# Network Design and Fleet Allocation Model for Vessel Operation

by

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Submitted to the Department of Mechanical Engineering and the Department of Civil and Environmental Engineering
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## Abstract

Containership operators in the U.S. are confronted with a number of problems in the way they make critical fleet allocation decisions to meet the increase of shippers' demands. Instead of the empirical approach, this research describes an optimization method for the fleet allocation problem. This methodology is applied by generating hypothetical values for a hypothetical firm. The endeavor of this method is to facilitate ship operations by allocating available fleet to maximize capacity and covering all the demands with the lowest cost.

The problem solving process is subdivided into three sub-models: the string simulation sub-model, the network design sub-model, and the fleet and cargo assignment sub-model. Each sub-model is explored by the combined approach of analysis and simulation, formulated as a Mixed Integer linear programming problem, implemented using the Optimization Programming language, and solved by CPLEX. This model provides several feasible fleet allocation proposals ranked by their profits, as well as yields the output of the detail cargo assignment at each port, the revenue, cost, and profit breakdown for each proposal.

Subsequently, various scenarios can be studied in great detail by developing a User Interface in Java programming language based on a determined proposal. This interface allows the carrier to evaluate hundreds or thousands of fleet allocation scenarios and to quickly focus on key characteristics and options that are most relevant. This program extends the deterministic optimization method into a model supporting the solution to stochastic problems.

| | |
|---|---|
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# Chapter 1

# Introduction

This chapter first describes the motivation for this research. Carriers require an effective way to solve the fleet allocation problem to optimize their operation and reduce the cost. Then we introduce the background information for the hypothetical case we use to discuss the optimal modeling process. Next, we present the assumptions, terminologies, and notations that are used in this research to facilitate the afterwards description. Finally, the thesis organization is presented.

## 1.1 Motivation

The commercially operating liner companies in U.S. are confronted with various problems in the way they make critical fleet allocation decisions to meet shippers' demands. Since the last decade, a good number of shippers have been indulged in seeking ways to outsource and reduce their manufacturing cost. This simulates the demand of international and domestic ocean transportation. According to a statistic of the American Association of Port Authorities, deep draft ports accommodate ocean-going vessels which carry more than 99 percent of U.S. overseas trade by weight and 61 percent by value. According to the U.S. Army Corps of Engineering, in addition to international cargoes, the inland and intracoastal waterways provides a low-cost, environmentally balanced means for moving nearly 200 million tons of coal and 125 million tons of liquids. One 3,300-ton barge carries the same tonnage as a string of 33 rail cars, or 110 tank trucks spanning three miles [1].

All these necessitate a high reliability for ships and an adequate carrying capacity. For the shipping industry, it is a tremendously expensive and risky investment to update one's fleet. Thus, how to allocate existing fleet to maximize capacity and cover all the demands without involving a large amount of capital investment and highly swelled fuel cost attracts the focus of many analyzers.

The effectiveness of the fleet capacity is determined mainly by the design of the network and the allocation of the fleet. Because of the complexity of the problem, there is no straightforward way to help operators to arrange their resources in an absolutely optimal style. Commonly, operators make decisions based on their experience and the sense of the market to obtain a trade off between the reliability and the lower operating cost. This research is an attempt to describe such a model that can be used to obtain an optimal allocation of available fleet, by presenting the process of our proposed approach in a case study using hypothetical data from a hypothetical United States liner. The model is implemented by breaking the entire fleet allocation problem into three sub-problems, and applying both analysis and simulation approach to solve each of them. Additionally, a user interface is presented to simulate diverse scenarios, and support the carriers' long term planning and short term operations adjustment. The result of the model achieves a sound cost saving for the carrier. Moreover, there exists a great potential for the fleet allocation model to be used to support strategic and tactical decision-marking of carriers.

## 1.2 Hypothetical Background Information

The containership operator, Hampton Shipping, LLC, transports more than 135,000 Forty-foot Equivalent Units (FEU) every year, in the U.S. West Coast/Asia trade route. The core business of Hampton Shipping is the ocean transportation of temperature controlled containers, which are generally called reefer containers. When being transported by ship, reefer units have to be connected to the on-board power supply system, which requires the vessels to be equipped with relatively large diesel generators. Currently, Hampton Shipping schedules three different weekly services, which run seven large diesel-generator vessels, to handle all the cargos. Trade Lane I consists of six ports: U.S. Port D, Non U.S. Port R, Non U.S. Port S, and three U.S. West Coast ports –U.S. Port A, U.S. Port B, and U.S. Port C.

To maintain competitive in the containership transportation, providing a high level of service is of greatest value of a liner. This requires a high level of reliability and an adequate container capacity. Currently (2005), the potential shortage of capacity is driven by the growth of trade as well as slot charters. Hence, it is imperative to search for a certain effective way to assign the container capacity for Hampton Shipping.

In the last several decades, the decision group of Hampton has successfully levered such kind of crisis several times, by its abundant experience and the acuminous wisdom of shipping industry. However, with the increasing complexity of the network structure and the rise in vessel price and fuel cost, the decision group urges a more theoretical and reliable way to optimize the fleet allocation.

Therefore, it is necessary to build a model to reconsider the optimal arrangement of strings, the network design, and the profit break down to obtain an economical way to satisfy all the cargo volume as well as maximize Hampton Shipping' total profit. To achieve this, in addition to Trade Lane I, we amplify our scope to include Trade Lane II, to cover the company's entire shipping business.

In the modeling of Hampton Shipping, the optimization process is formulated as a linear problem, implemented in the modeling language OPL Studio 3.7, and solved by CPLEX 7.0. After obtaining the most economic way to arrange Hampton Shipping' fleet scheduling and allocation, we develop a user interface to simulate several scenarios to test and compare the effect of changing key operating characteristics. Our aim is to provide a mathematical and theoretical view of the fleet allocation problem. Furthermore, our model can work as a tutorial tool for the company for operating optimization and profit analysis problems.

## 1.3 General Assumptions

Before we present the details of the fleet allocation problem, we first describe some general assumptions used in this research. As most commercial liner companies, our hypothetical company operates containerships in a regular scheduled service carrying diverse cargoes from port to port at set rates. In our model, the solving process is based on the following statement of the assumptions:

- **Focus on container transportation**

  In this model, we only consider the container transportation business of Hampton Shipping, all expressed in FEU (Forty-Foot Equivalent Unit).

- **Use through rate**

  The freight rate means the through rate to customers, including the ocean freight, the inland trucking or railroad rates, and all the surcharges correspondingly.

- **Large diesel-generator vessels are required for reefer containers**

  To maintain the ideal atmosphere for sensitive produce, Hampton's temperature controlled containers replaces consumed oxygen through a unique air exchange system, which requires an on-board power supply system. Currently, only those vessels which are equipped with large diesel-generators could provide such on-board power supply systems. Hence, large diesel-generator vessels are required for reefer containers. Meanwhile, there are no constraints for the standard container trade.

  In fact, more than 90% cargo transported between any two U.S. ports requires reefer containers, hence, the trade to and from two U.S. ports must be in vessels equipped with large diesel-generator.

- **Include both direct sailing and transshipment sailing**

  The shipping itineraries include both direct sailing and transshipment sailing. We do not discriminate the difference of level of service between them. However, to avoid an extremely low level of service, we do not consider the situation of itineraries of which more than one time transshipment would occur.

- **Use average rates and costs**

Averages for rates and costs are used for all containers of different size and type (e.g. refrigerated, dry box); general customers are differentiated from slot charters.

- **Achieve equipment balance**

For each trade lane, except in a certain slot charter, the amount of equipment should be balanced in both directions.

## 1.4 Terminologies and Notations

To facilitate the description of the fleet allocation model and the user interface development, here, we present the common terminologies and notations which we will use throughout the thesis.

### 1.4.1 Terminologies

In describing the model for the fleet allocation and user interface development problem, we define the following terms. Professor Cynthia Barnhart's former work on Fleet Assignment Model (FAM) is used for reference. [3]

A *voyage leg* is a nonstop trip of a vessel from an origin port to a destination port (one departure and one arrival). A *market* is an ordered origin-destination port pair, in which direction shippers wish to consign the shipment. For example, an FEU needs to be consigned from U.S. Port A to U.S. Port D, and thus U.S. Port A-U.S. Port D is a *market*, which is distinct from its *opposite market* U.S. Port D-U.S. Port A Hereby, we can interpret the equipment balance as the volume of equipment flow in a market should be equal to the volume in its opposite market.

A *service* is a string of vessels which make a particular voyage and serve a particular set of markets, i.e. a *service* is a string of voyage legs, which compound into a closed loop and follow a fixed route. An *itinerary* in a particular market consists of a specific sequence of scheduled voyage legs, in which the first leg originates from the origin port at a particular time and the final leg terminates at the final destination port at a later time. For a specific market, it may have several *itineraries*, considering direct sailings, transshipment sailings, as well as different services. We call the beginning port of a service as the "*service base*" port, although the shape of the service is a loop and it is pointless to obtain the so called beginning port. Actually any port can be the "*service base*". Nevertheless, assigning one specific port as the "*service base*" helps us to define a service, and the simulation algorithms can be described easily both to the programmers and the users.

To preserve the stability of the level of service, all the services need to be maintained as fixed day-of-week sailings. That is the "*weekly service rule*". For example, strings of two ships must have a 14 day time for a round trip voyage, strings of three ships, 21 days, and etc. If there is so specific declaration, all the services that carriers are willing to provide has to satisfy the weekly service rule in this thesis.

## 1.4.2 Notations

In describing the model for the fleet allocation and user interface development problem, the following notations are used.

UPA: U.S. Port A
UPB: U.S. Port B
UPC: U.S. Port C
UPD: U.S. Port D
NPR: Non U.S. Port R
NPS: Non U.S. Port S
NPT: Non U.S. Port T
UPE: U.S. Port E
UPF: U.S. Port F
UPG: U.S. Port G

## 1.5 Thesis Organization

This thesis is organized into five chapters. Chapter Two reviews in detail the problem definition and the planning process. In Chapter Three, we present the entire model by breaking it into three sub-models: string simulation sub-model, network design sub-model and fleet and cargo assignment sub-model; each sub-model is described by its objective, algorithm, and the output. The user interface development is introduced in Chapter Four, with its function and designing. In Chapter Five, we conclude the research with its final output, result, and its evaluation. Afterward we discuss the general use of this model, the pros and cons of it, as well as the applications and scope for future work.

# Chapter 2

# Problem Definition and Planning Process

This chapter outlines the problem definition of the fleet allocation model, as well as the specifications related to the case for Hampton Shipping. In addition, it covers the decisions and design specifications made concerning the model. This chapter is to functionally outline the requirements and complete solution seeking process to the proposed fleet allocation model and the user interface development problem.

## 2.1 Problem Definition

The primary objective of this research is to study such a model that can be used to obtain an optimal allocation of available fleet to maximize the profit of carrier, by presenting the process of a case study using data from a hypothetical United States liner—Hampton Shipping. Considering the background information of Hampton Shipping we discussed at Chapter One, we can define the problem with its specifications concerning the hypothetical operating situation of Hampton Shipping.

In this specific case, the problem discussed is the network design and fleet allocation problem in Trade Lane I and Trade Lane II of Hampton Shipping. To be more precise, the question is: *How do we design scheduled network services and allocate the fleet properly to carry all the desired container volume and maximize the company's total annual profit?*

To solve the problem, we need to declare the problem definition and limitations in details, as discussed below.

**Objectives**:

- **Simulate all feasible fleet allocation solutions**

  The model for this problem can simulate all feasible fleet allocation solutions to carry all the demanded container volume. The objective of this model is not only to obtain the single one optimized solution, but also to track all the reasonable optimal answers and enlarge the potential solution field. It provides carriers an opening solution field to support decisions of non-economic purpose.

- **Output annual profit sheet**

  Based on the feasible fleet allocation solutions simulated, the model can calculate and output an annual profit sheet for each solution, including the revenue, cost, and profit for each service.

- **Output load information at port**

  The model's outputs can show the cargo unloaded and loaded information at each port, as well as the equipment flow in each market.

- **Provide user interact**

  The models allow users to change key operating characteristics, compare results, and quickly focus on the key characteristics and options that are most relevant.

- **Provide the ability of sensitivity analysis**

  Users can evaluate hundreds or thousands of fleet allocation scenarios by changing the value of variables. Users can execute sensitivity analysis independently, as well as be aware of the change of the assignment to rearrange adjustment.

The model also allows the user to see all the model inputs, described below.

**Inputs:**

- **Ships**

  The model starts by considering all existing ships in the current fleet plus potential new vessels being considered. Ships are defined in terms of FEU capacity, sea speed, operating costs, fuel consumption and capital costs (typically represented by annual lease costs).

The detail input data of ships is shown at Chapter Three.

- **Cargo**

Port to port cargo volumes are presented in six categories (loaded and empty FEUs of Hampton and other lines with contractual agreements). Freight rates are included for each port pair for each of the six categories. The slot charter agreement with Firm A is also included.

The detail input data of cargo is shown at Chapter Three.

- **Ports**

Each port is defined in terms of in & out time, port charges, and cargo handling costs.

The detail input data of ports is shown at Chapter Three.

The constraints used in the model are as following:

**Constraints**

- **Fixed Day-of Week Sailings**

In order to maintain fixed day-of-week sailings, all possible combinations of strings of similarly sized ships must be considered. By definition, strings of two ships must have a 14 day time for a round trip voyage; strings of three ships, 21 days, etc. Where ships make a round trip in a number of days not divisible by 7 (e.g. 10.5 days), the itinerary is adjusted in order to keep the weekly service constraint (e.g. an itinerary that includes 2 round trips for a total of 21 days).

- **Large diesel-generator vessels**

The large diesel-generator vessels are required for the transportation of reefer containers.

- **Satisfied total demand volume**

All the feasible proposals should be based on carrying all desired container volume between each pair of port.

- **Satisfied demand volume for each vessel**

The capacity of each vessel should be greater than the volume.

We discuss all the objectives, inputs, constraints in a great detail in Chapter Three.

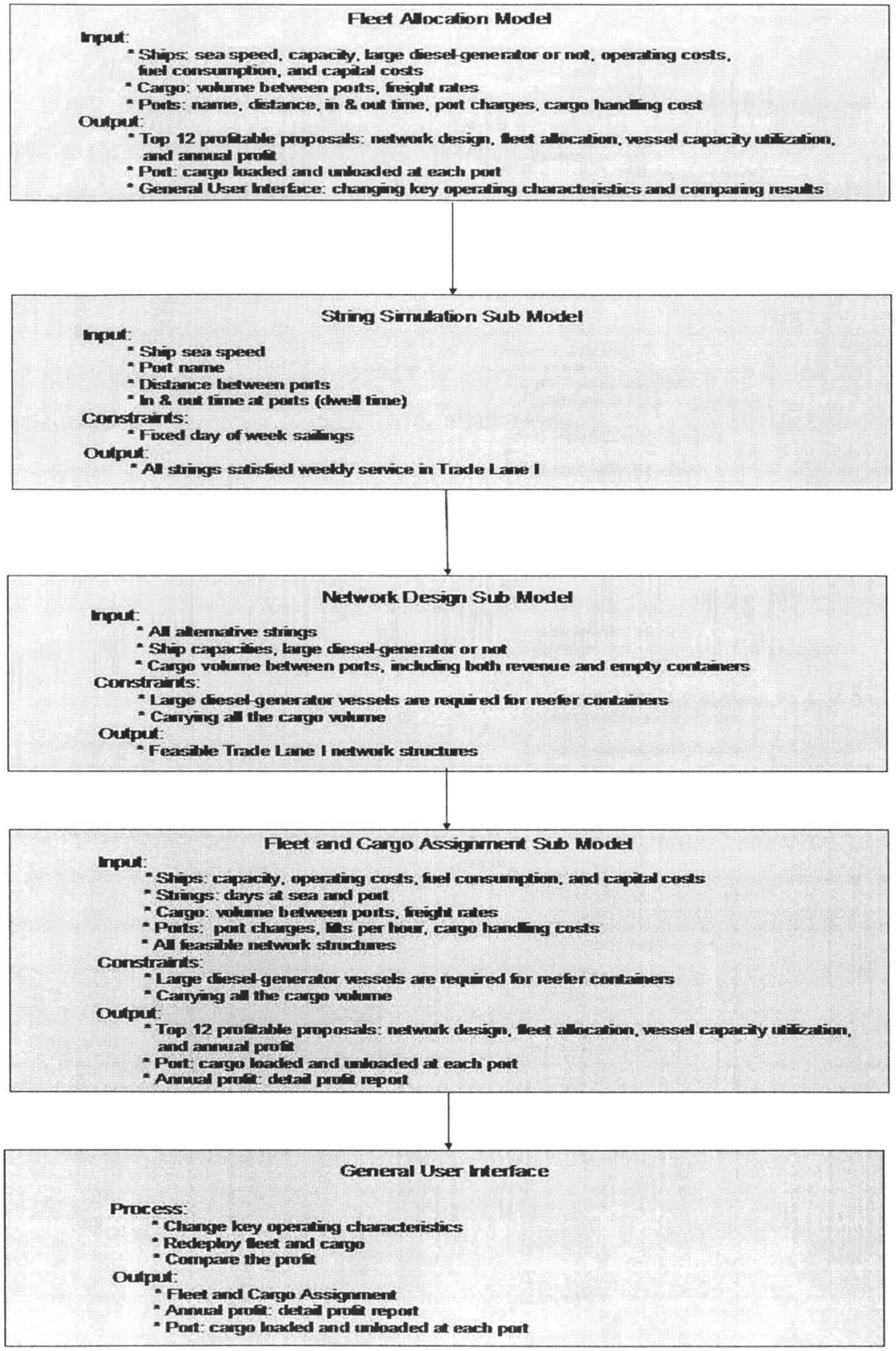
## 2.2 Planning Process

The goal of this problem is to maximize annual profits by efficiently using existing (and possibly additional) vessel capacity. The solution to handle the desired cargo flow may require redesigning the network structures and replacing some part of the fleet. The level of service should not be degraded in the solution. In our modeling process, we change the network structures as well as the fleet allocation to obtain an economical way to solve the capacity problem. All our modeling process is based on this approach.

We subdivide this complex problem into three simple models and one graphic user interface (GUI) development. The models include: string simulation sub-model, network design sub-model, and fleet and cargo assignment sub-model; the user interface allows users to change some key operating characteristics to compare the effects of them. The input, constraints, and output of each model are shown in Figure 2—1. We introduce each sub-model and describe it in detail in the following chapters.

Considering the complexity of this problem, it is difficult to solve the fleet allocation problem and to output all required information by building a single model. From the design of strings, to the structure of networks, until the final fleet and cargo assignment, the model involves many levels of variables with millions of combinations of them. Thus, it is helpful if we divided the model into several sub-models, and solve one at a time. Based on the output of one sub-model, we could eliminate the infeasible solutions and narrow the scope of the next sub-model. Thus we can increase the efficiency of the model, and focus on the feasible solutions only. We are trying to split an entire stochastic problem into several deterministic sub-problems, and smooth the solving process.

Figure 2—1 Flowchart of Fleet Allocation Model and User Interface Development



**Fleet Allocation Model**

Input:
- * Ships: sea speed, capacity, large diesel-generator or not, operating costs, fuel consumption, and capital costs
- * Cargo: volume between ports, freight rates
- * Ports: name, distance, in & out time, port charges, cargo handling cost

Output:
- * Top 12 profitable proposals: network design, fleet allocation, vessel capacity utilization, and annual profit
- * Port: cargo loaded and unloaded at each port
- * General User Interface: changing key operating characteristics and comparing results

**String Simulation Sub Model**

Input:
- * Ship sea speed
- * Port name
- * Distance between ports
- * In & out time at ports (dwell time)

Constraints:
- * Fixed day of week sailings

Output:
- * All strings satisfied weekly service in Trade Lane I

**Network Design Sub Model**

Input:
- * All alternative strings
- * Ship capacities, large diesel-generator or not
- * Cargo volume between ports, including both revenue and empty containers

Constraints:
- * Large diesel-generator vessels are required for reefer containers
- * Carrying all the cargo volume

Output:
- * Feasible Trade Lane I network structures

**Fleet and Cargo Assignment Sub Model**

Input:
- * Ships: capacity, operating costs, fuel consumption, and capital costs
- * Strings: days at sea and port
- * Cargo: volume between ports, freight rates
- * Ports: port charges, lifts per hour, cargo handling costs
- * All feasible network structures

Constraints:
- * Large diesel-generator vessels are required for reefer containers
- * Carrying all the cargo volume

Output:
- * Top 12 profitable proposals: network design, fleet allocation, vessel capacity utilization, and annual profit
- * Port: cargo loaded and unloaded at each port
- * Annual profit: detail profit report

**General User Interface**

Process:
- * Change key operating characteristics
- * Redeploy fleet and cargo
- * Compare the profit

Output:
- * Fleet and Cargo Assignment
- * Annual profit: detail profit report
- * Port: cargo loaded and unloaded at each port

We subdivide this complex problem into three simple models and one graphic user interface (GUI) development. The first sub-model—string simulation—uses the information on existing strings and the distance between each pair of ports; estimates the vessel sailing speed, transit time at sea, and dwelling time at port, then simulates all strings satisfied by the constraint of a weekly service (i.e. the number of days of the round trip must be divisible by 7).

In Step II, based on all possible strings, we design networks and allocate vessels. The eligible network structures should provide links between each pair of ports that has cargo flow, as well as consider the requirement of reefer container transportation.

The fleet and cargo assignment sub-model is the most important step of this model. Inheriting the feasible network structures and fleet allocation from former steps, we calculate the detailed information of cargo deployment, vessel capacity utilization, and the cargo loaded and unloaded at each port. Besides these, we break down the revenue, cost, and profit structure for each proposal to get the total trade lane earnings before interest, tax, depreciation and amortization (EBITDA). (Technically, this is not a true EBITDA calculation since we include annual lease payments as capital costs.)

After these three steps for the modeling, we develop a graphic user interface (GUI) to support user simulating different scenarios by changing key characteristics of operation. By comparing the changes in costs and profits of each element, we provide the user the ability of sensitivity analysis. The model provides the user with a direct view to realize the relevance of operation elements.

