APPENDIX E
SIMULATION AND ECONOMIC MODEL

BACKGROUND

The primary problem identified in the Baltimore Harbor Anchorages Reconnaissance Study (1992) was one of deep draft vessel delays: delays in vessels arriving and departing the port; delays experienced by terminals waiting for vessels to arrive; delays in loading and unloading commodities. Delays incurred by a vessel, or to a vessel, would have ramifications to the rest of the vessel activity and possibly also to the infrastructure activities providing support to that vessel and its commodity cargo. These delays increase vessel time in the system and increase the cost of the voyage and the commodities being transported. Given the limited scope of the reconnaissance study effort and its focus on 1989 existing traffic, no long-range scenarios of activity in the port were developed. To properly evaluate this problem in the feasibility study, it had to be better defined and examined.

In order to more fully assess the impacts of alternative improvements on the Port of Baltimore navigation system, it was necessary to develop a “without project” condition that would appropriately depict the activities, interrelationships, and interdependencies that comprise the navigation system. The “without project” condition is the most likely condition expected to prevail over the length of the planning period in the absence of the Federal government’s implementing plans for improvement. Not only was development of this alternative important to a good understanding of the system components and of how the system works, but also because the “without-project” condition provided the baseline against which alternative Federal improvements to the port system were evaluated.

To develop the “without-project” condition, current operations (circa 1994-1995) and activities likely to be experienced by the Port of Baltimore between the years 2000 and 2050 (a 50-year planning horizon) were identified. Through detailed discussions with the representatives of the Association of Maryland Pilots, the Baltimore Maritime Exchange, tug operators, docking pilots, vessel agents, and terminal operators, an understanding was obtained of the navigation practices and operations in place in the Port of Baltimore. This effort traced the generic movement of deep-draft vessels in the system, and identified decision points in the voyage, routes used, operating speeds, distance, and elapsed time.

To improve on the 1989 vessel data used previously in the reconnaissance study, a data set was developed for the feasibility study that reflected foreign commodity vessel activity for the three-year period of 1991 through 1993. This was an important element of the overall analysis, because the data set reflected increasing use of the newly constructed 50-foot main channel into the Port of Baltimore (completed in late 1990). It provided information on vessels requiring use of anchorages; it provided a pattern of arrivals, departures, and time in port; and provided terminal destination and cargo. To further assist in defining the “without-project” condition, long-range commodity forecast models were specifically developed for this study. These models provided detailed forecasts of the commodity types and commodity tonnage likely to flow through the Port of Baltimore for the years 2000-2050. Given the forecast commodity mix, commodity tonnages and the Port’s existing channel system, a detailed vessel fleet profile was also forecast. This profile produced estimates of vessel types, sailing drafts, and vessels likely to call on the Port of Baltimore. This data set was also developed in ten-year increments for the period 2000-2050. Additional effort focused on identifying labor costs, pilot fees, vessel operating costs, time in port, and dispatch and demurrage costs.

Known plans for infrastructure improvement (additional terminals and berths) were reflected in the "without project" operating condition. Furthermore, given the landside productivity realized over time, an average time "at berth" for vessels expected to call on the port was incorporated into the "without project" condition. This average time "at berth" of 24 hours was based on actual arrive/depart data which implicitly accounted for start times of union and non-union gangs.

Anchorage use is a factor that influences the port community's ability to move vessels through the navigation system. While regulations exist governing and limiting use of anchorages in the Port of Baltimore, anecdotal data and vessel movement records indicated non-enforcement of these non-structural management measures. For the purposes of the feasibility analysis, however, the existing regulations for managing vessel use of anchorages were incorporated into the "without project" condition along with a simulated enforcement scenario.

FEASIBILITY ANALYSIS OF WITHOUT PROJECT CONDITION

During the review and approval of the reconnaissance study in the early 1990's, queuing analysis and simulation modeling were identified as the best techniques with which to identify waiting (queuing) times and to quantify costs associated with queues. With input from experts in the areas of navigation analysis, systems modeling, and operations research, simulation modeling was selected as the more appropriate of these two techniques. Simulation modeling allows for a system-wide assessment of the impacts of various alternatives at various locations within the port system. Simulation is a way to perform sampling experiments on a system. Rather than solving analytically (such as through use of a static queuing model) for time spent in the system and associated operational costs, simulation modeling solves for a discrete "length of time" for any number of vessel arrivals and services. The result is a simulation of actual operation of the queuing process where the aggregate results of these individual events are recorded. Simulation provides the ability to capture the dynamics of a system.

Simulation modeling is usually required in those situations that possess a great deal of complexity and some level of uncertainty or variability. The problems encountered in the Port of Baltimore are highly variable and include such factors as vessel arrival and departure times, loading and unloading, origins and destinations, and route selection. It is important to note that the level of detail to which an element is modeled should depend on the questions to be investigated with the simulation model. It is not possible to completely mimic the activity of the system. At the same time important characteristics should be captured. While the computer program simulates vessel traffic movement; it does not mimic traffic movement. However, the simulation program is calibrated to actual traffic for key characteristics (such as vessel type, length, breadth, and terminal destination). In this fashion, program runs will produce vessel flows (i.e. movements) that have characteristics similar to that observed in the real world. The average number of simulated departures from a given port will be close to that of the actual port. The average number of vessels in the simulated channel system at any point in time will be similar to that observed. By simulating the environment in this manner, one can analyze the effect of alternative scenarios on the system's effectiveness without physically implementing the changes. In short, vessel transits in the navigation system over time are identified outside the simulation environment. These vessel transits are routed through the modeled system for a discrete length of time under "without project" and "with project" conditions. The difference in system operating costs between the two "project" conditions is the basis for establishing the economic merits (benefits) of the federal project.

Another important aspect of simulation modeling is that a single run of the simulation does not provide a definitive answer. Within each environment, several simulation runs of several simulated days must be executed. Multiple runs are required to determine the variability present. For the analyses undertaken as part of the feasibility study, five simulation runs were produced for the "without project" condition (and each alternative considered). Each simulation routine was executed for a 150-day period of activity in the Port of Baltimore.

A number of factors are potentially influential in simulating channel and anchorage operations. These may include items such as vessel data, channel and anchorage configuration, berth and terminal location and operation, operating policies, weather, and accidents. For the feasibility study, the primary items addressed were the first four factors. No attempt was made to account directly for weather conditions over time, and casualty effects were not significant to the analysis. The simulation model developed for the Port of Baltimore vessel movement system consisted of about 4000 lines of code that define the typical and optional movement patterns that occur in the port system. Figure E-1 provides an overview of the system and the options available to vessels.

Figure E-1 reflects the basic elements of vessel transit in the Port of Baltimore system. Any vessel entering the system is either destined for Piney Point, Maryland, or one of the many terminals and docking facilities in the Port of Baltimore. The system developed and used in the feasibility study ignored all Piney Point traffic since they would not use any of the anchorages slots. Some vessel movements and stops are fundamental, undertaken by every vessel that enters the system. These activities are represented in Figure E-1 by solid lines and rectangles. Such fundamentals include transit time from entry point to dock; maneuvering within a branch channel; berthing and de-berthing activities; servicing of vessel at dock; and departure. Other movements and stops are auxiliary or optional, in the sense that they facilitate the effectiveness of the Port of Baltimore system, but are not undertaken by every vessel during a trip. Such auxiliary elements are entry into, departure from, or use of an anchorage, and layovers at docks.

The opportunities for vessel interactions are abundant and are illustrated within Figure E-1. Interactions may be either flow-oriented or facility-based. Flow-oriented interactions include vessel meetings on channels, vessel passings on channels, and vessel holds for transit completions. Facility-based interactions include anchorage exclusions and dock departure holds. Anchorage exclusions occur when a vessel is precluded from using an anchorage because of the presence of another vessel in the anchorage.

The simulation input files contain information on the various terminals servicing the vessels calling on the Port of Baltimore. Anchorage and branch channels "data cells" are also identified

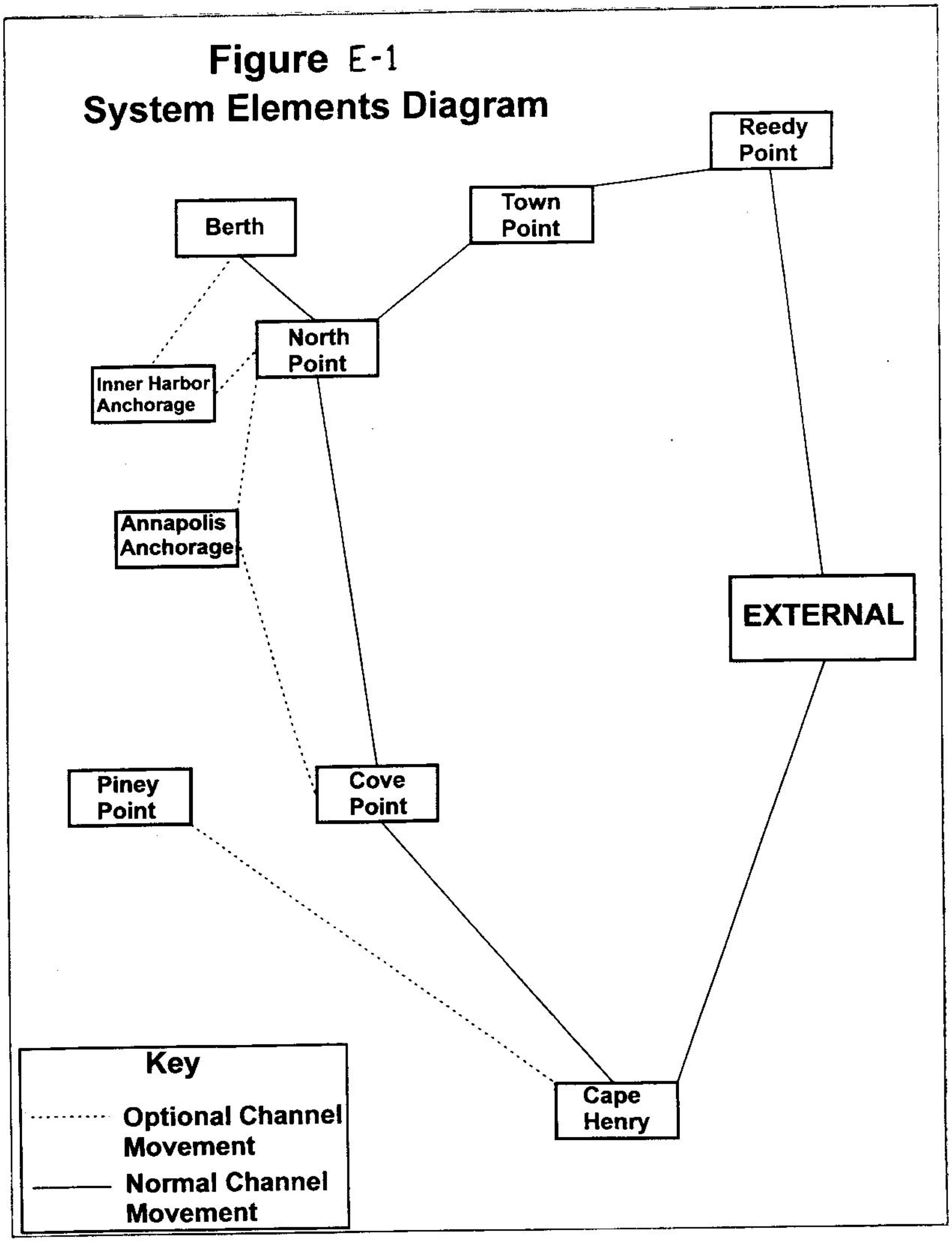

Figure E-1
System Elements Diagram

by ship count and ultimate terminal destination. Ship classes calling on the port for the period of time(s) considered are represented by vessel types referred to in previous sections.

Figure E-2 provides a definition of these various vessel types. To assist in defining capacity requirements in anchorages and branch channels, the vessel classes forecast to call on the Port of Baltimore were defined in terms of averages for width, draft, length overall, and vessel operating costs.

Figure E-3 provides a listing of the vessel dimensions by particular class. This information reflects the average size of all vessels (U.S.-flagged and foreign-flagged vessels) in each class and is taken from information contained in the FY 1995 Corps of Engineers Planning Guidance for Deep Draft Vessel Costs. This information also served as the basis for determining operating costs for the vessels. Figure E-4 provides a listing of the vessel class distributions forecast to call on the Port of Baltimore over the study period.

Various simulation runs using the 1991-1993 vessel movement data were produced to identify the most appropriate year, season, or period to use as the starting point for the establishment of the "without project" condition. The following periods were considered: winter 1991; spring 1991; summer 1991; fall 1991; cumulative 1991; cumulative 1992; cumulative 1993; and 1991-1993 cumulative. The 1991-1993 smoothed period and its vessel operating characteristics served as the basis for simulating the "without project" condition alternative and the various "with project" condition runs.

The distribution of vessel types and vessel calls represented in this period provided the basis for allocating vessel activity to the various terminals and berths expected to exist during the planning period. This allocation was done for each of the benchmark years (2000 – 2050) and includes terminals and berths not present in the existing condition but likely to be operational during the planning period.

Shown in Figure E-5 is a sample simulation output file (developed during the early phases of the feasibility study) that summarizes the results of one 150-day simulation of vessel activity in the port. System operating costs include vessel operating costs; pilotage costs; dispatch - demurrage costs; and total operating costs. To develop the "without project" condition operating costs for vessels using the Port of Baltimore navigation system, randomly-generated simulations produced a minimum of five output scenarios for each benchmark year. During the course of the simulation modeling process, total cost outputs indicated increasing demands were being placed on the available port infrastructure due to a combination of factors, including but not limited to, increased vessel calls, limited loading/unloading capacity, and loading/unloading productivity rates.

ALTERNATIVES EVALUATION

With knowledge of the current system of operating and routing vessels, the various terminal locations and berths, and the distribution of traffic to the terminals, simulation runs were completed for each of the benchmark years (2000 – 2050) to identify "without project" elapsed time in system and associated costs. These simulations were executed based on vessels arriving

Figure E-2
Definition of Vessel Types

AA - General Cargo > 10,000 DWT
AB - General Cargo < 10,000 DWT
A1 - Cellular < 1000 TEU
A2 - Cellular 1000-2499 TEU
A3 - Cellular 2500-3999 TEU
A4 - Cellular 4000-5999 TEU
A5 - Cellular 6000-7999 TEU
A6 - Cellular > 8000 TEU
AE - Roll On/Roll Off > 10,000 DWT
AF - Roll On/Roll Off < 10,000 DWT
BA - Reefer (Refrigerated Vessel)
DA - Bulk < 20,000 DWT
DB - Bulk 20-40,000 DWT
DC - Bulk 40-80,000 DWT
DD - Bulk 80-100,000 DWT
DE - Bulk 100-175,000 DWT
DF - Bulk > 175,000 DWT
EA - Combination < 20,000 DWT
EB - Combination 20-40,000 DWT
EC - Combination 40-80,000 DWT
ED - Combination 80-100,000 DWT
EE - Combination 100-175,000 DWT
EF - Combination > 175,000 DWT
FA - Tanker < 10,000 DWT
FB - Tanker 10-40,000 DWT
FC - Tanker 40-80,000 DWT
FD - Tanker 80-100,000 DWT
FE - Tanker 100-175,000 DWT
FF - Tanker 175-250,000 DWT
FG - Tanker > 250,000 DWT
PA - Product Tanker < 10,000 DWT
PB - Product Tanker 10-40,000 DWT
PC - Product Tanker 40-80,000 DWT
PD - Product Tanker 80-100,000 DWT
PE - Product Tanker > 100,000 DWT
GA - Gas Tanker
HB - Vehicle Carrier
XX - Other

Note: DWT = Deadweight Tonnage, TEU = Twenty Foot Equivalent Units

Figure E-3
Class Definitions

Class	Width (feet)	Draft (feet)	Length Overall (LOA, feet)
A1	73	25	482
A2	94	34	676
A3	112	41	853
A4	117	43	905
AA	76	32	542
AB	64	25	447
AE	76	32	542
AF	64	25	447
DA	67	28	478
DB	83	34	583
DC	105	43	717
DD	119	49	780
DE	136	55	910
EC	109	42	585
ED	125	47	800
FA	76	30	519
FB	87	34	585
FC	109	42	585
FD	125	47	800
HB	64	25	447
PA	76	30	519
PB	87	34	585
PC	109	42	585
PD	125	47	800

Figure E-4
Vessel Calls Per Day

	2000	2010	2020	2030	2040	2050
Number/day	9.4	13.2	20.8	28.6	40.0	55.6
Percentage By Class	%	%	%	%	%	%
AA	11	9				
AB	2	1				
A1	3	4	5	6	6	5
A2	23	22	20	19	18	17
A3	6	7	9			
A4	3	6	9	12	16	20
AE	16	17	16	15	15	14
AF	1					
DA	5	6	4	3	2	1
DB	6	6	6	5	4	3
DC	3	3	2			
DD	1					
DE	2	3	4	4	5	7
EC	1					
ED	1					
FA	1					
FB	1					
FC	1					
FD	1					
HB	8	8	8	8	7	7
PA	1					
PB	1					
PC	1					
PD	1					

Figure E-5
Sample Simulation Output File

```
SMOOTH Baltimore existing condition 2000          S00A091      119

Existing condition rand1

        anchorage #      1 is anc1
        anchorage #      2 is anc2
        anchorage #      3 is anc3
        anchorage #      4 is anc4
        anchorage #      5 is anc5
        anchorage #      6 is anc6
        anchorage #      7 is annap
doing       1 runs, each of       150 days

~~~~~~~~~~~~~~~          SYSTEM COSTS          ~~~~~~~~~~~~~~~
~~~~~~~~~~~~~~~                                ~~~~~~~~~~~~~~~
```

CLASS	TRIPS	TIME (HRS)	OP.COST ($)	PIL.COST ($)	D.D.COST ($)	TOTAL ($)
A1	41	1361.	1004274.	43865.	0.	1048139.
A2	324	10768.	13675481.	279470.	0.	13954951.
A3	98	3260.	4864130.	86174.	0.	4950305.
A4	39	1281.	2131285.	32172.	0.	2163457.
AA	143	4836.	3632109.	125108.	-1265538.	2491679.
AB	29	989.	569576.	24806.	-256686.	337696.
AE	220	7569.	5684207.	179287.	0.	5863494.
AF	17	557.	320598.	15051.	0.	335649.
DA	73	2519.	1420514.	92113.	-636078.	876549.
DB	107	3926.	2716911.	100359.	-867132.	1950137.
DC	46	1900.	1687208.	105643.	-285763.	1507088.
DD	19	700.	734812.	52891.	-145085.	642618.
DE	30	1960.	2416115.	32243.	47542.	2495900.
EC	20	773.	895136.	15844.	-152435.	758545.
ED	14	788.	1018771.	10252.	-27002.	1002021.
FA	12	451.	401420.	11209.	-97406.	315222.
FB	12	398.	386799.	9627.	-107333.	289093.
FC	16	598.	692874.	14357.	-130821.	576411.
FD	15	548.	708148.	13248.	-126373.	595023.
HB	123	4585.	2640793.	97890.	-1000196.	1738488.
PA	19	697.	621400.	12991.	-159131.	475260.
PB	18	616.	597829.	16906.	-159122.	455613.
PC	11	428.	495890.	8490.	-84580.	419800.
PD	14	492.	636571.	10708.	-119534.	527745.
TOW	0	0.	0.	0.	0.	0.
TOTAL	1460		49952852.	1390705.	-5572673.	45770885.

```
~~~~~~~~~~~~~~~          SYSTEM COSTS          ~~~~~~~~~~~~~~~
~~~~~~~~~~~~~~~                                ~~~~~~~~~~~~~~~
```

CLASS	TRIPS	TIME (HRS)	OP.COST ($)	PIL.COST ($)	D.D.COST ($)	TOTAL ($)
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A3	98	3260.	4864130.	86174.	0.	4950305.
A4	39	1281.	2131285.	32172.	0.	2163457.
AA	143	4836.	3632109.	125108.	-1265538.	2491679.
AB	29	989.	569576.	24806.	-256686.	337696.
AE	220	7569.	5684207.	179287.	0.	5863494.
AF	17	557.	320598.	15051.	0.	335649.
DA	73	2519.	1420514.	92113.	-636078.	876549.
DB	107	3926.	2716911.	100359.	-867132.	1950137.
DC	46	1900.	1687208.	105643.	-285763.	1507088.
DD	19	700.	734812.	52891.	-145085.	642618.
DE	30	1960.	2416115.	32243.	47542.	2495900.
EC	20	773.	895136.	15844.	-152435.	758545.
ED	14	788.	1018771.	10252.	-27002.	1002021.
FA	12	451.	401420.	11209.	-97406.	315222.
FB	12	398.	386799.	9627.	-107333.	289093.
FC	16	598.	692874.	14357.	-130821.	576411.
FD	15	548.	708148.	13248.	-126373.	595023.
HB	123	4585.	2640793.	97890.	-1000196.	1738488.
PA	19	697.	621400.	12991.	-159131.	475260.
PB	18	616.	597829.	16906.	-159122.	455613.
PC	11	428.	495890.	8490.	-84580.	419800.
PD	14	492.	636571.	10708.	-119534.	527745.
TOW	0	0.	0.	0.	0.	0.
TOTAL	1460		49952852.	1390705.	-5572673.	45770885.

and departing the Port of Baltimore system and intermediate movements while in the port system. Most of these intermediate movements are definite, in the sense that they must occur, while some movements are optional in that they don't always occur. Figure E-6 provides an illustration of the salient vessel movements that occur while vessels are moving within the navigation system.

