FORTRAN SIMULATION OF AN OIL TANKER FLEET

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ABSTRACT

This paper describes the design and development of a discrete simulation model (written in Fortran) of a distribution network supplied by a tanker fleet. The model simulates a tanker fleet of up to 50 ships, each of which can visit up to 10 distribution facilities. A total of 30 distribution facilities are allowed. The paper describes how data available only in graphical form was processed for input to the model. A unique method of data verification is also discussed.

INTRODUCTION

The model described in this paper was developed for the Transportation Department of American International Oil Company, which required a means of quickly evaluating different tanker fleet configurations. Their primary interest is the design of tanker fleets which will satisfy forecasted demand at the lowest total cost. To solve this problem we developed a discrete simulation model written in Fortran IV. It is currently operational on an IBM System 360 Model 75.

WHY FORTRAN

Fortran was chosen as the programming language over GPSS, the only other readily available language, for the following reasons:

1. The computational and input capabilities of GPSS were not adequate.
2. The recycling type of simulation needed was not easily obtainable using GPSS.
3. The desired output reports could not be produced using GPSS.
4. The model could be developed faster using Fortran.

FEATURES OF THE MODEL

The model simulates the activities of an oil tanker fleet which delivers refined products from a group of refineries to a network of distribution facilities and simulates the inventories at all distribution facilities. Its major features are listed below.

1. The simulation can run for any number of years.
2. Many data cases can be processed during one computer run.
3. The data from the first data case is available to all other data cases.
4. The monthly product demands, initial inventory levels, tanker cargo allocation, and product delivery amounts are user specified.
5. The model allows up to 4 products (gasoline, kerosene, etc).
6. The model can handle 50 tanker and 30 distribution facilities.
7. Each tanker can visit up to 10 distribution facilities.
8. A tanker can load additional product during a trip.
9. The time between ports is subject to enroute delay.
10. The model generates tanker trip summaries, inventory excess or depletion warnings, and monthly, yearly and multi-year operating summaries, for all distribution facilities, by product.

DATA VALIDATION

An important aspect of any simulation is the validation of input data. This is a particularly important task in this simulation because much of the data is available only in graphical form. Figures 1 and 2 show the charts for one port. These charts are used by the port authorities to compute time in port and port costs for a tanker. It is vital that the port time and port cost data be available during the simulation.

We obtained the port time and port cost data in machineable form by using a curve fitting program to generate a fifth degree polynomial equation for each curve. The coefficients for each equation are stored in memory for use during simulation runs. A total of 389 sets of coefficients were obtained and stored in this manner.