The model can easily be modified to change such variables as the cargo volume, freight rates, and number and characteristics of ships. If small changes in volume (or other factors) do not produce changes in the "optimal" fleet allocation, then the user knows that the results are not particularly sensitive to those changes. If the results are altered with these small changes in inputs, then the user knows that these factors require careful attention.

In the following chapters, we discuss each step in a great detail. Chapter Three presents each of the sub-models, and Chapter Four outlines the user interface development.

# Chapter 3

# Modeling Process and Algorithm Description

This chapter describes the modeling process and algorithm of the fleet allocation model by discussing each of its sub-models—string simulation sub-model, network design sub-model, and fleet and cargo assignment sub-model in a great detail. It covers the problem description, the algorithm, the implementation in optimal programming language, and the output of each sub-model.

## 3.1 String Simulation Sub-Model

This section describes the string simulation sub-model of the fleet allocation model We begin from the problem description, including the objectives, required data, and the constraint. Then we discuss the modeling algorithm as well as how to implement it into the optimal programming language. After that, the output of the string simulation sub-model is presented.

### 3.1.1 Problem Description

Building the string simulation sub-model is the first step in the entire problem solving process. All the further optimization modeling and analysis processes are based on the feasible strings simulated. The sub-model enumerates all the possible strings that the carrier can provide for weekly services. This model provides the raw shape of the ocean transportation network that could be further optimized in the following sub-models, and it only reflects the supply ability of the carrier without considering the market demand or any of the economic factors.

As we know, ocean transportation has fewer requirements on the infrastructure, hence for most carriers, if there are two seaports existing; carriers can develop a voyage between those two ports without facing infrastructure barriers as other modes do. Technically, for any two seaports, carriers could develop two voyage legs, an inbound voyage and an outbound voyage, between them, no mater how little the demand in that market and how long the shipping distance could be. For example, there are seven ports in the Trade Lane I of Hampton Shipping, and thus we could obtain total $P_7^2 = 7 \times 6 = 42$ different voyage legs which provide links between all pair of ports.

In addition to the original and destination of a voyage leg, we can describe it by other parameters, such as the voyage distance and the sailing time. Accompanied with the dwell time, the in and out time of each port, we can enumerate all the possible sequence sets of these forty two voyage legs, as well as their total trip time, and then select the ones which satisfy the weekly service rule.

Currently the main shortage of vessel capacity arises in the U.S. West Coast/Asia trade route; hence, in this section, we simulate only the strings in the U.S. West Coast/Asia trade route, which consists of seven ports -U.S. Port A, U.S. Port B, U.S. Port C, U.S. Port D, Non U.S. Port R, Non U.S. Port S, and Non U.S. Port T.

The string simulation sub-model can be described as the following:

### Objective

Use OPL Studio or other programming languages to enumerate all possible strings suitable for a weekly service in the U.S. West Coast/Asia Trade Lane I. There are millions of ways to set the sequence of voyage legs, 120 of which are looped strings:

$C_7^2 + C_7^3 + C_7^4 + C_7^5 + C_7^6 + C_7^7 = (7 \times 6 \div 2) \times 2 + (7 \times 6 \times 5 \div 3 \div 2) \times 2 + (7) + (1) = 120$ .

Furthermore, the weekly service rule could eliminate the majority of these strings. Hence, the scope of the network has been significantly narrowed down. The sub-model reduces the redundant work in the following modeling process, and increases the efficiency of the optimization process.

## Data Required

- Ship sea speed is estimated as 21 knots which is described in the next section.
- Distance between ports is depicted in Table 3—1.

**Table 3—1 Distance between Ports in Nautical Miles**

| From\To | U.S. Port A | U.S. Port B | U.S. Port C | U.S. Port D | Non U.S. Port R | Non U.S. Port S | Non U.S. Port T |
|---|---|---|---|---|---|---|---|
| U.S. Port A | x | 151.02 | 1387.42 | 4206.02 | 8801.86 | 11045.34 | 160.79 |
| U.S. Port B | 611.13 | x | 99.23 | 1026.69 | 459.73 | 392.77 | 1906.19 |
| U.S. Port C | 510.82 | 12.24 | x | 1528.80 | 5880.72 | 4547.91 | 4549.06 |
| U.S. Port D | 1663.50 | 3814.18 | 2076.57 | x | 2025.82 | 9438.99 | 7324.52 |
| Non U.S. Port R | 9862.85 | 2590.83 | 10108.84 | 356.22 | x | 2975.41 | 2940.85 |
| Non U.S. Port S | 5373.90 | 3641.55 | 9547.12 | 3400.23 | 2826.50 | x | 135.73 |
| Non U.S. Port T | 710.54 | 4161.86 | 5958.51 | 4641.84 | 1129.33 | 674.36 | x |

- Average in and out time at ports (dwell time before cargo handling) is depicted in Table 3—2; this is the average port time.

**Table 3—2 Dwell time at Ports**

| | In and Out Time (Days) |
|---|---|
| U.S. Port A | 1.3 |
| U.S. Port B | 1 |
| U.S. Port C | 1.3 |
| U.S. Port D | 1.1 |
| Non U.S. Port R | 0.8 |
| Non U.S. Port S | 0.6 |
| Non U.S. Port T | 0.6 |

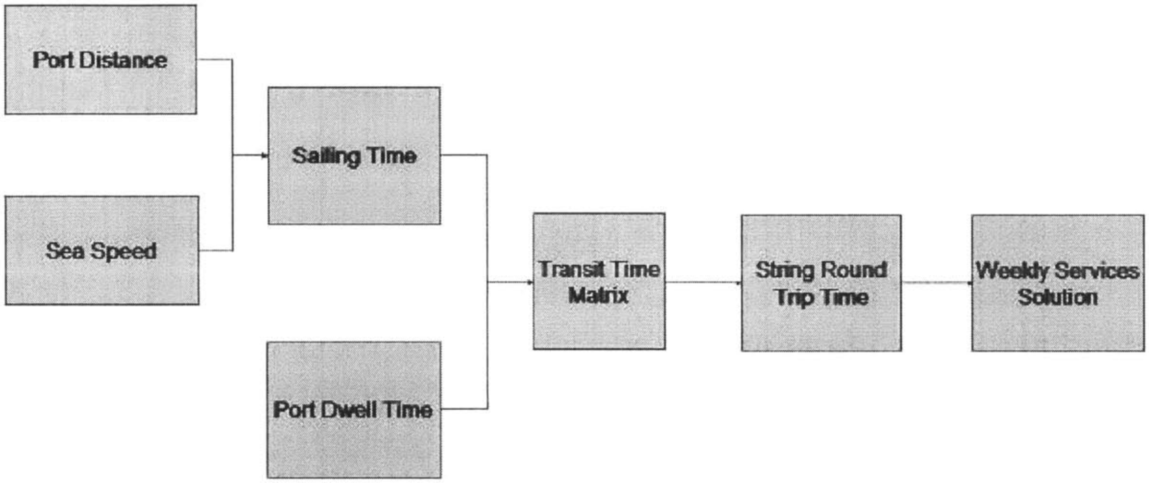
## Constraints

- For a continuous string, the beginning of a voyage leg should be the ending of the last voyage leg.
- For a looped string, the ending of the last voyage leg is the beginning of the first voyage leg. That is, the string begins at its voyage base as well as ends at the same base.
- For a fixed day-of-week sailing, the round trip time of a string has to satisfy the weekly service rule.

## 3.1.2 Algorithm for String Simulation Sub-Model

The string simulation sub-model requires enumerating all the qualified services for the network. The figure below shows the general task flow of this sub-model:

**Figure 3—1 String Simulation Sub-Model Task Flow**



Currently, all of these processes are done with the assumption that there is no extra barrier (cost difference, infrastructure difficulty, etc.) among the setting of strings. The sub-model provides the carrier with all the possible strings that allow for a condition to be set for the application of the network.

The first mission of the string simulation sub-model is to obtain a transit time matrix, which consists of the sailing time at sea between ports and the average dwell time at each port. This is achieved by processing existing data, including port distances, sailing speed, and average dwell time.

For generating the strings we require the distance between various ports. This is represented in Table 3—1.

In this model, the sailing speed at sea is estimated as 21 knots, which is the speed of the fastest vessel in the existing fleet. The model uses the highest speed to provide real trips more flexibility. Essentially, in the real word, it is more practical to slow down and spend more time at port rather than speed up and accelerate the loading process. Additionally, for the commercial ships, there is no significant difference in speed for technical, safety, and economy reasons. Therefore, 21 knots is a realistic estimate imitating the sailing speed for all the vessels.

Typically, we obtain the sailing time at sea by dividing the distance by the estimated sailing speed 21 knots. Together with the average dwell time at each port, we acquire the transit time matrix, which includes the sailing time at sea and the average dwell time at port, as shown in Table 3—3.

**Table 3—3 Transit Time Matrix (The Diagonal Represents the Average Dwell Time at Ports; Others Shows the Sailing Time between Two Ports)**

| | U.S. Port A | U.S. Port B | U.S. Port C | U.S. Port D | Non U.S. Port R | Non U.S. Port S | Non U.S. Port T |
|---|---|---|---|---|---|---|---|
| U.S. Port A | 1.30 | 0.30 | 2.75 | 8.35 | 17.46 | 21.92 | 0.32 |
| U.S. Port B | 1.21 | 1.00 | 0.20 | 2.04 | 0.91 | 0.78 | 3.78 |
| U.S. Port C | 1.01 | 0.02 | 1.30 | 3.03 | 11.67 | 9.02 | 9.03 |
| U.S. Port D | 3.30 | 7.57 | 4.12 | 1.10 | 4.02 | 18.73 | 14.53 |
| Non U.S. Port R | 19.57 | 5.14 | 20.06 | 0.71 | 0.80 | 5.90 | 5.84 |
| Non U.S. Port S | 10.66 | 7.23 | 18.94 | 6.75 | 5.61 | 0.60 | 0.27 |
| Non U.S. Port T | 1.41 | 8.26 | 11.82 | 9.21 | 2.24 | 1.34 | 0.60 |

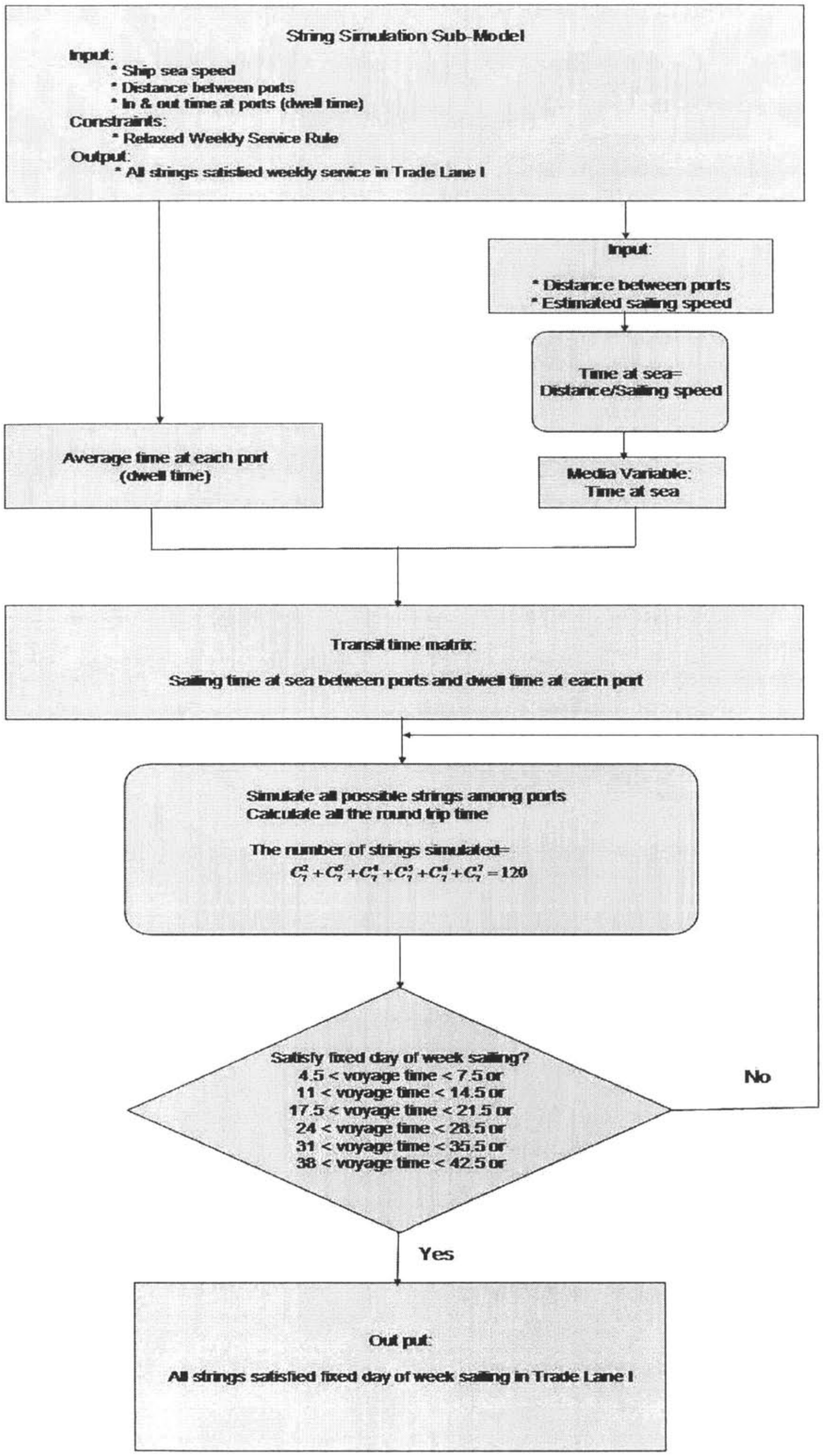
In this sub-model, we need to relax the weekly service rule by broadening the scope of fixed day-of week service. For example, based on the highest sailing speed 21 knots, a string whose round trip time is 4.5 days can adjust to a 7 day trip by slowing down the sailing speed at sea, or setting aside enough time for port queuing. On the other hand, it is not pragmatic for a vessel to speed up and work in a tight schedule to catch a weekly sailing. Hence, we provide the following definition of a relaxed fixed day-of week service:

A string is deemed as a 7 day sailing, if the round trip time is from 4.5 days to 7.5 days;
A string is deemed as a 14 day sailing, if the round trip time is from 11 days to 14.5 days;
A string is deemed as a 21 day sailing, if the round trip time is from 17.5 days to 21.5 days;
A string is deemed as a 28 day sailing, if the round trip time is from 24 days to 28.5 days;
A string is deemed as a 35 days sailing, if the round trip time is from 31 days to 35.5 days.

Now we have attained all the required input data and the constraints. We can use OPL Studio or other programming languages to write the code, solve the problem, and help us to obtain all the qualified weekly services.

Based on our objective and available data, we represent the solution process as a flowchart, depicted in Figure 3—2.

Figure 3—2 Flowchart of the String Simulation Sub-Modal



### 3.1.3 Mixed Integer Problem Formulation and Implementation Using OPL

The sub-model can be modeled into a linear programming problem, and the object and the constraints can be rewritten into several mathematical functions. The problem can be described as:

$$Solve(i, j, k, l, m, n, o) \qquad \forall\, i, j, k, l, m, n, o \in \{All\ Seven\ Ports\}$$

$$\left\{\begin{array}{ll}
if\ \{T_{ii} + T_{ij} + T_{jj} + T_{ji} \in W\}; & //\ Service\ Time\ for\ Two\ Port\ Service \\
or\ if\ \{T_{ii} + T_{ij} + T_{jj} + T_{jk} + T_{kk} + T_{ki} \in W\}; & \\
or\ if\ \{T_{ii} + T_{ij} + T_{jj} + T_{jk} + T_{kk} + T_{kl} + T_{ll} + T_{li} \in W\}; & \\
or\ if\ \{T_{ii} + T_{ij} + T_{jj} + T_{jk} + T_{kk} + T_{kl} + T_{ll} + T_{lm} + T_{mm} + T_{mi} \in W\}; & \\
or\ if\ \{T_{ii} + T_{ij} + T_{jj} + T_{ji} + T_{kk} + T_{kl} + T_{ll} + T_{lm} + T_{mm} + T_{mn} + T_{nn} + T_{ni} \in W\}; & \\
or\ if\ \{T_{ii} + T_{ij} + T_{jj} + T_{ji} + T_{kk} + T_{kl} + T_{ll} + T_{lm} + T_{mm} + T_{mn} + T_{nn} + T_{no} + T_{oo} + T_{oi} \in W\}; & \\
W \in \{4.5, 7.5\} \cup \{11, 14.5\} \cup \{17.5, 21.5\} \cup \{24, 28.5\} \cup \{31, 35.5\} \cup \{38, 42.5\}; & //\ Weekly\ Service\ Rule
\end{array}\right\}$$

We use OPL Studio and CPLEX to solve the problem and obtain all the feasible 13692 strings, 120 of which are unique. From this feasible set, we eliminate those strings which do not satisfy the fixed day-of week services.

### 3.1.4 Output from the String Simulation Sub-Model

The solution to the string simulation model provides the following number of possible strings with varying lengths of time: one 7-day sailing, three 14-day sailings, two 21-day sailings, nineteen 28-day sailings, and twenty-one 35 day sailings, as shown in Table 3—4.

**Table 3—4 Output from the String Simulation Sub-Model**

| String Type | String Description |
|---|---|
| 7-day sailing | UPA--UPB--UPA |
| 14-day sailing | UPC--UPD--UPC |
| | UPA--UPB--UPD--UPA |
| | UPB--UPC--UPD--UPB |
| 21-day sailing | UPD--NPS--UPD |
| | UPD--NPR--NPT--UPD |
| 28-day sailing | UPA--NPS--UPA |
| | UPB--NPS--UPB |
| | UPA--UPB--NPR--UPA |
| | UPA--UPB--NPS--UPA |
| | UPA--UPC--NPR--UPA |
| | UPA--UPD--NPS--UPA |
| | UPA--NPR--NPS--UPA |
| | UPA--NPS--NPT--UPA |
| | UPB--UPC--NPR--UPB |
| | UPB--UPC--NPS--UPB |
| | UPB--UPD--NPS--UPB |
| | UPB--NPR--NPS--UPB |
| | UPB--NPS--NPT--UPB |
| | UPC--UPD--NPR--UPC |
| | UPC--NPR--NPT--UPC |
| | UPA--UPB--UPC--NPR--UPA |
| | UPA--UPB--UPD--NPR--UPA |
| | UPA--UPC--UPD--NPR--UPA |
| | UPB--UPC--UPD--NPR--UPB |
| 42-day sailing | UPA--UPC--UPD--NPS--UPA |
| | UPA--UPC--NPR--NPS--UPA |
| | UPB--UPC--UPD--NPS--UPB |
| | UPA--UPB--UPC--UPD--NPS--UPA |
| | UPA--UPB--UPC--NPR--NPS--UPA |
| | UPA--UPB--UPC--NPS--NPT--UPA |
| | UPA--UPB--UPD--NPR--NPS--UPA |
| | UPA--UPB--UPD--NPS--NPT--UPA |
| | UPA--UPB--NPR--NPS--NPT--UPA |
| | UPA--UPC--UPD--NPR--NPS--UPA |
| | UPA--UPC--UPD--NPS--NPT--UPA |
| | UPA--UPC--NPR--NPS--NPT--UPA |
| | UPB--UPC--UPD--NPR--NPS--UPB |
| | UPB--UPC--UPD--NPS--NPT--UPB |

| | |
|---|---|
| | UPB--UPC--NPR--NPS--NPT--UPB |
| | UPA--UPB--UPC--UPD--NPR--NPS--UPA |
| | UPA--UPB--UPC--UPD--NPS--NPT--UPA |
| | UPA--UPB--UPC--NPR--NPS--NPT--UPA |
| | UPA--UPB--UPD--NPR--NPS--NPT--UPA |
| | UPA--UPC--UPD--NPR--NPS--NPT--UPA |
| | UPB--UPC--UPD--NPR--NPS--NPT--UPB |

We use these output strings as the input data for the next step: itinerary design sub-model. We can notice that existing services—US3 (UPB—UPC—UPD—UPB) and IN1 (UPA—UPB—UPD—NPR—NPS—NPT—UPA) are already presented. This verifies and validates the solution we have obtained for the string simulation sub-model.

## 3.2 Network Design Sub-Model

This section describes the network design sub-model of the fleet allocation model. We begin from the problem description, including the objectives, required data, and the constraint. Then we discuss the modeling algorithm as well as how to implement it into the optimal programming language. After that, the output of the network design sub-model is presented.

### 3.2.1 Problem Description

Referring to the output of the string simulation sub-model, the scope of the candidate services has been constricted into 46, compared to the former 120. This extraction contributes to confine the number of enumerations in the network design sub-model from at least $C_{120}^{3} = 120\times119\times118\div3\div2 = 280840$ times to $C_{46}^{3} = 46\times45\times44\div3\div2 = 18216$ times; correspondingly, the simulation load is decreased into only six percent.

The ambition of the fleet allocation model is to deliver the most profitable way to carry all the cargo; hence all the potential solutions are restricted into the ones that can meet the cargo demand.

In this sub-model, we need to investigate all the diverse combinations of the candidate strings— the network structure, and identify the ones which have the ability to carry the desired cargo volume in all the markets with the feasible ships and eliminate the others. To achieve this, we use the output of the string simulation sub-model and the data of available vessels as well as the demand in each market to obtain acceptable network structures for the U.S. West Coast/Asia Trade Lane I. In this process, we roughly assign the fleet into the network and calculate the maximum carrying capacity of each market of the network, which helps us to eliminate the infeasible networks.

In this case we reassign all the fleet in the U.S. continent/Trade Lane I, and only evaluate the remaining ships in the U.S. continent/Trade Lane II.

The network design sub-model can be described as following:

### Objective

Use OPL Studio or other programming languages to enumerate all the possible combinations of candidate strings to build the ocean transportation network structure; roughly assign the potential fleet into the network and search for the network which has the capacity to carry all desired cargo volume at each market. All the feasible network solutions will serve as the base of the final fleet allocation problem. Appendix I provides a description of OPL Studio.