Repeated simulations of vessels moving through the harbor system and the multiple vessel/pilot/tug/interactions that typically occur yielded estimates of elapsed time and costs incurred while in the port system. This was done for the six benchmark years (2000 – 2050). Through the use of this simulation modeling capability, coupled with the forecasts of commodity tonnage and vessel calls to the Port of Baltimore, effects of proposed channel and anchorage modifications on the overall system were evaluated to determine the viability of such modifications without actually having to construct them.

BRANCH CHANNEL ALTERNATIVES

Modifications considered for the branch channels servicing the terminals included deepening, widening, and various combinations of deepening and widening. The simulation model was utilized to evaluate each branch channel alternative absent other possible improvements so as to estimate total system impacts caused by each proposed alternative. Because any branch channel improvement will impact not only the specific terminal(s) adjacent to the branch channel but also the entire port operating system, this approach provided a means for tracing impacts on the entire port operating system. Figure E-7 and Figure E-8 illustrate this concept. The illustrations in Figure E-7 reflect the existing and "without project" operation of a generic branch channel in the port system. At time zero, Vessel 1 prepares to depart from berth. Vessel 2 waits for Vessel 1 to pass and provide room for Vessel 2 to move toward its berth area. In this illustration Vessel 2 doesn't begin its transit until time 220 minutes.

A generic branch channel improvement is illustrated in Figure E-8. Due to a channel improvement (deepening or widening), Vessel 1 passes Vessel 2 at time 205 minutes and reduces its travel time by 15 minutes. Additionally, Vessel 2 is now able to safely proceed to its berth area at time 205 realizing a time saving of 15 minutes. If the port operating system consisted of these 2 vessels, there would be a total savings of 30 minutes realized to the system. However, there are many more than two vessels present in the port system with Vessel 1 and Vessel 2; consequently savings caused by the generic branch channel improvement and the departure of Vessel 1 will be more than 30 minutes. Once Vessel 2 completes its loading or unloading operation and departs the berth, additional savings accrue to all vessels in the system at that time. Figure E-9 indicates the system areas or "frames" where impacts of branch channel improvements may be realized by the Port of Baltimore navigation system.

Modifications considered for the various anchorages servicing vessels in the Port of Baltimore system also included deepening, widening, and various combinations of deepening and widening. The simulation model was utilized to evaluate each of several anchorage alternatives absent other possible improvements so as to estimate total system impacts caused by each proposed anchorage alternative. Because any anchorage improvement will impact not only

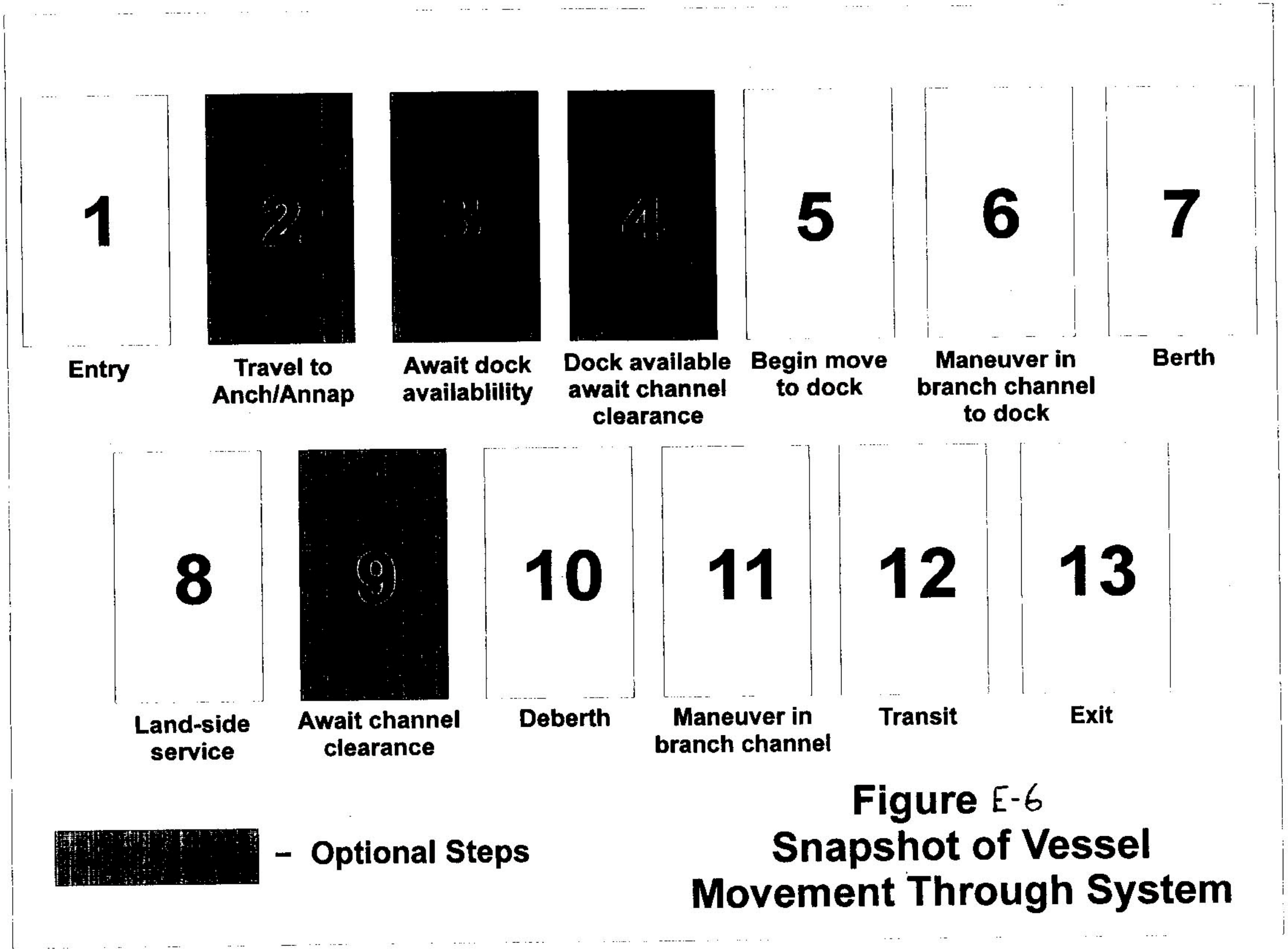
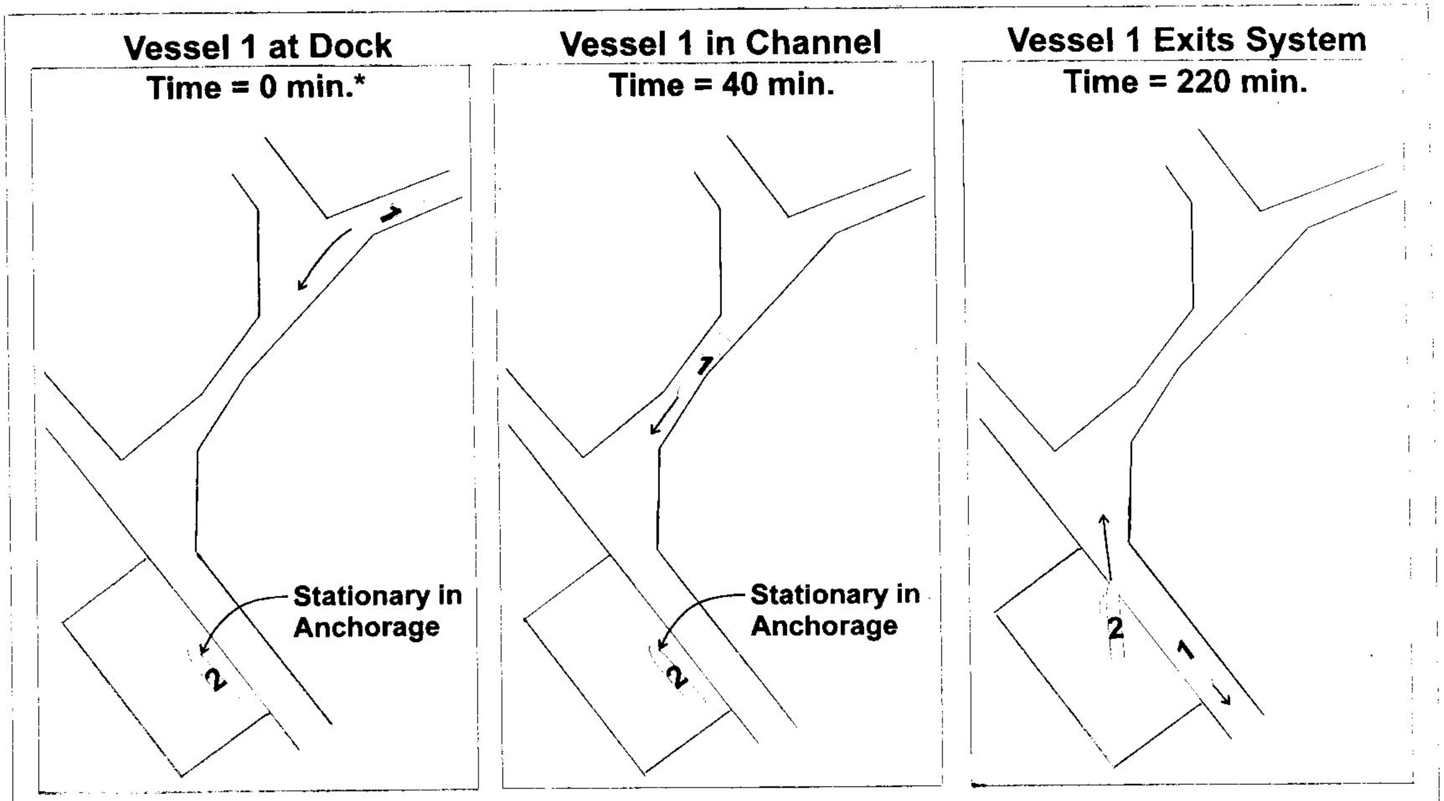


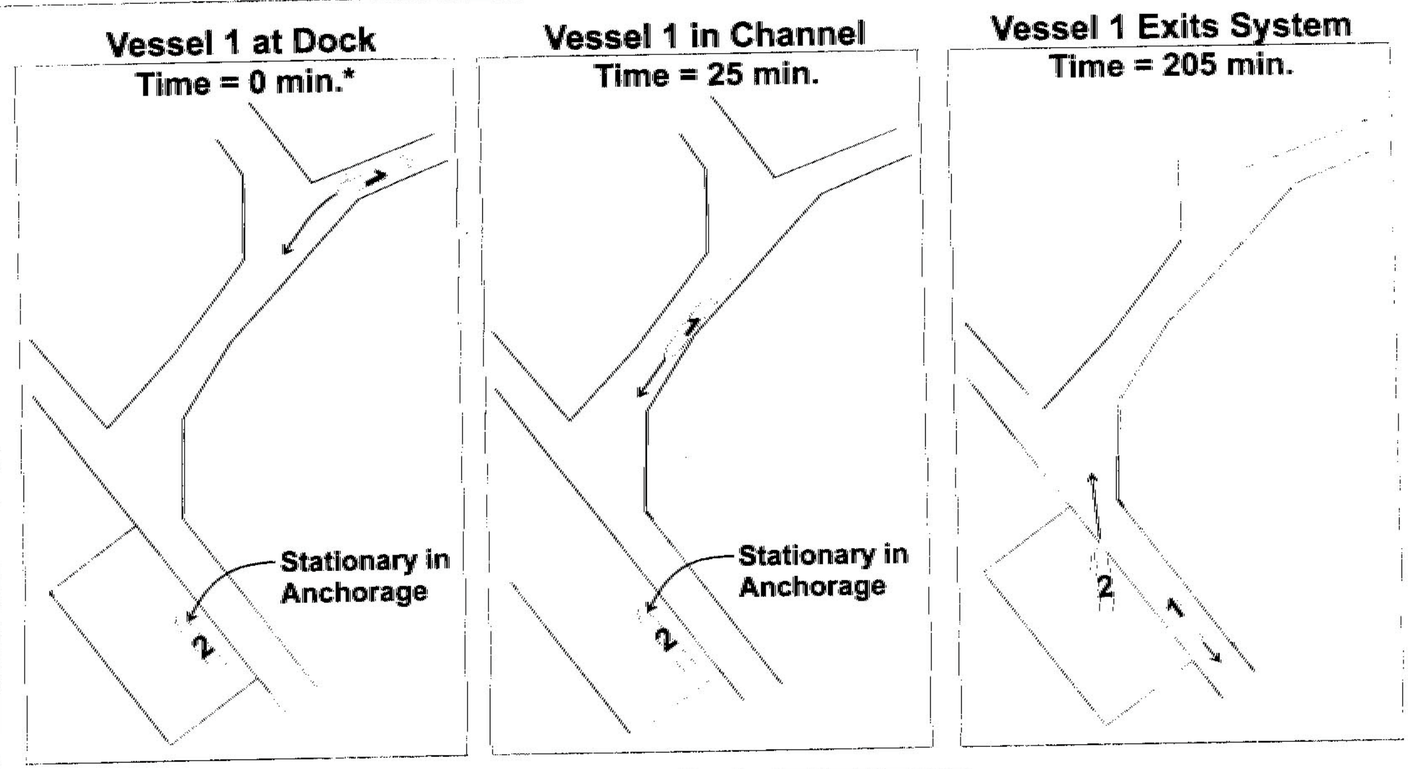
Figure E-6
Snapshot of Vessel Movement Through System



Narrative:
Vessel 1 departing Generic Branch Channel
Vessel 2 next into Generic Branch Channel

Figure E-7
Branch Channel Existing Condition

* Time estimates are for illustrative purposes only



Narrative:
Vessel 1 departing branch channel
Vessel 2 next into branch channel

Reductions - Time Savings

Vessel 1	15 minutes
Vessel 2	15 minutes
Total	30 minutes

* Time estimates are for illustrative purposes only

Figure E-8
Branch Channel Improved Condition Maneuver Time Reduced 15 min.

Figure E-9
SYSTEM ELEMENTS IMPACTED BY IMPROVEMENTS*

System element num**	Improved Branch Channels: Direct Impact	Improved Branch Channels: System Impact	Improved Anchorages: Direct Impact	Improved Anchorages: System Impact
1	-	-	-	-
2	-	Y	Y - Selection	Y
3	-	Y	-	Y
4	-	Y	-	Y
5	-	-	Y	Y
6	Y	-	-	-
7	-	-	-	-
8	-	-	-	-
9	-	Y	-	Y
10	-	-	-	-
11	Y	-	-	-
12	-	-	-	-
13	-	-	-	-

* Impacts may be positive or negative
** Numbers refer to system elements shown in Figure E-6

the specific terminal(s) for which the primary vessel is destined but also the entire port operating system, this approach provided a means for tracing impacts on the entire port operating system. Figures E-10 and E-11 illustrate this concept.

The illustrations in Figure E-10 reflect the existing and "without project" interaction of a generic channel and anchorage in the port system. At time zero, Vessel 1 prepares to depart from berth. Vessel 2 waits at the Annapolis Anchorage for Vessel 1 to pass and provide room for Vessel 2 to move toward its berth area. The vessels must wait because two large vessels cannot pass in the Craighill Channel, which runs between Annapolis and Baltimore. In this illustration, Vessel 2 doesn't begin its transit until time 220 minutes. A generic harbor anchorage improvement is illustrated in Figure E-11. Due to an anchorage improvement (deepening or widening), Vessel 1 passes Vessel 2 at time 60 minutes and Vessel 2 is at its berth at time 120 minutes. This reduces travel time of Vessel 2 by 280 minutes. If the port operating system consisted of these two vessels, there would be total savings of 280 minutes realized to the system. However, there are many more than two vessels present in the port system with Vessel 1 and Vessel 2; consequently savings caused by the generic anchorage improvement and the arrival of Vessel 2 to berth will be more than 280 minutes. Once Vessel 2 completes its loading or unloading operation and departs the berth, additional savings accrue to all vessels in the system at that time. Figure E-9 indicates the system areas or "frames" where anchorage improvements may be realized by the Port of Baltimore navigation system.

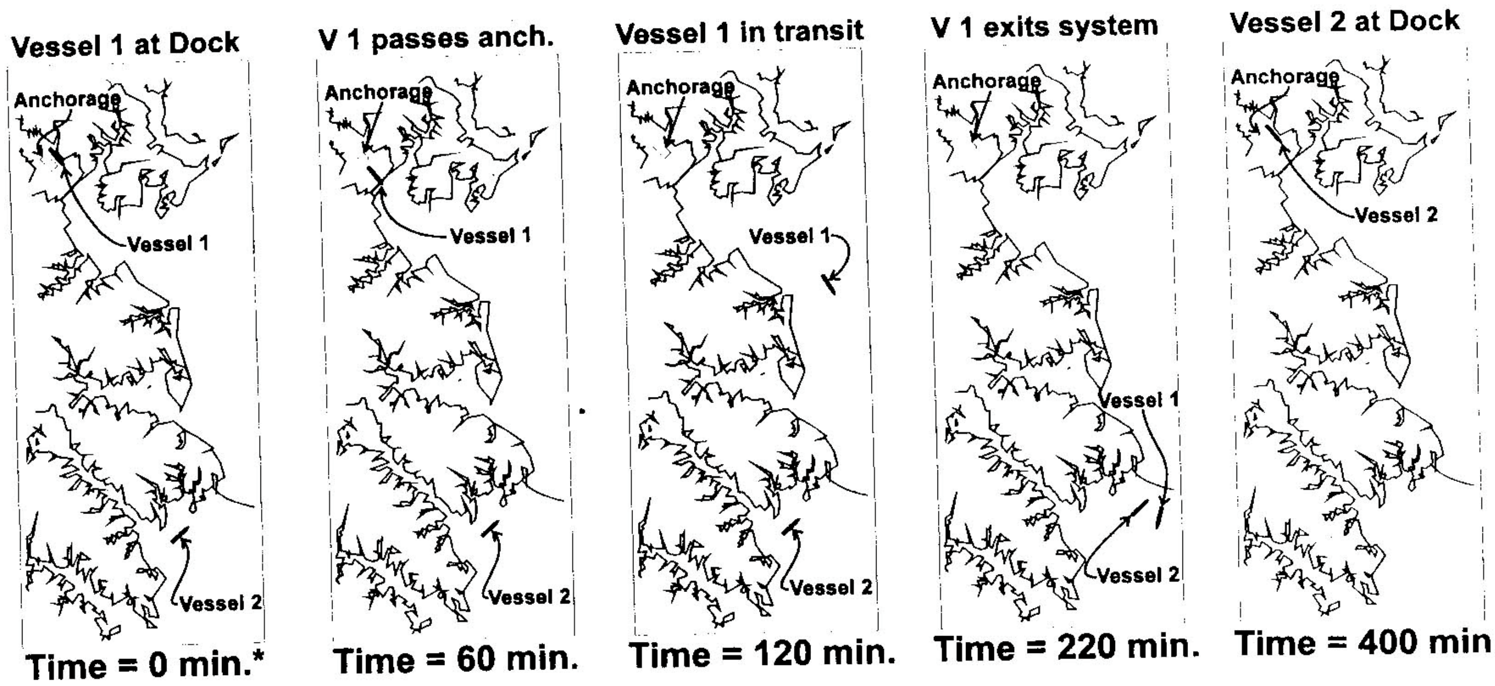
ELEMENTS OF SIMULATION

The Galveston District of the U.S. Army Corps of Engineers began exploring the possibility of modifications of the Houston and Galveston Ship Channels in the late 1980's. In the fall of 1989, the Galveston District contacted Dr. Michael Racer of the Industrial and Systems Engineering Program at Memphis State University to assist in the analysis. To aid the Galveston District in this task, a simulation program was written. This program simulates vessel traffic in the channel to a very detailed level. Using this simulation, the impact of any of a number of decisions can be addressed. These include:

- channel modifications (width and depth)
- traffic changes (e.g. alternate vessel types)
- policy changes (e.g. passing/meeting protocol)
- port usage changes (e.g. addition/deletion of a facility, increase/decrease in utilization)
- flexibility to model other channel environments

Modifications required by the Baltimore District were for the purposes of modeling the value of anchorage modifications and branch channel improvements. This led to the introduction of the following into the simulation:

- anchorage definition
- pilot costs
- dispatch and demurrage costs
- maneuvering times in branch channels
- berthing, deberthing and loading/offloading times in docks



Narrative:

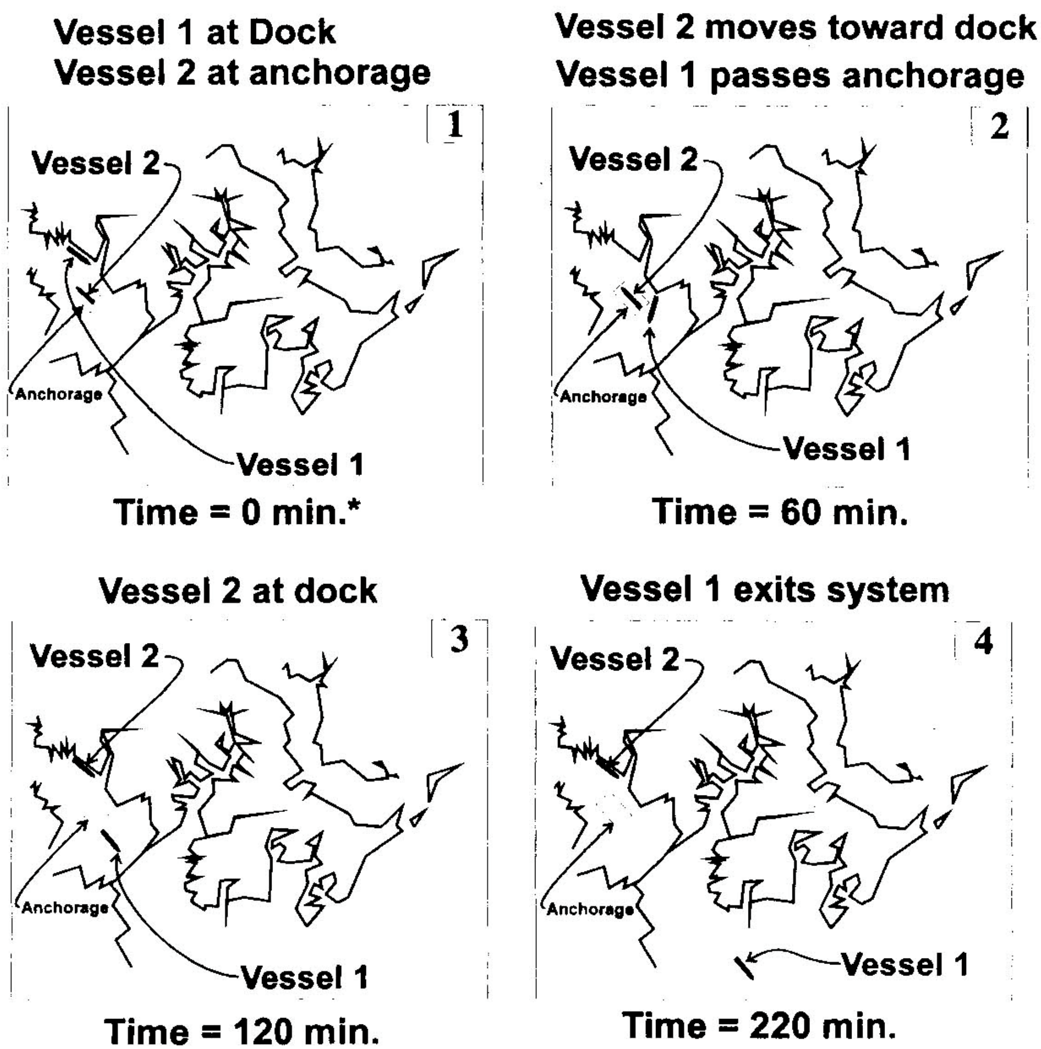
Vessel 1 departing berth

Vessel 2 next at berth; too large to anchor in harbor. Anchors at Annapolis

Figure E-10

Anchorage Existing Condition

* Time estimates are for illustrative purposes only



* Time estimates are for illustrative purposes only

Narrative:

Vessel 1 departing berth

Vessel 2 next at berth; anchors at enlarged anchorage in harbor

Reductions - Time Savings

Vessel 2	280 minutes
Total	280 minutes**

** Compare to Figure 5.19 in which vessel 2 arrives at the dock at time=400 minutes vs. 120 minutes in this scenario

Figure E-11
Enlarged Anchorage in Harbor

The following documentation/resources were used in developing the simulation model:

- VTS Houston/Galveston Information, Rev. 3/89
- The Ports of Galveston and Texas City, Texas, Port Series #23, Rev. 1985, U.S. Army Corps of Engineers
- The Port of Houston, Texas, Port Series #24, Rev. 1989, U.S. Army Corps of Engineers
- Final Feasibility Report and Environmental impact Statement Galveston Bay Area Navigation Study Volume 3 Appendix C. Navigation Economics Vessel/Tow Traffic Data (1989)
- discussions with Galveston District staff
- discussions with Clifford Kidd (Baltimore District team member)

There are a large number of ports in the Houston/Galveston system. The channel is large and non-homogeneous - over sixty miles of channel and subchannel, varying in width and depth. There are a great many variable elements in the channel system. From the system-wide viewpoint, vessel traffic is highly variable. The simulation models the departure of vessels from ports. Those elements of a given vessel trip which are determined according to probabilistic distributions are:

- time of departure
- class of vessel
- destination

Departure rates for the ports were determined from historical data. It was found that the exponential distribution provided a good fit to the observed rates. Vessel class and destination are also chosen with regard to a port-specific distribution, supplied by the user.

It is important to point out that the program simulates traffic movement; it does not mimic traffic. That is, a run of the program will produce vessel flows that have characteristics similar to that observed in the real world. The <u>average</u> number of simulated departures from a given port will be close to that of the actual port. The <u>average</u> number of vessels in the simulated channel system at any point in time will be similar to that observed. By simulating the environment in this manner, we may analyze the effect of alternate scenarios on the system effectiveness, without physically implementing the changes. Using the simulation code for the problem faced by Galveston District, the impact of widening and deepening parts of the channel can be assessed. Using forecasts of vessel types, channel traffic was simulated over a fifty-year period.

To develop a meaningful simulation analysis, it is important for the user to have a very thorough understanding of the system being simulated. The user must identify those characteristics which significantly influence the system, and in particular the questions to be addressed in the analysis. In the Houston/Galveston effort, it was found that seasonalities did exist, with respect to channel traffic. In addition, because the modifications are long term efforts, it was necessary to analyze traffic patterns well into the future. To accommodate these, data was collected on traffic in each of four seasons. (Channel seasons are closely related to natural seasons. In other environments, it may be necessary to model fewer, or more, seasons.)

The Galveston District also developed a forecast of future vessel classes and volumes for the channel. Using this information, and current seasonal data, future seasonal forecasts were created.

One further issue of importance in simulation modeling is to remember that a single run of the simulation does not provide the definitive answer. Within each environment, the user must make several simulation runs of several days. The number of days and number of runs can be determined by the user as he collects results. As an example, suppose that the evaluation measure is total system cost. The user must make several runs to determine the variability present. From this, the user may choose the number of runs and period simulated so as to bring the observed variance down to an acceptable level.

ESSENTIAL ELEMENTS OF THE ENVIRONMENT

A number of factors are potentially influential in simulating channel operations. These may include the following:

- vessel data (size, origin, destination, etc.)
- channel configuration (depth, width, shape, presence of subchannels, etc.)
- port location/operation
- operating policies
- weather
- accidents

In the current application, the primary factors are the first four. No attempt is made to account for weather conditions, and casualty effects are not critical for the problem at hand.

Since the essence of the channel simulation problem is to assess the impact of system modifications, it is very important to understand the traffic moving through the channel and various subchannels, as well as to represent realistically that channel structure. Port operations are important only in that this dictates the supply of vessels traveling the channel (the program has been structured in a modular fashion, as to allow for future extensions as needed).

The simulation has the capability to model channel traffic from two different perspectives, dependent on the needs of the user. In the first instance, in which the focus of the analysis is on channel modifications, the creation of traffic flows may be accomplished by specifying departure rates for the various docks and source points in the system. While this ignores the relationship between vessels inbound to a specific port and those outbound from that port, it does essentially capture the vessel movement levels. This is the methodology applied to the Galveston Channel Study.

The second methodology, applied to the Baltimore Anchorages Study, allows for the creation of vessels only at source points (e.g. from the ocean). These vessels are than managed throughout the system, coordinating inbound, port service, and outbound actions.

We discuss each of the major entities in the model below, providing detailed data requirements in a later section. Each entity has a set of attributes. These attributes are utilized in the simulation to guide the actions and interactions of the entities. We classify these attributes as follows:

- input: provided by the user, or determined from user-defined inputs
- dynamic: changing as the simulation progresses; these attributes are generally internally required, and of no general use to the operator
- calculated: performance statistics

VESSEL CLASS MODEL

At a high level, it can be recognized that there exist some commonalties among vessels. In order to simplify the modeling process, the program allows any number of vessel classes to be defined. The number defined will depend on the user – how much diversity is necessary to answer the questions to be addressed. The reasons for discriminating between vessel classes are numerous, and situation-dependent. In the Houston/Galveston model, it is necessary to distinguish vessels primarily on structure - draft and width in particular. However, in another environment it may be more important to distinguish based on operating costs (such may be the case when preparing an analysis for channel port operators, for instance). By allowing the user to define he/she has the capability to investigate a wide range of issues.

Each vessel class has the following attributes:

a cls.ident	class identifier (input)
a cls.draft	operating draft of this class (input)
a cls.speed	max speed of class (input)
a cls.turn.speed	turning speed of class (input)
a cls.cost	hourly operating cost (input)
a cls.pilot.cost	hourly pilotage cost (input)
a cls.miles	total mileage for the class (calculated)
cls.tot.cost	total cost for boats of this class (calculated)
a cls.tot.time	total time in system for this class (calculated)
a cls.trip.ct	# trips of this class (calculated)
a cls.unf.miles	total mileage for the class - unfinished trips (calculated)
a cls.unf.tot.cost	total cost for boats of this class - unf. trips (calculated)
a cls.unf.trip.ct	# trips of this class - unf.trips (calculated)
a cls.bm.width	beam width (input)
a cls.length	length of class (input)
a cls.prior	prioritization scheme (input)
a cls.disp.cost	cost of dispatch/demurrage for this class (input)
a cls.dock.size	# dock slots required (input)
a cls.disp.time	time period from which disp/demur calculated (input)
a cls.acc.disp.demur	accumulated disp/demurrage costs for the class (calculated)

a cls.acc.pilot.cost	total costs of pilotage in the cell (calculated)

VESSEL MODEL

The second level of vessel definition is port-specific. That is, the vessel must be defined with respect to its origin and destination. Internally, the vessel is also linked to a particular vessel class, and the information pertinent to that class.

Each vessel has the following attributes:

a bt.new	0=new,1=old (dynamic)
a bt.ident	identifier for boat (input)
a bt.init.time	time at which boat began trip (calculated)
a bt.tot.miles	miles traveled (calculated)
a bt.speed	current boat speed (dynamic)
a bt.locn	distance into cell (dynamic)
a bt.heading	heading at present (dynamic)
a bt.back.flag	true" if backing up, "false" otherwise (dynamic)
a bt.back.width	if backing, cell width required for pass; else 0 (dynamic)
a bt.pres.cell	present cell location (dynamic)
a bt.next.cell	next cell location (dynamic)
a bt.dest	destination port (input)
a bt.orig	origination port (input)
a bt.class	type of boat (input)
a bt.genl.head.ew	a E/W heading indicator (dynamic)
a bt.genl.head.ns	a N/S heading indicator (dynamic)
a bt.nxt.event.time	time of boat's next event (dynamic)
a bt.next.turn	pointer into bt.set (dynamic)
a bt.update.time	time boat position was last updated (dynamic)
a bt.destroy.flag	flags whether a boat has been in casualty (dynamic)
a bt.idle.time	idle time of vessel (calculated)
a bt.dispatch.cut	time from which dispatch/demurrage is counted (calculated)
a bt.priority	vessel priority (input)
a bt.posn	status flag (dynamic)
a bt.ult.dest	ultimate destination of the vessel (input)
a bt.ult.orig	first vessel origination of the vessel (input)
a bt.cl.start	time at which the vessel started in the current cell (dynamic)
a bt.anc.arrival	time of arrival at anchorage, if applicable (calculated)
a bt.dd.arrive	time from which to allocate dispatch/demurrage rate (calculated)
owns a bt.set	itinerary (input)

STRUCTURE MODEL- CELL

There are essentially two components in describing the physical character of the channel. These are the development of a cell structure, and the definition of wide spots. We first discuss the cells.

There may be long stretches of the channel in which the appearance of the channel is constant. Recognition of this facilitated the development of the simulation, and increases the efficiency of the run-time. The channel is defined with respect to a major axis - primarily north - south, or primarily east - west. By defining the other cells adjacent to each cell, we can represent the entire channel structure, including sub-channels and turns without requiring excessive modeling of ship maneuvers.

Each cell has the following attributes:

a cl.ident	cell identifier (input)
a cl.level	level off of main channel (calculated)
a cl.length	length of cell (input)
a cl.width	width of cell (input)
a cl.depth	depth of cell (input)
a cl.spd.limit	cell speed limit (input)
a cl.intersec	"true" if at an intersection; "false" otherwise (input)
a cl.level.dist	distance to next level from cell edge (input)
a cl.level.joiner	cell connecting this one to next lower level (input)
a cl.label.dir	direction to main channel (input)
a cl.north	cell N of this one (input)
a cl.east	cell E of this one (input)
a cl.south	cell S of this one (input)
a cl.west	cell W of this one (input)
a cl.casualty.rate	rate of casualties in this cell (input)
a cl.tot.miles	total mileage of ships departing ports in this cell (calculated)
a cl.tot.time	total operation time of ship departing this cell (calculated)
a cl.unf.tot.miles	total unfinished mileage of ships departing ports in t (calculated)
a cl.unf.tot.time	total unfinished operation time of ship departing this cell (calculated)
a cl.tow.tow.mt.casualty	# tow/tow meet casualties in this cell (calculated)
a cl.tow.ship.mt.casualty	# tow/ship " "
a cl.ship.ship.mt.casualty	# ship/ship " "
a cl.tow.tow.ps.casualty	# tow/tow pass casualties in this cell (calculated)
a cl.tow.ship.ps.casualty	# tow/ship " "
a cl.ship.ship.ps.casualty	# ship/ship " "
a cl.tow.tow.mt.count	# tow/tow meetings in this cell (calculated)
a cl.tow.ship.mt.count	# tow/ship " "
a cl.ship.ship.mt.count	# ship/ship " "
a cl.tow.tow.ps.count	#tow/tow passings in this cell (calculated)
a cl.tow.ship.ps.count	# tow/ship " "
a cl.ship.ship.ps.count	# ship/ship " "
a cl.depart.ct	# departures from ports in the cell (calculated)
a cl.depart.delay	total of delay times for departures (calculated)

a cl.branch.flag	indicates whether a cell is a branch channel (input)
a cl.capacity	if branch, this is capacity, else INF (input)
a cl.pilot.flag	1 if cell must be piloted, 0 otherwise (input)

STRUCTURE - WIDE.SPOT

In situations for which a stretch of the channel may be fairly homogeneous, but spotted by vessel turnouts, we include the modeling of wide spots in each cell. These are locations at which a vessel may wait for other vessels to pass before continuing (in the Craighill Channel, these wide spot locations are the Craighill Angle and the Cutoff Angle). Such waiting is necessary when passing and meeting rules restrict such events.

Each wide spot has the following attributes:

a ws.cell	cell in which spot is located (input)
a ws.locn	distance of wide.spot into cell (input)

PORT MODEL

The ports in the system drive the activities in the simulation. A port may be truly a functioning operation, or may represent some other source of vessels. For the Port of Baltimore model, one port was modeled, while the Houston/Galveston model had two additional ports were modeled - one for the sea, and another one for the anchorage area. A port is defined with respect to its location, and characteristics of departing vessels.

Each port has the following attributes:

a pt.cell	cell in which port is located (input)
a pt.locn	distance of port from cell's leading edge (input)
a pt.name	name of port (input)
a pt.depart.ct	# boats departed port (dynamic)
a pt.class.ct	# classes of boats in port (input)
a pt.dest.ct	# ports served (input)
a pt.class.type.ptr	pointer to array-class ID (calculated)
a pt.class.frac.ptr	pointer to array -fraction of each class (calculated)
a pt.class.num.dest.ptr	pointer to array - #destinations served by each class (calculated)
a pt.class.freq.ptr	pointer to array-departure frequency of class (calculated)
a pt.class.dest.ptr	pointer to array-destinations of class (calculated)
a pt.class.dest.frac.ptr	pointer to array-fraction of class with destination (calculated)
a pt.rate.p1	departure rate parameter 1 from port (input)
a pt.rate.p2	not used
a pt.svc.time	time to complete service in dock (input)
a pt.capac	# slots in the port (input)
a pt.usage	# slots in the port being utilized (dynamic)
a pt.anc.flag	flag indicating whether a port is an anchorage (input)
a pt.deberth	time to deberth (input)

a pt.berth	time to berth (input)
a pt.maneuver	time to maneuver into dock (input)
a pt.lay.cost	cost to layover in dock (input)
a pt.idle.cost	cost to sit idle (input)
a pt.depart	# departures from port (calculated)
a pt.arrive	# arrivals to port (calculated)

ANCHORAGE MODEL

This element in the simulation model captures the essential characteristics of an anchorage, for the purpose of allowing a vessel to wait. A wait may be necessitated when a dock is full, or channel traffic precludes the movement of the vessel.

Each anchorage has the following attributes:

an anc.port	port with which anchorage is associated (input)
an anc.index	anchorage ID (input)
an anc.num.slots	# anchor positions (input)
an anc.type	normal or overflow (input)
an anc.depth	depth in anchorage (input)
an anc.prior.flag	prioritization scheme (input)
an anc.wait.lim	wait limit (input)

Within each anchorage, there are then a number of tie-ups, each with its own set of attributes. The specific attributes of the tie-up are:

an atu.usage	current user of the slot (dynamic)
an atu.depth	depth of the tie.up (input)
an atu.length	max allowable length in the slot (input)

THE SIMULATION MODEL

The simulation consists of roughly 4000 lines of computer code. This program has been written to execute on an IBM-compatible personal computer, and has been tested on a Pentium-processor driven machine.

EVENTS

The activity of the simulation is driven by the creation of event routines within the code. The following ten events form the core of the channel simulation model:

E.BT.ARRIVE	arrival of a vessel to its destination port
E.BT.BACKUP	initiation of a vessel backup
E.BT.BEGIN	departure of a vessel from a port

E.BT.MEET	meeting of two vessels in a channel
E.BT.MOVE	change in movement of a vessel
E.BT.PASS	passing of one vessel by another in a channel
E.BT.TURN	turn of a vessel from one channel to another
E.DOCK.DONE	completion of dock utilization
E.LAYOVER.DONE	completion of a layover
E.STOP.SIM	termination of the simulation

Each event is described in more detail below.

E.BT.ARRIVE

This event essentially identifies the arrival of a vessel at the appropriate destination port. A variety of trip statistics are collected (these statistics will be discussed in detail in a later section). If the vessel is a tow (barge or tug-barge combination), a new assignment is determined, and a departure is scheduled for the tow.