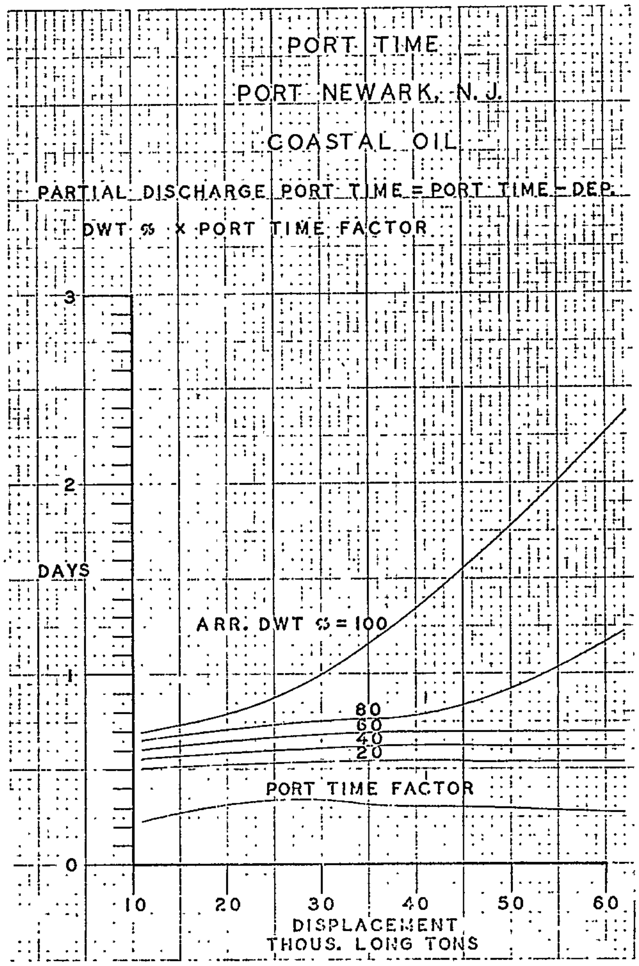

Figure 1

Original Port Time Graph

The next step was the task of validating the coefficients. To do this we developed a separate Fortran program which evaluated each equation. The output of the program was a set of Calcomp plots. Each plot contained the data corresponding to one of the original charts. This technique provided us a means of visually checking each curve fit. Figures 3 and 4 show the Calcomp plots produced by evaluating the equations obtained by fitting the curves shown in Figures 1 and 2. The most important lesson learned during the development of the model is that the plotter is a powerful tool for data validation.