### Data Required

- The output from the string simulation sub-model: all 46 feasible strings as shown in Table 3—4.
- Ship characteristics as shown in Table 3—5, including capacity and whether the ship is equipped with large diesel-generator or not.

**Table 3—5 Ship Characteristics**

| Vessel Name | Capacity Unit (FEU) | Equipped with large diesel-generator |
|---|---|---|
| FN1 | 1000 | No |
| FN2 | 1000 | No |
| FN3 | 1000 | No |
| FN4 | 1000 | No |
| FN5 | 1000 | No |
| FN6 | 1000 | No |
| UJ1 | 910 | Yes |
| UJ2 | 910 | Yes |
| UJ3 | 880 | Yes |
| UJ4 | 880 | Yes |
| UJ5 | 880 | Yes |
| UJ6 | 880 | Yes |
| UJ7 | 725 | Yes |
| UJ8 | 700 | Yes |
| UJ9 | 650 | Yes |
| UJ10 | 650 | Yes |
| UJ11 | 600 | Yes |
| UJ12 | 600 | Yes |
| UJ13 | 600 | Yes |

- Cargo demand volume in each market, including revenue and empty containers, Table 3—6 shows the revenue FEU demand volume.

**Table 3—6 FEU Demand in all Markets in Trade Lane I**

| From\To | U.S. Port A | U.S. Port B | U.S. Port C | U.S. Port D | Non U.S. Port R | Non U.S. Port S | Non U.S. Port T |
|---|---|---|---|---|---|---|---|
| U.S. Port A | * | - | - | 206 | 30 | - | - |
| U.S. Port B | - | * | - | 406 | 302 | - | - |
| U.S. Port C | - | - | * | 892 | 43 | - | - |
| U.S. Port D | 16 | 42 | 76 | * | 143 | - | - |
| Non U.S. Port R | 21 | 50 | - | 20 | * | - | - |
| Non U.S. Port S | 596 | 304 | - | 60 |  | * | - |
| Non U.S. Port T | - | - | - | - | - | - | * |

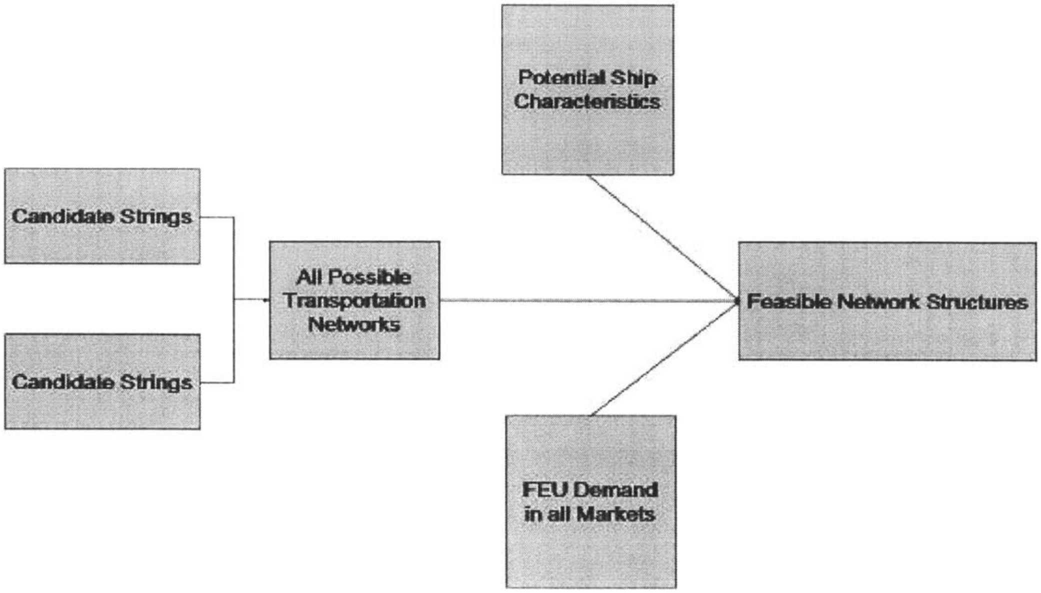
## Constraints

- The total network carrying capacity in a market can be declared as the sum of the capacity by all the capacities through every feasible itinerary, including both direct sailing and transshipment sailing.
- The total network carrying capacity in any market should be greater than the FEU demand of that market.
- The individual carrying capacity of a ship is subject to the large diesel-generator constraint; that is to say only the ship equipped with large diesel-generator can carry the reefer containers between two U.S. seaports, while the carrying capacity of those vessels without being equipped with large diesel-generator ships in a U.S. reefer market is zero.

## 3.2.2 Algorithm for Network Design Sub-Model

The network design sub-model leverages all the data related to strings, ships, and cargo to build the feasible transportation networks structure. The figure below shows the general task flow of this sub-model:

**Figure 3—3 Network Design Sub-Model Task Flow**



Exercising the data from Table 3—6, we could obtain the volume of empty containers through the equipment balance constraint in every market, which is shown in Table 3—7.

**Table 3—7 Empty Container Flow in Trade Lane I (FEU)**

| From\To | U.S. Port A | U.S. Port B | U.S. Port C | U.S. Port D | Non U.S. Port R | Non U.S. Port S | Non U.S. Port T |
|---|---|---|---|---|---|---|---|
| U.S. Port A | * | - | - | - | - | - | - |
| U.S. Port B | - | * | - | - | - | - | - |
| U.S. Port C | - | - | * | - | - | - | - |
| U.S. Port D | - | 200 | 574 | * | - | 515 | - |
| Non U.S. Port R | 30 | 35 | - | - | - | 320 | - |
| Non U.S. Port S | - | - | - | - |  | * | - |
| Non U.S. Port T | - | - | - | - | - | - | * |

On the basis of Table 3—6 and 3—7, we obtain the flow of total container demand as shown in Table 3—8.

**Table 3—8 Total Container Demand Flow in Trade Lane I (FEU)**

| From\To | U.S. Port A | U.S. Port B | U.S. Port C | U.S. Port D | Non U.S. Port R | Non U.S. Port S | Non U.S. Port T | Total |
|---|---|---|---|---|---|---|---|---|
| U.S. Port A | * | - | - | 186 | 30 | - | - | 216 |
| U.S. Port B | - | * | - | 306 | 302 | - | - | 608 |
| U.S. Port C | - | - | * | 743 | 43 | - | - | 786 |
| U.S. Port D | 16 | 242 | 345 | * | 143 | 450 | - | 1196 |
| Non U.S. Port R | 51 | 85 | - | - | * | 320 | - | 456 |
| Non U.S. Port S | 456 | 304 | - | 60 |  | * | - | 820 |
| Non U.S. Port T | - | - | - | - | - | - | * | 0 |
| Total | 523 | 631 | 345 | 1295 | 518 | 770 | 0 | 4082 |

Before we formulate the problem in the solver, we can compare all the data we have on the demand volume with the supply capacity of the available vessels. This analysis helps us restrict the potential solution in a much more narrow scope, and avoid the redundant simulation work afterwards. Based on the information from Table 3—5 and Table 3—8, we can derive the following conclusions as new constraints:

1. The total weekly demand volume from the U.S. West Coast ports (U.S. Port A, U.S. Port B, U.S. Port C) to U.S. Port D is 1295 FEU, while the carrying capacity of the largest

ship is 1000 FEU, thus there must be at least two strings between the U.S. West Coast ports and U.S. Port D market, otherwise the network is apparently infeasible.

2. The total weekly demand volume from Non U.S. Port S to the U.S. West Coast ports (U.S. Port A, U.S. Port B, U.S. Port C) is 996 FEU, including the revenue and the empty containers, which is only less than the carrying capacity of the largest vessel. However, if there is only one service in this market, the fleet should be formed by the largest vessels without being equipped with large diesel-generator instead of the smaller vessels being equipped with large diesel-generator, consequently the non-large diesel-generator fleet cannot carry the cargo inside the U.S. reefer markets.
3. To avoid an extremely low level of service, we would not consider the situation where transshipment occurs more than once for a specific container in its trip.

With the above conclusions serving as extra constraints, we can restrict the potential solution field into a much narrower scope, which eliminates the redundant work.

Currently, Hampton Shipping is assigning seven vessels to Trade Lane I. With the fixed demand in the future, we could calculate the predetermined revenue, thus our goal is to optimize the overall cost, a direct way of which is to reduce the number of running vessels. We could classify the networks by the number of vessels. Generally, we will choose the structure of network with the least number of vessels to satisfy all the demand. Table 3—9 lists all the possible network structure from seven vessels to nine vessels from composed by the available strings simulated from string simulation. (Please note there is only one 7-day sailing, three 14-day sailings, two 21-day sailings, nineteen 28-day sailings, and twenty-one 35-day sailings available.)

**Table 3—9 List of Network Structures and Feasibility**

| | 7-Day/1 Ship | 14-Day/2 Ships | 21-Day/3 Ships | 28-Day/4 Ships | 42-Day/6 Ships | Numbers | Feasibility |
|---|---|---|---|---|---|---|---|
| **8 Ship Network** | | | | | | | |
| 1 | | 1 | | | 1 | 63 | C |
| 2 | | | 1 | 1 | | 38 | B |
| 3 | 1 | 1 | | 1 | | 57 | C |
| 4 | 1 | | 2 | | | 1 | AB |
| 5 | | 2 | 1 | | | 6 | A |
| 6 | 1 | 3 | | | | 1 | A |
| **9 Ship Network** | | | | | | | |
| 7 | | | 1 | | 1 | 42 | C |
| 8 | 1 | 1 | | | 1 | 63 | C |
| 9 | | | | 2 | | 171 | C |
| 10 | 1 | | 1 | 1 | | 38 | C |
| 11 | | 2 | | 1 | | 57 | A |
| 12 | | 1 | 2 | | | 3 | A |
| 13 | 1 | 2 | 1 | | | 6 | A |
| **10 Ship Network** | | | | | | | |
| 14 | | | | 1 | 1 | 399 | C |
| 15 | 1 | | 1 | | 1 | 42 | C |
| 16 | | 2 | | | 1 | 63 | |
| 17 | 1 | | | 2 | | 171 | C |
| 18 | | 1 | 1 | 1 | | 114 | C |
| 19 | 1 | 2 | | 1 | | 57 | A |
| 20 | | 3 | 1 | | | 2 | A |

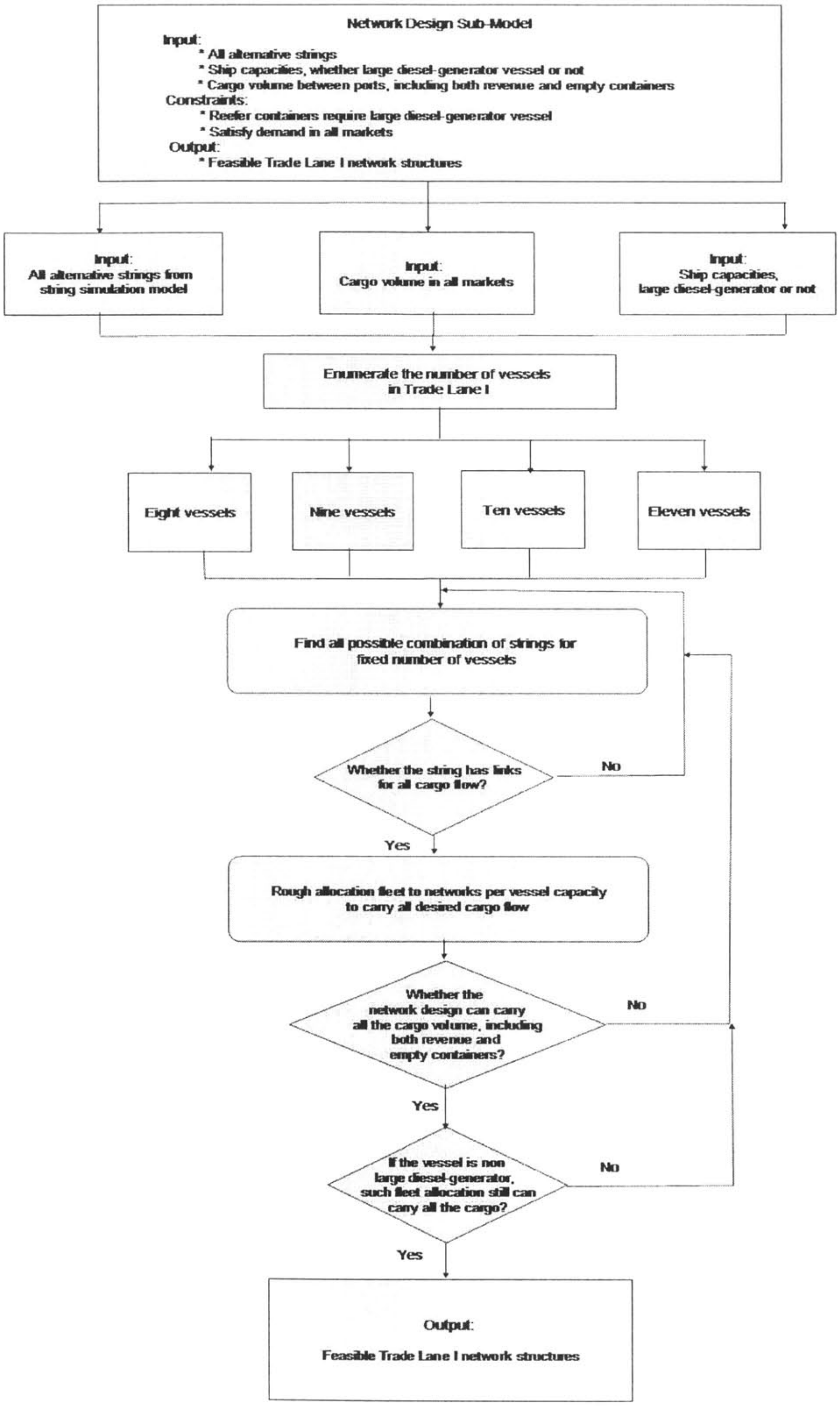
**Table 3—10 Reasons for Infeasibility**

| | Reason for Infeasibility |
|---|---|
| A | Can not provide link to all the markets |
| B | Can not satisfy constraint #1 |
| C | Can not satisfy constraint #1 and #2 in the same time |

The *Feasibility* column shows the reason why the network structure is infeasible as shown in detail in Table 3—10. In our problem, there is only one network structure that can satisfy all the constraints as well as serve the demand in all the market—one 42-day sailing, and two 14-day sailings. This conclusion reduces the further workload significantly. We can just simulate the network as the only structure by ten vessels. If this network structures is acceptable, we do not need to consider the network using eleven or more vessels to keep the lowest cost.

We represent the solving process as a flowchart, shown in Figure 3—4.

Figure 3—4 Flowchart of Network Design Sub-model



### 3.2.3 Mixed Integer Problem Formulation and Implementation Using OPL

The network design sub-model can be modeled into a linear programming problem, and the object and the constraints can be rewritten into several mathematical functions. The problem can be described as:

**Objective function:**

$$\text{Minimize } (VN_{Trade\ Lane\ I}),$$

**Constraints:**

$$\sum C_{ij} \geq \sum D_{ij},$$

$$0\% \leq U_i \leq 95\%.$$

where:

$VN_{Trade\ Lane\ I}$, denotes the number of vessels running in Trade Lane I

$C_{ij}$ denotes the capacity between port i and port j

$D_{ij}$ denotes the cargo volume between port i and port j

Following the above analysis, for this problem we obtain there is only one network structure that provides the ability to meet all the demands and satisfy all the constraints. By enumerating each structure, it presents us the entire fixed network scope we could design for the fleet allocation model. Owing to the monotony of this problem, we can list all specific network structures without using the computer. For more intricate problems, we could use the programming language to simulate all the feasible solution sets.

### 3.2.4 Output of Network Design Sub-model

The solution to the model is listed as Table 3—11. In the following sub-model, we simulate the detailed information on the feasible networks. At this point we refer to these network assignments as proposals.

**Table 3—11 Output from the network design sub-model (Please refer to Table 3—11 for service notation)**

| Proposal Name | 42 day sailing service | Slot Chartered from Firm A | 14 day sailing service | 14 day sailing service |
|---|---|---|---|---|
| Proposal 1 | IN1 | US4 | US3 | US1 |
| Proposal 2 | IN2 | US4 | US3 | US1 |
| Proposal 3 | IN3 | US4 | US3 | US1 |
| Proposal 4 | IN4 | US4 | US3 | US1 |
| Proposal 5 | IN5 | US4 | US3 | US1 |
| Proposal 6 | IN6 | US4 | US3 | US1 |
| Proposal 7 | IN7 | US4 | US3 | US1 |
| Proposal 8 | IN1 | US4 | US2 | US1 |
| Proposal 9 | IN2 | US4 | US2 | US1 |
| Proposal 10 | IN3 | US4 | US2 | US1 |
| Proposal 11 | IN4 | US4 | US2 | US1 |
| Proposal 12 | IN5 | US4 | US2 | US1 |
| Proposal 13 | IN6 | US4 | US2 | US1 |
| Proposal 14 | IN7 | US4 | US2 | US1 |

The notations are given in the following Table 3—12.

**Table 3—12 Service notation for Table 3—11**

| Service Name | Round Trip Time | Vessels Required | Routes |
|---|---|---|---|
| IN1 | 42 | 6 | UPA--UPB--UPD—NPR--NPS—UPA |
| IN2 | 42 | 6 | UPA--UPB--UPD-NPR--NPS--NPT—UPA |
| IN3 | 42 | 6 | UPA--UPC--UPD—NPR--NPS—UPA |
| IN4 | 42 | 6 | UPA--UPC--UPD--NPR--NPS--NPT—UPA |
| IN5 | 42 | 6 | UPB--UPC--UPD—NPR--NPS—UPB |
| IN6 | 42 | 6 | UPB--UPC--UPD--NPR--NPS--NPT—UPB |
| IN7 | 42 | 6 | UPA--UPB--UPC--UPD—NPR--NPS--NPT—UPA |
| US2 | 14 | 2 | UPC--UPD—UPC |
| US3 | 14 | 2 | UPB--UPC—UPD—UPB |
| US1 | 14 | 2 | UPA--UPB—UPD—UPA |
| US4 | 7 | 0 | UPC—UPD |

## 3.3 Fleet and Cargo Assignment Sub-Model

This section describes the fleet and cargo assignment sub-model of the fleet allocation model. We begin from the problem description, including the objectives, required data, and the constraint. Then we discuss the modeling algorithm as well as how to implement it into the optimal programming language. After that, the output of the fleet and cargo assignment sub-model are presented.

### 3.3.1 Problem Description

The operation sub-model is the most important step in the entire model. Inheriting the fourteen proposed network structures, we allocate the fleet and deploy cargo into each proposal Based on these precise assignments, we calculate the detailed information on cargo deployment, vessel capacity utilization, and the cargo loading and unloading factor at each port. Moreover, we break down the revenue, cost, and profit structure for each proposal to obtain the total trade lanes earnings before interest, tax, and depreciation (EBITDA) of three trade lanes.

The fleet allocation and operation optimization sub-model is described as following:

**Objectives:**

Use the network designed at the network design sub-model; simulate all the feasible fleet and cargo assignment for all these networks correspondingly. Calculate the detail operation information, including revenue, cost, and profit. Output the ten most profitable assignments, which can serve as the decision base for the carrier.

**Data Required:**

- Detail information on Strings (the output of string simulation sub-model)

- All feasible network structures (the output of network design sub-model)
- Ship Information, including carrying capacity, operating cost, fuel consumption, and capital cost.
- Cargo Information, including the volume and the freight rate for each market
- Port Information, including the port charges and the cargo handling costs

**Constraints:**

- The total fleet carrying capacity in a market can be declared as the sum of the capacity by all the capacities of vessels through every feasible itinerary, including both direct sailing and transshipment sailing.
- The total fleet carrying capacity in any market should be greater than the FEU demand of that market.
- The individual carrying capacity of a ship is subject to the large diesel-generator constraint; that is to say only the ship equipped with large diesel-generator can carry the reefer containers between two U.S. seaports, while the carrying capacity of those vessels without being equipped with large diesel-generator ships in a U.S. reefer market is zero.

**Output:**

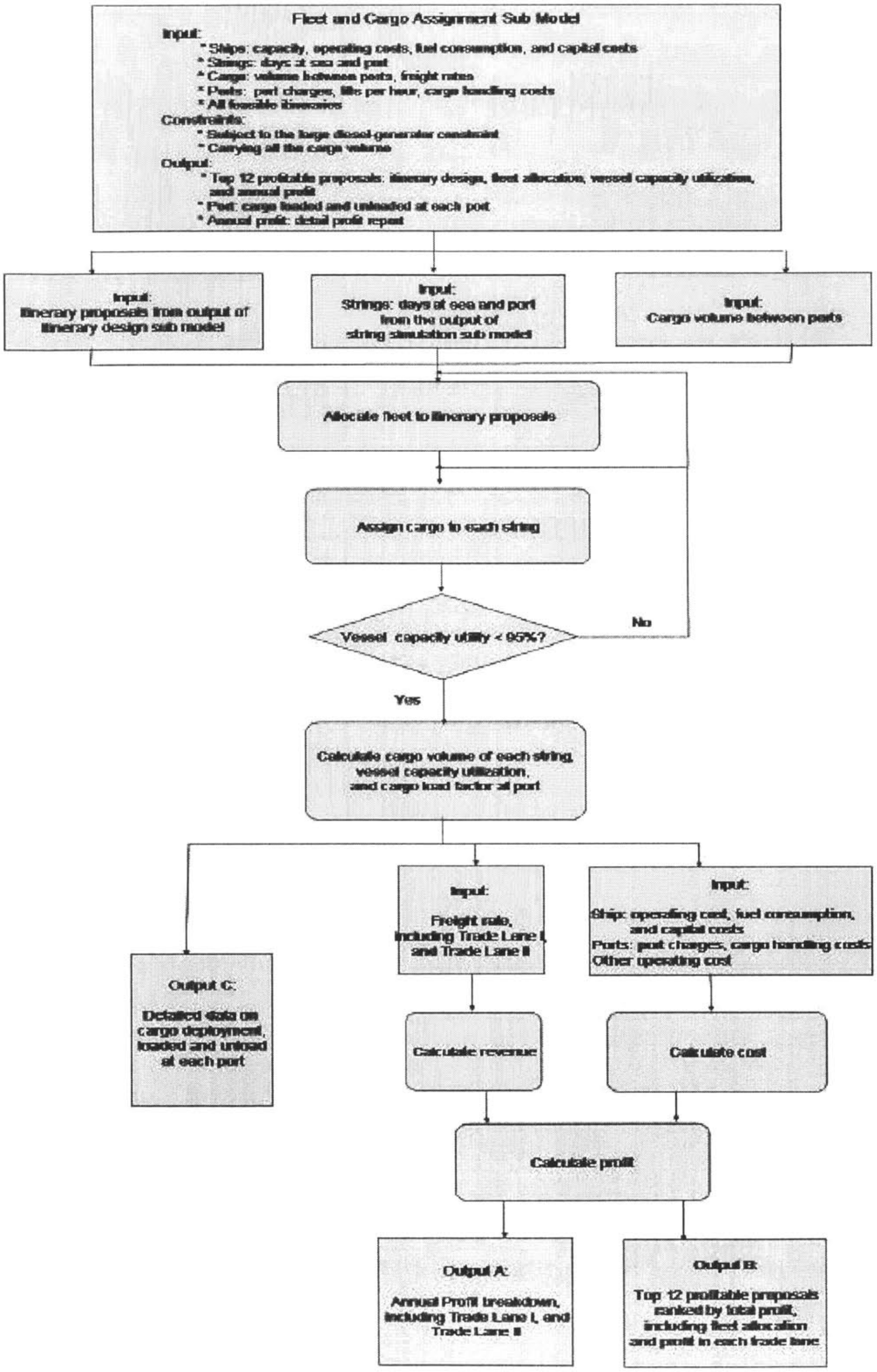
The final output of this sub-model can be separated into three parts:

- The spreadsheet on the total profit of the top ten profitable fleet and cargo assignments of Hampton Shipping, including Trade Lane I and Trade Lane II, as well as the fleet allocation.
- The spreadsheet on the revenue, cost, and profit break down for those assignments.
- The spreadsheet on the loading and unloading volume at port for those assignments.

