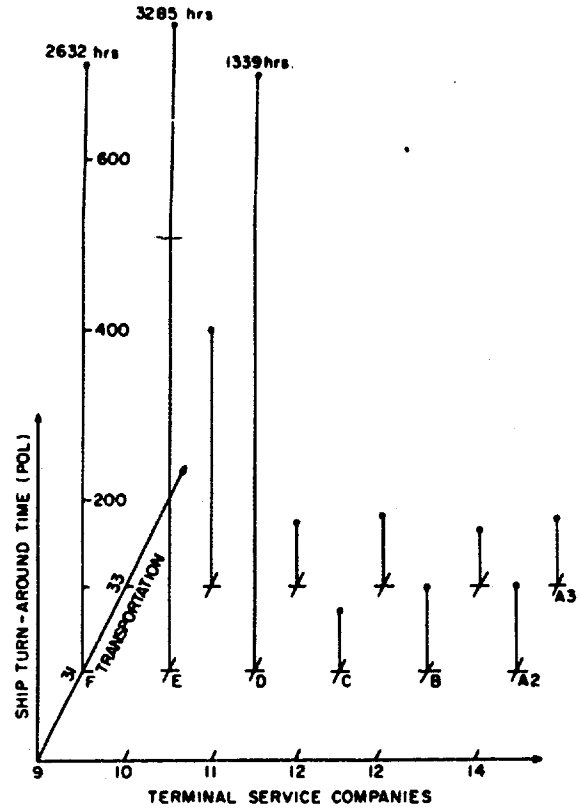

FIGURE 5. Response surface points, POL tanker turn-around.

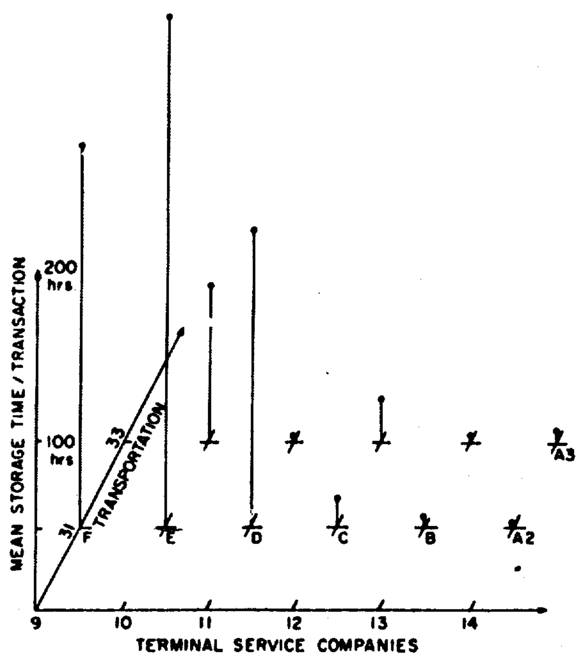

Figure 6. Response surface points, temporary storage.

choose a terminal service level on this basis. Of course, some troop ceiling or constraint is needed to give this method of selection real significance. It is also evident that the gradient is nearly flat until it begins to ascend, and that it then increases markedly. This would indicate that the logistics planner must pay close attention to the accuracy of arrival input data, to include any anticipated changes, especially in an increasing direction.

CONCLUSIONS

The difficulties of quantitative analysis were due to the nature of the problem under study; however, a worthwhile qualitative analysis was readily afforded from the simulation's results. Two specific conclusions of significant value were derived. First, the simulation clearly shows that the standard procedures for determining discharge and clearance capacities take insufficient account of the effects of variability in the system. The smallest satisfactory troop level was provided in operating policy D-3. This policy indicated a 253 percent commitment of transportation and a 138 percent commitment of terminal service units compared to the levels determined by prescribed methods. Second, the response surfaces for turn-around times and temporary storage levels indicate that an extremely steep gradient exists as a function of troop levels. Therefore, arrival rates must be accurately predicted, or a safety margin must be provided when troop ceilings are determined.

The approach to the problem in this paper has been at the field manual level, using the kind of data and information available to a general staff. The effort has been to make this model as general and also as usable as the field manual. The tradeoff between efforts in adapting this simulation to a real problem and in preparing a detailed, highly sophisticated simulation of a specific harbor complex is particularly significant. It can be measured in man-hours versus man-years and thus presents a planning aid for rapid identification of feasible alternatives. In practice, it appears that such alternatives are dependent on planning procedures contained in current field manuals. Although the conclusions of this paper simply verify what has been well established in the analytical quarters, they do demonstrate a significant departure from the existing field manual planning values. This demonstrated departure represents the real contribution of the paper.

To be sure such factors as variability in ship arrivals, ship loads, berth productivity, inland transport, and types of commodities are important considerations in any particular port problem; however, there is always the tradeoff between model complexity and ease of modeling. GPSS III is capable of incorporating such complexities, but since current doctrinal references do not yet reflect the dictates of those established analytical principles, it seems appropriate to sacrifice complexity for simplicity in an effort to illustrate the fallibility of currently prescribed procedures for determining discharge and clearance capacities. This model is an effort at such an illustration using an "off the shelf" capability. It is, hopefully, understandable at the field manual level and adaptable to general staff problems and procedures.

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