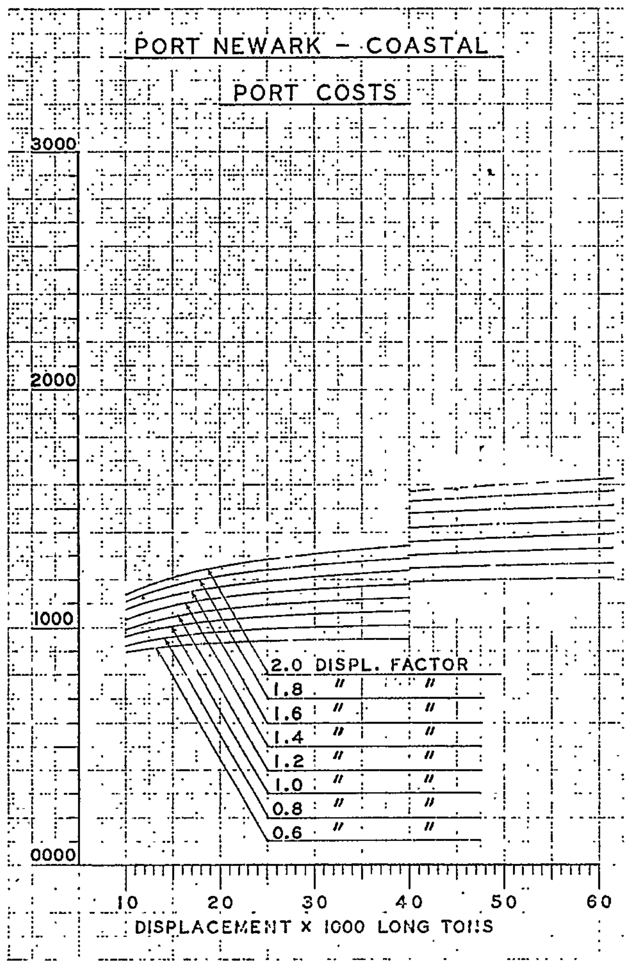

Figure 2

Original Port Costs Graph

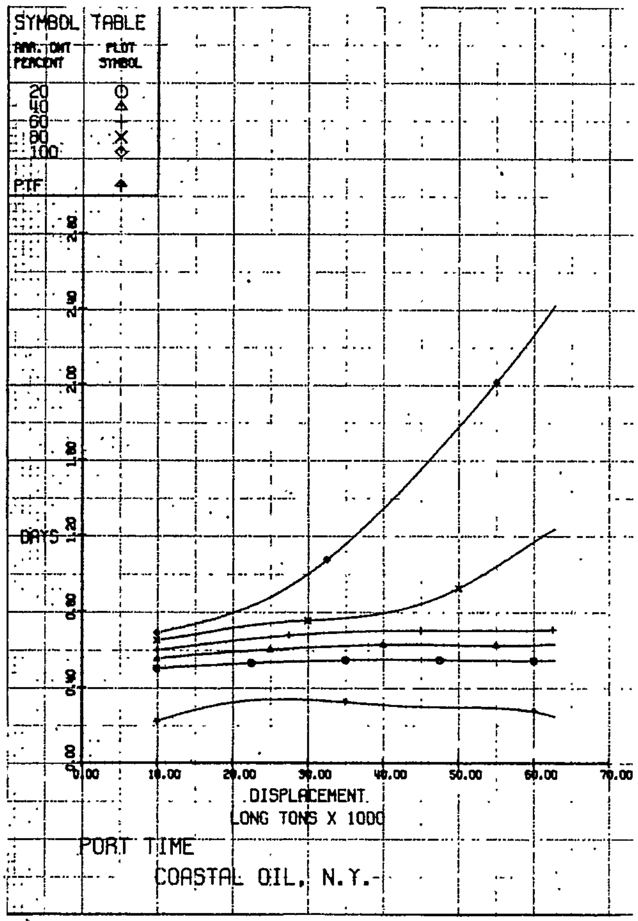

Figure 3

CalComp Plot of Generated Port Time Graph

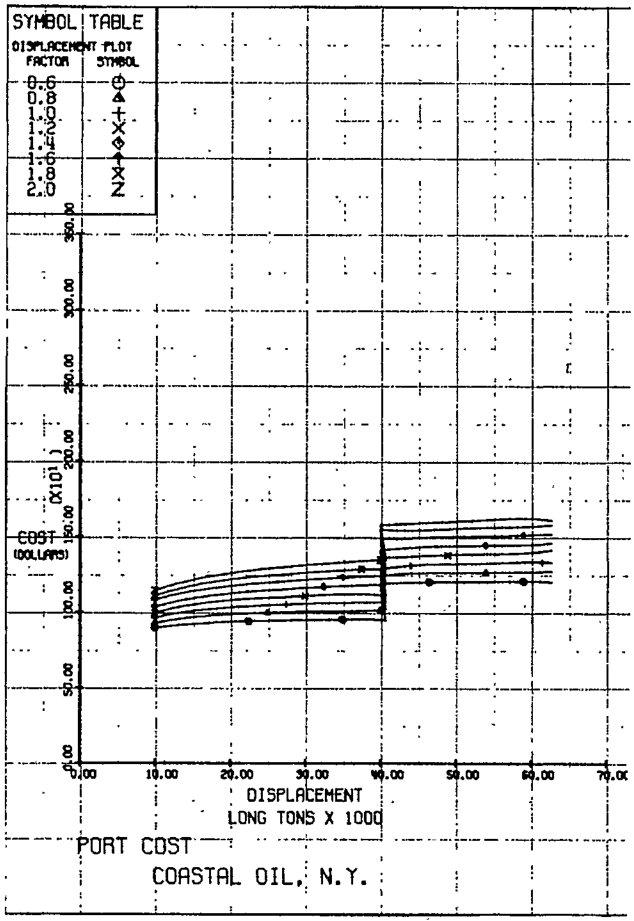

Figure 4

CalComp Plot of Generated Port Costs Graph

INPUT

The simulation model is controlled by data supplied by the user at execution time. This data, punched on cards, contains:

1. Number of years to run simulation
2. Number of simulation periods per month
3. Output report selections
4. Product names
5. Output page heading
6. Tanker specifications
7. Tanker routings
8. Product storage capacities for each distribution facility
9. Initial inventory levels
10. Monthly demand for products
11. Enroute delay data

INPUT PROCESSING

The model allows all data cases to use the data from the first data case. All data from that first case is saved in memory. Each piece of data has associated with it a unique storage pointer. To process additional data cases the following steps are executed:

1. Fetch the data for the first data case from storage.
2. Read in data cards which delete or replace original data, or will add new data using the storage pointer to select the correct date.
3. Transfer the new data file to the pre-simulation processor.

PRE-SIMULATION PROCESSING

Before the actual simulation starts a great deal of work is accomplished. This work I call pre-simulation processing. In this step three major internal simulation tables are prepared. These tables are the heart of the simulation process. During simulation data is continually being obtained from the tables and new data is continually being stored in the tables.

Tanker Data Table

This table contains the following data about each tanker:

1. Displacement
2. Speed
3. Physical dimensions
4. Cargo allocations
5. Fuel consumption rates
6. Fixed operating cost per day

In total there are 25 entries for each tanker, requiring a total of 1,250 storage locations for the Tanker Data Table.

Tanker Routing Data Table

This table contains data about the route each tanker follows, such as:

1. Port numbers (in order of arrival)
2. Trip time between ports
3. Amount of cargo to load or unload
4. Port costs for each port
5. Next arrival time at each port

There are 20 entries for up to 10 ports for each tanker in this table. The Tanker Routing Data Table requires 10,000 storage locations.