### 3.3.2 Algorithm for Fleet and Cargo Assignment Sub-Model

Figure 3—5 shows the flowchart of the fleet and cargo assignment process.

Figure 3—5 Flowchart of the Fleet and Cargo Assignment Process.



From the network design sub-model, we obtained 14 proposals which use the least number of ships in Trade Lane I: ten vessels. In the fleet and cargo assignment sub-model, based on the output of prior sub-models, together with the cargo volume, the first step is to allocate ships and deploy cargo for each proposal. To reserve ample space for the further increase of cargo volume and season peaks, we require the vessel capacity utilization less than 95 percent in the forehaul or headhaul direction. Hence in this step, we adjust the fleet and cargo assignment, as shown in the flowchart, to achieve this purpose.

After we fix the fleet allocation of each proposal in Trade Lane I, we redeploy the remaining vessels to Trade Lane II. In both trade lanes, the fleet and cargo assignment is subject to the constraints given below:

- The individual carrying capacity of a ship is subject to the large diesel-generator constraint
- The vessels running in the same strings are of a similar size
- The vessel capacity utilizations are less than 95 percent in the forehaul direction
- Direct sailing is preferred to transshipment sailing
- The equipment movement is in balance; the cargo assignment should include the empty container

The second step of this sub-model is to calculate the detailed information on each proposal, which includes the vessel capacity utilization, cargo carried by each string, and cargo loaded and unloaded number at each port.

Based on the cargo assignment and freight rate for general customers and slot charters, we can obtain the revenue. We note the value of revenue is the same in each proposal, so the precise can be a verification of the model. In addition to this, we can calculate the cost, and EBITDA.

## 3.3.3 Fleet and Cargo Assignment Process

### 3.3.3.1 Objective & Overview

In the fleet and cargo assignment sub-model, we need to allocate vessels to the proposals that were obtained from the network design sub-model. The 14 proposals obtained from network design sub-model are tabulated in Table 3—13, and the characteristics of the vessels are shown in Table 3—5.

The objective of the fleet assignment is to assign appropriate vessels to each service (except US4 service) in Trade Lane I and Trade Lane II for each proposal. All the further operating simulations and profit calculations are based on this fleet assignment.

The fleet assignment is subject to the large diesel-generator constraint, as well as the capacity of carrying all desired cargo volume for each pair of ports.

### 3.3.3.2 Fleet and Cargo Assignment Process

The fleet assignment is modeled as a semi-automated process, which is based on both logical analyses requiring human input and further use of computer simulation. The entire process is divided into three steps:

Step 1: Default initial fleet assignments
Step 2: Assignment of fleet using computer simulation
Step 3: Adjustment

The flow chart is shown in Figure 3—6.

Figure 3—6 Flow chart of fleet assignment

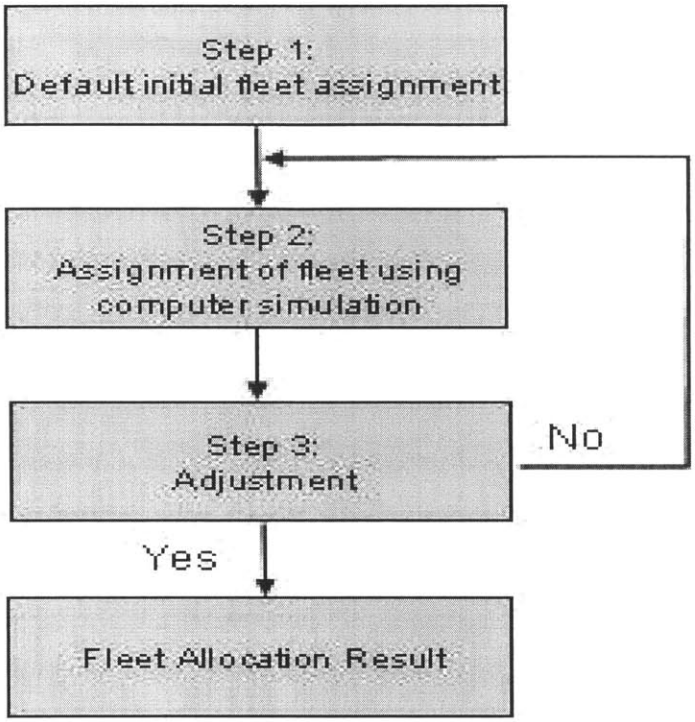


**Table 3—13 Fleet Assignment Proposals**
**(Please refer to Table 3—14 for notation)**

| Proposal Name | Trade Lane I | | | Trade Lane II | | |
|---|---|---|---|---|---|---|
| Proposal 1 | IN1 | US2 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 2 | IN2 | US2 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 3 | IN3 | US2 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 4 | IN4 | US2 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 5 | IN5 | US2 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 6 | IN6 | US2 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 7 | IN7 | US2 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 8 | IN1 | US3 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 9 | IN2 | US3 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 10 | IN3 | US3 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 11 | IN4 | US3 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 12 | IN5 | US3 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 13 | IN6 | US3 | US1 | US6/US7 | US8/US9 | US10 |
| Proposal 14 | IN7 | US3 | US1 | US6/US7 | US8/US9 | US10 |

Table 3—14 Notation for Table 3—13

| Service Name | Round Trip Time | Vessels Required | Routes |
|---|---|---|---|
| IN1 | 42 | 6 | UPA--UPB--UPD--NPR--NPS—UPA |
| IN2 | 42 | 6 | UPA--UPB--UPD--NPR--NPS--NPT—UPA |
| IN3 | 42 | 6 | UPA--UPC--UPD--NPR--NPS—UPA |
| IN4 | 42 | 6 | UPA--UPC--UPD--NPR--NPS--NPT--UPA |
| IN5 | 42 | 6 | UPB--UPC--UPD--NPR--NPS—UPB |
| IN6 | 42 | 6 | UPB--UPC--UPD--NPR--NPS--NPT--UPB |
| IN7 | 42 | 6 | UPA--UPB--UPC--UPD--NPR--NPS—NPT--UPA |
| US2 | 14 | 2 | UPC--UPD—UPC |
| US3 | 14 | 2 | UPB--UPC--UPD--UPB |
| US1 | 14 | 2 | UPA--UPB--UPD--UPA* |
| US4 | 7 | 0 | UPC—UPD |
| US6/US7 | 7 | 1 | U.S. Port E---U.S. Port F---U.S. Port E |
| US8/US9 | 14 | 2 | U.S. Port E---U.S. Port G---U.S. Port E---U.S. Port F---U.S. Port E |
| US10 | 21 | 1 | U.S. Port E---U.S. Port I---U.S. Port H---U.S. Port E---U.S. Port H---U.S. Port E |

## Step 1: Default Initial Fleet Assignment

Before we begin the fleet assignment process, we need to analyze the available data, get the basic logical relationship among each element, and fix the initial assignment to make the computation efficient. Specifically, we need to analyze the network structures, vessels, and cargo characteristics.

**After analyzing 14 *network proposals,* we observe the following:**

- The International service (IN1/IN2/IN3/IN4/IN5/IN6/IN7) is the only service available from Non U.S. Port S to the U.S. West Coast for dry constrainer trade.
- All the three services of each proposal sail from the U.S. West Coast to U.S. Port D.

**After analyzing *the desired cargo volume,* we observe:**

- The weekly volume from Non U.S. Port S to the U.S. West Coast is 920 FEUs.
- The weekly volume from U.S. West Coast to U.S. Port D is 1402 FEUs.

**After analyzing *the ship characteristics*, we observe:**

- The capacities of four largest large diesel-generator vessels are 910, 910, 880, and 880 FEUs.
- The capacity of each non large diesel-generator vessel is 1000 FEUs.

From above information regarding vessels, networks, and cargo, we can obtain some basic conclusions regarding fleet assignment:

The vessels running at the international dry container trade service which is the only service available from Non U.S. Port S to the U.S. West Coast should be the non large diesel-generator vessels; meanwhile the international dry container trade service cannot carry the reefer container from the U.S. West Coast to the other U.S. ports. This conclusion is the basic for the solution to the next step.

## Step 2: Assignment of Fleet Using Computer Simulation

We fix the non large diesel-generator vessels on the international dry container service. Now we need to solve the final fleet assignment for the other services. This assignment is based on the cargo volume of each service.

### Obtaining Service Link Matrices A, B, and C

For ease of discussion, let's use proposal 1 as an example to explain the algorithm. In Trade Lane I, the proposal No.1 consists of IN1, US1, and US2 services as shown in Table 3—13. We start by rewriting the proposal in the format for OPL. Each service can be written as a 7 x 7 matrix, the row is the head (i.e. the first) port, and the column is the end (i.e. the last) port. Each element $A_{ij}$ represents the number of links from port $i$ to port $j$. The IN1 service link matrix **A** is shown in Table 3—15, US1 link matrix **B** as Table 3—16, and US2 link matrix **C** as Table 3—17.

**Table 3—15** **IN1 Service Link Matrix A**

| | UPA (j=1) | UPB (j=2) | UPC (j=3) | UPD (j=4) | NPR (j=5) | NPS (j=6) |
|---|---|---|---|---|---|---|
| UPA (i=1) | - | 0 | 0 | 0 | 1 | 1 |
| UPB (i=2) | 0 | - | 0 | 0 | 1 | 1 |
| UPC (i=3) | 0 | 0 | - | 0 | 0 | 0 |
| UPD (i=4) | 0 | 0 | 0 | - | 1 | 1 |
| NPR (i=5) | 1 | 1 | 0 | 1 | - | 1 |
| NPS (i=6) | 1 | 1 | 0 | 1 | 1 | - |

**Table 3—16** **US1 Service Link Matrix B**

| | UPA | UPB | UPC | UPD | NPR | NPS |
|---|---|---|---|---|---|---|
| UPA | - | 1 | 0 | 1 | 0 | 0 |
| UPB | 1 | - | 0 | 1 | 0 | 0 |
| UPC | 0 | 0 | - | 0 | 0 | 0 |
| UPD | 1 | 1 | 0 | - | 0 | 0 |
| NPR | 0 | 0 | 0 | 0 | - | 0 |
| NPS | 0 | 0 | 0 | 0 | 0 | - |

**Table 3—17** **US2 Service Link Matrix C**

| | UPA | UPB | UPC | UPD | NPR | NPS |
|---|---|---|---|---|---|---|
| UPA | - | 0 | 0 | 0 | 0 | 0 |
| UPB | 0 | - | 0 | 0 | 0 | 0 |
| UPC | 0 | 0 | - | 1 | 0 | 0 |
| UPD | 0 | 0 | 1 | - | 0 | 0 |
| NPR | 0 | 0 | 0 | 0 | - | 0 |
| NPS | 0 | 0 | 0 | 0 | 0 | - |

## Obtaining Direct Link Matrix D:

Adding all three matrices **A**, **B**, and **C** together, we obtain matrix **D** (direct link matrix) which stands for the total number of links between two ports in Proposal 1. Please refer Table 3—18.

$$D = A + B + C \qquad (1)$$

Please note this is true only for the direct link.

### Obtaining Transshipment Link Matrix E:

To obtain transshipment links, we use the properties of direct link matrix **D**. If any pair of elements of matrix **D** satisfies following constraints:

$$D_{ij} \times D_{jk} \neq 0, \qquad (2)$$

$$D_{ik} = 0,$$

$$\text{where } i, j, k \in \{1,2,3,4,5,6\},$$

the transshipment coefficient

$$E_{ik} += 1. \qquad (3)$$

$E_{ik}$ is the number of transshipment links between port $i$ and $j$. Thus we obtain the transshipment matrix **E** as shown in Table 3—19.

We assume that we do not consider the situation of three transshipments as part of an origin to destination movement, as $D_{ij} + D_{jk} + D_{kl} = E_{il}$ in our analysis, because this has very low level of service and high cost.

**Table 3—18 Direct Link Matrix D**

| | UPA | UPB | UPC | UPD | NPR | NPS |
|---|---|---|---|---|---|---|
| UPA | - | 1 | 0 | 1 | 1 | 1 |
| UPB | 1 | - | 0 | 1 | 1 | 1 |
| UPC | 0 | 0 | - | 1 | 0 | 0 |
| UPD | 1 | 1 | 1 | - | 1 | 1 |
| NPR | 1 | 1 | 0 | 1 | - | 1 |
| NPS | 1 | 1 | 0 | 1 | 1 | - |

**Table 3—19 Transshipment Link Matrix E**

| | UPA | UPB | UPC | UPD | NPR | NPS |
|---|---|---|---|---|---|---|
| UPA | - | 0 | 1 | 0 | 0 | 0 |
| UPB | 0 | - | 1 | 0 | 0 | 0 |
| UPC | 1 | 1 | - | 0 | 1 | 1 |
| UPD | 0 | 0 | 0 | - | 0 | 0 |
| NPR | 0 | 0 | 1 | 0 | - | 0 |
| NPS | 0 | 0 | 1 | 0 | 0 | - |

### Obtaining Cargo Volume Matrix

Besides the service link matrix, we need a cargo volume matrix **F** in Table 3—20, which includes the cargo volume of both revenue and empty containers between two ports. WE USE HYPOTHETICAL VALUES FOR ALL MODEL PARAMETERS IN THIS THESIS.

**Table 3—20 Cargo Volume Matrix F**

| | UPA | UPB | UPC | UPD | NPR | NPS |
|---|---|---|---|---|---|---|
| UPA | * | - | - | 206 | 30 | - |
| UPB | - | * | - | 406 | 302 | - |
| UPC | - | - | * | 892 | 43 | - |
| UPD | 16 | 242 | 650 | * | 143 | 515 |
| NPR | 51 | 85 | - | 25 | * | 320 |
| NPS | 596 | 304 | - | 50 | | * |

After obtaining the service link matrix **D** & **E**, and the cargo volume matrix **F** for the Trade Lane I, we also apply the optimization algorithm to the Trade Lane II.

### Trade Lane I

The proposed algorithm has the following main steps:

1. **Testing the feasibility**

First we need to test whether the proposal has links to each pair of ports which has cargo flow. We use the formulation:

$$\sum_{i=1}^{6}\sum_{j=1}^{6} I_{ij} * F_{ij} = \sum_{i=1}^{6}\sum_{j=1}^{6} F_{ij}, \tag{4}$$

where, $F_{ij}$ is the desired cargo volume from port i to port j as shown in Table 9,

$I_{ij}$ is the unit coefficient of all the links. That is to say,

$$I_{ij} \equiv 1 \text{, if} \tag{5}$$

$$D_{ij} + E_{ij} \geq 1 .$$

We calculate both sides of the above equation (4). We observe that proposal 1 satisfies the above formulation. It means that proposal 1 provide links to all the cargo flow.

## 2. Cargo Assignment

In this part, we will solve the cargo assignment problem. We obtain the cargo volume of each service first, and then we can allocate the proper vessels accordingly. In other words, we use cargo volume matrix **F**, link matrix **D** & **E**, to solve all the cargo volume variables between any two ports of each service. The detail process can be divided into:

i. Initialize volume variables for direct sailing

- Initialize the link which has $D_{ij} = 1$.

We initialize variables according to the direct sailing matrix **D**. If there is only one link from port *i* to port *j*, the volume of this link is equal to the desired cargo volume between these two ports. For example US2 service provides the only link from UPC to UPD, so this link carries all the cargo from UPC to UPD. We obtain $V_{UPC-UPD}^{US2} = C_{UPC-UPD} = 746$. In other words, we can solve for the volume of the links which have a value $D_{ij} = 1$.

- Initialize the link which has $D_{ij} = 2$.

If $D_{ij} = 2$, thus $V_{ij}^{servie1} = V_{ij}^{service2} = \frac{1}{2} F_{ij}$.

(In proposal 1, we do not have $D_{ij} = 2$, but in other proposals, we do encounter this situation)

- Initialize the link which has $D_{ij} = 0$

We set all the non-initialized $V_{ij} = 0$.

ii. Solve variables for transshipment sailing

Now we solve the volume variables related to the cargo transshipment using an iterative process.

The transshipment cargo is obtained from the equation:

$$E_{ik} = D_{ij} + D_{jk} \geq 2\,. \tag{6}$$

Based on this, we update

$$V_{ij}^{n} = V_{ij}^{n-1} + F_{ik}\,, \tag{7}$$

where $V_{ij}^{n}$ represents $V_{ij}$ at the n iteration step;

similarly

$$V_{jk}^{n} = V_{jk}^{n-1} + F_{ik}\,, \tag{8}$$

### 3. Obtain Cargo Assignment

Implementing the above algorithm using OPL, we obtain the cargo assignment of proposal 1. Please refer Table 3—21.

**Table 3—21 Cargo Assignment in Trade Lane I**

| | | UPA | UPB | UPC | UPD | NPR | NPS |
|---|---|---|---|---|---|---|---|
| IN1 | UPA | - | 430 | - | - | - | - |
| | UPB | - | - | - | 400 | - | - |
| | UPD | - | - | - | - | 920 | - |
| | NPR | - | - | - | - | - | 920 |
| | NPS | 920 | - | - | - | - | - |
| US2 | UPC | - | - | - | 710 | - | - |
| | UPD | - | - | 212 | - | - | - |
| US1 | UPA | - | 718 | - | - | - | - |
| | UPB | - | - | - | 678 | - | - |
| | UPD | 720 | - | - | - | - | - |

From cargo assignment table, we observe the highest volume for each service is:

$$V_{MAX}^{\ \ IN1} = 920 \ \ FEU$$
$$V_{MAX}^{\ \ US2} = 718 \ \ FEU$$
$$V_{MAX}^{\ \ US1} = 710 \ \ FEU$$

**Trade Lane II**

We apply the same procedure we described for Trade Lane I. We have obtained the cargo volume matrix between any two ports in Table 3—22. The direct link matrix **D** is in Table 3—23.

**Table 3—22 Cargo Volume Matrix F for Trade Lane II**

| | U.S. Port E | U.S. Port F | U.S. Port G | U.S. Port H | U.S. Port I |
|---|---|---|---|---|---|
| U.S. Port E | - | 1196 | 470 | 250 | 40 |
| U.S. Port F | 1261 | - | 0 | 0 | 0 |
| U.S. Port G | 432 | | - | 0 | 0 |
| U.S. Port H | 203 | 0 | 0 | - | 0 |
| U.S. Port I | 25 | 0 | 0 | 0 | - |

**Table 3—23 Direct Link Matrix D for Trade Lane II**

| | U.S. Port E | U.S. Port F | U.S. Port G | U.S. Port H | U.S. Port I |
|---|---|---|---|---|---|
| U.S. Port E | - | 2 | 1 | 1 | 1 |
| U.S. Port F | 2 | - | 0 | 0 | 0 |
| U.S. Port G | 1 | 0 | - | 0 | 0 |
| U.S. Port H | 2 | 0 | 0 | - | 0 |
| U.S. Port I | 0 | 0 | 0 | 1 | - |

Similarly, we obtain the cargo assignment in Table 3—24.

**Table 3—24 Cargo Assignment in Trade Lane II**

| | | U.S. Port E | U.S. Port F | U.S. Port G | U.S. Port H | U.S. Port I |
|---|---|---|---|---|---|---|
| US6/US7 | U.S. Port E | - | 823 | - | - | - |
| | U.S. Port F | 876 | - | - | - | - |
| US9/US8 | U.S. Port E | - | 417 | 564 | - | - |
| | U.S. Port F | 417 | - | - | - | - |
| | U.S. Port G | 528 | - | - | - | - |
| US10 | U.S. Port E | - | - | - | 310 | 80 |
| | U.S. Port H | 399 | - | - | - | - |
| | U.S. Port I | - | - | - | 80 | - |

From cargo assignment table, we observe the highest volume for each service is:

$$V_{MAX}^{US6/US7} = 876\ FEU$$

$$V_{MAX}^{US8/US9} = 528\ FEU$$

$$V_{MAX}^{US10} = 399\ FEU$$

### Fleet Allocation for Both Trade Lanes

With the cargo assignment of all three trade lanes, we can derive the capacity requirement for each service as shown in Table 3—25.