E.BT.BACKUP

This routine marks the time at which a vessel must begin traveling in the reverse direction, to allow for a legal passing. Once this is done, the next action of the vessel is determined.

E.BT.BEGIN

When a vessel initiates a port departure, a number of actions must be taken. This routine scans the local channel area to make sure that the vessel can safely exit from the port, avoiding oncoming traffic. If this is not the case, departure is delayed until the appropriate time. Once a safe departure is determined, the next event involving this vessel is determined.

E.BT.MEET

The following inputs are provided by the user, with respect to the function of two vessels meeting in a channel:

meet_margin = distance, in feet, at which vessels must initiate meeting protocol
draft_ratio_limit_1
draft_ratio_limit_2
width_ratio_limit = limits on draft ratios of the two vessels
speed_reduction_matrix_size = number of elements in speed reduction array
ratio_array(i)
reduc_array(i) = speed reduction array elements, i = 1...array size

The inputs reflect the discussion of meeting protocol described in Section 7.4.3.6.2 of the *Galveston Bay Area Navigation Study*. The Port of Baltimore meeting protocol was similar to the Galveston protocol with adjustments as recommended by the Association of Maryland Pilots (for instance, vessel draft is not a factor in the Port of Baltimore meeting criteria). Draft ratio limits and the beam width ratio limit are used to define those situations in which a meeting is not possible, and a backup must occur. When a meeting is allowed, the (ratio_array,reduc_array) determine the amount by which the vessels must slow down for a proper meeting. The procedure followed simulates the “Texas Chicken Maneuver.”

When two vessels are scheduled to meet, a number of statistics are collected. Casualty probabilities are modeled in a very rudimentary fashion. For each cell, the probability of a casualty occurring during an encounter has been determined. Random casualties are marked, based on this distribution. Since this was not considered to be of much concern with respect to the Port of Baltimore system, little attention was paid to this aspect.

When two vessels are scheduled to meet, the combined beam width ratio of the vessels is calculated. If this exceeds the maximum allowable ratio (as established in EM 1110-2-1613, *Hydraulic Design of Deep Draft Navigation Projects*, January 1994), the vessel of smaller beam is backed up. Otherwise, the appropriate speed reduction for meeting is determined, via a table look-up. Vessel speeds are reduced accordingly. If either boat had previously been backing up, and is now allowed to continue forward motion, then this is done. The next event for each vessel is determined at the conclusion of the meeting.

<u>E.BT.MOVE</u>

A variety of movements are considered in this routine. These are:

- § initiation of a turn
- § completion of a turn
- § completion of travel in a cell

If a turn is being initiated, an E.BT.TURN event is scheduled.

If a cell completion or turn completion is scheduled, the transition is marked. Vessel speed is revised if necessary. If the vessel is backing up, and has found a wide enough place to wait, the vessel is stopped; otherwise, it continues to back up.

<u>E.BT.PASS</u>

Vessel passing protocol is similar to that of the meeting, discussed earlier. Inputs are similar. Statistics are collected, and casualties are modeled to a limited degree.

<u>E.BT.TURN</u>

When a turn is identified, this event recognizes the cell into which the vessel is moving, and changes the course of the vessel appropriately. If other vessels are near the intersection and the vessel is currently in a subchannel, the vessel waits until that time at which it is safe to make the transition. If the turn is allowed, the routine then determines the time at which the turn will be completed.

E.DOCK.DONE

This event marks the conclusion of a dock service. The event initiates the departure of the vessel, either to its ultimate destination, or an intermediate one (anchorage or layover).

E.LAYOVER.DONE

This event marks the conclusion of a layover. The conclusion may be either voluntary - in that the vessel is moving to its ultimate destination or an anchorage - or it may be involuntary - in which case the layover is being terminated and the vessel must locate a new layover point.

E.STOP.SIM

E.STOP.SIM terminates an iteration of the simulation at a time specified by the user.

FUNCTIONS

The simulation consists of one function - OPPOSITE - which is used to reverse the direction of travel that must back up.

ROUTINES

The simulation consists of a number of routines, which provide support to the main activities, as dictated by the events. These routines are:

MAIN	driver
R.BT.CASUALTY	handles casualties
R.BT.DEPART	supports vessel port departure
R.CLEAN.UP	supports simulation termination
R.END.BOAT.EVENTS	cancels all events for a vessel when necessary
R.FINAL.STATS	calculates and prints final statistics
R.INITIALIZE	initializes all data and variables
R.NXT.MOVE	supports determination of next vessel activity
R.RD.DATA	data input
R.RTE.CREATOR	determines route for a vessel, from origin to destination
R.START.TOWS	starts all tow activities in the simulation
R.UPDATE.BOAT	re-evaluates vessel location
R.VERIFY	verifies vessel characteristics
SNAP.R	debug aid

MAIN

This routine is the driver for the entire simulation. The user is prompted to define the length of time for each simulation, as well as the number of simulation runs to be done. Data is input. An E.STOP.SIM is scheduled. Vessel departures are scheduled for each port in the system. Tow movements are initiated. When the simulation is terminated, statistics are collected, and all arrays reinitialized as necessary.

R.BT.CASUALTY

When a casualty has occurred, this routine collects statistics. Casualties are defined with respect to vessel types, as well as locations. Activities for both vessels involved are ceased.

R.BT.DEPART

In the original simulation of the Port of Baltimore, vessel departures were exponentially distributed. This routine supports the departure of a vessel from a port. The vessel class is determined, using the characteristics of the port provided by the user. In the same fashion, a destination port is selected. The route for the vessel is determined, and the first activity - an E.BT.BEGIN - is scheduled according to the departure rate of vessels from the port. Prior to the LRR analysis, the simulation model was revised such that departures were not a separate independent feature, but rather part of a single vessel trip.

R.CLEAN.UP

This routine simply releases all storage utilized by the routine during the simulation.

R.END.BOAT.EVENTS

When the simulation determines that a new event will preempt the previously calculated activity of a vessel, this routine is called to cancel all relevant events. Activities of other vessels may also be impacted; in this case, new activities are determined for those vessels.

R.FINAL.STATS

The following statistics are compiled and displayed:

- passing
    - by cell of encounter
        - tow_tow
        - tow_ship
        - ship_ship
    - summary
- meeting
    - by cell of encounter
        - tow_tow
        - tow_ship
        - ship_ship
    - summary
- system costs (finished trips)
    - by vessel class
        - total expense($)
        - number of trips

number of miles
cost/trip
cost/mile
summary

§ system costs (unfinished trips)
- by vessel class
  - total expense($)
  - number of trips
  - number of miles
  - cost/trip
  - cost/mile
- summary

§ delays
- by cell of departure
  - average delay (hours)
  - number of departures
- summary

§ casualties
- by cell of encounter
  - tow_tow
  - tow_ship
  - ship_ship
- summary

§ travel (finished trips)
- by cell of departure
  - miles traveled
  - time traveled (hours)
  - average rate (miles/hour)
- summary

§ travel (unfinished trips)
- by cell of departure
  - miles traveled
  - time traveled (hours)
  - average rate (miles/hour)
- summary

Statistics were collected independently on finished and unfinished trips, to accommodate the determination of annual system costs. Finished trip data is dependent heavily on the length of time simulated; unfinished trips, on the other hand, represent a snapshot of system activity. Since the earlier Port of Baltimore feasibility runs, this routine has been revised to better reflect complete vessel trips; consequently, the LRR analysis does not include any partial or incomplete trips.

<u>R.INITIALIZE</u>

This routine initializes some variables.

R.NXT.MOVE

This routine is one of the most substantial in the entire simulation. This routine determines the next activity that will involve a vessel at any point in time. When called, the routine determines which of the six events - E.BT.ARRIVE, E.BT.BACKUP, E.BT.MEET, E.BT.MOVE, E.BT.PASS, or E.BT.TURN - will occur next. In addition, for a vessel currently backing up, this routine will identify the nearest wide spot in the channel. The appropriate event is then scheduled.

R.RD.DATA

All data input - except for number of runs, and simulation period - are read via this routine.

R.RTE.CREATOR

When a vessel departure is scheduled, this routine determines the path to be followed by the vessel, including all turns. A route file is created, storing all relevant information for the vessel.

R.START.TOWS

The user specifies the number of tows operating in the system, and the expected amount of idle time between assignments for a tow. This routine starts tows in accordance with the user-supplied information.

R.SUMMARY.STATS

This routine provides a summary printout of the per-iteration finished trip costs. Average results over the run are also calculated.

R.UPDATE.BOAT

This routine updates the location when necessary. Vessel travel distance is increased, and vessel speed is modified when appropriate.

R.VERIFY

This routine verifies that the position of a vessel is a valid one.

SNAP.R

This routine provides debug support, and can be modified with regard to the particular debug needs.

DATA REQUIREMENTS

There are two input files required. The first input file describes the structure of the system, containing all static information. The second file is used to define the traffic pattern. By separating the data in this fashion, a variety of dynamic issues, such as seasonal influences and traffic forecasting issues can be explored.

{Anything in **bold** characters is considered a key word, and must be entered as shown.}

{inputs shown in outline form indicate numbers supplied by the user.}

We begin by developing the contents of file one - the structure file

STRUCTURE FILE FORMAT

1. *Header line:* The file begins with a header line(s). This is included to allow the user to include a detailed descriptor of the file contents. The header is echoed in the output.

format:

< header information **<**

The program looks for the opening '<'. Everything lying between the '<'s is considered as comment.

2. *Seeds*: There are five random number strings used in the simulation. These are tied to five different random event types occurring in the program such as time between vessel arrivals, class of arrival vessel, and dock destination. The user may allow the simulation to select the seeds, or may supply his own.

format (all integers; unformatted):

old.seeds

or

new.seeds

seed1 seed2 seed3 seed4 seed5

3. *Sensitivity Analysis Parameters*: (These are not currently used, but were part of preliminary analysis.)

format (all reals; unformatted):

1.0 1.0 0.0 1.0

4. *System Configuration*: These two parameters provide the general structure of the system. The first parameter indicates the number of cells in the network; the second identifies the major axis of orientation of the system.

format (2 integers; unformatted):

num_cells orient (0=north-south, 1=east-west)

5. *Cell information*: There are a number of parameters specified for each cell. Each cell is

numbered sequentially, up to num_cells. Each cell is given a name, chosen by the user. The remainder of the cell input defines the cell speed limit (knots), the cell casualty rate (probability of occurrence/meeting), and the cells adjacent to the cell. In addition, the user provides the cell depth (feet), the length (miles), and the width (feet). Two flags indicate whether the cell must be piloted ("1"=yes), and whether the cell is a branch channel ("1" = yes).

format (type as shown; unformatted):

cell_id (integer)
cell_name (text)
cell_speed_limit (real)
cell_casualty_rate (real)
cell_north_neighbor (integer)
cell_eastern_neighbor (integer)
cell_southern_neighbor (integer)
cell_western_neighbor (integer)
cell_depth (integer)
cell_length (real)
cell_width (integer)
cell_pilot_flag (integer)
cell_branch_flag (integer)

6. *Number of vessel classes*: Following the input of all cell information, the user provides the number of vessel classes to be defined.

format (integer, unformatted):

num_class

7. *Vessel class information*: For each vessel class, the user supplies information about the vessels of this class: identifier, vessel dimensions (feet), maximum speed (knots), turning speed (knots), operating cost ($/hour), pilotage cost ($/hour), dispatch cost($/hour prior to the agreed upon time limit), dispatch time (hours).

format (type as shown; unformatted):

class_ID (text)
class_beam_width (integer)
class_draft (integer)
class_length (integer)
class_speed (integer)
class_turn_speed (integer)
class_cost (real)
class_disp_cost (integer)
class_disp_time (integer)

NOTE: The class_ID of tow vessels must be "TOW."

8. *Wide spots*: The software allows for the introduction of a wide spot into an otherwise homogeneous cell. Each wide spot is defined by location (cell number and distance into the cell), and may include a descriptor.

format: (integer, real, text; unformatted; one wide spot per line):

wide_spot_cell wide_spot_dist descriptor(optional)

9. *Passing information*: As discussed earlier, in the section on E.BT.PASS, the passing policy is reflected in the data input.

format (type as shown, unformatted):

pass.margin (integer)

comb_bm_width_ratio_pass (real)

passer_draft_ratio_limit (real)

passee_draft_ratio_limit (real)

pass_array_dimension (integer)

pass_beam_width(i)(real) pass_speed_reduction(i) (real)

i = 1...pass_array_dimension

NOTE: pass_beam_width(1) must be 0.0, and pass_beam_width (pass_array_dimension) must be 1.0.

10. *Meeting information*: As discussed earlier, in the section on E.BT.MEET, the passing policy is reflected in the data input. There is also an additional parameter - casualty_reduc - which allows the user to investigate the impact of scaling up and down the casualty rates.

format (type as shown, unformatted):

meet.margin (integer)

draft_ratio_backup_limit1 (real)

draft_ratio_backup_limit2 (real)

width_ratio_backup_limit (real)

casualty_reduc (real)

meet_array_dimension (integer)

meet_beam_width(i)(real) meet_speed_reduction(i) (real)

i = 1...meet_array_dimension

NOTE: meet_beam_width(1) must be 0.0, and meet_beam_width (meet_array_dimension) must be 1.0.

11. *Turning information*: Two parameters influence turning - a distance limit and a time limit. If there is no vessel within a certain distance, in miles, of the turning point and no vessels will arrive at that point within the allotted time, in minutes, the turn is allowed; otherwise the vessel must wait.

format (2 reals; unformatted):

turn_dist_limit turn_time_limit

12. *Anchorage information:* The user must specify information concerning each of the defined anchorages in the system. Because of the operational similarities between a port and an anchorage, the two share some characteristics, and each anchorage is defined in the seasonal file with respect to these characteristics. Following are the characteristics specific to an anchorage. Each anchorage has two identifiers, a number and a textual name. For each anchorage, the user defines the number of tie-ups and the depth (in feet). Note that all tie-ups in a single anchorage are of the same depth. For each tie-up, a length (in feet) is entered. This length is the length of the longest possible vessel that could use this anchorage. Priority and wait limits are in-place but not utilized currently.

format(as indicated, unformatted)

anc_ID (integer) anc_name (text)

anc_num_slots (integer) anc_depth (integer)

anc_length_array (integer) anc_priorities (integer)

anc_wait.lim (integer)

13. *Run information:* Two parameters define the run, number of replications and number of days simulated

format(as indicated, unformatted)

num_runs (integer) run_length (integer)

SEASONAL FILE FORMAT

The seasonal file contains information that may vary while a particular structure is held constant. This variation may be due to forecasting with respect to the current environment or modeling of seasonal attributes.

1. *Header line:* The file begins with a header line(s). This is included to allow the user to include a detailed descriptor of the file contents. The header is echoed in the output.

format:

< header information <

The program looks for the opening '<'. Everything lying between the '<'s is considered as comment.

2. *Seasonal tow information*: Since tow operations may vary, we have included here two parameters indicating the number of tows in the system, as well as the average time between dispatch (in minutes), once a task has been completed.

format (integer,real; unformatted):

tow_count tow_departure_rate

3. *Port count*: The user must specify the number of ports in the system.

format (integer; unformatted):

port_count

4. *Port information*: For each port the user must define a number of parameters. These include information about the port's location, as well as the activity from that port - vessel departure rate, number of destinations served, vessel types. It was determined through analysis of the Port of Baltimore data that the exponential distribution is a very close approximation to the true departure pattern of vessels.

format (type as shown; unformatted):

port_name (text)	defined by the user
port_cell (integer)	cell in which port is located
port_dist (integer)	distance into the cell of the port
port_departure_rate (real)	average number of days between departures
port_classes_used (integer)	number of vessels exiting this port
port_dests (integer)	number of destinations served by this port

for each class of vessel repeat the following:

pt_cls_id(i) (text)	vessel class exiting the port; name must match with one in the structure file
pt_cls_frac(i) (real)	proportion of vessels from this port of this class
pt_cls_dest(i) (integer)	number of destinations served by this class from this port

for each (port,class) pair repeat the following:

pt_cls_dest(i,j) (text)	destination port; name must match with one in the structure file
pt_cls_frac(i,j) (real)	proportion of vessels of this class departing from this port for this destination

---

SAMPLE INPUT/FEASIBILITY STUDY - SEASONAL

```
<SMOOTH Baltimore p5 condition 2000<
TOW.INFO   0  .25
39
    AGRICO
        26   .57      0.0
        0  0
        1
        24   .75  .5
        0.0
        0.0
    AMSTAR
        26   2.08     0.0
```

```
    0    0
    1
    24   .75  .5
    0.0
    0.0
APEX
    26   2.84      0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
ATLTERM
    26   2.84     0.0
    0    0
    2
    24   .75  .5
    0.0
    0.0
ATT
    23   1.32      0.0
    0    0
    2
    24   .75  .5
    0.0
    0.0
BAYSIDE
    26   2.08     0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
CANTGRN
    22   .1       0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
CBORE
    18   1.95      0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
CHESA
    18   1.95      0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
```

CLINTON
26 .95 0.0
0 0
1
24 .75 .5
0.0
0.0
CONOCO
26 2.27 0.0
0 0
1
24 .75 .5
0.0
0.0
CONSOL
22 .1 0.0
0 0
1
24 .75 .5
0.0
0.0
CURTISBAY
26 2.65 0.0
0 0
1
24 .75 .5
0.0
0.0
DMT
20 .6 0.0
0 0
13
24 .34 .5
0.0
0.0
HAWKINS
18 2.08 0.0
0 0
1
24 .75 .5
0.0
0.0
HESS
26 1.7 0.0
0 0
1
24 .75 .5
0.0
0.0
LAZA
26 .76 0.0
0 0
1
24 .75 .5

```
    0.0
    0.0
LPT
    26   2.08       0.0
    0    0
    6
    24   .75  .5
    0.0
    0.0
NATGYP
    26   .38        0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
NAVAL
    26   2.65       0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
NLPT
    26   2.46       0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
PERIDOT
    18   1.95       0.0
    0    0
    2
    24   .75  .5
    0.0
    0.0
SEAGIRT
    22   .4         0.0
    0    0
    4
    24   .34  .5
    0.0
    0.0
SEALAND
    8    .05        0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
SLPT
    23   .95        0.0
    0    0
```

```
    5
    24   .55  .5
    0.0
    0.0
SPPT
    3    1.5      0.0
    0    0
    4
    24   .75  .5
    0.0
    0.0
STT
    26   2.84      0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
TOYOTA
    26   3.03      0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
USGYP
    18   .95       0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
VISTA
    12   .01       0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
WWALL
    26   3.41      0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
SEA
    1    .01  .106
    24   15
    A1   .03  6
        DMT       9
        SLPT      8
        SPPT      2
        LPT       1
```

SEALAND 1
CANTGRN 1
A2 .23 4
SEAGIRT 49
SLPT 32
DMT 65
USGYP 1
A3 .07 3
SEAGIRT 22
DMT 13
SPPT 1
A4 .03 2
DMT 18
SEAGIRT 1
AA .11 8
DMT 46
LPT 11
SLPT 43
LAZA 4
AMSTAR 5
NLPT 4
SEAGIRT 7
STT 1
AB .02 9
DMT 6
CANTGRN 2
LAZA 4
AMSTAR 2
CLINTON 2
SLPT 3
WWALL 3
CBORE 1
CONSOL 1
AE .16 6
DMT 112
ATLTERM 12
SLPT 31
TOYOTA 14
CHESA 5
USGYP 1
AF .01 1
DMT 18
DA .05 10
SLPT 4
USGYP 22
NATGYP 6
DMT 6
SPPT 5
AMSTAR 2
CLINTON 2
NLPT 3
CONSOL 1
AGRICO 1
DB .06 15

CANTGRN 8
LPT 13
SLPT 5
HAWKINS 6
CLINTON 8
DMT 36
AMSTAR 5
SPPT 6
BAYSIDE 21
CONSOL 7
ATT 4
NLPT 1
CHESA 1
CBORE 1
USGYP 1