Distribution Facilities Data Table

This table contains data about each distribution facility. The type of data items stored in this table are shown in the following listing:

1. Monthly demand by product
2. Inventory capacity by product
3. Inventory level by product
4. Number of periods with inventory overage or shortage
5. Delivery amount data
6. Cost data

This table contains 34 entries for each product for each distribution facility. A total of 4,080 storage locations are needed for this table.

During Pre-simulation Processing every storage location in these tables is either filled with a value or set to zero. The values may come from input or be computed. It is here that the coefficients obtained from fitting the graphical data described earlier are used to obtain the port time and port cost values. Pre-simulation Processing prepares the simulation process for correct execution.

SIMULATION PROCESSING

During the simulation the basic unit of time is the simulation period specified by the user, which represents a span of hours during one month. If there are 60 simulation periods per month this would mean that the model is cycled every 12 hours. During each simulation period, the following steps are performed:

1. For each port, identify all tankers scheduled to arrive.
2. For each tanker unloading facility:
   - (a) Increase the inventory level of all products by the amount delivered, if a tanker is due to arrive during the period.
   - (b) Decrease the inventory level of all products by the per period demand.
   - (c) Test for any overage or shortage inventory. If an overage or shortage does exist, generate a message (Figure 9) and maintain a record of the amount involved.

YEAR	2	MONTH	10	PERIOD	25	PORT	PORTLAND, ME.	PRODUCT	GASOLINE	OVER-SUPPLIED BY 4782 BBLS.
YEAR	6	MONTH	9	PERIOD	11	PORT	BALTIMORE, MD.	PRODUCT	KEROSENE	UNDER-SUPPLIED BY 3371 BBLS.

Figure 9

Over/Under Supply Messages

(d) Compute the cost of delivering the products to the distribution facility, if a delivery was made.
(e) Update total values for fuel, operating, and port costs, if a delivery was made.

3. For each tanker loading facility, if a tanker is due to arrive during the period:
   (a) Compute costs occurred at loading facility.
   (b) Update total values for fuel, operating, and port costs.
   (c) Generate end of tanker trip summary output. (Figures 5a and 5b)
   (d) Check if tanker is due for yearly maintenance and, if so, adjust next arrival times to reflect scheduled maintenance time used and generate a message. (Figure 6)
   (e) Compute the next arrival time for each port on the tanker's route.
   (f) Compute the return trip costs and allocate these costs to each distribution facility based on the percentage of the total cargo delivered.

RUN 10 -- CONFIGURATION A 11 -- 22/11/67

YEAR 1 TRIP NUMBER 1 PERIOD STARTED 1.00 PERIOD ENDED 21.29 PERIOD ARRIVED 22 PAGE NUMBER 1

VESSEL PARTICULARS TANKER NUMBER 1

LENGTH	588 FEET	DISPLACEMENT	36883 LONG TONS	AT SEA FUEL CONSUMPTION	63 TONS/DAY
BEAM	84 FEET	DEADWEIGHT	29826 LONG TONS	IN PORT FUEL CONSUMPTION	17 TONS/DAY
DRAFT	34 FEET	SERVICE SPEED	16 KNOTS 384 MILES/DAY	FIXED OPERATING COSTS	5567 DOLLARS/DAY

PORT	OPERATION AT PORT	CARGO TONS	TONS PERCENT	DISTANCE FROM LAST PORT (MILES)	SEA DAYS	PORT DAYS	TOTAL TIME (DAYS)	SEA FUEL (TONS)	PORT FUEL (TONS)	TOTAL FUEL (TONS)	FUEL PRICE (DOLS.)	FUEL COST (DOLS.)	DISPLACEMENT FACTOR	TOTAL PORT COSTS (DOLLARS)
TEXAS CITY, TEXAS	LOAD	28512	100	0	0.0	1.3	1.3	0.0	22.0	22.0	15.0	329.49	1.3	887.24
PORTLAND, MAINE	UNLOAD	5702	20	2128	5.5	0.6	6.2	349.1	10.4	359.5	15.0	5392.20	1.9	2794.71
CHELSEA, MASS.	UNLOAD	11405	40	74	0.2	0.6	0.8	12.1	10.6	22.7	15.0	340.61	1.4	1550.72
PROVIDENCE, R.I.	UNLOAD	11405	40	254	0.7	0.5	1.2	41.7	8.9	50.5	15.0	757.96	0.8	1442.49
YORKTOWN, VA.	LOAD	28512	100	353	0.9	1.3	2.3	57.9	22.9	80.8	15.3	1236.34	1.3	1578.36
PROVIDENCE, R.I.	UNLOAD	11405	40	353	0.9	0.4	1.3	57.9	6.8	64.8	15.3	990.78	1.7	1597.47
PORTLAND, ME.	UNLOAD	5702	20	298	0.8	0.6	1.3	48.9	9.7	58.6	15.3	895.96	1.3	2635.39
CHELSEA, MASS.	UNLOAD	11405	40	74	0.2	0.6	0.8	12.1	10.6	22.7	15.3	347.52	0.8	1401.15
RETURN TRIP		0	0	2084	5.1	0.0	5.1	321.8	0.0	321.8	14.7	4730.37	0.0	0.00
TOTALS							20.3					15021.21		13887.53