**Table 3—25 Capacity Requirement**

| Service | Highest Volume | Vessels Required |
|---|---|---|
| IN1 | 920 | 6 |
| US6/US7 | 718 | 1 |
| US1 | 710 | 2 |
| US2 | 876 | 2 |
| US8/US9 | 528 | 2 |
| US10 | 399 | 1 |
| | | |
| | | |
| | | |

**Table 3—26 Fleet Allocation Result**

| Fleet Allocation |
|---|
| 1000 x 6 |
| 880 x 1 |
| 880 x 2 |
| 910 x 2 |
| 725 + 700 |
| 570 x 3 |
| 880 |
| 650 |
| 600 x 3 |

The final fleet allocation criteria can be described as:

1. The fleet allocation should consider the ordinal of the capacity of each service.
2. Vessels running in the same string should be similarly sized ships.
3. Now, we have two vessels which have capacity of 910 FEU and four with capacity of 880 FEU. Considering US6/US7 only needs one vessel, if the capacity required of US1, US2, AND US6/US7 are all less than 910 FEU, we choose the vessels with 910 FEU to the US1 or US2 service.

4. Considering there are 120 FEU from UPC to UPD slot chartered to the US4 service, so if the capacity required of US1 and US2 are both less than 880 FEU, and US1 ≤ US2 +120, we allocate the vessels with 910 FEU to the US2 service.
5. The vessel utilization should be less than 95%

The final fleet allocation result is shown in Table 3—26.

## Step 3: Adjustment

If we cannot obtain a feasible result from step 2, we have to turn back and do step 2 again. We could slightly change the volume variable between the ports which has two links ($D_{ij}=2$), until we obtain the final fleet allocation result. In this example proposal 1, we can get the final result from step 2 directly as shown in Table 3—27.

**Table 3—27 Fleet Allocation Result for Proposal 1**

| The U.S. West Coast/Trade Lane I | | | The continental U.S./Trade Lane II | | | Surplus | | |
|---|---|---|---|---|---|---|---|---|
| Vessel | Capacity | Service | Vessel | Capacity | Service | Vessel | Capacity | Service |
| FN1 | 1000 | IN1 | UJ4 | 880 | US6/US7 | UJ3 | 880 | N/A |
| FN2 | 1000 | IN1 | UJ5 | 880 | US1 | UJ13 | 650 | N/A |
| FN3 | 1000 | IN1 | UJ6 | 880 | US1 | UJ14 | 600 | N/A |
| FN4 | 1000 | IN1 | UJ7 | 725 | US8/US9 | UJ15 | 600 | N/A |
| FN5 | 1000 | IN1 | UJ8 | 700 | US8/US9 | UJ16 | 600 | N/A |
| FN6 | 1000 | IN1 | UJ12 | 650 | US10 | | | |
| UJ1 | 910 | US2 | | | | | | |
| UJ2 | 910 | US2 | | | | | | |

Applying the same scenario to each proposal as general, we obtain the final fleet allocation form as shown in Table 3—28.

## Table 3—28 Fleet Allocation Final Result

| Name | Capacity Unit (FEU) | Proposal1 | Proposal2 | Proposal3 | Proposal4 | Proposal 5&6 | Proposal7 | Proposal8 | Proposal9 | Proposal10 | Proposal11 | Proposal12 | Proposal13 | Proposal14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FN1 | 1000 | IN2 | IN7 | IN3 | IN3 | Infeasible | IN1 | IN1 | IN2 | IN3 | IN4 | IN5 | IN6 | IN7 |
| FN2 | 1000 | IN2 | IN7 | IN3 | IN3 |  | IN1 | IN1 | IN2 | IN3 | IN4 | IN5 | IN6 | IN7 |
| FN3 | 1000 | IN2 | IN7 | IN3 | IN3 |  | IN1 | IN1 | IN2 | IN3 | IN4 | IN5 | IN6 | IN7 |
| FN4 | 1000 | IN2 | IN7 | IN3 | IN3 |  | IN1 | IN1 | IN2 | IN3 | IN4 | IN5 | IN6 | IN7 |
| FN5 | 1000 | IN2 | IN7 | IN3 | IN3 |  | IN1 | IN1 | IN2 | IN3 | IN4 | IN5 | IN6 | IN7 |
| FN6 | 1000 | IN2 | IN7 | IN3 | IN3 |  | IN1 | IN1 | IN2 | IN3 | IN4 | IN5 | IN6 | IN7 |
| UJ1 | 910 | US2 | US2 | US1 | US1 |  | US2 | US3 | US3 | US1 | US1 | US3 | US3 | US3 |
| UJ2 | 910 | US2 | US2 | US1 | US1 |  | US2 | US3 | US3 | US1 | US1 | US3 | US3 | US3 |
| UJ3 | 880 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| UJ4 | 880 | US6/US7 | US6/US7 | US6/US7 | US6/US7 |  | US6/US7 | US6/US7 | US6/US7 | US6/US7 | US6/US7 | US6/US7 | US6/US7 | US6/US7 |
| UJ5 | 880 | US1 | US1 | US2 | US2 |  | US1 | US1 | US1 | US3 | US3 | US1 | US1 | US1 |
| UJ6 | 880 | US1 | US1 | US2 | US2 |  | US1 | US1 | US1 | US3 | US3 | US1 | US1 | US1 |
| UJ7 | 725 | US8/US9 | US8/US9 | US8/US9 | US8/US9 |  | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 |
| UJ8 | 700 | US8/US9 | US8/US9 | US8/US9 | US8/US9 |  | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 |
| UJ9 | 650 | US10 | US10 | US10 | US10 |  | US10 | US10 | US10 | US10 | US10 | US10 | US10 | US10 |
| UJ10 | 650 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| UJ11 | 600 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| UJ12 | 600 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| UJ13 | 600 |  |  |  |  |  |  |  |  |  |  |  |  |  |

## 3.3.4 Mixed Integer Problem Formulation and Implementation using OPL

The fleet and cargo assignment sub-model can be modeled into a linear programming problem, and the object and the constraints can be rewritten into several mathematical functions. For the Trade Lane I, the problem can be described as:

**Objective function:**

$$\text{Maximize } (\sum_{i=1}^{N} P_i),$$

**Constraints:**

$$\sum C_{ij} \geq \sum D_{ij}$$

$$0\% \leq U_i \leq 95\%$$

where:

$T_{ij}$ denotes the transit time between port j and port j

$VN_{Trade\ Lane\ I,}$ denotes the number of vessels running at Trade Lane I

$P_{ij}$ denotes the profit of each service

$C_{ij}$ denotes the capacity between port i and port j

$D_{ij}$ denotes the cargo volume between port i and port j

$U_i$ denotes the utilization of each vessel.

As in the case of the other sub-models, we use the formulation in the former sections and OPL to enumerate the entire situation and obtain the ones that satisfy all the constraints.

## 3.3.5 Output from Fleet and Cargo Assignment Sub-Model

The output is as shown in Table 3—29. The service detail is as shown in Table 3—30.

Table 3—29 Output from Fleet and Cargo Assignment Sub-Model: Top 12 Profitable Proposals

| Vessel Name | Capacity Unit (FEU) | Proposal1 | Proposal7 | Proposal2 | Proposal8 | Proposal3 | Proposal14 | Proposal9 | Proposal4 | Proposal12 | Proposal10 | Proposal13 | Proposal11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FN1 | 1000 | IN1 | IN7 | IN2 | IN1 | IN3 | IN7 | IN2 | IN4 | IN5 | IN3 | IN6 | IN4 |
| FN2 | 1000 | IN1 | IN7 | IN2 | IN1 | IN3 | IN7 | IN2 | IN4 | IN5 | IN3 | IN6 | IN4 |
| FN3 | 1000 | IN1 | IN7 | IN2 | IN1 | IN3 | IN7 | IN2 | IN4 | IN5 | IN3 | IN6 | IN4 |
| FN4 | 1000 | IN1 | IN7 | IN2 | IN1 | IN3 | IN7 | IN2 | IN4 | IN5 | IN3 | IN6 | IN4 |
| FN5 | 1000 | IN1 | IN7 | IN2 | IN1 | IN3 | IN7 | IN2 | IN4 | IN5 | IN3 | IN6 | IN4 |
| FN6 | 1000 | IN1 | IN7 | IN2 | IN1 | IN3 | IN7 | IN2 | IN4 | IN5 | IN3 | IN6 | IN4 |
| UJ1 | 910 | US2 | US2 | US2 | US3 | US1 | US3 | US3 | US1 | US3 | US1 | US3 | US1 |
| UJ2 | 910 | US2 | US2 | US2 | US3 | US1 | US3 | US3 | US1 | US3 | US1 | US3 | US1 |
| UJ3 | 880 |  |  |  |  |  |  |  |  |  |  |  |  |
| UJ4 | 880 | US6/US7 | US6/US7 | US6/US7 | US6/US7 | US6/US7 | US6/US7 | US6/US7 | US6/US7 | US6/US7 | US6/US7 | US6/US7 | US6/US7 |
| UJ5 | 880 | US1 | US1 | US1 | US1 | US2 | US1 | US1 | US2 | US1 | US3 | US1 | US3 |
| UJ6 | 880 | US1 | US1 | US1 | US1 | US2 | US1 | US1 | US2 | US1 | US3 | US1 | US3 |
| UJ7 | 725 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 |
| UJ8 | 700 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 | US8/US9 |
| UJ9 | 650 | US10 | US10 | US10 | US10 | US10 | US10 | US10 | US10 | US10 | US10 | US10 | US10 |
| UJ10 | 650 |  |  |  |  |  |  |  |  |  |  |  |  |
| UJ11 | 600 |  |  |  |  |  |  |  |  |  |  |  |  |
| UJ12 | 600 |  |  |  |  |  |  |  |  |  |  |  |  |
| UJ13 | 600 |  |  |  |  |  |  |  |  |  |  |  |  |
| Profit Rank |  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Total Trade Lane I Profit (Million) |  | 32.98813 | 32.13484 | 32.12585 | 31.63829 | 31.28943 | 30.785 | 30.77602 | 30.41798 | 30.21418 | 30.10295 | 29.54858 | 29.2315 |
| Trade Lane II Profit (Million) |  | 44.33947 | 44.33947 | 44.33947 | 44.33947 | 44.33947 | 44.33947 | 44.33947 | 44.33947 | 44.33947 | 44.33947 | 44.33947 | 44.33947 |
| Total Profit EBITDA (Million) |  | 77.3276 | 76.47431 | 76.46532 | 75.97776 | 75.6289 | 75.12447 | 75.11549 | 74.75745 | 74.55365 | 74.44242 | 73.88805 | 73.57097 |

## Table 3—30 Service detail

| Service Name | Round Trip Time | Vessels Required | Routes |
|---|---|---|---|
| IN1 | 42 | 6 | UPA--UPB--UPD--NPR--NPS—UPA |
| IN2 | 42 | 6 | UPA--UPB--UPD--NPR--NPS--NPT—UPA |
| IN3 | 42 | 6 | UPA--UPC--UPD--NPR--NPS—UPA |
| IN4 | 42 | 6 | UPA--UPC--UPD--NPR--NPS--NPT—UPA |
| IN5 | 42 | 6 | UPB--UPC--UPD--NPR--NPS—UPB |
| IN6 | 42 | 6 | UPB--UPC--UPD--NPR--NPS--NPT—UPB |
| IN7 | 42 | 6 | UPA--UPB--UPC--UPD--NPR--NPS--NPT—UPA |
| US2 | 14 | 2 | UPC--UPD—UPC |
| US3 | 14 | 2 | UPB--UPC--UPD—UPB |
| US1 | 14 | 2 | UPA--UPB--UPD--UPA* |
| US4 | 7 | 0 | UPC—UPD |
| US6/US7 | 7 | 1 | U.S. Port E---U.S. Port F---U.S. Port E |
| US8/US9 | 14 | 2 | U.S. Port E---U.S. Port G---U.S. Port E---U.S. Port F---U.S. Port E |
| US10 | 21 | 1 | U.S. Port E---U.S. Port I---U.S. Port H---U.S. Port E---U.S. Port H--U.S. Port E |

# Chapter 4

# User Interface Development

This chapter outlines the function design and the development process of the Graphic user Interface (GUI) of the fleet allocation model for Hampton Shipping. The development of the user interface based on the preconcerted proposal extends the scope of the fleet allocation model, and provides the user the ability of conducting sensitivity analysis. This interface allows the carrier to evaluate hundreds or thousands of fleet allocation scenarios and to quickly focus on key characteristics and options that are most relevant. This program extends the deterministic optimization method into a model supporting the solution to stochastic problems.

## 4.1 The Intention of the User Interface Development

The primary function of this program—the graphic user interface of the fleet allocation problem—is to accept user input data, and then to utilize that input data to calculate the cargo assignment in each service, and further to obtain the detail revenue, cost and profit break down to the assignment.

As we discussed previously, OPL studio can help us to solve the fleet allocation problem and obtain the several optimal solutions, without any knowledge of the other languages and the interaction with users. This prevents the attempt of conducting sensitivity analysis without changing the basic coding as well as the alert of presentiment for the obsolescence of the model. Furthermore, the process of rebuilding the OPL model is not a straightforward process for the managers who do not have the knowledge of OPL studio.

Generally, the life of an approved network design and fleet allocation solution could be at least two to three years. Both the shippers and the carriers are not willing to accept the unstableness of their contracted schedule and services with a high switch cost. Thus, once we obtain a solution to the network design and fleet allocation problem, the most appealing thing for the carrier is not to keep maintaining the OPL solution, but to keep analyzing the routine operation and making slight adjustment to obtain the maximized profit by a relatively easy way.

To solve this problem and help the managers enjoying the model more, a friendly graphic user interface (GUI) is needed, which can accept the input effectively and efficiently output the detailed cost and profit break down that can be used in a company's routine analyzing environment. And the interface will be implemented by Java which is a more popular programming language and can be easily updated by the users.

However, a satisfactory solution to the network design and fleet allocation problem is the pre-requisite for the development of the Java graphic user interface. The assumption of the interface is based on an applicable and acceptable proposal, which could be one of the proposals we obtain from the previous OPL model to the fleet allocation problem, or a new one that will be applied in the future network.

In this case for Hampton Shipping, we choose the proposal 1 as discussed in Chapter Three as the base proposal. All the changes and the corresponding fleet and cargo reassignment are based on this preconcerted proposal.

## 4.2 The Function of the Graphic user Interface

The User Interface is designed to accept input data, and calculate a detail revenue, cost, and profit breakdown. Integral to how the user reacts is the definition of what represents the interface, in the context of a preconcerted network structure. Since the fleet allocation was solved initially by the OPL model, the definition of the interface is "a program that reflects the change of user input, obtains the cargo assignment which is based on the existing network, and gets the new revenue, cost, and profit of the network."

The definition of the existing network within the context of the real operation application varies. It could be one of the solutions simulated from the OPL model, or an optimal solution chosen by the carrier based on its experience and knowledge.

Therefore, the requirement is to fix the fleet allocation solution which will be used in the real operation. That is, the OPL model provides us some solutions from the view of theory; however, the user interface is developed on the real application that the company identified. It is this requirement that we are looking to solve in this user interface. The purpose of solving this requirement will be to help out companies looking to make daily analysis and adjustment appropriately without changing the whole structure of the existing network schedule, or to testify whether the network has reached its capacity limitation

To satisfy the demand of the users, the user interface needs to possess the following functions:

**Functions:**

- **Input**

  To obtain the data that related to the cargo volume, ship parameter, and operating expenses are sorted by all three trade lanes —Trade Lane I and Trade Lane II. Store all input data into the database for output.

- **Set Value**

To smooth the data input process, the interface should have the function of setting the data value as default, changing them by some percentage, and setting all values into zero. Table 4—1 lists all the data that related with fleet operation and discussion. Figure 4—1 to Figure 4—4 shows the function of each Input and Set Value interface.

- **Calculate**

The program needs to process all the input data and default parameters, and calculate the detailed cargo assignment, the revenue, cost, and profit breakdown.

- **Output**
  - **As Diagram**

To show the result, the program should display the calculated financial number, including both the proposed number and the ones obtained by the user's new data in terms of diagram.

Figure 4—2 is the output window.

  - **As Spreadsheet**

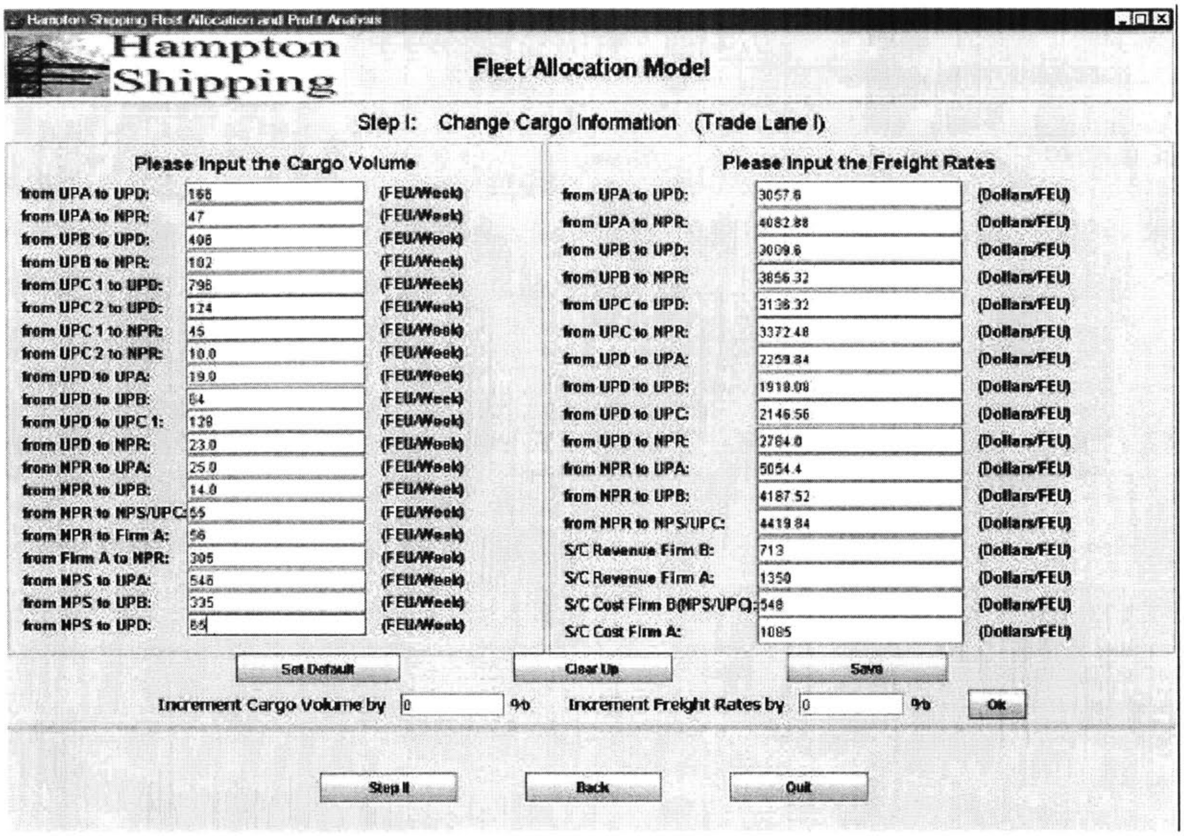
For the further analysis, the program need output a spreadsheet recoding all the input, output, and detailed cargo assignment information. Similar to the output of the diagram, the spreadsheet should cover both the base proposed information and the one of new data. Figure 4—3 is the spreadsheet sample.