DC .03 12
SPPT 24
AMSTAR 1
CONSOL 13
SLPT 1
NLPT 8
STT 1
BAYSIDE 6
CLINTON 1
DMT 1
USGYP 2
HAWKINS 1
LPT 1

DD .01 2
CONSOL 2
SPPT 3

DE .02 3
CONSOL 11
BAYSIDE 2
SPPT 1

EC .01 5
CONSOL 3
CLINTON 1
BAYSIDE 1
DMT 1
HESS 1

ED .01 2
CONSOL 6
BAYSIDE 2

FA .01 2
STT 1
USGYP 1

FB .01 1
DMT 1

FC .01 5
APEX 2
HESS 7
STT 3
NLPT 1

```
        LPT       1
    FD   .01  4
        APEX      3
        CLINTON   3
        LPT       1
        HESS      1
    HB   .08  5
        TOYOTA    19
        SEAGIRT   6
        DMT       42
        ATLTERM   11
        CHESA     6
    PA   .01  6
        SLPT      3
        STT       10
        NLPT      2
        DMT       1
        PERIDOT   5
        VISTA     8
    PB   .01  3
        STT       1
        DMT       1
        PERIDOT   1
    PC   .01  6
        NLPT      3
        HESS      2
        LAZA      1
        STT       2
        VISTA     1
        CONOCO    1
    PD   .01  2
        DMT       1
        HESS      1
    9999
    0    .75  .5
    0.0
    0.0
ANC1_LOCN
    10   1.05   -10
    0  0
    1
    999.0  0.0  0.0
    0.0
    0.0
ANC2_LOCN
    10   .8   -10
    0  0
    1
    999.0  0.0  0.0
    0.0
    0.0
ANC3_LOCN
    10   .4   -10
    0  0
```

```
        1
        999.0  0.0  0.0
        0.0
        0.0
    ANC4_LOCN
        8    .05   -10
        0  0
        1
        999.0  0.0  0.0
        0.0
        0.0
    ANC5_LOCN
        6    .2   -10
        0  0
        1
        999.0  0.0  0.0
        0.0
        0.0
    ANC6_LOCN
        6    .1   -10
        0  0
        1
        999.0  0.0  0.0
        0.0
        0.0
    ANNAP_LOCN
        1    .1    -10
        0  0
        1
        999.0  0.0  0.0
        0.0
        0.0
```

SAMPLE INPUT/FEASIBILITY STUDY - STATIC

```
<p5 condition rand1<

new.seeds
103235  99267  24680  53178  12345
1.0  1.   0.   1.

26   0
1    cape_henry
    15   0.0
    2    0    0    0
    50   54   1000
    1  0
2    junc_1
    15   0.0
    3    17   1    0
```

```
     50   .1   1000
     1  0
3    brewerton
     12   0.0
     4    0    2    0
     50   2    600
     1  0
4    fm1
     8    0.0
     5    0    3    0
     50   .29  700
     0  0
5    junc_2
     3    0.0
     6    0    4    18
     50   .40  700
     0  0
6    fm2
     3    0.0
     7    0    5    0
     50   .29  700
     0  0
7    junc_3
     3    0.0
     8    19   6    0
     50   .21  700
     0  0
8    fm3
     3    0.0
     9    0    7    0
     50   .21  700
     0  0
9    junc_4
     3    0.0
     10   20   8    0
     50   .12  700
     0  0
10   fm4
     3    0.0
     11   0    9    0
     50   1.15 700
     0  0
11   junc_5
     3    0.0
     12   22   10   0
     50   .17  700
     0  0
12   fm5
     3    0.0
     13   0    11   0
     50   .21  700
     0  0
13   junc_6
     3    0.0
```

14 0 12 23
50 .23 700
0 0
14 tunnel
3 0.0
15 0 13 0
50 .81 600
0 0
15 junc_7
3 0.0
16 0 14 26
50 .15 600
0 0
16 east
3 0.0
0 0 15 0
50 .35 600
0 0
17 c&d
12 0.0
0 0 15 0
50 12 600
0 0
18 curtis_bay
3 0.0
0 5 0 0
50 2.3 400
0 0
19 e_dundalk
3 0.0
0 0 0 7
38 .69 300
0 0
20 w_dundalk
3 0.0
0 21 0 9
42 .81 350
0 0
21 sd_connect
3 0.0
0 0 0 20
42 .46 350
0 0
22 w_seagirt
3 0.0
0 0 0 11
42 .58 500
0 0
23 ferry_bar
3 0.0
0 13 0 24
42 2 600
0 0
24 j_fb

```
    3    0.0
    25   23   0    0
    42   .17  600
    0  0
25   slpt
    3    0.0
    0    0    24   0
    50    .29  600
    0  0
26   west
    3    0.0
    0    15   0    0
    50    3.5 600
    0  0



25
A1   73   25   482  17   17   738  140         0  72
A2   94   34   676  18   18   1270 141.4       0  72
A3   112  41   853  20   20   1492 142.12      0  72
A4   117  43   905  20   20   1664 142.12      0  72
AA   76   32   542  17   17   751  141.4     417  72
AB   64   25   447  17   17   576  140       417  72
AE   76   32   542  17   17   751  141.4       0  72
AF   64   25   447  17   17   576  140         0  72
DA   67   28   478  14   14   564  140       417  72
DB   83   34   583  14   14   692  141.4     417  72
DC   105  43   717  14   14   888  142.12    417  72
DD   119  49   780  14   14   1049 142.12    417  72
DE   136  55   910  14   14   1233 142.6     417  72
EC   109  42   585  14   14   1158 141.4     417  72
ED   125  47   800  14   14   1293 142.12    417  72
FA   76   30   519  14   14   891  141.4     417  72
FB   87   34   585  14   14   971  141.4     417  72
FC   109  42   585  14   14   1158 141.4     417  72
FD   125  47   800  14   14   1293 142.12    417  72
HB   64   25   447  17   17   576  140       417  72
PA   76   30   519  14   14   891  141.4     417  72
PB   87   34   585  14   14   971  141.4     417  72
PC   109  42   585  14   14   1158 141.4     417  72
PD   125  47   800  14   14   1293 142.12    417  72
TOW  150  25   800  15   15   0    0           0  72

0

1000   .5   .5   .95
5
   0     1.0
   .25   1.0
   .38    .5
   .53    .375
   1.0    .375
1000   .95   .75   .50
```

```
1.0
5
  0     1.0
  .25   1.0
  .38    .500
  .53    .333
 1.00    .333

2.  4.


1    anc1 2
     35
     550 550
     0
     9999
2    anc2 1
     42
     890
     0
     9999
3    anc3 3
     35
     550  550  550
     0
     9999
4    anc4 1
     42
     690
     0
     9999
5    anc5 3
     20
     550  550  550
     0
     9999
6    anc6 3
     25
     550  550  550
     0
     9999
7    annap     9999

     1  150
     5  73
```

SAMPLE OUTPUT/FEASIBILITY STUDY

Two output files are provided, depending on the needs of the user.
The outputs are explained in **bold** text.

Output File - Unit 7

SMOOTH Baltimore g1 condition 2000 p5 condition rand1

headers echoed

today is 01/28/1997
time is 18:51:42

run information

seed1	103235
seed2	99267
seed3	24680
seed5	53178
seed10	12345

seeds for the run

FINAL STATISTICS FOR THE RUN

---

passing counts, by type of encounter, counts are only provided in those cells for which there was at least one passing

~~~~~~~~~~~~~~~ PASSING STATISTICS ~~~~~~~~~~~~~~~

cell	tow.tow.passes	tow.ship.passes	ship.ship.passes
cape_henry	0	0	10
fm1	0	0	52
fm2	0	0	1
fm5	0	0	4
TOTALS	0	0	67

meeting counts, by type of encounter, counts are only provided in those cells for which there was at least one meeting

~~~~~~~~~~~~~~~ MEETING STATISTICS ~~~~~~~~~~~~~~~

cell	tow.tow.meetings	tow.ship.meetings	ship.ship.meetings
cape_henry	0	0	1450
brewerton	0	0	77
fm1	0	0	16
junc_2	0	0	69
fm2	0	0	53
junc_3	0	0	46
fm3	0	0	43
junc_4	0	0	9
fm4	0	0	55
junc_5	0	0	2
fm5	0	0	10
junc_6	0	0	6
tunnel	0	0	6
w_dundalk	0	0	5
w_seagirt	0	0	2
ferry_bar	0	0	1
west	0	0	16
TOTALS	0	0	1866

for each vessel class, information on total costs, #trips, # of miles, and unit costs are provided. this section addresses only

those trips which were completed.

~~~~~~~~~~~~~~~ SYSTEM COSTS ~~~~~~~~~~~~~~~

~~~~~~~~~~~~~~~ finished trips ~~~~~~~~~~~~~~~

CLASS	COSTS	#TRIPS	#MILES	cost/trip	cost/mile
A1	1033722.625	41	4825.420	25212.747	214.22
A2	13943340.000	323	38066.176	43168.235	366.29
A3	4946578.500	98	11554.090	50475.291	428.12
A4	2176489.750	39	4539.580	55807.429	479.45
AA	3737968.750	143	17020.734	26139.642	219.61
AB	589934.500	29	3505.429	20342.569	168.29
AE	5868198.500	220	25994.945	26673.630	225.74
AF	327270.125	17	1975.060	19251.184	165.70
DA	1508151.000	73	8592.464	20659.603	175.52
DB	2806920.000	107	12804.222	26232.897	219.22
DC	1796759.250	46	5359.051	39059.984	335.28
DD	782128.938	19	2164.740	41164.681	361.30
DE	2600566.250	30	3532.549	86685.542	736.17
EC	942822.688	20	2406.520	47141.134	391.78
ED	1100778.750	14	1661.680	78627.054	662.45
FA	421556.313	12	1436.980	35129.693	293.36
FB	397179.125	12	1435.548	33098.260	276.67
FC	731075.625	16	1991.560	45692.227	367.09
FD	739180.000	15	1866.380	49278.667	396.05
HB	2760257.750	123	14877.499	22441.120	185.53
PA	645071.875	19	2305.517	33951.151	279.79
PB	619869.125	18	2153.760	34437.174	287.81
PC	527182.813	11	1368.800	47925.710	385.14
PD	656078.562	14	1664.420	46862.754	394.18
TOW	0.	0	0.	0.	0.
TOTAL	$ 51659080.813	1459	173103.	125 35407.18	298.43

for each vessel class, information on total costs, #trips, # of miles, and unit costs are provided. this section addresses only those trips which were not completed.

~~~~~~~~~~~~~~~

~~~~~~~~~~~~~~~ unfinished trips ~~~~~~~~~~~~~~~

CLASS	COSTS	#TRIPS	#MILES	cost/trip	cost/mile
A1	0.	0	0.	0.	0.
A2	7953570.000	9	468.555	883730.000	16974.67
A3	0.	0	0.	0.	0.
A4	0.	0	0.	0.	0.
AA	8291.161	1	58.090	8291.161	142.73
AB	0.	0	0.	0.	0.
AE	21394.424	1	58.090	21394.424	368.30
AF	10971.703	1	58.090	10971.703	188.87
DA	17965.107	1	60.670	17965.107	296.11
DB	22517.961	1	64.340	22517.961	349.98
DC	0.	0	0.	0.	0.
DD	0.	0	0.	0.	0.
DE	0.	0	0.	0.	0.
EC	0.	0	0.	0.	0.

ED	0.	0	0.	0.	0.
FA	0.	0	0.	0.	0.
FB	0.	0	0.	0.	0.
FC	0.	0	0.	0.	0.
FD	0.	0	0.	0.	0.
HB	33986.250	1	63.210	33986.250	537.67
PA	0.	0	0.	0.	0.
PB	31037.033	1	62.670	31037.033	495.25
PC	0.	0	0.	0.	0.
PD	0.	0	0.	0.	0.
TOW	0.	0	0.	0.	0.
TOTALS	8099733.640	16	893.715	506233.352	9062.99

this section provides information on the average delay time for a vessel which completed a trip. Information is only provided for those cells which originated finished trips.

~~~~~~~~~~~~~~~ SYSTEM DELAYS ~~~~~~~~~~~~~~~

CELL	AVE. DELAYS(hrs.)	#DEPARTURES
cape_henry	1.40681	1526
brewerton	29.94513	48
fm3	27.03810	2
fm4	25.49917	60
fm5	36.06461	5
curtis_bay	32.95547	69
w_dundalk	29.58659	602
w_seagirt	38.03356	277
ferry_bar	30.60020	183
west	35.48377	280
TOTALS	16.8755	3052

not used

~~~~~~~~~~~~~~~ SYSTEM CASUALTIES ~~~~~~~~~~~~~~~

	MEETINGS			PASSINGS		
CELL	tow.tow	tow.ship	ship.ship	tow.tow	tow.ship	ship
TOTALS	0	0	0	0	0	0

information for finished trips, on total travel, time in system, and rate. information is only provided on those cells which originated a complete trip.

~~~~~~~~~~~~~~~ TRAVEL(by cell departed) ~~~~~~~~~~~~~~~

~~~~~~~~~~~~~~~ finished trips ~~~~~~~~~~~~~~~

CELL	MILES TRAVELED	TIME TRAVELED	AVE RATE
brewerton	5336.661	1602.733	3.330
fm3	114.660	33.666	3.406
fm5	589.400	201.685	2.922
curtis_bay	7783.501	2477.433	3.142
w_dundalk	69750.117	20090.850	3.472
w_seagirt	32802.820	11703.626	2.803
ferry_bar	21882.488	6384.108	3.428
west	34843.383	11368.689	3.065
TOTALS	173103.031	53862.790	3.214

information for unfinished trips, on total travel, time in system, and rate. information is only provided on those cells which originated an incomplete trip.

~~~~~~~~~~~~~~~ unfinished trips ~~~~~~~~~~~~~~~

CELL	MILES TRAVELED	TIME TRAVELED	AVE RATE
cape_henry	523.485	6260.510	.084
fm4	63.210	59.004	1.071
curtis_bay	123.340	63.817	1.933
w_dundalk	58.090	29.721	1.955
ferry_bar	61.250	30.998	1.976
west	64.340	32.540	1.977
TOTALS	893.715	6476.590	.138

Output File - Unit 9

This file is an excerpt from the unit 7 output.

SMOOTH Baltimore g1 condition 2000
p5 condition rand1

doing 1 runs, each of 150 days

~~~~~~~~~~~~~~~ SYSTEM COSTS ~~~~~~~~~~~~~~~
~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~

CLASS	TRIPS	TIME (HRS)	OP.COST ($)	PIL.COST ($)	D.D.COST ($)	TOTAL ($)
A1	41	1401.	1033723.	44495.	0.	1078218.
A2	323	10979.	13943340.	279544.	0.	14222884.
A3	98	3315.	4946578.	85920.	0.	5032498.
A4	39	1308.	2176490.	32269.	0.	2208758.
AA	143	4977.	3737969.	125108.	-1236183.	2626893.
AB	29	1024.	589935.	24806.	-249317.	365423.
AE	220	7814.	5868198.	179281.	0.	6047480.
AF	17	568.	327270.	15051.	0.	342322.
DA	73	2674.	1508151.	94159.	-603252.	999059.
DB	107	4056.	2806920.	103825.	-844847.	2065899.
DC	46	2023.	1796759.	109533.	-250386.	1655907.
DD	19	746.	782129.	55236.	-133156.	704208.
DE	30	2109.	2600566.	31612.	99522.	2731700.
EC	20	814.	942823.	16268.	-142598.	816493.
ED	14	851.	1100779.	10485.	-7334.	1103929.
FA	12	473.	421556.	11209.	-92694.	340071.
FB	12	409.	397179.	9340.	-105645.	300874.
FC	16	631.	731076.	13271.	-123942.	620404.
FD	15	572.	739180.	13248.	-121369.	631059.
HB	123	4792.	2760258.	98000.	-953131.	1905126.
PA	19	724.	645072.	13108.	-153162.	505017.
PB	18	638.	619869.	16906.	-154361.	482414.
PC	11	455.	527183.	7584.	-78950.	455817.
PD	14	507.	656079.	10708.	-116389.	550398.
TOW	0	0.	0.	0.	0 .	0.
TOTAL	1459	53863.	51659081.	1400965.	-5267195.	47792851.
~~~~~~~~~~~~~~~

RUNNING THE SIMULATION

1. The simulation must be run within the SIMLAB (SIMSCRIPT language) environment. Once in SIMLAB, enter:

```
sel channel
```

This will select the channel subdirectory. This subdirectory is the location of the executable modules.

2. The first step in executing the system is to assign the logical units. There are four files required, as discussed earlier:

unit 2 - seasonal data file

unit 3 - structure file

unit 7 - output file

unit 9 - secondary output file (this is an excerpt of the unit 7 output file)

```
assi 3 < hsc40.dat
assi 2 < nov4019.inp
assi 7 > nov4019.out
assi 9 > nov4019s.out
```

3. After the logical units have been assigned, at the prompt type:

```
run
```

The program will begin execution, and prompt for the number of iterations to be done, and the number of days to be simulated within each iteration.

LRR ANALYSES

As part of the recent effort to examine the feasibility of constructing the Baltimore Harbor Anchorages and Channels project, various aspects of the earlier work were updated to reflect current conditions. Because of the passage of time, several workshops were convened to review the merits of simulation and the simulation model of the Port of Baltimore navigation system. Simulation model inputs were revisited and forecasts of commodity tonnage and vessel calls to the Port of Baltimore were evaluated in light of more recent foreign deep draft vessel activity.

Model inputs were examined and those determined to have significant physical or operational changes were updated to reflect the current Port of Baltimore navigation system and its operations. Physical dimensions and capacities of anchorages, channels, active terminals and berthing areas (data cells) represented in the feasibility study simulation model were reviewed by Baltimore District personnel; the simulation model was subsequently revised to more accurately reflect the current physical dimensions of the port system.

Vessel traffic information was updated to reflect year 2000 actual arrivals and departures. With assistance from the Baltimore Maritime Exchange, the Waterborne Commerce Statistics Center, and several consultants, vessel trip and commodity information was collected and analyzed. Vessel arrivals and departures for year 2000 were categorized according to date, class, draft, terminal or berth destination, and anchorage use (the 2000 vessel traffic count was not as high as that represented in the 1995 traffic forecast and simulation runs). This vessel call information then became an input to the simulation model for year 2000.

Whereas three years of vessel activity had been collected and analyzed during the feasibility study effort, this recent effort analyzed year 2000 traffic movements in the Port of Baltimore navigation system. In general, the vessel class types identified in the feasibility study were found to still be applicable. Several additional vessel types were considered for inclusion in the year 2000 vessel profile to better represent the full range and diversity of vessels utilizing the port system. Military vessels, deep-draft commercial passenger vessels, and other deep draft vessels (equipment, cable, etc.) were identified as users of the port and these vessel types were added to the simulation model. While the movements of these vessels are reflected in the refinements to the model, operating costs related to these vessel movements are shown as zero costs.

Vessel traffic and commodity tonnage through the Port of Baltimore in 2000 exhibited an increase over the 1999 traffic levels. Foreign vessel traffic (1,671 arrivals) through the Port of Baltimore for the first ten months of 2001 continues to rise with a 7.9 percent increase over the same period in 2000 (1,548). Commodity tonnage processed through the port also continues its steady rise. Preliminary figures indicate that for the first half of 2001, 13,794,000 short tons were handled at the various port terminals. This 1.74 percent increase over comparable year 2000 numbers indicates that steady growth continues but at a lesser rate than the growth in vessel calls. This reflects a gradual change in the bulk-non-bulk cargo relationship and the relative share of imports to exports. Export volumes are down but import volumes are at 98 percent of the level forecast in 1995. One reason vessel transits are growing at a faster rate then commodity tonnage is due to the shift from large bulk vessels carrying large quantities of bulk cargo to smaller non-bulk specialized vessels carrying smaller quantities of non-bulk cargo. Another reason vessel transits are growing faster than commodity tonnage is because the Port of Baltimore is a very attractive location for import activity. The new lines calling on the port are continuing the growth trend in imports.

Based on the growth in traffic and tonnage since 1998-1999, the year 2001 activity, and the port's continued success in executing long-term contracts with shipping companies, vessel arrivals are forecast to grow at a rate of four percent per year, or 40 percent every decade. This growth in vessel arrivals to the port was, then reflected in the simulation runs for the "without project" and "with project" benchmarks.

Vessel speeds used in the original model were obtained through discussions with officials of the Baltimore Maritime Exchange (BME) and the Association of Maryland Pilots (AMP). The BME and the AMP were contacted in summer 2001 to review the 1994-1995 information. The average speed information was reviewed and confirmed to be the current average operating speeds in the Port of Baltimore. These speeds are as follows:

- 3 knots average speed for intra-harbor movement;
- 8-10 knots average between Fort Carroll and North Point;
- 12 knots average speed between North Point to Brewerton/Swan Point up into
- the C&D approach;
- 15 knots average speed from North Point to the southern approaches;
- 15-20 knots average speed in the main channel and naturally deep waters from
- Chesapeake City to Cape Henry.

As part of the feasibility analysis, an average hourly vessel operating cost was developed for each of the vessel classes represented in the model. These average vessel costs were developed from information contained in the U.S. Army Corps of Engineers publication, IWR Deep Draft Vessel Operating Costs for FY 1995 and included domestic vessel operating costs in the derivation of average hourly vessel costs. For the current analysis, the latest available IWR publication was used. Vessel operating costs reflected in the simulation model are based on Economic Guidance Memorandum 00-06, dated 1 June 2000. In general, the current IWR vessel operating cost publication reflects a decrease from vessel operating cost information relied upon during the feasibility study.

This was accomplished for the various classes (A1, A2, A3, A4, AA, AB, DA, DB, DC, DD, DE, FA, FB, FC, FD, PA, PB, PC, and PD) as follows:

- Identify the IWR-defined vessels of the class with DWT (or TEU) close to the class defined for the simulation;
- Of those IWR classes similar in DWT (TEU), identify the one which most closely resembles the simulation class in terms of LOA, Draft, and Beam;
- Use that vessel class cost.

The remaining vessel classes (AE, AF, EC, ED, HB) were not contained in the IWR data. Maritime experts from WEFA Consulting Group suggested the following cost equivalencies: AE=A3; AF=A1; HB=A1; EC=DC; and ED=DD.

The average hourly vessel cost is based solely on “at sea” cost information presented for foreign-flag deep-draft vessel classes. While U.S.-flag vessels continue to call on the Port of Baltimore, the current simulation analysis treats these vessels as foreign vessels; consequently, their higher overall operating costs aren’t reflected in this simulation model. Because the latest published guidance reflects marine bunker fuel prices on a monthly five-year rolling average that ends in December 1999, the simulation analysis doesn’t reflect the steady rise in the cost of marine bunker fuel that has occurred since December 1999.

The IWR average “at sea” foreign vessel costs were also used for time in anchorage. This was appropriate because anchorage activity in the modeling environment can be as little as 15-30 minutes. Crewmembers generally remain on-board and engines continue to operate especially if the vessel is waiting to move to berth. Engines are cut during bunkering/refueling operations but this was determined not to be a significant cost factor.

Charges associated with tug assistance (typically two tugboats) and docking pilot services were researched. Evaluation of the docking pilot charges and their block rate fee structure led to this element not being included in this analysis.

Pilotage costs related to vessel movements in the port navigation system are also a component of the system operating cost profile. The pilotage rates are subject to review and approval by the Maryland Public Service Commission and typically are in effect for a two-year period. During the summer of 2001, the current rate schedule approved for use by the AMP was obtained and used to estimate pilotage charges on an hourly basis. These rates are calculated based on a formula that accounts for vessel breadth, depth, length overall, and time that an AMP pilot is on board the vessel. Table E-1 presents the current hourly pilotage cost computations. Because the simulation reflects the average vessel class profile in the model, the calculated pilotage fees also represent the average vessel class size.

Another cost component reflected in the current analysis is dispatch-demurrage. Dispatch and demurrage are terms that refer to costs paid by or to ship charterers in the event the vessel completes its loading/unloading activity ahead of the contractually agreed-to time or beyond the contractually-agreed to time. While the model output does include the dispatch and demurrage cost, which is a common practice in the Port of Baltimore, for the LRR analyses this cost was not included in the benefit calculations. Further discussion of this issue can be found in the next section, Key Issues.

Two samples of the LRR input files are provided on the following pages. As part of the current reanalysis, the number of simulation runs was increased from five runs per scenario in the feasibility report to 25 simulation runs per scenario. This was done to provide sufficient output for allowing the average of the simulations to better approach the mean of the distribution. Due to duplicate seeds between model runs or non-matching seeds in the "with project" and "without project" runs, four sets of runs were eliminated, leaving 21 simulation runs for the analysis. This was deemed to be more than sufficient for statistical accuracy and significance, and confidence in the project justification. A summary of the run outputs is provided in Table E-2.

TABLE E-1

GENERAL PILOTAGE FEES FOR THE AVERAGE VESSEL REPRESENTED FOR EACH VESSEL CLASS -YEAR 2000

Vessel Class	Beam	Draft	Length	PILOTAGE UNITS (LOAxBEAMxDEPTH)/10,000	HOURLY FEE	Vessel Class
A1	73	25	482	87.965	**$ 179.00**	A1
A2	94	34	676	216.0496	**$ 386.64**	A2
A3	112	41	853	391.6976	**$ 621.64**	A3
A4	117	43	905	455.3055	**$ 679.60**	A4
AA	76	32	542	131.8144	**$ 236.28**	AA
AB	64	25	447	71.52	**$ 179.00**	AB
AE	76	32	542	131.8144	**$ 236.28**	AE
AF	64	25	447	71.52	**$ 179.00**	AF
DA	67	28	478	89.6728	**$ 179.00**	DA
DB	83	34	583	164.5226	**$ 295.35**	DB
DC	105	43	717	323.7255	**$ 559.08**	DC
DD	119	49	780	454.818	**$ 679.60**	DD
DE	136	55	910	680.68	**$ 831.41**	DE
EC	109	42	585	267.813	**$ 479.72**	EC
ED	125	47	800	470	**$ 693.40**	ED
FA	76	30	519	118.332	**$ 211.22**	FA
FB	87	34	585	173.043	**$ 309.67**	FB
FC	109	42	585	267.813	**$ 479.72**	FC
FD	125	47	800	470	**$ 693.40**	FD
HB	64	25	447	71.52	**$ 179.00**	HB
PA	76	30	519	118.332	**$ 211.22**	PA
PB	87	34	585	173.043	**$ 309.67**	PB
PC	109	42	585	267.813	**$ 479.72**	PC
PD	125	47	800	470	**$ 693.40**	PD
TOW	150	25	800	0	**$ -**	TOW

NOTE: **Basic service rate is $179.00 per hour.**
Charges are billed by the hour and minute underway.
Calculated rates above don't include surcharge fee for vessels transiting the Canal
Minimum hours billed is 3 hours one way.
Maximum hours billed is 16 hours one way.

SAMPLE INPUT/BALTIMORE HARBOR LRR -- STATIC

This input file contains information that remains static through the typical simulation environment. This file contains information on the channel system structure, vessel class definitions, and anchorage configurations. Items have been highlighted and commented to indicate how changes are reflected.

```
 < t7 condition A''rand2 <          This header line indicates basic information about the file – in
                                    this case, the with project condition, 2nd replication
new.seeds
14357  21769  90135  74530  53706                  seeds change for each replication of simulation
1.0  1.   0.   1.

26   0
1    cape_henry
     15   0.0
     2    0    0    0
     50   54   700
     1  0
2    junc_1
     15   0.0
     3    17   1    0
     50   .1   700
     1  0
3    brewerton
     12   0.0
     4    0    2    0
     50   2    700
     1  0
4    fm1
     8    0.0
     5    0    3    0
     50   .29  700
     0  0
5    junc_2
     3    0.0
     6    0    4    18
     50   .40  700
     0  0
6    fm2
     3    0.0
     7    0    5    0
     50   .29  700
     0  0
7    junc_3
     3    0.0
     8    19   6    0
     50   .21  700
     0  0
8    fm3
     3    0.0
     9    0    7    0
```

```
     50   .21  700
     0  0
9    junc_4
     3    0.0
     10   20   8    0
     50   .12  700
     0  0
10   fm4
     3    0.0
     11   0    9    0
     50   1.15 700
     0  0
11   junc_5
     3    0.0
     12   22   10   0
     50   .17  700
     0  0
12   fm5
     3    0.0
     13   0    11   0
     50   .21  700
     0  0
13   junc_6
     3    0.0
     14   0    12   23
     50   .23  700
     0  0
14   tunnel
     3    0.0
     15   0    13   0
     49    .81  600
     0  0
15   junc_7
     3    0.0
     16   0    14   26
     49    .15  600
     0  0
16   east
     3    0.0
     0    0    15   0
     49    .35  950
     0  0
17   c&d
     12   0.0
     0    0    0   2
     35   12    600
     0  0
18   curtis_bay
     3    0.0
     0    5    0    0
     50   2.3  400
     0  0
19   e_dundalk
     3    0.0
```

```
     0    0    0    7
     42   .69  400
     0  0
20   w_dundalk
     3    0.0
     0    21   0    9
     42   .81  500
     0  0
21   sd_connect
     3    0.0
     0    0    0    20
     42   .46  500
     0  0
22   w_seagirt
     3    0.0
     0    0    0    11
     42   1.2  500
     0  0
23   ferry_bar
     3    0.0
     0    13   0    24
     42   1.6  600
     0  0
24   j_fb
     3    0.0
     25   23   0    0
     36   .17  400
     0  0
25   slpt
     3    0.0
     0    0    24   0
     36    .29  400
     0  0
26   west
     3    0.0
     0    15   0    0
     40    3.5 600
     0  0

40
A1   73   25   482  17   17   597  179.00      0  72
A2   94   34   676  18   18   1093 386.64      0  72
A3   112  41   853  20   20   1515 621.64      0  72
A4   117  43   905  20   20   1621 679.60      0  72
AA   76   32   542  17   17   664  236.28    417  72
AB   64   25   447  17   17   453  179.00    417  72
AE   76   32   542  17   17   1515 236.28      0  72
AF   64   25   447  17   17   597  179.00      0  72
DA   67   28   478  14   14   514  179.00    417  72
DB   83   34   583  14   14   560  295.35    417  72
DC   105  43   717  14   14   702  559.08    417  72
DD   119  49   780  14   14   799  679.60    417  72
DE   136  55   910  14   14   1080 831.41    417  72
EC   109  42   585  14   14   702  479.72    417  72
```

ED 125 47 800 14 14 799 693.40 417 72
FA 76 30 519 14 14 663 211.22 417 72
FB 87 34 585 14 14 686 309.67 417 72
FC 109 42 585 14 14 812 479.72 417 72
FD 125 47 800 14 14 957 693.40 417 72
HB 64 25 447 17 17 597 179.00 417 72
PA 76 30 519 14 14 663 211.22 417 72
PB 87 34 585 14 14 686 309.67 417 72
PC 109 42 585 14 14 812 479.72 417 72
PD 125 47 800 14 14 957 693.40 417 72
XM1 45 21 109 14 14 0 0 0 72
XM2 30 15 180 14 14 0 0 0 72
XM3 42 15 279 14 14 0 0 0 72
XM4 45 21 405 14 14 0 0 0 72
XM5 75 30 600 14 14 0 0 0 72
XM6 105 40 950 14 14 0 0 0 72
X01 35 12 120 14 14 0 0 0 72
X02 35 15 250 14 14 0 0 0 72
X03 50 20 300 14 14 0 0 0 72
X04 70 30 750 14 14 0 0 0 72
X05 80 35 580 14 14 0 0 0 72
XP1 73 27 537 14 14 0 0 0 72
XP2 94 27 750 14 14 0 0 0 72
XP3 105 27 800 14 14 0 0 0 72
XP4 110 27 859 14 14 0 0 0 72
TOW 150 25 800 15 15 0 0 0 72

0

1000 .5 .5 .95
5
0 1.0
.25 1.0
.38 .5
.53 .375
1.0 .375
1000 .95 .75 .50
1.0
5
0 1.0
.25 1.0
.38 .500
.53 .333
1.00 .333

2. 4.

	Anchorage parameters indicate the various characteristics of the anchorages. These were modified throughout the preliminary analyses to identify the most cost-effective alternative.
1 anc1 2	anchorage ID #slots
35	anchorage depth
550 550	length of each slot
0	priority - unused
9999	time limit - unused

```
2    anc2 1
     25
     550
     0
     9999
3    anc3 2
     42
     690   890
     0
     9999
4    anc4 1
     35
     690
     0
     9999
5    anc5 3
     20
     600   600   600
     0
     9999
6    anc6 2
     20
     600   600
     0
     9999
7    annap     9999

     1  150
     5  73
```

SAMPLE INPUT/BALTIMORE HARBOR LRR -- DYNAMIC

This input file contains information that changes within the typical simulation environment. This file contains information on the docks, vessel arrival patterns, and anchorage locations Items have been highlighted and commented to indicate how changes are reflected.

< updated Baltimore t7 condition 2000 XPAX XMIL XOTH TURNING BASIN BASE% <

As in the static file, this file also includes a header line, indicating the particular case. In this case, we are modeling the year 2000 with project condition

```
TOW.INFO   0  .25
43
     AGRICO
          26   .57      0.0
          0  0
          1
          24   .75  .5
          0.0
          0.0
     AMSTAR
          26   2.08     0.0
```

```
    0    0
    1
    24   .75  .5
    0.0
    0.0
APEX
    26   2.84      0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
ATLTERM
    26   2.84     0.0
    0    0
    2
    24   .75  .5
    0.0
    0.0
ATT
    23   1.32      0.0
    0    0
    2
    24   .75  .5
    0.0
    0.0
BAYSIDE
    26   2.08     0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
CANTGRN
    22   .1       0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
CBORE
    18   1.95      0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
CHESA
    18   1.95      0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
```

CHEVRON
12 .01 0.0
0 0
1
24 .75 .5
0.0
0.0
CITGO
26 2.65 0.0
0 0
1
24 .75 .5
0.0
0.0

CLINTON
26 .95 0.0
0 0
1
24 .75 .5
0.0
0.0
CONOCO
26 2.27 0.0
0 0
1
24 .75 .5
0.0
0.0
CONSOL
22 .1 0.0
0 0
1
24 .5 .5
0.0
0.0
CURTISBAY
26 2.65 0.0
0 0
1
24 .75 .5
0.0
0.0
DMT
20 .6 0.0
0 0
13
24 .34 .5

The last 2 parameters – maneuvering and berthing/deberthing time – were modified to reflect the impact of branch channel improvements on vessel movement times.

0.0
0.0
HAWKINS
18 2.08 0.0

```
    0    0
    1
    24   .75   .5
    0.0
    0.0
HESS
    26   1.7         0.0
    0    0
    1
    24   .75   .5
    0.0
    0.0
INNHAR
    16   .33         0.0
    0    0
    1
    24   .75   .5
    0.0
    0.0
LAZA
    26   .76         0.0
    0    0
    1
    24   .75   .5
    0.0
    0.0
LIQUID
    12   .01         0.0
    0    0
    1
    24   .75   .5
    0.0
    0.0
LPT
    26   2.08        0.0
    0    0
    6
    24   .75   .5
    0.0
    0.0
NATGYP
    26   .38         0.0
    0    0
    1
    24   .75   .5
    0.0
    0.0
NAVAL
    26   2.65        0.0
    0    0
    1
    24   .75   .5
    0.0
    0.0
```

NLPT
26 2.46 0.0
0 0
1
24 .75 .5
0.0
0.0
PERIDOT
18 1.95 0.0
0 0
2
24 .75 .5
0.0
0.0
SEAGIRT
22 .4 0.0
0 0
4
24 .34 .5
0.0
0.0
SEALAND
8 .05 0.0
0 0
1
24 .75 .5
0.0
0.0
SLPT
23 .95 0.0
0 0
5
24 .55 .5
0.0
0.0
SPPT
3 1.5 0.0
0 0
4
24 .75 .5
0.0
0.0
STT
26 2.84 0.0
0 0
1
24 .75 .5
0.0
0.0
TOYOTA
26 3.03 0.0
0 0
1
24 .75 .5

```
    0.0
    0.0
USGYP
    18   .95       0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
VISTA
    12   .01       0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
WWALL
    26   3.41      0.0
    0    0
    1
    24   .75  .5
    0.0
    0.0
 SEA
    1    .01  .205
```

The last value, indicates the average time (in days) between successive arrivals. This parameter is reduced to reflect the increases in arrivals from one decade to another. For the re-runs, based on 2000 actual arrivals, this number was changed to reflect that actual occurrence, rather than the projected value. The time between arrivals has a significant impact on the system. Similar to a roadway, as you make significant increases in the number of vessels using the system, evidence of congestion appears.

```
    35   15
    A1   .004  2
```

The first value indicates the vessel type, and the second the fraction of arriving vessels of that class. These values were also changed for the recent runs, to reflect the observed shift from 1990 to 2000 of fewer, and larger, vessels.

```
        SEAGIRT   7
        SLPT      1
    A2   .141  3
        SEAGIRT  147
        SLPT     104
        SPPT       1
    A4   .054  1
        SEAGIRT   96
    AA   .096  9
        CLINTON   46
        NLPT      41
        SLPT      28
        DMT       25
        LAZA      10
        AMSTAR     9
        SEAGIRT    8
        CONSOL     3
```

CURTISBAY 1
AB .051 10
CLINTON 29
SPPT 13
LAZA 11
SLPT 10
CANTGRN 8
AMSTAR 5
CONSOL 5
DMT 4
NLPT 4
CURTISBAY 2
AE .064 4
DMT 81
SLPT 31
SPPT 2
CLINTON 1
AF .018 5
CLINTON 21
LAZA 4
DMT 2
SPPT 1
SLPT 4
DA .048 9
USGYP 37
HAWKINS 17
CLINTON 10
CURTISBAY 8
SPPT 6
AMSTAR 4
CANTGRN 1
LAZA 1
NLPT 1
DB .07 12
CLINTON 32
LAZA 21
AMSTAR 15
SPPT 12
CONSOL 9
VISTA 8
HAWKINS 7
NLPT 9
CANTGRN 6
STT 3
BAYSIDE 2
NATGYP 1
DC .096 9
SPPT 95
CONSOL 19
NATGYP 17
CLINTON 13
NLPT 11
HAWKINS 11
CURTISBAY 3

DMT 2
LAZA 1
DD .006 2
SPPT 8
CONSOL 2
DE .008 1
CONSOL 15
EC .01 1
CONSOL 18
ED .01 3
CONSOL 15
CLINTON 1
SPPT 1
FB .034 7
APEX 28
STT 9
HAWKINS 5
HESS 5
DMT 3
LAZA 1
NLPT 1
FC .013 3
HESS 13
APEX 2
STT 1
HB .233 6
DMT 233
TOYOTA 81
ATLTERM 54
CHESA 25
SLPT 21
NLPT 1
PA .007 3
NLPT 7
VISTA 3
HESS 1
PB .024 8
STT 15
NLPT 7
HAWKINS 6
VISTA 6
DMT 4
LAZA 2
APEX 1
CLINTON 1
PC .012 6
HESS 13
NLPT 2
VISTA 3
STT 1
APEX 1
CHESA 1
XM1 .0005 1

In these runs, various domestic classes were added –

XM1..XP4. Consequently, more vessels were identified as using the system. Generally it is assumed that such vessels, because of dimensions, have relatively little impact on overall vessel flow.