TOTAL FUEL COST	15021.21
TOTAL OPERATING COST	112980.69
TOTAL VOYAGE COST	141889.37
TOTAL ENROUTE DELAY	0.0 DAYS

CARGO PAYLOAD

	AVAILABLE DWT	TRIP FUEL	WATER	STORES AND CREW	CARGO DWT	LIGHTSHIP WEIGHT
IN TONS	29826	964	50	300	28512	7057
PERCENT	80.9	2.6	0.1	0.8	77.3	19.1

Figure 5a

Tanker Trip Summary Output--Page 1

PRODUCT TRANSPORTATION COST

VOYAGE COSTS

RUN 10 -- CONFIGURATION A 11 -- 22/11/67

YEAR 1 TRIP NUMBER 1 PERIOD STARTED 1.00 PERIOD ENDED 21.29 PERIOD ARRIVED 22 PAGE NUMBER 2

PRODUCT TRANSPORTATION COST

UNIT PRODUCT COSTS

LOADING PORT NAME	UNLOADING PORT NAME	AMOUNT UNLOADED (TONS)	DISCHARGE DAYS	TON DAYS	TRANSPORT COST/TON (DOLLARS)	. . . TRANSPORT COST/BBL (CENTS) . . . AMOCO	HOUSEBR	DIESEL	2FUELOIL
TEXAS CITY, TEXAS	PORTLAND, ME.	5702	6.2	35072	1.0017	0.0	0.0	0.0	13.3562
TEXAS CITY, TEXAS	CHELSEA, MASS.	11405	7.0	79437	1.1343	0.0	0.0	0.0	15.1244
TEXAS CITY, TEXAS	PROVIDENCE, R.I.	11405	8.1	92924	1.3269	0.0	0.0	0.0	17.6923
YORKTOWN, VA..	PROVIDENCE, R.I.	11405	11.7	133842	1.9112	0.0	0.0	0.0	25.4828
YORKTOWN, VA.	PORTLAND, ME.	5702	13.1	74583	2.1302	0.0	0.0	0.0	28.4030
YORKTOWN, VA.	CHELSEA, MASS.	11405	13.9	158470	2.2629	0.0	0.0	0.0	30.1719
TOTALS				871238					

TRANSPORT COST/TON DAY = 0.16286 DOLLARS

----- CONVERSION FACTORS IN BBLS/TON -----

8.80 8.90 7.80 7.50

Figure 5b

Tanker Trip Summary Output--Page 2

TANKER NUMBER 1 ENTERED DRY DOCK ON PERIOD 16 FOR 10 PERIODS

TANKER NUMBER 3 ENTERED DRY DOCK ON PERIOD 52 FOR 17 PERIODS

TANKER NUMBER 2 ENTERED DRY DOCK ON PERIOD 110 FOR 8 PERIODS

Figure 6

Messages Generated for Yearly Maintenance Period

The program will cycle through these steps until the desired number of years have been simulated. In addition to the above, the program performs several other tasks, but not during every simulation period. Those tasks are described below.

1. Generate the initial tanker summary at the start of the simulation. This provides the user with the same output generated at the end of each tanker trip. In this way, the user can obtain only monthly or yearly summaries and still have a copy of the end of trip output.
2. Setup the counters to control the operations of the simulation process.
3. Generate end of month, end of year (Figure 7) and total all years summary (Figure 8) output.