**Table 4—1 Input Variables of the User Interface**

|  |  |  |  |  | fixed in OPL | variable by user |
|---|---|---|---|---|---|---|
| Ship Costs |  |  |  |  |  |  |
|  | Operating expenses |  |  |  |  |  |
|  |  | lease costs (capital) |  | $$/day |  | x |
|  |  | Manning |  | $$/day |  | x |
|  |  | M&R |  | $$/day |  | x |
|  |  | overhaul (d/dk) |  | $$/day |  | x |
|  |  | Insurance |  | $$/day |  | x |
|  |  | Other |  | $$/day |  | x |
|  |  | Fuel consumption |  | mt/day |  | x |
|  |  | Fuel price |  | $$/mt |  | x |
|  | capacity (by vessel) |  |  | Feu |  | x |
|  | Speed |  |  | Kts | x |  |
| Port |  |  |  |  |  |  |
|  | distance table |  |  | Nm | x |  |
|  | port charges |  |  | $$/call | x |  |

| | | | | | | |
|---|---|---|---|---|---|---|
| | ctnr handling costs | | | $$/box | x | |
| | in & out time | | | Days | x | |
| | dwell time | | | Days | x | |
| Cargo | | | | | | |
| | port to port volumes | | | Feu | | x |
| | freight rates | | | | | |
| | | 40' rfr | | $$/ctnr | avg'd outside the model for feu rate | |
| | | 45'dry | | $$/ctnr | avg'd outside the model for feu rate | |
| | | 40' dry | | $$/ctnr | avg'd outside the model for feu rate | |
| | | 20' dry | | $$/ctnr | avg'd outside the model for feu rate | |
| | | Feu | | $$ | | x |
| Growth Rates | | | | | | |
| | Costs | | | | | tba |
| | freight rates | | | | | tba |
| Transportation Expense | | | | | | |
| | Trucking | | | | | |
| | | Avg. Moves per Load | | % of ttl loads | | x |
| | | Cost per Move | | $$/ctnr | | x |
| | Rail | | | | | |
| | | Avg. Moves per Load | | % of ttl loads | | x |
| | | Cost per Move | | $$/ctnr | | x |
| | barge (UPD tradelane only, smalled cost applied to all loads) | | | | | |
| | | Avg. Moves per Load | | % of ttl loads | 100% | |
| | | Cost per Move / Moves | | | | |
| | | | U.S. Port D | $$/ctnr | | x |
| | | | Non U.S. Port R | $$/ctnr | | x |
| Garage (maintenance) | | | | $$/revenue ld | | x |
| Warehouse (CFS) | | | | $$/revenue ld | | x |
| Yard & Gate (terminal chg) | | | | $$/revenue ld | | x |
| Container Rent (rolling stk) | | | | $$/revenue ld | | x |
| Assessments (union) | | | | $$/revenue ld | | x |
| Cargo Claims (% Rev.) | | | | $$/revenue ld | x | |
| Bad Debt Exp. (% Rev.) | | | | $$/revenue ld | x | |
| Ttl Other (A&G, S&M, O'head, etc.) | | | | | x | |
| Slot Charter Arrangements | | | | | | |
| | Firm A | | expense | $$/ctnr | x | |
| | Firm B (NPS/UPC) | | expense | $$/ctnr | x | |
| | Firm B | | revenue | $$/ctnr | x | |
| | Firm A | | revenue | $$/ctnr | x | |
| | Firm D | | revenue | $$/ctnr | x | |
| | Firm B / FIRM C | | revenue | $$/ctnr | x | |

Figure 4—1 Change Cargo Information Input Interface:



Please Input the Cargo Volume

| | | |
|---|---|---|
| from UPA to UPD: | 166 | (FEU/Week) |
| from UPA to NPR: | 47 | (FEU/Week) |
| from UPB to UPD: | 406 | (FEU/Week) |
| from UPB to NPR: | 102 | (FEU/Week) |
| from UPC 1 to UPD: | 796 | (FEU/Week) |
| from UPC 2 to UPD: | 124 | (FEU/Week) |
| from UPC 1 to NPR: | 45 | (FEU/Week) |
| from UPC 2 to NPR: | 10.0 | (FEU/Week) |
| from UPD to UPA: | 19.0 | (FEU/Week) |
| from UPD to UPB: | 84 | (FEU/Week) |
| from UPD to UPC 1: | 128 | (FEU/Week) |
| from UPD to NPR: | 23.0 | (FEU/Week) |
| from NPR to UPA: | 25.0 | (FEU/Week) |
| from NPR to UPB: | 14.0 | (FEU/Week) |
| from NPR to NPS/UPC: | 55 | (FEU/Week) |
| from NPR to Firm A: | 56 | (FEU/Week) |
| from Firm A to NPR: | 305 | (FEU/Week) |
| from NPS to UPA: | 546 | (FEU/Week) |
| from NPS to UPB: | 335 | (FEU/Week) |
| from NPS to UPD: | 85 | (FEU/Week) |

Please Input the Freight Rates

| | | |
|---|---|---|
| from UPA to UPD: | 3057.6 | (Dollars/FEU) |
| from UPA to NPR: | 4082.88 | (Dollars/FEU) |
| from UPB to UPD: | 3009.6 | (Dollars/FEU) |
| from UPB to NPR: | 3856.32 | (Dollars/FEU) |
| from UPC to UPD: | 3138.32 | (Dollars/FEU) |
| from UPC to NPR: | 3372.48 | (Dollars/FEU) |
| from UPD to UPA: | 2259.84 | (Dollars/FEU) |
| from UPD to UPB: | 1918.08 | (Dollars/FEU) |
| from UPD to UPC: | 2146.56 | (Dollars/FEU) |
| from UPD to NPR: | 2784.0 | (Dollars/FEU) |
| from NPR to UPA: | 5054.4 | (Dollars/FEU) |
| from NPR to UPB: | 4187.52 | (Dollars/FEU) |
| from NPR to NPS/UPC: | 4419.84 | (Dollars/FEU) |
| S/C Revenue Firm B: | 713 | (Dollars/FEU) |
| S/C Revenue Firm A: | 1350 | (Dollars/FEU) |
| S/C Cost Firm B(NPS/UPC): | 548 | (Dollars/FEU) |
| S/C Cost Firm A: | 1085 | (Dollars/FEU) |

Increment Cargo Volume by 0 %

Increment Freight Rates by 0 %

WE USE HYPOTHETICAL VALUES FOR ALL MODEL PARAMETERS. The description of input and functions for Change Cargo Information Input Interface is as following:

**Input:**

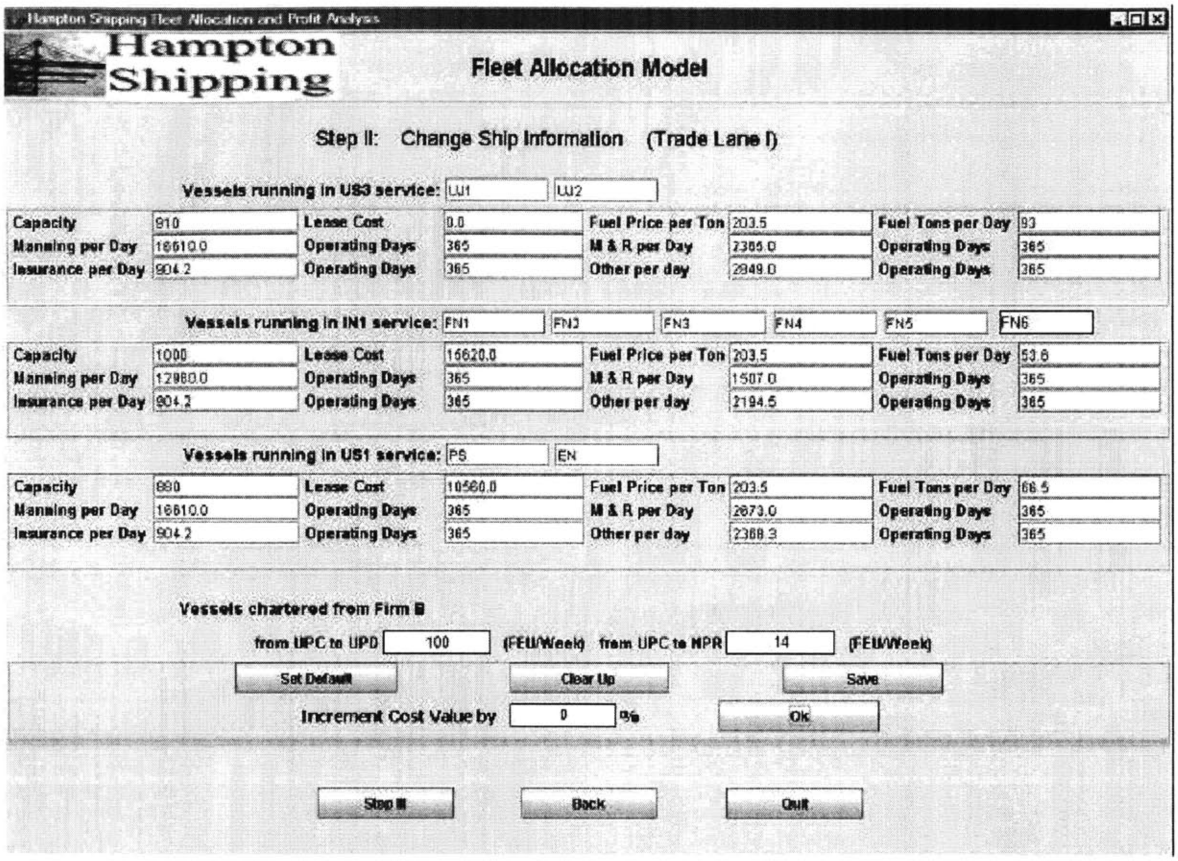
- Cargo Volume at each market
- Freight Rates at each market

**Functions:**

- Set Default Value
- Clear Up all Input to zero
- Increase value by certain percentage
- Save into database

- Go to Other Input Interface
- Go back to the main manual

**Figure 4—2 Change Ship Information Input Interface:**



Step II: Change Ship Information (Trade Lane I)

Vessels running in US3 service: LU1 LU2

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Capacity | 910 | Lease Cost | 0.0 | Fuel Price per Ton | 203.5 | Fuel Tons per Day | 93 |
| Manning per Day | 16610.0 | Operating Days | 365 | M & R per Day | 2385.0 | Operating Days | 365 |
| Insurance per Day | 904.2 | Operating Days | 365 | Other per day | 2849.0 | Operating Days | 365 |

Vessels running in IN1 service: FN1 FN2 FN3 FN4 FN5 FN6

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Capacity | 1000 | Lease Cost | 15620.0 | Fuel Price per Ton | 203.5 | Fuel Tons per Day | 53.6 |
| Manning per Day | 12980.0 | Operating Days | 365 | M & R per Day | 1507.0 | Operating Days | 365 |
| Insurance per Day | 904.2 | Operating Days | 365 | Other per day | 2194.5 | Operating Days | 365 |

Vessels running in US1 service: PS EN

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Capacity | 880 | Lease Cost | 10560.0 | Fuel Price per Ton | 203.5 | Fuel Tons per Day | 66.5 |
| Manning per Day | 16610.0 | Operating Days | 365 | M & R per Day | 2873.0 | Operating Days | 365 |
| Insurance per Day | 904.2 | Operating Days | 365 | Other per day | 2388.3 | Operating Days | 365 |

Vessels chartered from Firm B

from UPC to UPD 100 (FEU/Week) from UPC to NPR 14 (FEU/Week)

Increment Cost Value by 0 %

The description of input and functions for Change Ship Information Input Interface is as following:

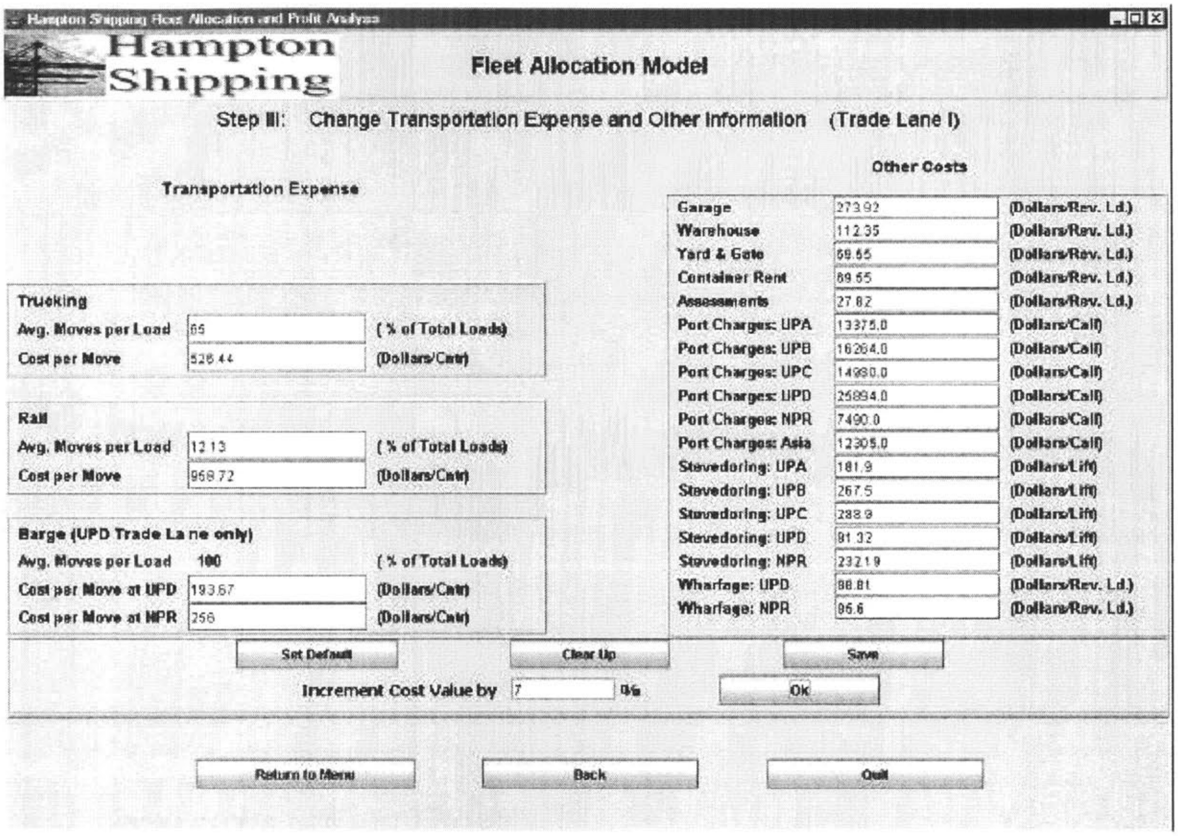
**Input:**

- Vessel Name
- Vessel capacity and operation cost
- Vessel operation days

**Function:**

- Set Default Value
- Clear Up all Input to zero
- Increase value by certain percentage
- Save into database
- Go to Other Input Interface
- Go back to the main manual

**Figure 4—3 Change Transportation Expenses and Other Information Input Interface:**



Step III: Change Transportation Expense and Other Information (Trade Lane I)

Transportation Expense

Trucking

| | | |
|---|---|---|
| Avg. Moves per Load | 65 | ( % of Total Loads) |
| Cost per Move | 526.44 | (Dollars/Cntr) |

Rail

| | | |
|---|---|---|
| Avg. Moves per Load | 12.13 | ( % of Total Loads) |
| Cost per Move | 968.72 | (Dollars/Cntr) |

Barge (UPD Trade Lane only)

| | | |
|---|---|---|
| Avg. Moves per Load | 100 | ( % of Total Loads) |
| Cost per Move at UPD | 193.67 | (Dollars/Cntr) |
| Cost per Move at NPR | 256 | (Dollars/Cntr) |

Other Costs

| | | |
|---|---|---|
| Garage | 273.92 | (Dollars/Rev. Ld.) |
| Warehouse | 112.35 | (Dollars/Rev. Ld.) |
| Yard & Gate | 69.65 | (Dollars/Rev. Ld.) |
| Container Rent | 69.65 | (Dollars/Rev. Ld.) |
| Assessments | 27.82 | (Dollars/Rev. Ld.) |
| Port Charges: UPA | 13375.0 | (Dollars/Call) |
| Port Charges: UPB | 16264.0 | (Dollars/Call) |
| Port Charges: UPC | 14980.0 | (Dollars/Call) |
| Port Charges: UPD | 25894.0 | (Dollars/Call) |
| Port Charges: NPR | 7490.0 | (Dollars/Call) |
| Port Charges: Asia | 12305.0 | (Dollars/Call) |
| Stevedoring: UPA | 181.9 | (Dollars/Lift) |
| Stevedoring: UPB | 267.5 | (Dollars/Lift) |
| Stevedoring: UPC | 288.9 | (Dollars/Lift) |
| Stevedoring: UPD | 81.32 | (Dollars/Lift) |
| Stevedoring: NPR | 232.19 | (Dollars/Lift) |
| Wharfage: UPD | 88.81 | (Dollars/Rev. Ld.) |
| Wharfage: NPR | 86.6 | (Dollars/Rev. Ld.) |

Increment Cost Value by 7 %

The description of input and functions for Change Transportation Expenses and Other Information Input Interface is as following:

**Input:**

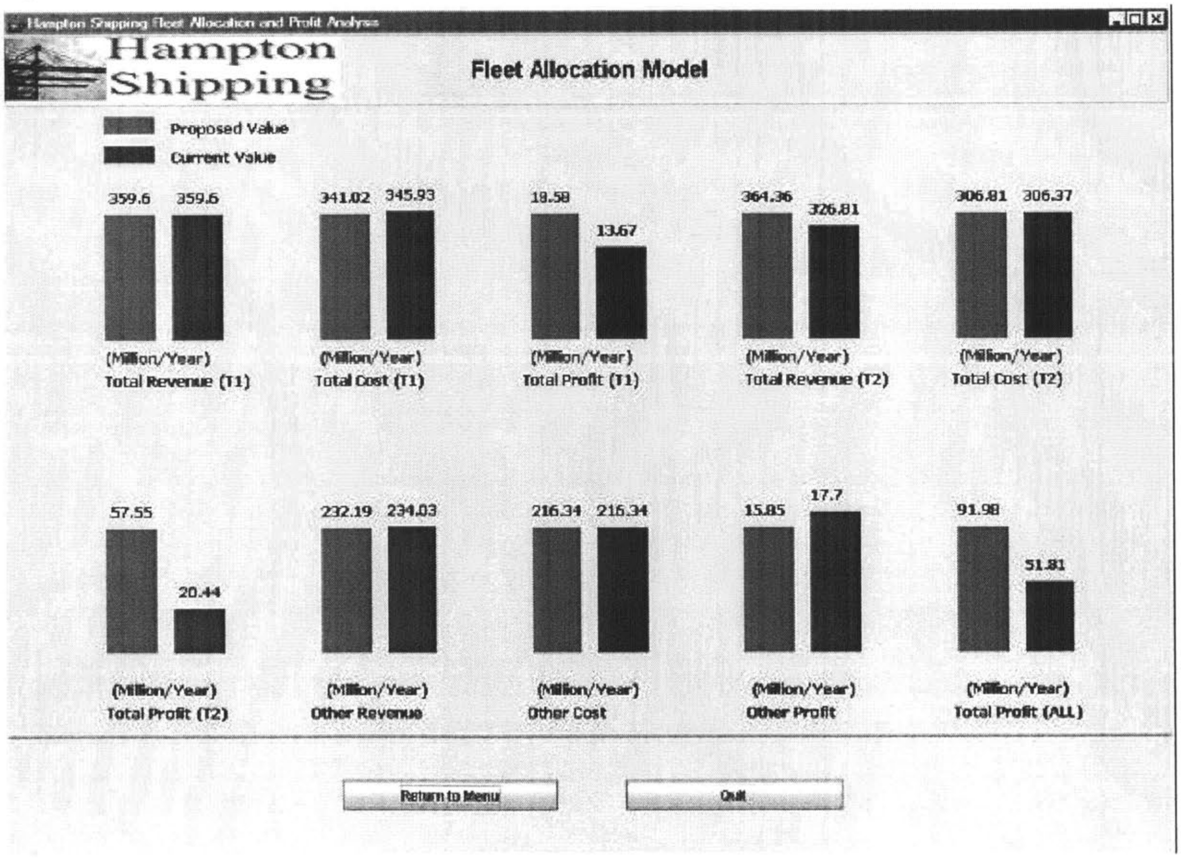
- Transportation Expenses

- Other Costs

**Function:**

- Set Default Value
- Clear Up all Input to zero
- Increase value by certain percentage
- Save into database
- Go to Other Input Interface
- Go back to the main manual
- Quit the program

**Figure 4—4 Output Interface**



The description of output and functions for Change Transportation Expenses and Other Information Input Interface is as following:

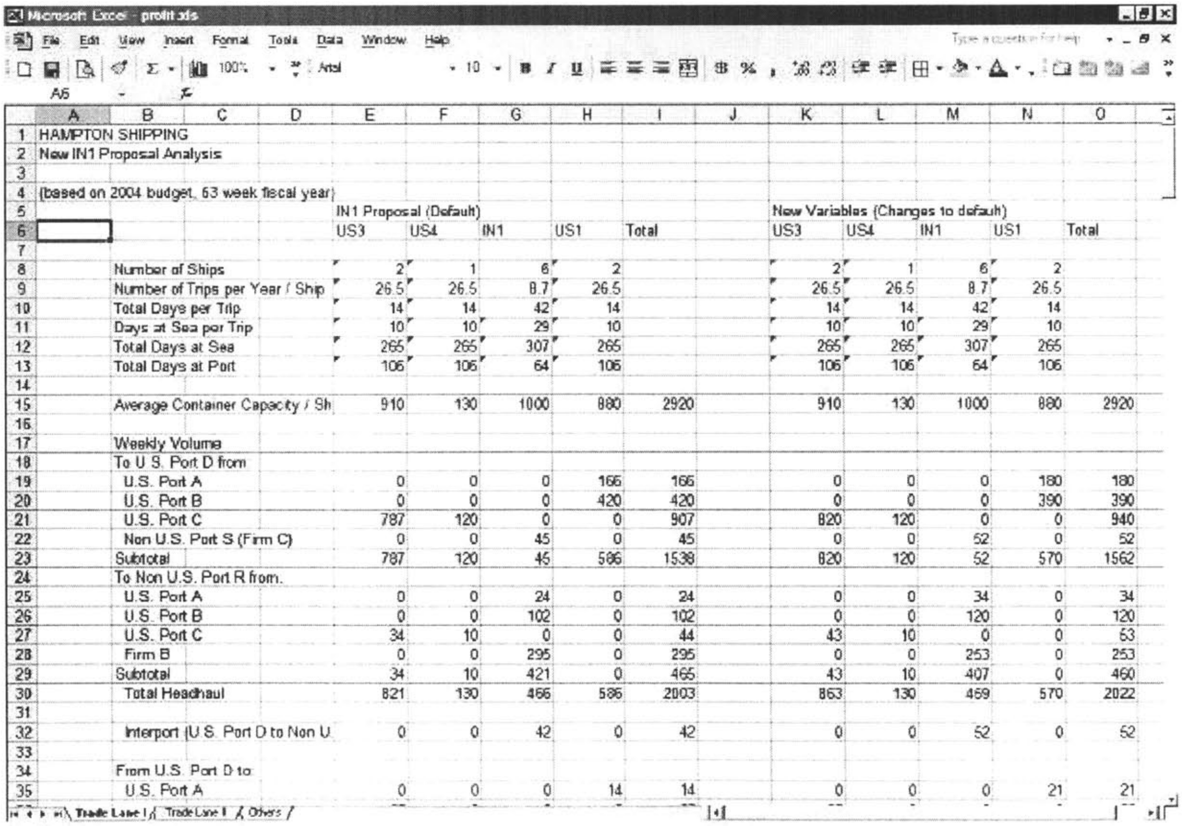
**Output:**

- Total Revenue per each trade lane
- Total Cost per each trade lane
- Total Profit per each trade lane
- Total Revenue for all trade lanes

**Function:**

- Go back to the main manual
- Quit the Program

**Figure 4—5 Excerpt of Detailed Spreadsheet**



| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | HAMPTON SHIPPING | | | | | | | | | | | | | | |
| 2 | New IN1 Proposal Analysis | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | |
| 4 | (based on 2004 budget, 53 week fiscal year) | | | | | | | | | | | | | | |
| 5 | | | | | IN1 Proposal (Default) | | | | | | New Variables (Changes to default) | | | | |
| 6 | | | | | US3 | US4 | IN1 | US1 | Total | | US3 | US4 | IN1 | US1 | Total |
| 7 | | | | | | | | | | | | | | | |
| 8 | | Number of Ships | | | 2 | 1 | 6 | 2 | | | 2 | 1 | 6 | 2 | |
| 9 | | Number of Trips per Year / Ship | | | 26.5 | 26.5 | 8.7 | 26.5 | | | 26.5 | 26.5 | 8.7 | 26.5 | |
| 10 | | Total Days per Trip | | | 14 | 14 | 42 | 14 | | | 14 | 14 | 42 | 14 | |
| 11 | | Days at Sea per Trip | | | 10 | 10 | 29 | 10 | | | 10 | 10 | 29 | 10 | |
| 12 | | Total Days at Sea | | | 265 | 265 | 307 | 265 | | | 265 | 265 | 307 | 265 | |
| 13 | | Total Days at Port | | | 106 | 106 | 64 | 106 | | | 106 | 106 | 64 | 106 | |
| 14 | | | | | | | | | | | | | | | |
| 15 | | Average Container Capacity / Sh | | | 910 | 130 | 1000 | 880 | 2920 | | 910 | 130 | 1000 | 880 | 2920 |
| 16 | | | | | | | | | | | | | | | |
| 17 | | Weekly Volume | | | | | | | | | | | | | |
| 18 | | To U.S. Port D from | | | | | | | | | | | | | |
| 19 | | U.S. Port A | | | 0 | 0 | 0 | 166 | 166 | | 0 | 0 | 0 | 180 | 180 |
| 20 | | U.S. Port B | | | 0 | 0 | 0 | 420 | 420 | | 0 | 0 | 0 | 390 | 390 |
| 21 | | U.S. Port C | | | 787 | 120 | 0 | 0 | 907 | | 820 | 120 | 0 | 0 | 940 |
| 22 | | Non U.S. Port S (Firm C) | | | 0 | 0 | 45 | 0 | 45 | | 0 | 0 | 52 | 0 | 52 |
| 23 | | Subtotal | | | 787 | 120 | 45 | 586 | 1538 | | 820 | 120 | 52 | 570 | 1562 |
| 24 | | To Non U.S. Port R from. | | | | | | | | | | | | | |
| 25 | | U.S. Port A | | | 0 | 0 | 24 | 0 | 24 | | 0 | 0 | 34 | 0 | 34 |
| 26 | | U.S. Port B | | | 0 | 0 | 102 | 0 | 102 | | 0 | 0 | 120 | 0 | 120 |
| 27 | | U.S. Port C | | | 34 | 10 | 0 | 0 | 44 | | 43 | 10 | 0 | 0 | 53 |
| 28 | | Firm B | | | 0 | 0 | 295 | 0 | 295 | | 0 | 0 | 253 | 0 | 253 |
| 29 | | Subtotal | | | 34 | 10 | 421 | 0 | 465 | | 43 | 10 | 407 | 0 | 460 |
| 30 | | Total Headhaul | | | 821 | 130 | 466 | 586 | 2003 | | 863 | 130 | 469 | 570 | 2022 |
| 31 | | | | | | | | | | | | | | | |
| 32 | | Interport (U.S. Port D to Non U. | | | 0 | 0 | 42 | 0 | 42 | | 0 | 0 | 52 | 0 | 52 |
| 33 | | | | | | | | | | | | | | | |
| 34 | | From U.S. Port D to | | | | | | | | | | | | | |
| 35 | | U.S. Port A | | | 0 | 0 | 0 | 14 | 14 | | 0 | 0 | 0 | 21 | 21 |

## 4.3 The Advantages and Limitations of the Graphic User Interface Development

As we discussed formerly, the graphic user interface is developed by Java, which is different from the optimal programming language we used to formulate and solve the fleet allocation model. Therefore, there exist several pros and cons for the compatibility for the OPL model and the Java interface.