```
    INNHAR     1
XM2  .0025  2
    INNHAR     4
    NLPT       1
XM3  .002  2
    SPPT       1
    INNHAR     2
XM4  .004  4
    INNHAR     1
    CANTGRN    2
    NLPT       3
    SPPT       2
XM5  .006  6
    CLINTON    2
    LAZA       2
    SPPT       1
    ATT        4
    SLPT       1
    INNHAR     1
XM6  .006  3
    SPPT       6
    CLINTON    5
    SLPT       1
X01  .005  6
    SEAGIRT    1
    CITGO      2
    APEX       2
    STT        1
    AMSTAR     1
    SPPT       3
X02  .003  1
    INNHAR     6
X03  .001  1
    INNHAR     2
X04  .003  1
    ATT        6
X05  .0025  4
    AMSTAR     1
    SPPT       1
    CHEVRON    1
    LIQUID     1
XP1  .0012  1
    DMT        10
XP2  .0008 1
    DMT        7
XP3  .0002 1
    DMT        2
XP4  .0002 1
    DMT        2
9999
0    .75   .5
```

```
    0.0
    0.0
ANC1_LOCN
    10   1.05   -10
    0  0
    1
    999.0  0.0  0.0
    0.0
    0.0
ANC2_LOCN
    10   .8   -10
    0  0
    1
    999.0  0.0  0.0
    0.0
    0.0
ANC3_LOCN
    10   .4   -10
    0  0
    1
    999.0  0.0  0.0
    0.0
    0.0
ANC4_LOCN
    8    .05   -10
    0  0
    1
    999.0  0.0  0.0
    0.0
    0.0
ANC5_LOCN
    6    .2   -10
    0  0
    1
    999.0  0.0  0.0
    0.0
    0.0
ANC6_LOCN
    6    .1   -10
    0  0
    1
    999.0  0.0  0.0
    0.0
    0.0
ANNAP_LOCN
    1    .1    -10
    0  0
    1
    999.0  0.0  0.0
    0.0
    0.0
```

TABLE E-2 – SIMULATION RUN OUTPUT

WITHOUT PROJECT				WITH PROJECT			
Simulation Run #	**Year 2000**	**Vessel Calls**	**Unit Cost**	**Simulation Run #**	**Year 2000**	**Vessel Calls**	**Unit Cost**
1	$26,546,037	783	$33,902.98	1	$26,241,795	783	$33,514.43
2	$24,611,766	750	$32,815.69	2	$24,330,305	750	$32,440.41
3	$23,392,938	728	$32,133.16	3	$22,858,320	728	$31,398.79
4	$22,565,818	697	$32,375.64	4	$22,044,510	697	$31,627.70
5	$24,166,222	732	$33,013.96	5	$23,881,033	732	$32,624.36
6	$24,262,388	752	$32,263.81	6	$23,956,192	752	$31,856.64
7	$24,450,491	754	$32,427.71	7	$24,147,048	754	$32,025.26
8				8			
9	$25,787,990	761	$33,886.98	9	$25,243,714	761	$33,171.77
10	$23,534,544	737	$31,932.90	10	$23,104,502	737	$31,349.39
11	$23,854,567	704	$33,884.33	11	$23,547,764	704	$33,448.53
12	$23,980,447	730	$32,849.93	12	$23,716,983	730	$32,489.02
13	$23,134,315	716	$32,310.50	13	$22,870,660	716	$31,942.26
14	$22,276,670	686	$32,473.28	14	$21,942,630	686	$31,986.34
15	$24,662,529	777	$31,740.71	15	$24,377,915	777	$31,374.41
16				16			
17	$23,758,767	716	$33,182.64	17	$23,504,619	716	$32,827.68
18	$22,715,129	690	$32,920.48	18	$22,429,003	690	$32,505.80
19				19			
20	$23,702,122	737	$32,160.27	20	$23,418,985	737	$31,776.10
21	$22,394,417	689	$32,502.78	21	$22,059,817	689	$32,017.15
22	$22,399,403	683	$32,795.61	22	$22,244,964	685	$32,474.40
23				23			
24	$23,734,341	725	$32,737.02	24	$23,310,489	725	$32,152.40
25	$22,694,935	694	$32,701.64	25	$22,484,455	695	$32,351.73
Average	$23,744,087	725.8	$32,714.86	Average	$23,415,033	725.9	$32,254.98
	150-day savings:		$329,054	150-day unit savings:	$459.88		
	365-day savings:		**$800,698**				

Note: Runs which contained duplicate seeds were deleted from the economic analysis. Values are at October 1999 price levels.

TABLE E-2 – SIMULATION RUN OUTPUT

WITHOUT PROJECT				WITH PROJECT			
Simulation Run #	**Year 2010**	**Vessel Calls**	**Unit Cost**	**Simulation Run #**	**Year 2010**	**Vessel Calls**	**Unit Cost**
1	$35,984,819	1060	$33,947.94	1	$35,531,636	1060	$33,520.41
2	$34,434,256	1025	$33,594.40	2	$33,928,588	1023	$33,165.78
3	$35,603,631	1001	$35,568.06	3	$31,907,164	1002	$31,843.48
4	$31,711,517	969	$32,726.02	4	$31,222,346	969	$32,221.20
5	$33,307,978	1009	$33,010.88	5	$32,774,170	1009	$32,481.83
6	$33,750,690	1045	$32,297.31	6	$33,254,689	1045	$31,822.67
7	$34,897,910	1051	$33,204.48	7	$34,252,895	1052	$32,559.79
8				8			
9	$34,857,580	1049	$33,229.34	9	$34,584,696	1049	$32,969.20
10	$35,158,174	1045	$33,644.19	10	$34,476,877	1045	$32,992.23
11	$34,527,612	990	$34,876.38	11	$33,814,622	991	$34,121.72
12	$33,011,288	994	$33,210.55	12	$34,703,270	994	$34,912.75
13	$32,761,997	1003	$32,664.00	13	$32,229,892	1003	$32,133.49
14	$31,633,931	975	$32,445.06	14	$30,960,650	975	$31,754.51
15	$34,401,456	1065	$32,301.84	15	$33,967,030	1065	$31,893.92
16				16			
17	$33,879,583	997	$33,981.53	17	$33,270,478	996	$33,404.09
18	$33,766,383	1002	$33,698.99	18	$33,234,150	1002	$33,167.81
19				19			
20	$33,861,973	1024	$33,068.33	20	$32,997,531	1025	$32,192.71
21	$32,847,617	1000	$32,847.62	21	$32,532,424	1000	$32,532.42
22	$33,077,309	982	$33,683.61	22	$32,360,705	982	$32,953.87
23				23			
24	$35,105,686	1017	$34,518.87	24	$34,818,587	1017	$34,236.57
25	$32,226,995	980	$32,884.69	25	$31,562,979	980	$32,207.12
Average	$33,848,018	1013.5	$33,400.19	Average	$33,256,447	1013.5	$32,813.69
	150-day savings:		$591,572	150-day unit savings:	$586.50		
	365-day savings:		**$1,439,491**				

Note: Runs which contained duplicate seeds were deleted from the economic analysis. Values are at October 1999 price levels.

TABLE E-2 – SIMULATION RUN OUTPUT

WITHOUT PROJECT				WITH PROJECT			
Simulation Run #	**Year 2020**	**Vessel Calls**	**Unit Cost**	**Simulation Run #**	**Year 2020**	**Vessel Calls**	**Unit Cost**
1	$46,135,897	1356	$34,023.52	1	$45,370,515	1356	$33,459.08
2	$46,141,332	1284	$35,935.62	2	$43,495,392	1284	$33,874.92
3	$60,677,493	1289	$47,073.31	3	$58,307,033	1289	$45,234.32
4	$43,090,752	1221	$35,291.36	4	$40,363,113	1221	$33,057.42
5	$45,872,374	1294	$35,450.06	5	$44,767,951	1295	$34,569.85
6	$44,405,658	1302	$34,105.73	6	$43,328,075	1303	$33,252.55
7	$46,155,357	1353	$34,113.35	7	$44,914,400	1355	$33,147.16
8				8			
9	$49,576,463	1345	$36,859.82	9	$44,817,548	1349	$33,222.79
10	$49,682,766	1368	$36,317.81	10	$48,336,697	1368	$35,333.84
11	$42,901,260	1270	$33,780.52	11	$41,857,813	1270	$32,958.91
12	$43,163,620	1281	$33,695.25	12	$42,478,651	1282	$33,134.67
13	$43,893,944	1257	$34,919.61	13	$41,608,770	1265	$32,892.31
14	$42,038,807	1269	$33,127.51	14	$41,523,973	1270	$32,696.04
15	$44,575,470	1368	$32,584.41	15	$43,553,570	1368	$31,837.40
16				16			
17	$43,445,211	1275	$34,074.68	17	$42,748,539	1275	$33,528.27
18	$42,961,530	1296	$33,149.33	18	$42,442,634	1297	$32,723.70
19				19			
20	$56,191,734	1306	$43,025.83	20	$54,947,483	1307	$42,040.92
21	$42,204,435	1279	$32,997.99	21	$41,541,708	1280	$32,454.46
22	$43,430,682	1279	$33,956.75	22	$42,460,640	1279	$33,198.31
23				23			
24	$51,025,760	1302	$39,190.29	24	$49,877,874	1302	$38,308.66
25	$43,110,984	1237	$34,851.24	25	$42,094,685	1237	$34,029.66
Average	$46,222,930	1296.7	$35,644.00	Average	$44,801,765	1297.7	$34,521.68
	150-day savings:		$1,421,165	150-day unit savings:	$1,122.32		
	365-day savings:		**$3,458,168**				

Note: Runs which contained duplicate seeds were deleted from the economic analysis. Values are at October 1999 price levels.

TABLE E-2 – SIMULATION RUN OUTPUT

WITHOUT PROJECT				**WITH PROJECT**			
Simulation Run #	**Year 2030**	**Vessel Calls**	**Unit Cost**	**Simulation Run #**	**Year 2030**	**Vessel Calls**	**Unit Cost**
1	$56,753,728	1635	$34,711.76	1	$55,382,726	1635	$33,873.23
2	$78,152,669	1555	$50,258.95	2	$77,327,518	1555	$49,728.31
3	$89,536,863	1574	$56,884.92	3	$89,201,182	1574	$56,671.65
4	$66,086,338	1496	$44,175.36	4	$65,927,789	1497	$44,039.94
5	$65,275,744	1566	$41,683.11	5	$52,123,540	1580	$32,989.58
6	$60,617,216	1573	$38,536.06	6	$52,691,441	1588	$33,181.01
7	$74,938,607	1595	$46,983.45	7	$74,178,341	1594	$46,535.97
8				8			
9	$75,410,152	1607	$46,926.04	9	$72,979,363	1608	$45,385.18
10	$70,759,527	1657	$42,703.40	10	$70,294,639	1655	$42,474.10
11	$53,637,414	1563	$34,316.96	11	$52,850,938	1564	$33,792.16
12	$81,655,771	1533	$53,265.34	12	$81,849,357	1533	$53,391.62
13	$51,095,394	1520	$33,615.39	13	$50,134,652	1521	$32,961.64
14	$71,867,193	1545	$46,515.98	14	$72,208,433	1546	$46,706.62
15	$68,332,496	1625	$42,050.77	15	$52,757,534	1636	$32,247.88
16				16			
17	$62,755,352	1553	$40,409.11	17	$59,541,252	1554	$38,314.83
18	$66,681,951	1588	$41,991.15	18	$66,391,294	1587	$41,834.46
19				19			
20	$89,526,599	1586	$56,448.04	20	$88,549,303	1585	$55,867.07
21	$75,653,112	1566	$48,309.78	21	$75,987,888	1565	$48,554.56
22	$73,991,839	1522	$48,614.87	22	$72,212,519	1522	$47,445.81
23				23			
24	$82,733,868	1584	$52,230.98	24	$85,464,148	1582	$54,022.85
25	$65,279,759	1512	$43,174.44	25	$64,425,530	1511	$42,637.68
Average	$70,511,504	1569.3	$44,943.14	Average	$68,213,304	1571.0	$43,459.82
	150-day savings:		$2,298,200	150-day unit savings:	$1,483.32		
	365-day savings:		**$5,592,287**				

Note: Runs which contained duplicate seeds were deleted from the economic analysis. Values are at October 1999 price levels.

TABLE E-2 – SIMULATION RUN OUTPUT

WITHOUT PROJECT				WITH PROJECT			
Simulation Run #	**Year 2040**	**Vessel Calls**	**Unit Cost**	**Simulation Run #**	**Year 2040**	**Vessel Calls**	**Unit Cost**
1	$71,594,972	1939	$36,923.66	1	$69,963,170	1939	$36,082.09
2	$105,278,695	1839	$57,247.79	2	$104,994,928	1840	$57,062.46
3	$118,147,149	1833	$64,455.62	3	$115,051,582	1835	$62,698.41
4	$96,009,101	1755	$54,706.04	4	$95,090,050	1754	$54,213.26
5	$66,092,790	1894	$34,895.88	5	$64,891,762	1894	$34,261.75
6	$86,467,341	1845	$46,865.77	6	$83,189,779	1846	$45,064.89
7	$103,366,891	1841	$56,147.14	7	$103,679,372	1840	$56,347.48
8				8			
9	$71,797,518	1914	$37,511.76	9	$101,581,706	1876	$54,148.03
10	$96,956,867	1913	$50,683.15	10	$90,956,354	1917	$47,447.24
11	$82,649,775	1829	$45,188.50	11	$64,447,174	1862	$34,611.80
12	$102,598,452	1788	$57,381.68	12	$100,151,881	1787	$56,044.70
13	$80,445,143	1781	$45,168.52	13	$60,085,871	1813	$33,141.68
14	$104,653,338	1778	$58,860.15	14	$105,314,989	1778	$59,232.28
15	$95,472,853	1884	$50,675.61	15	$91,929,345	1884	$48,794.77
16				16			
17	$94,514,419	1804	$52,391.58	17	$88,260,702	1811	$48,735.89
18	$93,029,015	1818	$51,171.08	18	$93,793,074	1815	$51,676.62
19				19			
20	$115,376,379	1863	$61,930.42	20	$114,952,857	1862	$61,736.23
21	$101,780,060	1827	$55,708.85	21	$102,701,757	1828	$56,182.58
22	$99,465,926	1768	$56,259.01	22	$95,807,965	1773	$54,037.21
23				23			
24	$112,046,303	1843	$60,795.61	24	$111,553,794	1842	$60,561.23
25	$93,527,414	1776	$52,661.83	25	$91,981,886	1775	$51,820.78
Average	$94,822,400	1834.9	$51,791.89	Average	$92,875,238	1836.7	$50,661.97
	150-day savings:		$1,947,162	150-day unit savings:	$1,129.92		
	365-day savings:		**$4,738,094**				

Note: Runs which contained duplicate seeds were deleted from the economic analysis. Values are at October 1999 price levels.

KEY ISSUES

During the course of the post-feasibility analyses, several issues about the validity of the model have been raised. In particular, it has been suggested that there might be some flaws in the logic of the simulation program. This program has been utilized in quite a number of environments over the past decade. Four simulation analysts reviewed the model as part of the feasibility study. All major "discrepancies" identified in the program have been identified and investigated – all validating the simulation logic. On the contrary, in those cases in which fundamental "discrepancies" have arisen, the simulation has pointed to the need for rethinking the current operation in question. Most recently, the idiosyncratic performance of the simulation in one instance highlighted the demand of the Port of Baltimore system for an additional dock facility. The quality of the logic of the simulation is, without question, solid; the quality of supporting calculations are well within acceptable standards and provide the required insight into the relevant performance characteristics of the Port of Baltimore. However, to address questions about the modeling logic and implementation, detailed discussions of these modeling concerns are provided below.

Disbenefits. Through time an increasing number of the simulation runs result in higher costs under the with-project conditions (i.e., disbenefits). The incidence of this occurring increases over time from zero or one run (in years 2000, 2010, and 2020) to four runs in 2030 and five runs in 2040.

Vessel arrivals in the simulation model are based on a first-come-first-served (FCFS) protocol in both the "without project" condition and the "with project" condition. That is, the vessel assigned to an anchorage is the first vessel arriving to the Port of Baltimore system that can't proceed to its dock and, therefore, is placed at an anchorage. Recall, that five small anchorages near Seagirt and Dundalk in the "without project" condition become three large and improved anchorages in the "with project" condition. One potential cause for "disbenefits" in the later years could arise as a consequence of smaller vessels having the same priority for anchorage utilization as larger vessels (as the overall fleet size increases, there will be a larger number of small vessels in the later years). For instance, suppose that two small vessels in the "without project" condition use two anchorages simultaneously. If, in the "with project" condition those two anchorages are combined into one larger, improved anchorage, then the second vessel arrival will be restricted from anchorage—resulting in longer delays.

Another effect of the FCFS policy is that the vessel selected to be placed in a just-vacated anchorage is one that likely has been waiting awhile at the Annapolis anchorage. The implication of this is that the vessel is also more likely to be getting close to being able to proceed to its dock assignment. Thus, it is likely in the later years, when volumes are very high and dock space at a premium, that short anchorage stays are very frequent.

The reason that "disbenefits" seem to increase in later years is a function of the total vessel traffic volume and fixed resources. As the number of vessels increases, more vessels are competing for the same number of resources (spaces). In the first example above, the competition between smaller and larger vessels is heightened as the respective volumes of each increase. In the second example, the competition is for both anchorage space and dock space. This could potentially foster some delays if sufficient port infrastructure (dock space) is not in place to fully accommodate the vessel mix and vessel growth in the later years (the simulation modeling effort did not introduce additional terminal/dock capacity in the later years).

It is possible that the "disbenefit" could be reduced through the introduction of more terminal/dock capacity. However, this added capacity would eventually be fully utilized as traffic volumes increase. This capacity could be extended, and "disbenefits" further reduced, with development of a well-defined management policy for providing vessels access to anchorage and terminal/dock resources. Such a policy should, at a minimum, take into account the following characteristics of waiting vessels: class, time until dockage, operating costs, and dock location. Therefore, if additional landside facilities were in place, or should become in place during the period of analysis, the benefits from the recommended project would increase.

Time in Cell Statistics. Average vessel speed by model cell is an input to the simulation model. As previously noted, these speeds were obtained from discussions with pertinent Port of Baltimore officials. The time in cell output "reports" on the progress of vessels transiting the various sections of the harbor on the inbound and outbound trip. The "best-case" rate represents the optimum average channel speed that a vessel would travel within a cell if no other vessels were in that particular channel cell. The headings on the time in cell statistics should be as follows, for each cell:

- Vessel class
- #inbound trips using the cell
- average rate of travel (mph) for inbound vessels
- #outbound trips using the cell
- average rate of travel (mph) for outbound vessels
- maximum allowable rate of travel in cell, for the vessel class

In some instances the average rate of travel exceeds the maximum average speed allowed. Table E-3 provides an example to indicate why this arises. Please note that in most instances the averages do fall at or below the maximum; for those rare cases in which the average exceeds the maximum, the differences are slight (always less than a tenth of a mile per hour).

As an example, suppose that a set of vessels must travel two miles each. The maximum allowable rate is 12 miles per hour. In the table we have "generated" a set of 22 random errors (column 1), for 22 vessels. Suppose that these represent errors in the actual value of distance reported traveled. (Note that one-thousandth is very small; indeed thirteen of the 22 randomly generated cases have errors less than one-ten-thousandth.) Column two would then be the calculated distance. Suppose further this distance is rounded to 4 decimal places. The first column under "Rate of Travel" indicates calculated distance traveled divided by exactly one-sixth of an hour (which could in itself generate a roundoff error) – that is, column three ("2+error distance") divided by one-sixth. "Rounded rate of travel" indicates "roundoff distance divided by one-sixth, and "roundoff (rounded rate of travel)" is the rounded value of "Rounded rate of travel". For all three cases of the variously defined "Rates of Travel" the average of the 22 vessels exceeds the maximum of 12, and is approaching one-hundredth of a mile per hour.

TABLE E-3 – ROUNDOFF ERRORS

	DISTANCE TRAVELED			RATE OF TRAVEL (distance/time)		
	Random Error	2 + Error Distance	Roundoff Distance	Calculated Rate of Travel	Rounded Rate of Travel	Roundoff (rounded rate of travel)
1	0.001244304	2.0012443	2.0013	12.00746582	12.0078	12.0078
2	0.003031119	2.00303112	2.0031	12.01818672	12.0186	12.0186
3	0.001669503	2.0016695	2.0017	12.01001702	12.0102	12.0102
4	9.98749E-05	2.00009987	2.0001	12.00059925	12.0006	12.0006
5	0.000312973	2.00031297	2.0004	12.00187784	12.0024	12.0024
6	0.004320974	2.00432097	2.0044	12.02592584	12.0264	12.0264
7	0.000353343	2.00035334	2.0004	12.00212006	12.0024	12.0024
8	0.000159777	2.00015978	2.0002	12.00095866	12.0012	12.0012
9	2.13373E-05	2.00002134	2.0001	12.00012802	12.0006	12.0006
10	0.000130562	2.00013056	2.0002	12.00078337	12.0012	12.0012
11	0.001981409	2.00198141	2.002	12.01188845	12.012	12.012
12	0.001272937	2.00127294	2.0013	12.00763762	12.0078	12.0078
13	0.001767218	2.00176722	2.0018	12.01060331	12.0108	12.0108
14	0.000340294	2.00034029	2.0004	12.00204176	12.0024	12.0024
15	0.000792229	2.00079223	2.0008	12.00475337	12.0048	12.0048
16	0.000697624	2.00069762	2.0007	12.00418574	12.0042	12.0042
17	0.000253171	2.00025317	2.0003	12.00151903	12.0018	12.0018
18	0.000513213	2.00051321	2.0006	12.00307928	12.0036	12.0036
19	0.000276947	2.00027695	2.0003	12.00166168	12.0018	12.0018
20	0.000772515	2.00077251	2.0008	12.00463509	12.0048	12.0048
21	0.003190928	2.00319093	2.0032	12.01914557	12.0192	12.0192
22	0.001685764	2.00168576	2.0017	12.01011459	12.0102	12.0102
Average	0.001131274	2.00113127	2.001172727	12.00678764	12.00703636	12.00703636
Rounded average	0.0012	2.0012	2.0012	12.0068	12.007	12.007

Model Inputs. There was a concern that some model inputs could adversely impact the proper measurement of economic benefits between the with-project and without-project condition. Subsequently, it was important that the modeled system accurately reflect the with-project and without project physical features. At the beginning of the LRR model analyses, all input parameters were verified and documented to assure the validity of model runs. These inputs included: (1) channel widths; (2) channel depths; (3) channel lengths; (4) physical dimensions and cell locations of all anchorages; (5) location of all channel connections in harbor channel system; (6) vessel speed limits in harbor channels; (7) vessel meeting situations and forward speed criteria basis (the sailing draft or design draft); (8) proportion of Cape Henry and C&D Canal route traffic; (9) proportion of vessels using each of the anchorage sites in the with-project and without-project condition; (10) pilotage costs for vessel types; (11) ILA labor contract start times at berths and the relationship of dock labor start time and the requirements for anchorages; and (12) calibration of existing condition model run with the year 2000 Baltimore Maritime Exchange (BME) data.

Each of these parameters is discussed below in detail:

(1) Channel Widths: Some discrepancies in this input were found in the model as it was used during the feasibility-level effort. The channel widths as defined in the version of the model used for all the LRR analyses were reviewed with Baltimore District Operations Division personnel and consultation of navigation charts and published information on anchorage dimensions. This information was checked to assure accuracy. The LRR model runs utilized the correct dimensions.

(2) Channel Depths: Some discrepancies in this input were found in the model as it was used during the feasibility-level effort. The channel depths as defined in the version of the model used for all the LRR analyses were reviewed with Baltimore District Operations Division personnel and consultation of navigation charts and published information on anchorage dimensions. This information was checked to assure accuracy. The LRR model runs utilized the correct dimensions.

(3) Channel Lengths: Some discrepancies in this input were found in the model as it was used during the feasibility-level effort. The channel lengths as defined in the version of the model used for all the LRR analyses were reviewed with Baltimore District Operations Division personnel and consultation of navigation charts and published information on anchorage dimensions. This information was checked to assure accuracy. The LRR model runs utilized the correct dimensions.

(4) Physical dimensions and cell locations of all anchorages: These inputs were thoroughly reviewed with Baltimore District Operations Division personnel and consultation of navigation charts and published information on anchorage dimensions. This information was corrected as necessary before the LRR analysis was conducted.

(5) Location of all channel connections in the harbor channel system: These inputs were thoroughly reviewed with Baltimore District Operations Division personnel and consultation of navigation charts. This information was corrected as necessary before the LRR analysis was conducted.

(6) Vessel speed limits in harbor channels: Average speeds of vessels moving in the port were initially obtained in 1995. This information was reviewed by the Association of Maryland Pilots (AMP) and the Baltimore Maritime Exchange in summer 2001. As a result of this review, no changes occurred in average vessel speed. The values used in the modeling effort are shown above.

(7) Vessel meeting situations and forward speed criteria basis: The vessel meeting criteria used in the model is based on AMP's criteria as discussed in the simulation model section earlier in this appendix. Similar criteria were put into code for the original *Galveston Bay Area Navigation Study* but with input from the AMP, were modified to fit the unique circumstances of the Port of Baltimore.