CONCLUSION

This paper has discussed a discrete simulation model written in Fortran. The reasons for choosing Fortran were given. A technique for using graphical data and for validation of data using plotting were also discussed. Finally the organization and functioning of the actual simulation process were presented. The development of this model shows that Fortran is a powerful simulation language which should be considered whenever a complex simulation model is needed.

YEARLY PORT SUMMARY

PRODUCT GASOLINE YEAR 1

PORT NAME	AMOUNT DELIVERED (BBLS.)	AVERAGE COST (DOLLARS)	PERIODS WITH UNDER SUPPLY	PERIODS WITH OVER SUPPLY	TOTAL AMOUNT UNDER SUPPLY (BBLS.)	TOTAL AMOUNT OVER SUPPLY (BBLS.)	NUMBER OF DELIVERIES
PORTLAND, ME.	0	0.0	0	0	0	0	0
CHELSEA, MASS.	983710	15219.00	0	253	0	104645	23
PROVIDENCE, R.I.	0	0.0	0	0	0	0	0
RENNSELAER, N.Y.	0	0.0	341	0	402994	0	0
METROPOLITAN, N.Y.	0	0.0	292	0	535194	0	0
CIRILLO BROS., N.Y.	1558094	6558.00	0	266	0	38036	53
COASTAL OIL, N.Y.	779047	2732.00	116	0	234563	0	53
CARTERET, N.J.	983710	16018.00	320	0	2696660	0	23
PHILADELPHIA, PA.	684928	21816.00	331	0	2147826	0	16
BALTIMORE, MD.	0	0.0	331	0	1700857	0	0
WILMINGTON, N.C.	1598112	23679.00	80	207	87799	78650	16
SAVANNAH, GA.	769920	12891.00	0	296	0	43154	24
JACKSONVILLE, FLA.	0	0.0	0	0	0	0	0
PORT EVERGLADES, FLA.	485061	33403.00	348	0	1226391	0	17
TAMPA, FLA.	513336	15577.00	342	0	1136991	0	24
NEW HAVEN, CONN.	0	0.0	0	0	0	0	0

YEARLY FLEET SUMMARY

TOTAL FUEL COSTS 526783.69 TOTAL OPERATING COSTS 5062947.00 TOTAL PORT COSTS 666217.50

TOTAL FLEET COSTS 6256547.00

Figure 7

Yearly Port Summary Output

ALL YEARS PORT SUMMARY

PRODUCT GASOLINE YEAR 3

PORT NAME	AMOUNT DELIVERED (BBLS.)	AVERAGE COST (DOLLARS)	PERIODS WITH UNDER SUPPLY	PERIODS WITH OVER SUPPLY	TOTAL AMOUNT UNDER SUPPLY (BBLS.)	TOTAL AMOUNT OVER SUPPLY (BBLS.)	NUMBER OF DELIVERIES
PORTLAND, ME.	0	0.0	0	0	0	0	0
CHELSEA, MASS.	2993900	15219.00	0	973	0	104645	70
PROVIDENCE, R.I.	0	0.0	0	0	0	0	0
RENNSELAER, N.Y.	0	0.0	1061	0	1246982	0	0
METROPOLITAN, N.Y.	0	0.0	1012	0	1873178	0	0
CIRILLO BROS., N.Y.	5115252	6558.00	0	986	0	38036	174
COASTAL OIL, N.Y.	2557626	2732.00	116	381	234563	58721	174
CARTERET, N.J.	2993900	16018.00	1040	0	8716644	0	70
PHILADELPHIA, MD.	2739712	21816.00	1051	0	6781810	0	64
BALTIMORE, MD.	0	0.0	1051	0	5384837	0	0
WILMINGTON, N.C.	6392448	23679.00	80	927	87799	78650	64
SAVANNAH, GA.	2277680	12891.00	0	1016	0	43154	71
JACKSONVILLE, FLA.	0	0.0	0	0	0	0	0
PORT EVERGLADES, FLA.	1826112	33403.00	1068	0	3762373	0	64
TAMPA, FLA.	1518619	15577.00	1062	0	3530973	0	71
NEW HAVEN, CONN.	0	0.0	0	0	0	0	0

ALL YEARS FLEET SUMMARY

TOTAL FUEL COSTS 1741647.00 TOTAL OPERATING COSTS 16971072.00 TOTAL PORT COSTS 2253191.00

TOTAL FLEET COSTS 20965888.00

Figure 8

Summary of All Years Output