**Pros:**

- **Easier to write**

  The programming language Java is much more widely used than ILOG OPL, thus it is easier for the managers to maintain and update the graphic user interface to reflect any adjustment needed.

- **Extend the model form deterministic to stochastic**

  The fleet allocation model solved by Optimization Programming Language is formulated on the deterministic demand, thus the model can not show the effect of the change of demand. Nevertheless, the user interface allows users to change demand and other variables in certain range to simulate the effect of stochastic scenarios.

- **Provide user interaction**

  The java interface can provide user interaction to accept input and to output the diagram to imitate changes, which can not be achieved by ILOG OPL.

- **Provide link to internet**

  The java interface can be easily linked to the internet, which will provide convenience and compatibility to the other tools of the entire company.

**Cons:**

- **The Java program can not link through OPL directly.**

Since Java and ILOG OPL are two different programming languages, the interface can not be linked and read the output directly from OPL. Thus, we need develop the model and the interface separately.

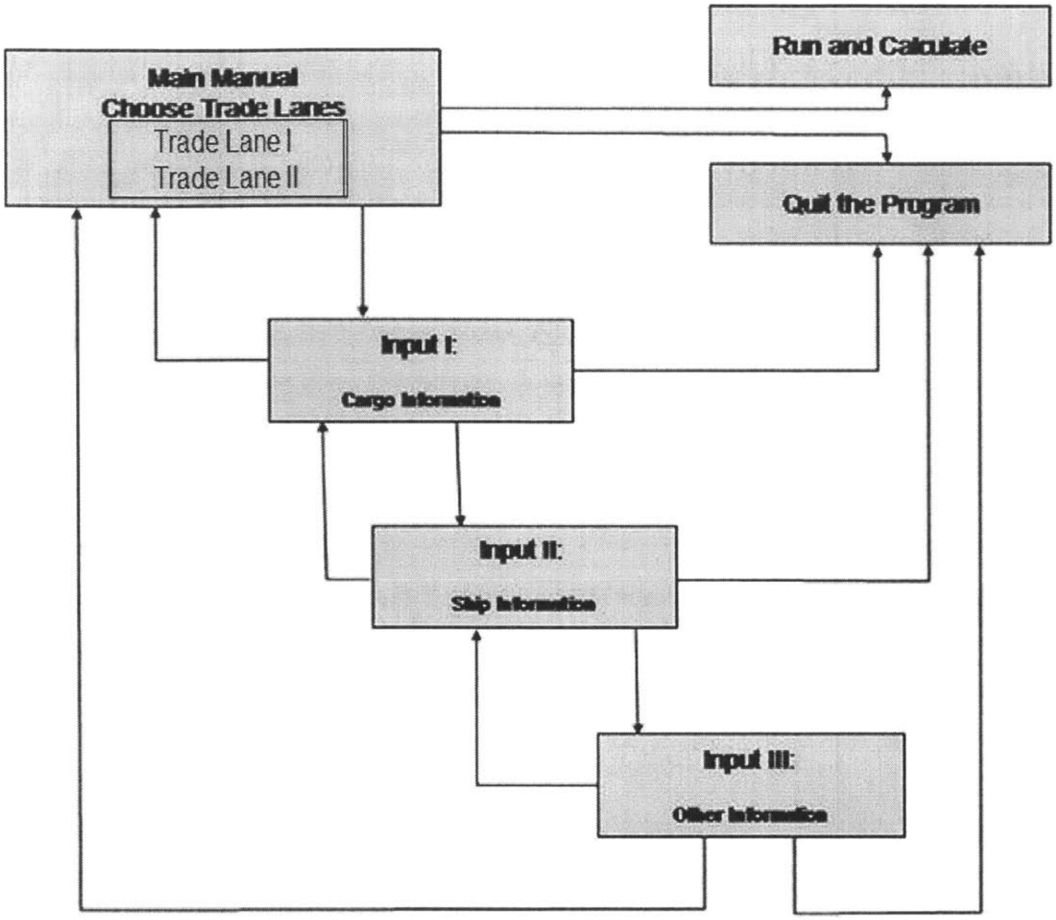
- **The program can only provide scenario simulation in a certain range**

The user interface is developed based on a preconcerted proposal. Users can change input, simulate diverse scenarios, as far as the demand is less than the carrying capacity of the initial proposal. If the demand is beyond certain level, the program will alert that the default solution to the fleet allocation model is infeasible, rather than provide a new solution to the new demands. Practically, the alert is a good sign to suggest the carrier solving the fleet allocation model again in Optimization Programming Language, considering the significantly change in the operating environment.

## 4.4 The Algorithm for the User Interface

The GUI is constitutive of a main manual window and three levels of input window. The structure of the interface is shown as Figure 4—6.

Figure 4—6 the structure of the user interface development



The GUI is developed by the Model-View-Controller (MVC) architecture. The main controller class interprets the inputs from the user and maps these user actions into commands that are sent to the controller of each window, which calls the view classes and the model classes to effect the appropriate change. The model methods manage the different data from the user inputs, respond to their instructions to calculate the new optimal solution to the fleet and cargo assignment, and send the new result to the view classes. View classes accept the information, show the output as diagram as well as export the detail information on the spreadsheet.

The user manual for the GUI is as attached.

# Chapter 5

# Results & Conclusions

## 5.1 Overview of Research Results

In this paper, we have formulated and solved a network design and fleet allocation model for carriers to optimize their operation and reduce the cost, in a demand-increased domestic and international shipping environment. Our formulation here, which is a combination of three mixed integer linear programming sub-models—string simulation sub-model, network design sub-model, and fleet and cargo assignment sub-model—provides an effective and efficient planning tool to strategically select feasible strings, network structures, and optimal fleet and cargo assignment across the physical sea port locations in line with the market demands.

Note that we use hypothetical values for model parameters. From the direct output of three sub-models of fleet allocation model, we obtain the proposal with the highest annual profit, which runs four weekly services on the U.S. West Coast/Trade Lane I: IN1 (UPA—UPB—UPD—NPR—NPS—NPT—UPA), US2 (UPC—UPD—UPC), US1 (UPA—UPB—UPD—UPA), and US4 (UPC—UPD).The total annual EBITDA of this proposal is $77.33 million, including $32.99 million from the Trade Lane I and $44.34 million from the Trade Lane II.

Table 5—1 gives a summary of the results on fleet allocation model on the three trade lanes.

**Table 5—1 Details for the Most Profitable Proposal**

| The U.S. West Coast/Trade Lane I | | | The continental U.S./Trade Lane II | | | Surplus | | |
|---|---|---|---|---|---|---|---|---|
| Vessel | Capacity | Service | Vessel | Capacity | Service | Vessel | Capacity | Service |
| FN1 | 1000 | IN1 | UJ3 | 880 | US6/US7 | UJ7 | 880 | N/A |
| FN2 | 1000 | IN1 | UJ4 | 880 | US1 | UJ13 | 650 | N/A |
| FN3 | 1000 | IN1 | UJ5 | 880 | US1 | UJ14 | 600 | N/A |
| FN4 | 1000 | IN1 | UJ7 | 725 | US8/US9 | UJ15 | 600 | N/A |
| FN5 | 1000 | IN1 | UJ8 | 700 | US8/US9 | UJ16 | 600 | N/A |
| UJ1 | 910 | US2 | UJ9 | 650 | US10 | | | |
| UJ2 | 910 | US2 | | | | | | |

Comparing the fleet and cargo assignment of this proposal with Hampton Shipping' initial allocation, we obtain following changes based on the new proposal, which can increase the annual profit of the entire company:

- Add a new US1 service to catch the major cargo increase from the U.S. West Coast Ports (mostly in U.S. Port B) to U.S. Port D.
- Update the existing US3 service to the US2, omitting calling at UPB to avoid service overlap with US1 and save costs.
- Update the vessels on the IN1 service to six non large diesel-generator equipped ships to catch all the reefer cargo from NPS to the U.S. West Coast.
- Redeploy the initial four large diesel-generator equipped ships to the US1 and the US3 service to enlarge the capacity of these two services.
- Combine US6/US7 at the Trade Lane II into one service, and allocate one large ship to handle all the cargo to save both capital and operating costs.
- Redeploy one of the initial large diesel-generator equipped ships of the US3 service to the US8/US9 service at the Trade Lane II.
- Redeploy the initial large diesel-generator equipped ship of the US8/US9 service to the US10 service at the Trade Lane II.

## 5.2 Apply the Model to More General Cases for Hampton Shipping

The fleet allocation model examined in this research is based on the deterministic demand forecasted using the data of Hampton Shipping in 2005. In fact, the demand of Hampton Shipping in the future is not deterministic, and the current solution could be obsolete. To apply the model into more general cases for Hampton Shipping, if cargo demands are changed or other operations environment is changed, we can use the user interface to validate the existing solution and seek for the better adjustment.

The following steps provide us a good clue for the extension of the model when the demand changes in the future.

Step 1: Check the Validation of New Data Using the User Interface

Input all the new value of variables into the user interface. If the existing fleet allocation solution is still valid for the new data, the carrier need not change the fleet and the existing network is still optimal. Afterward, the program would output a new spreadsheet on the detail cargo assignment and the annual revenue report. If the solution is still valid, you can stop at Step 1, otherwise, you need go to Step 2.

Step 2: Prepare to Reallocate the Fleet if the Existing Solution is not valid

If the program alerts the carrier that the existing solution is not valid any more, or the carrier obtain the vessel utility rate is great than a certain percentage, say 90%, the carrier need plan to design the network or reallocate the fleet and cargo. This can be achieved by the following methods:

- If the overall profit is very high, and the carrier do not want to change the network to interfere the majority of customers, the carrier could consider chartering some slots from other carriers to increase its carrying capacity.
- If the increased demand is highly concentrated in one or two markets, the carrier could consider adding a shuttle in these markets.
- If the carrier has decided to change the structure of network, and reallocate the fleet, the carrier needs go to Step 3 to begin to build the fleet allocation model again.

Step 3: Collect Date

The carrier needs to collect all the data needed for the fleet allocation model, including cargo demand, freight rates, available ship information, port parameters, and all the transportation and other expenses.

Step 4: Build the String Simulation Sub-Model or Use the Existing Results

The carrier can use Optimization Programming Language (OPL) or other programming languages to simulate all the feasible strings which satisfy the weekly service rule. Actually, if there is no new port being added, the carrier can just use the output strings from the String Simulation Sub-Model in this paper. For Hampton Shipping, given that there is no significant increase in the average sailing speed, the 46 strings from our former work could serve as the base strings in the future, as those are the only strings which could be run in a weekly schedule.

Step 5: Build the Network Design Sub-Model or Use the Existing Results

In the network design sub-model of this research, we obtained all the feasible network structures using nine vessels. Considering the extremely high investment in adding one more vessel, the carrier could reanalyze the obtained networks and reassign the fleet according to the demand density change in each market. For the leased vessels, the carrier can lease larger vessels in consistent with the existing network structure.

If all the vessels are already running in their full capacities, the carrier should use the algorithm presented in Chapter Three to update the network design sub-model to simulate the network structures using ten vessels. This could also be achieved by manually analyzing the new demand and add specific constraints.

Step 6: Build the Fleet and Cargo Assignment Sub-Model

After fixing the proper network structure, the carrier has to rebuild the fleet and cargo assignment sub-model for the new demand. The algorithm discussed in Chapter Three helps the carrier analyze the demand, and formulate it into a mixed integer linear programming problem. The algorithm allows the carrier to assign cargo and vessels alternatively, to obtain a lowest cost solution

Step 7: Develop a Graphic User Interface or Update the Existing One by Changing the Fleet Allocation Solution

Based on the new solution obtained from Step 6, the carrier needs to develop a new program to conduct sensitivity analysis. The functions and the design algorithm of this program can be developed as that in Chapter Four. Also the carrier can use the existing "Controller-View-Model" structure by just updating the Model classes to reflect the new fleet allocation solution.

The fleet allocation model could be extended to general use if the carrier maintains the model according to those seven steps. Both analytical and simulation methods are critical to prolong the application life of this model.

## 5.3 Evaluation of Methodology

In order to evaluate the relative success of the work described in this thesis, it is helpful to establish the context in which the work is positioned. Based on this research and some of the former work [3], I present the following metrics for the evaluation of my work.

One straightforward way to evaluate a model is to check whether the model can achieve the preset goals: to obtain the most profitable solution to carry all the cargo, as well as to present users with alternative proposals to support decision making. Our fleet allocation model achieves this goal by providing the optimal and other potential solutions. These solutions are based on solving the string simulation, the network design, and the fleet and cargo assignment problems. Our model offers carriers required information on their operational structures in addition to the solutions for critical planning problems.

The second criterion to evaluate a model is to check whether the model can reflect future change in operational environment and adjust its solution. In this research, the fleet allocation model is divided into two parts: an optimal modeling part and a user interface part. The former part is a deterministic model using a set of hypothetical data, and the latter part is a tool to provide users specific solutions based on their input. There exists a trade off in a modeling process between a deterministic model, which provides high accuracy, with a stochastic one which offers flexibility. We believe there are several ways to formulate this fleet allocation model, and it might be possible to obtain a more flexible and efficient approach.

Our research could provide some direction for future research. Our research could be used by those who are interested in the similar topics:

- To obtain the problem formulation and the development of model for the similar fleet allocation or other network problems

- To search for a better approach based on our observations, methodologies, or even discrepancies.

## 5.4 Recommendations for Future Research

Future work on the topic of fleet allocation model could be on how to formulate the model. It is widely agreed that for such a large scale complex problem it is infeasible to build a single model to solve all the uncertainties. Hence, the design of the structure and the function of the sub-models turns out to be extremely important. We employ a top down approach with three sub-models—string simulation sub-model, network design sub-model, and fleet and cargo assignment sub-model—to obtain optimal solutions progressively. In my view, this model could be redesigned in a more cross-functional style.

Another important direction for future research would be to make the model to be more stochastic. This could be achieved by extending the scope of the current model, or by introducing more interaction from user.

At present, our current implementation of the fleet allocation model is performed using two computer languages—Optimal Programming Language and Java—which raises an integration problem. Hence, an important domain for further research is the use of a more flexible computer language environment.

In addition, the considering of level of service is of significant importance during the modeling process. Extension of current method requires transferring qualitative issues into quantitative measurements.

This research is an attempt to describe a model that can provide a theoretical and reliable way to optimize the fleet allocation It is my sincere hope that this thesis will provide an interested reader with some direction in the broad topic of fleet allocation.

# Appendix I

## Introduction to OPL Studio

This section introduces the Optimization Programming Language (OPL). After having formulated the problem, the next step is to solve this problem using an optimization software. In this problem, the software that has been chosen as the optimization modeling language platform is ILOG OPL Studio 3.7. OPL is an optimization package that supports linear programming, integer programming, mixed integer programming, mixed quadratic programming, constraint programming, scheduling and modeling language. ILOG OPL Studio makes it much easier and faster to model and optimization problem.

### Optimization Programming Language (OPL)

In recent years, combinatorial optimization problems are becoming increasingly important. As is well-known, these problems are difficult from both the standpoints of computational complex and programming, since they require expertise in applied mathematics, algorithms, and software engineering.

It has been increasingly recognized that integer programming and constraint programming have complementary strengths in approaching combinatorial applications. Integer programming focuses on the objective function, while constraint programming focuses on the constraints. There are still some harder problems which use a combination of both. [11]

ILOG Optimization Programming Language (OPL) originated in an attempt to integrate constraints and integer programming, at both the language and the solver levels. OPL is part of a larger system that also includes OPL script, the OPL component library, and a development environment. OPL and its associated solver is an integrated development environment for mathematical programming and combinational optimization application. It is capable of solving large-scale linear programs and various classes of integer programs and proves very quick and efficient in solving large, complex optimization problems. [4] [5]

The interface of OPL Studio is shown in Figure 5.

## Choice of OPL in our problem

In our fleet allocation problem, the key variable is the number of containers assigned to each service, all of which are required to be integers. Thus the formulation is an integer linear problem that is subject to the constraints enumerated above in Chapter Three. In other words, the fleet allocation problem of Hampton Shipping is a combinatorial optimization application of integer and constraint programming. So we chose OPL and developed a semi-automated program to build models and use its solver to solve the problem.

```
initialize
forall (i in Proposals)
    c[i]= itinery[i].c;

Routes d[Proposals];
initialize
forall (i in Proposals)
    d[i]= itinery[i].d;

int+ NumberofShipsa[Proposals] = [2,2];
int+ NumberofShipsb[Proposals] = [1,1];
int+ NumberofShipsc[Proposals] = [5,5];
int+ NumberofShipsd[Proposals] = [2,2];
int+ TotalDaysperTripa[Proposals] = [14,14];
int+ TotalDaysperTripb[Proposals] = [14,14];
int+ TotalDaysperTripc[Proposals] = [35,35];
int+ TotalDaysperTripd[Proposals] = [14,14];
float+ DaysatSeaperTripa[Proposals] = [9.3,9.3];
float+ DaysatSeaperTripb[Proposals] = [10,10];
float+ DaysatSeaperTripc[Proposals] = [29.2,28.5];
float+ DaysatSeaperTripd[Proposals] = [10,10];
int+ AverageContainerCapacityShipa[Proposals] = [1025,1025];
```

Figure 5 Interface of OPL Studio

Figure 6 shows the flow chart on how we apply OPL to the fleet allocation problem.

## Implementation of Fleet Allocation Problem using OPL

The whole problem is subdivided into three sub-problems, for which we develop three sub-models: the string simulation sub-model, the network design sub-model, and the fleet and cargo assignment sub-model. We translate each sub-model into a linear programming problem, and rewrite the objective and constraints into several mathematical functions, according to the specific condition of each sub-model. The purpose of the model is to assign values to the decision variables that satisfy all constraints. As is typical in each linear problem with constraints and mathematical programming, the code can be divided into:

- The declaration of the data.

- The declaration of decision variables.
- The statement of constraints.