(8) Proportion of Cape Henry and C&D Canal route traffic: The model developed for the Port of Baltimore is a general representation of the port navigation system that simulates vessel activity through the port branch channels, anchorages, and

docks. Vessel activity, including anchorage use, and the distribution of vessel call arrival rates are based on the most recent data available (year 2000). The C&D Canal system was not specifically modeled in the Baltimore Harbor Anchorages and Channels simulation model. It was determined that this would have a minor impact on the overall analysis with respect to the problems and opportunities examined in this study. The simulation model was not designed to simulate two distinct arrival sources of vessels, and to incorporate this minor (relative to the more significant system aspects that were modeled) aspect into the analysis was not cost-effective. It is important to realize, however, that the vessel activity emanating from the C&D Canal or departing to the C&D Canal was accounted for in the pattern of vessel arrivals to docks and anchorages. All vessels entered the system from the Cape Henry direction in the model. As noted in the main report, Section 10.3.2.3, 74% of all incoming calls to the Port of Baltimore in year 2000 came from Cape Henry. Cape Henry handled 84% of the departing vessels.

(9) Proportion of vessels using each of the anchorage sites in the with-project and without-project condition: The proportion of vessels using the anchorage sites in the with-project and without-project condition is based on the year 2000 data. Analysis of this data indicates that about 20 percent of the vessels calling on the Port of Baltimore utilized anchorages on at least one leg of the trip. This relationship of anchorage use to total vessel activity was maintained in the without project condition over time. It is important to state that the vessel fleet in the improved condition is the same as the fleet in the without project condition and that total vessel calls for the simulated period of time are nearly identical. Because of the simulated improvements to the without project condition, it is possible that different vessel classes may use different anchorages than were used in the without project condition.

(10) Pilotage costs for vessel types: The current pilotage rate structure, as approved by the Maryland Public Service Commission, was used to estimate average hourly pilotage cost per vessel class. Vessel operating costs and pilotage costs associated with military vessels, passenger vessels and equipment vessels were not included in the current simulation analysis. Therefore, cost savings (benefits) related to the passenger vessels are not reflected in the simulation output. Inclusion of these cost savings would increase the net benefits currently presented in the LRR. These inputs were thoroughly reviewed and corrected as necessary before the LRR analysis was conducted.

(11) "ILA labor contract start times" is not a direct input to the system. To account for tying up at berth, loading, unloading, and departure, average time at berth was calculated based on observed data. Vessel time at berth is as good an indicator of vessel time in the system as ILA start times. It must also be noted that much of the labor at the Port is non-union (approximately 40 percent) and is not limited by ILA work rules. The average time at berth was held constant in both the with- and without-project condition. The benefits calculated by the model are derived from decreased transit times. The use of vessel time at berth is a good proxy for landside labor because it captures the dynamics of the landside-waterside interface. Fleet composition, number of vessels, and time at berth remained the same in both the without and with project conditions. A constant landside operation time for

both the with and without cases eliminates any added variability that would be contributed by a landside activity

(12) Calibration of existing condition model runs with the year 2000 Baltimore Maritime Exchange (BME) data: For the LRR analyses, year 2000 vessel data were used to provide current information on anchorage and branch channel activity. The simulation model is calibrated to this data. The model follows the actual performance of the year 2000 in that the number of vessels arriving to the system is close to the number observed in 2000. In addition, the breakdown of the arriving vessels – by class, by service dock, and by distribution over time – closely matches that of the year 2000. For the runs during the LRR analysis, the model was calibrated to actual year 2000 data as provided by BME.

The discrepancies in inputs as discussed above were corrected prior to the LRR model runs and found to account for approximately an 8% difference in calculated benefits. Subsequently, the runs done as part of the LRR process included the revised input data, and the benefits and BCR shown in this document reflect these corrections.

It must be noted that the fleet in the without-project condition is identical to that in the with-project condition for a given model run (that is, when identical model seeds are used). This was done to show a direct comparison of the without- to the with-project condition. The system was not modeled to determine how much it could handle in either condition, but rather to show how each condition would accommodate the anticipated level of vessel traffic.

Model Outputs. Several concerns with the model outputs from the feasibility phase have been voiced. These concerns included: (1) the desire to see transit time in hours and resulting vessel operating costs, for vessels that complete the system without an anchorage as compared to vessels that require an anchorage; (2) the desire to see system delay cost and hours and distance of the restricted reaches for meeting situations for simulation runs comparing with-project and without-project conditions; (3) instances of significant differences in system operating costs for successive simulation runs where the time difference is a few hours; and (4) instances of non-random and successively longer wait times at anchorages. To address the first two concerns, refinements to the model were made to capture additional output information. This information included vessel activity by cell and time in cell (both transit and anchoring time). An example of the total system output can be found in Appendix C of the LRR in the unlabeled tables following Table C-15. The last two issues (#3 and #4 above) were raised during a review of the feasibility results. The 21 LRR model runs did not result in instances of this type, so this concern is no longer an issue.

Vessel Operating Costs. As noted in the main report of the LRR, the model includes the latest deep-draft vessel operating costs. For this analysis, vessel operating costs reflected in the simulation model are based on Economic Guidance Memorandum 00-06, dated 1 June 2000, published by the US Army Corps of Engineers Institute for Water Resources (IWR). The at-sea vessel operating cost for each vessel class, as defined in this memorandum, was applied to the modeled vessel in each class for time in anchorage. The basis for this assumption and subsequent sensitivity analysis is discussed below.

The current vessel operating costs do not include a category for "at anchorage." "In-port" and "at-sea" are the two categories for which information is provided. For the Baltimore Harbor Anchorages and Channels simulation analysis, the "at-sea" vessel cost was used to report the cost to the "average" vessel in each class while at anchorage. The rationale for using the "at-sea" rates was that, unlike at dock, the vessels are in fact in a dynamic state – ready to proceed to port when called. Fuel costs are different than when the vessel is loading/unloading at the dock.

Recent discussion and correspondence with Baltimore maritime representatives indicated that current practice is to keep the system (engines) hot but not moving for the first 2 to 3 hours in anchorage. If a vessel is going to remain at anchorage for more than 3 hours, it will minimally operate the engines to run the generators. The primary difference between "in-port" and "at-sea" costs is fuel consumption and the price of fuel. Based on recent information from the maritime community, costs "at-anchorage" are less than the IWR "at-sea" published costs, but more than the IWR "in-port" published costs. Note that the use of tugs while in anchorage also add to the "at-anchorage" cost, which is not a component of "in-port" costs.

While the hourly costs associated with longer stays at anchorage may not be as high as short-term costs, these costs are still more expensive than being tied up at berth. Given that anchorage use by class and time at anchorage may vary from the without-project condition, use of a cost other than "at-sea" will have a downward effect on total vessel operating costs in the without- and with-project conditions and may have a slightly downward effect on the net benefits. Tug costs are not included in the simulation analysis; it is likely, however, that the with-project condition would result in an overall decrease in system-wide tug costs.

Based on IWR criteria, the difference in "in-port" versus "at-sea" costs is 22%. This number was derived as a weighted average of the IWR cost differential for various types of vessels considered in the proportion of their actual use in 2000 in the Port of Baltimore. Using the actual 2000 anchorage data, and assuming class equivalents as noted in the LRR Analyses section of this appendix, it was determined that 13% of anchored vessels (Annapolis and inner harbor) were tankers, 50% were bulk, 24% were cargo, and 13% were container ships (information was gleaned from Tables 15 and 19 of the LRR). Based on Table 6.2 in the feasibility report, the anchorages represent approximately 75% of the project benefits. It is important to note that Table 6.2 does not list benefits for the turning basin improvement, consequently 75% is an overstatement of benefits accruing to the anchorage improvements. Discussions with a representative of BME revealed that the cost in anchorage is between the "in-port" and "at-sea" costs, and is contingent on duration of stay. Nonetheless, the data above allows one to roughly assess the maximum impact of assuming the higher "at-sea" cost versus the lower "in-port" cost. It is understood that this assessment of maximum impact is not realistic since only long duration stays at anchorage would be impacted. Removing 22% of the benefits accruing to anchorage improvements would reduce total project benefits by 16.5% (22% of 75%). This would reduce the annual benefits as reported in Table 29 of the LRR from $2,622,000 to $2,189,000, which still exceeds the annual cost of $1,937,000. Therefore, even with this extremely conservative, and unrealistic, method, the project remains justified. It must be emphasized that this is a worst case estimate for two reasons. First, information from the maritime community confirms that costs "at-anchorage" are higher than "in-port" costs for all but long-duration stays at anchorage. Furthermore, the proportion of benefits attributed to the anchorage improvements is overstated because turning basin benefits are not included in this estimate.

Dispatch and Demurrage Costs. Dispatch-demurrage refers to a common worldwide maritime business practice of paying penalties or incentives associated with lengthy or short stays in port. Seldom applicable to container ships because they are owner-operated, these contract charter agreements apply to dry bulk, liquid bulk, general cargo and some roll-on/roll-off vessels.

The contract for hire between the vessel owner and charterer specifies a certain number of days for the charter to load and unload (discharge) a ship. Every charter has its own nuances; usually start times begin upon arrival and tendering of a "notice of readiness."

Once the agreed to time is exceeded, demurrage applies. Demurrage is an "agreed to" rate between the owners and charterers and is predicated on the size of the vessel and the market that exists in the maritime community. Demurrage rates average between $8,000 and $15,000 per day. It is a fee or penalty for exceeding the "contracted for" number of working days in a port. It is a fee the charterer pays to the owner.

Dispatch (or despatch) is a fee that the vessel owner pays to a charterer if the charter spends less than the "contracted for" number of days in port. The basic freight rate is set by the owner and is based on various costs of owning and operating a vessel. Included in the freight rate is an agreed to number of working days in a port. Because the owner has already chartered the vessel's subsequent trips, dispatch is the converse of demurrage; the owner pays the charterer for completing a port visit early. If the vessel exceeds its "contracted for" time, the owner can lose the subsequent charterer's business. This represents an opportunity cost to the vessel owner and the vessel charterer.

For these reasons, dispatch/demurrage was originally identified as an operating cost consideration in the feasibility analyses and included in the model. It is a long-standing and common business practice. It is based on vessel size and market conditions. It represents partial compensation to the owner, or charterer, for not having, or having, vessel availability for the next charter.

However, it is not clear if the dispatch and demurrage payments are resource costs for the consumption of labor, material and facility space, or transfer costs. Accordingly, these costs when used in the determination of benefits may potentially result in a determination that these benefits were calculated through a non-standard procedure. Consequently, the dispatch and demurrage costs were excluded from the benefit calculations in the LRR analyses to avoid any potential questions regarding applicability.

Pilotage Costs: Public concern has been raised that pilotage costs are not a valid resource cost. However, this benefit represents the savings in expense for pilot labor and is a valid benefit as outlined in Appendix E of ER 1105-2-100, the Planning Guidance Notebook, dated April 2000.

Overestimated Vessel Dimensions: The actual year 2000 fleet that called on the Port of Baltimore was used to develop the simulated fleet used in the model. A concern brought to the attention of the Corps was that the fleet defined during the 1995 feasibility analysis might have included ships of larger dimensions. It is unknown if this is the case; however, since the actual fleet was used for the model, any such discrepancies would be accounted for.

Associated Costs Not Included: The Port of Baltimore is planning two significant improvements in the future – construction of a new Berth #4 at the Seagirt Marine terminal and a new terminal with 4 extra berths at Masonville. These improvements were included in the analysis, but the associated costs of construction were not included as a project cost. This is because the improvements were assumed to occur whether or not the project was constructed. That is, the analysis assumes these improvements in the with- and without-project condition. Since it is assumed in both scenarios, it cannot be considered a cost of the Corps' navigation project.

Model Output Seems Unrealistic: The feasibility-level data that was analyzed by the public produced some outputs that were not intuitive. During the feasibility report, the model was set up to show one roundtrip as 2 trips, that is, one inbound and one outbound. This was a holdover from the model used for the Galveston District in assessing the impact of widening and deepening portions of the Houston Ship Channel. For that environment, the elements of importance in analyzing benefits were solely accrued by moving through the channel. No anchorage issues were involved. The benefits accrued by vessels being able to pass and meet more effectively. Consequently, the simulation was addressed as a "single-leg" model, in which vessels originated randomly (where the randomness mimicked actual conditions in the system) at some point in the system, proceeded to some destination and exited the simulation. In the Baltimore model, the focus was on complete roundtrips by vessels. The conditions of anchoring influenced a vessel's total time in the system. Consequently, the simulation code for the Baltimore analysis was modified so that all vessels arrive from the sea, proceed to a port, receive service, and then exit via the sea.

As part of the LRR effort, the feasibility simulation was refined to better reflect typical conditions. If, at the end of a 150-day simulation during the feasibility analyses, a ship was "caught" or "lost" in the system, the model may assign to that vessel high operating costs. However, this did occur in both the with- and without-project scenario. Therefore, these instances would functionally cancel one another out and minimize the effect. However, during the LRR analysis (in order to eliminate the potential that this scenario would alter the conclusions of the analysis), the model was refined to eliminate the "incomplete trips." Any trip that was not completed at the end of the 150-day simulation did not encounter the same operating cost dilemma as in the previous modeling effort due to algorithms added as part of the model refinement.

Use of Design Draft vs. Sailing Draft: The model does not capture actual sailing drafts. In reality, for any given class, vessels can arrive to the system under a wide range of sailing drafts. Consequently, the model captures only the design draft, design beam, and design length of the average vessel representing about 25 different vessel classes. The result is that there are some vessels with large design drafts that might occasionally be able to use a shallower anchorage but only if the anchorage area could accommodate the vessel's design length. Thus, the simulation model understates the ability of vessels to use the anchorages. For the current study, this is not thought to be an issue; however, there may be some understatement of anchorage benefits. It should be noted that the fleet draft and length is the same in the with- and without-project analyses. Further, the draft of the vessel, be it sailing or design, does not impact the length (fixed) of the vessel, which is frequently the controlling factor in anchorage usage.

The assumption of design draft versus sailing draft was necessitated because the data used as input to the model did not include this level of information. Future port traffic was stated conservatively based on this. Future projections were made on commodity tonnage to the Port of Baltimore. The number of vessels that would transport this tonnage was "backed into" by assuming that each vessel would sail at design draft, and figuring how much commodity tonnage these ships could carry. Therefore, by assuming that the vessels sail at design draft, the number of vessels was understated compared to the number that would be required had we assumed a sailing draft less than the design. Furthermore, by assuming design draft, we precluded from inner harbor anchorage use any ship that requires more than 42 feet of water at its design draft. In reality, these ships may be light-loaded and thereby able to use the anchorage.

Failed Simulation Runs in Feasibility Phase: In the feasibility phase, the model failed to complete on several simulation runs. Many factors can contribute to a model run not being completed, especially in the outyears when the existing port landside infrastructure may not be sufficient to handle the traffic. Ten runs per scenario were executed during the feasibility study. Some of these runs did not generate output due to vessels being "caught" or "lost" in the program after the trips had been completed. The version of the simulation used in the LRR addresses this situation. It is for these reasons that 25 runs were done in the with- and without-project conditions for each milestone year. Of these 25 runs, 21 were found to be acceptable for use in the analysis (several runs were not evaluated due to non-matching seeds in the with- and without- project environment). With the revisions to the model, which were made prior to the LRR economic analyses, no runs failed.

Conservative Approach to Benefits. In the LRR analyses, several assumptions were made that contributed to a conservative estimate of the project's benefits.

Tugboats were not included in the modeling analysis. Tugs are used in practice for anchorage as well as to navigate the channels. Usually in the Port of Baltimore system, two tugs are used to escort vessels to or from anchorages or berths. The resource costs associated with these tug movements are not reflected in the simulation model. With the channel improvements, the estimated 15 to 20-minute savings for the commercial vessels would also accrue to the tugs. This would result in further cost savings to the Port system with implementation of the project; these savings have not been reflected in the benefit calculations.

In addition, the model does not include shallow-draft vessel movements. This eliminates at least 50% of the vessels from the analysis. It is true that this fleet is heavily weighted toward the smaller end of the size range; however, they still occupy time at berth, add to traffic "congestion" and potentially use anchorage spaces.

Also, all deep-draft ships were assumed to sail under foreign flag. Since the U.S. flagged vessels operate at a higher cost, and would therefore realize greater benefits, this assumption understates the benefits of the project.

A first-come-first-served (FCFS) system was used to govern anchorage use in the model. This caused many instances of small ships consuming an anchorage slot while a much larger and more costly vessel had to wait further from berth. This is the cause of the dis-benefits seen in the out years of the analysis. Had a system been used that included prioritization of anchorage use, the benefits would have been greater, especially in the outyears as traffic grows.

Through October 2001, the port has seen an increase of 123 vessels over last year. That is a 7.9% increase in traffic over that used as the LRR baseline year. This exceeds the growth rate assumed in the model (4%). Furthermore, Baltimore is seeing a tremendous increase in the number of cruise ships calling on the Port. Benefits to cruise ships as well as equipment ships and military ships were not captured in the analysis. For these vessels, pilotage and other costs that are valid resource costs were not included in this analysis. This is another understatement of benefits.