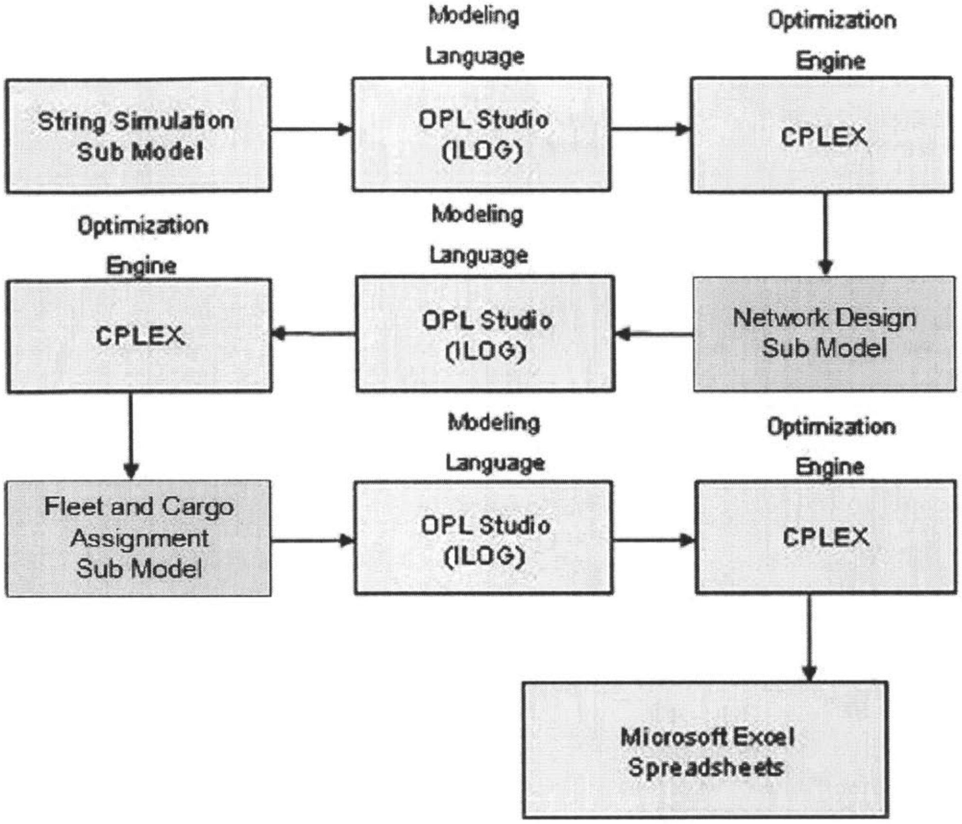


**Figure 6 Flow chart of OPL use in solving fleet allocation problem.**

The constraint solver can then be viewed as a simple iterative algorithm whose basic step consists of selecting a constraint and applying its constraint-satisfaction algorithm. The algorithm terminates when a constraint is inconsistent with respect to all combinations of variables. Associated with each constraint is a constraint-satisfaction algorithm whose primary role is to perform two main tasks:

1. To determine if the constraint is consistent with the variables, i.e., if there exist values for the variables in their domains that satisfy the constraint;

2. To apply a filtering algorithm to remove, from the domains of the constraint variables, values that do not appear in any of its solutions.

We specifically write the objective function and constraints corresponding to each of the sub model we want to solve.

a. The string simulation sub problem can be formulated as an optimization problem with:

**Objective function:**

$$\sum T_{ij} = 7 * I, \qquad \textit{(I is an integer)}$$

**Constraints:**

$$T_{ij} \in TransitMatrix.$$

b. The network design sub problem can be formulated as an optimization problem with:

**Objective function:**

$$\text{Minimize } (VN_{Trade\ Lane\ I}).$$

**Constraints:**

$$\sum C_{ij} \geq \sum D_{ij},$$

$$0\% \leq U_i \leq 95\%.$$

c. The fleet and cargo assignment sub problem can be formulated as an optimization problem with:

**Objective function:**

$$\text{Maximize } (\sum_{i=1}^{N} P_i),$$

**Constraints:**

$$\sum C_{ij} \geq \sum D_{ij}$$

$$0\% \leq U_i \leq 95\%$$

where:

$T_{ij}$ denotes the transit time between port j and port j

$VN_{Trade\ Lane\ I}$, denotes the number of vessels running at Trade Lane I

$P_{ij}$ denotes the profit of each service

$C_{ij}$ denotes the capacity between port i and port j

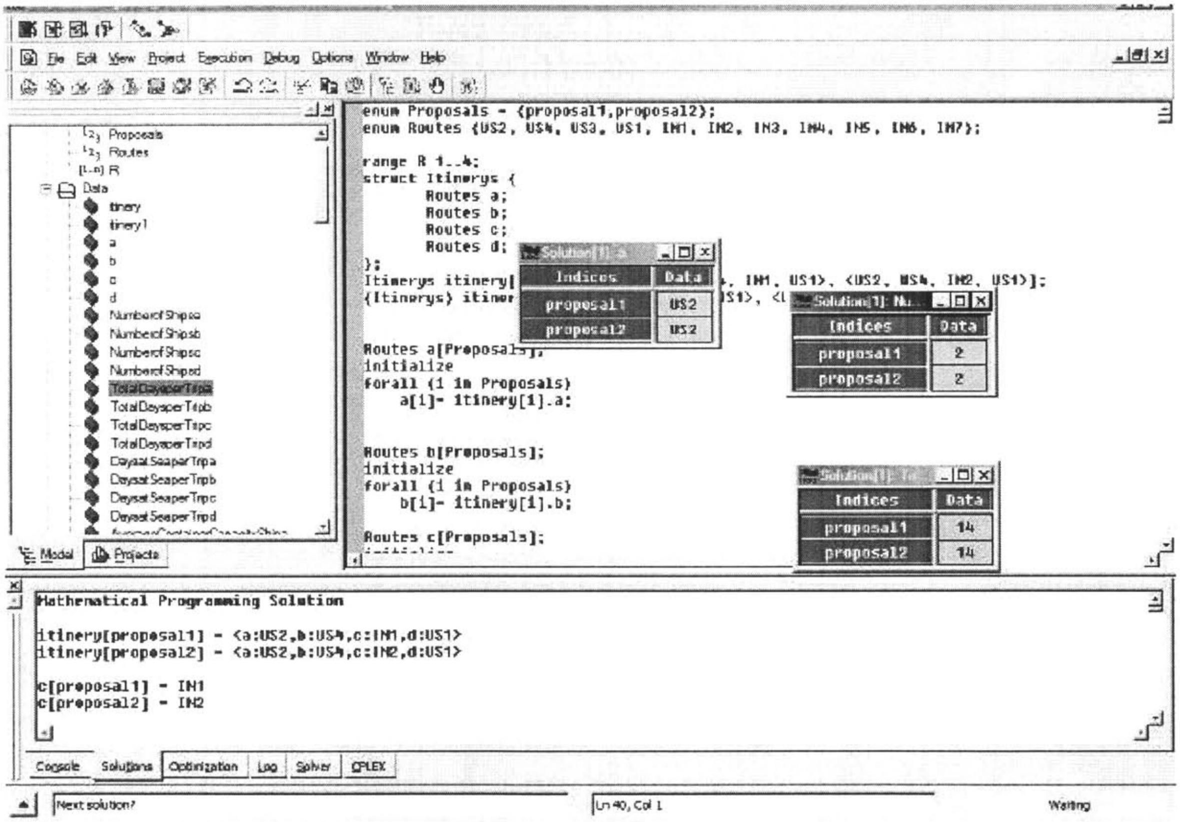
$D_{ij}$ denotes the cargo volume between port i and port j

$U_i$ denotes the utilization of each vessel.

## Output from OPL

Figure 7 shows the sample output for the Fleet Allocation problem using OPL Studio. The final output is exported as Microsoft Excel Spreadsheets which are attached at the end of the chapters discussing each of the sub-models.

Figure 7 Sample Output for Fleet Allocation Problem using OPL Studio.



```
enum Proposals = {proposal1,proposal2};
enum Routes {US2, US4, US3, US1, IN1, IN2, IN3, IN4, IN5, IN6, IN7};

range R 1..4;
struct Itinerys {
        Routes a;
        Routes b;
        Routes c;
        Routes d;
};
Itinerys itinery[                  , IN1, US1>, <US2, US4, IN2, US1>];
{Itinerys} itiner                 S1>, <

Routes a[Proposals];
initialize
forall (i in Proposals)
     a[i]= itinery[i].a;


Routes b[Proposals];
initialize
forall (i in Proposals)
     b[i]= itinery[i].b;

Routes c[Proposals];
```

| Indices | Data |
|---|---|
| proposal1 | US2 |
| proposal2 | US2 |

| Indices | Data |
|---|---|
| proposal1 | 2 |
| proposal2 | 2 |

| Indices | Data |
|---|---|
| proposal1 | 14 |
| proposal2 | 14 |

```
Mathematical Programming Solution

itinery[proposal1] = <a:US2,b:US4,c:IN1,d:US1>
itinery[proposal2] = <a:US2,b:US4,c:IN2,d:US1>

c[proposal1] = IN1
c[proposal2] = IN2
```

Appendix II

# User's Manual

# Fleet Allocation Model

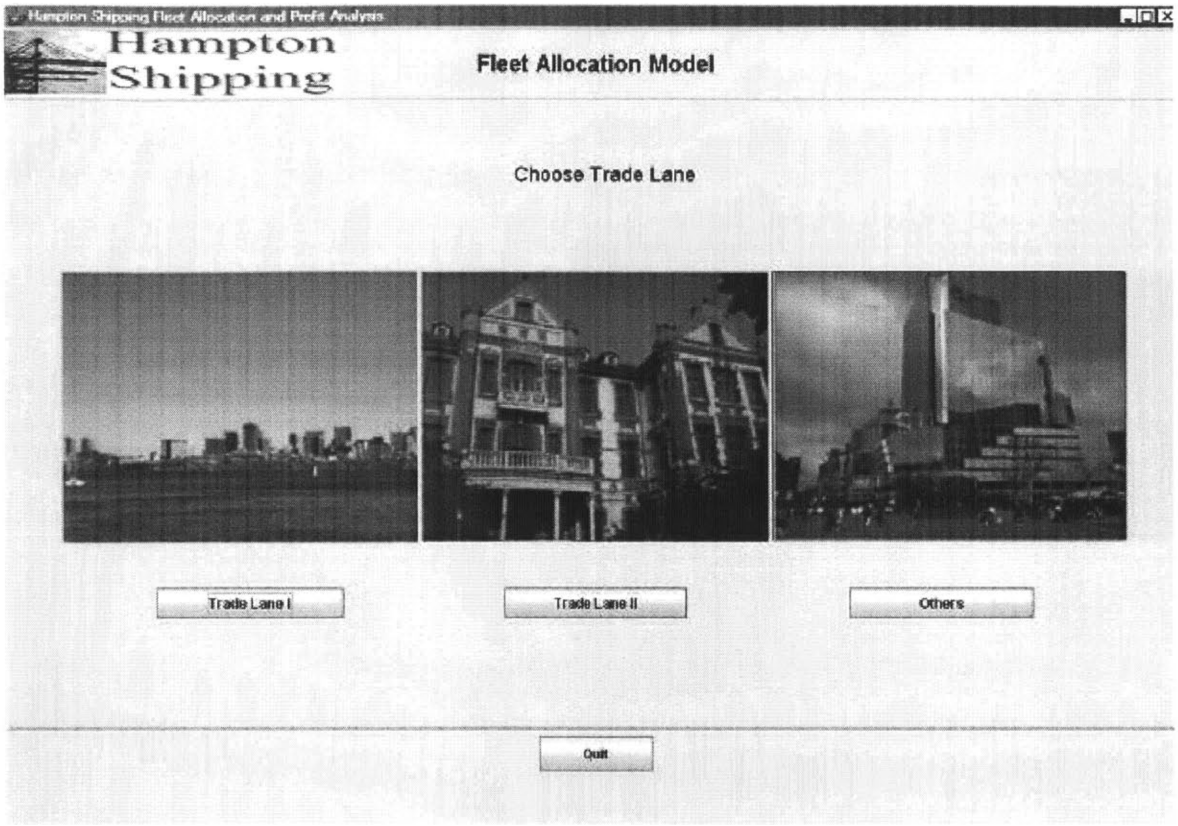
## Introduction

The fleet allocation model enables the user to change inputs and compare results in a professional and attractive way.

The program is conveniently designed into the form of a graphic user interface, and it is written in the form of a wizard. This wizard leads you step by step to collect all required information to compare different scenarios of fleet and cargo assignment. Information from our previous model run is used as the default scenario.

The input is subdivided into three steps: Step I—Change Cargo Information, Step II—Change Ship Information, and Step III—Change Transportation Expense and Other Information. In this manual, each of the steps is discussed.

## Choose Trade Lane

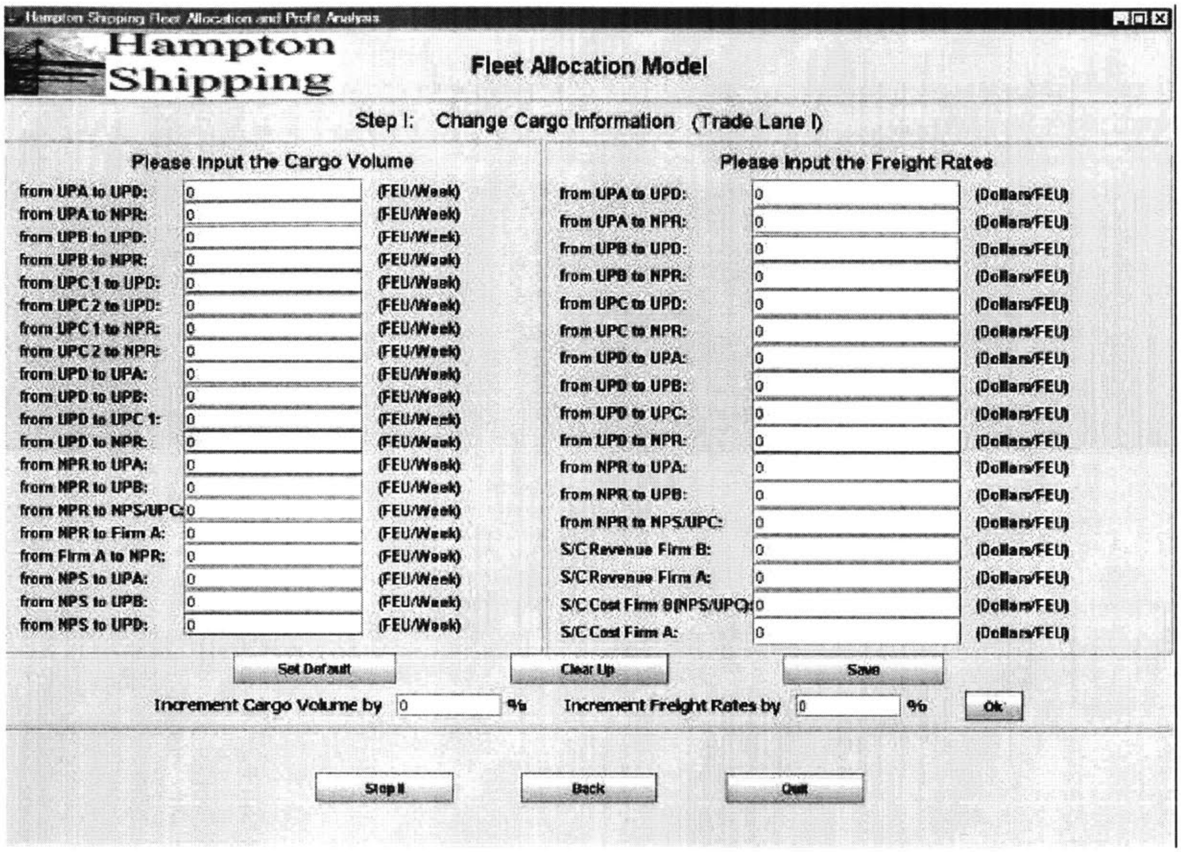


Choose Trade Lane Screen

Choose Trade Lane allows the user to change the cargo information in any of the trade lanes—the Trade Lane I, the Trade Lane II, and the others—by clicking three buttons. If you want to change the cargo volume and the freight rates in the Trade Lane I, you can just click Trade Lane I to move to the detail input screen, the same applies to the Trade Lane II and the others.

## Step I: Change Cargo Information

### Input Screen



from UPA to UPD: 0 (FEU/Week)
from UPA to NPR: 0 (FEU/Week)
from UPB to UPD: 0 (FEU/Week)
from UPB to NPR: 0 (FEU/Week)
from UPC 1 to UPD: 0 (FEU/Week)
from UPC 2 to UPD: 0 (FEU/Week)
from UPC 1 to NPR: 0 (FEU/Week)
from UPC 2 to NPR: 0 (FEU/Week)
from UPD to UPA: 0 (FEU/Week)
from UPD to UPB: 0 (FEU/Week)
from UPD to UPC 1: 0 (FEU/Week)
from UPD to NPR: 0 (FEU/Week)
from NPR to UPA: 0 (FEU/Week)
from NPR to UPB: 0 (FEU/Week)
from NPR to NPS/UPC: 0 (FEU/Week)
from NPR to Firm A: 0 (FEU/Week)
from Firm A to NPR: 0 (FEU/Week)
from NPS to UPA: 0 (FEU/Week)
from NPS to UPB: 0 (FEU/Week)
from NPS to UPD: 0 (FEU/Week)

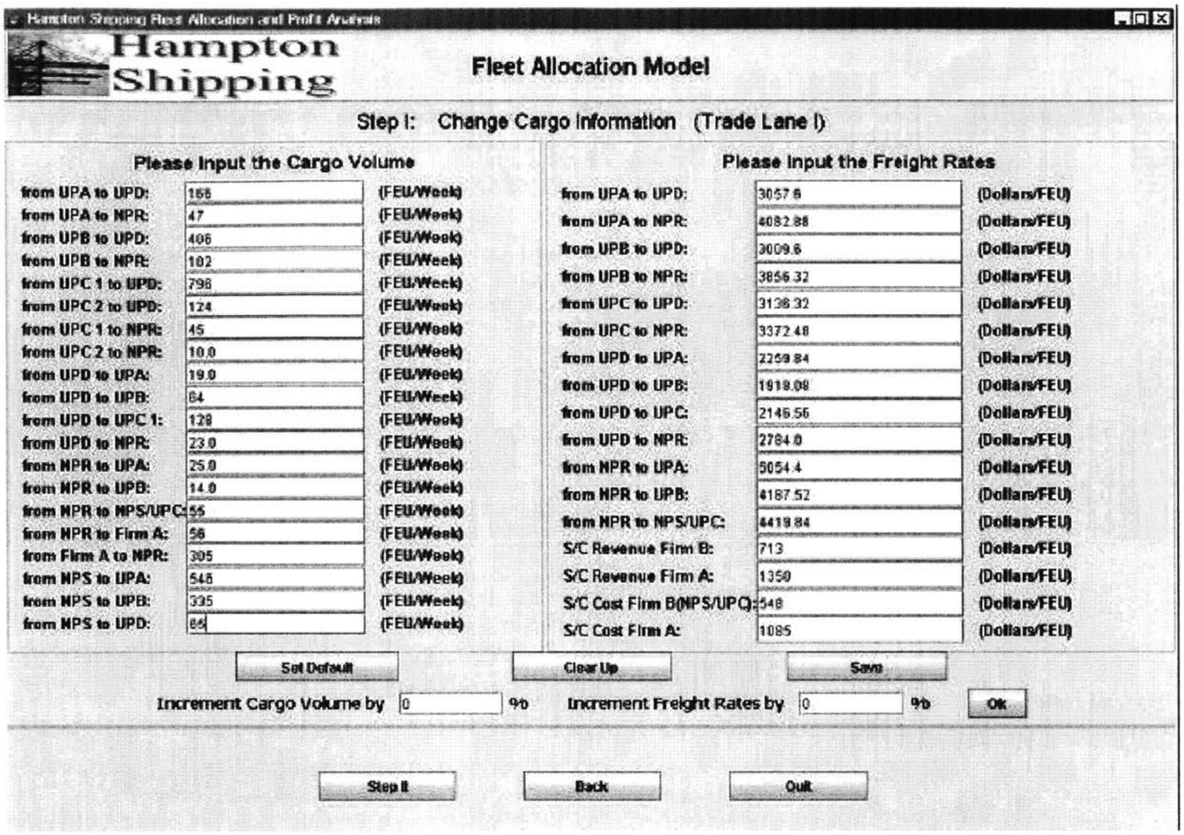
from UPA to UPD: 0 (Dollars/FEU)
from UPA to NPR: 0 (Dollars/FEU)
from UPB to UPD: 0 (Dollars/FEU)
from UPB to NPR: 0 (Dollars/FEU)
from UPC to UPD: 0 (Dollars/FEU)
from UPC to NPR: 0 (Dollars/FEU)
from UPD to UPA: 0 (Dollars/FEU)
from UPD to UPB: 0 (Dollars/FEU)
from UPD to UPC: 0 (Dollars/FEU)
from UPD to NPR: 0 (Dollars/FEU)
from NPR to UPA: 0 (Dollars/FEU)
from NPR to UPB: 0 (Dollars/FEU)
from NPR to NPS/UPC: 0 (Dollars/FEU)
S/C Revenue Firm B: 0 (Dollars/FEU)
S/C Revenue Firm A: 0 (Dollars/FEU)
S/C Cost Firm B(NPS/UPC): 0 (Dollars/FEU)
S/C Cost Firm A: 0 (Dollars/FEU)

Increment Cargo Volume by 0 %
Increment Freight Rates by 0 %

Step I: Change Cargo Information Screen

Change Cargo Information allows you to input the cargo volume and freight rates. The cargo volume includes all the existing cargo flow; the freight rates include both general rates and slot charter agreements.

## Set Value



Please Input the Cargo Volume

| | | |
|---|---|---|
| from UPA to UPD: | 168 | (FEU/Week) |
| from UPA to NPR: | 47 | (FEU/Week) |
| from UPB to UPD: | 406 | (FEU/Week) |
| from UPB to NPR: | 102 | (FEU/Week) |
| from UPC 1 to UPD: | 798 | (FEU/Week) |
| from UPC 2 to UPD: | 124 | (FEU/Week) |
| from UPC 1 to NPR: | 45 | (FEU/Week) |
| from UPC 2 to NPR: | 10.0 | (FEU/Week) |
| from UPD to UPA: | 19.0 | (FEU/Week) |
| from UPD to UPB: | 84 | (FEU/Week) |
| from UPD to UPC 1: | 128 | (FEU/Week) |
| from UPD to NPR: | 23.0 | (FEU/Week) |
| from NPR to UPA: | 25.0 | (FEU/Week) |
| from NPR to UPB: | 14.0 | (FEU/Week) |
| from NPR to NPS/UPC: | 55 | (FEU/Week) |
| from NPR to Firm A: | 56 | (FEU/Week) |
| from Firm A to NPR: | 305 | (FEU/Week) |
| from NPS to UPA: | 548 | (FEU/Week) |
| from NPS to UPB: | 335 | (FEU/Week) |
| from NPS to UPD: | 85 | (FEU/Week) |

Please Input the Freight Rates

| | | |
|---|---|---|
| from UPA to UPD: | 3057.6 | (Dollars/FEU) |
| from UPA to NPR: | 4082.88 | (Dollars/FEU) |
| from UPB to UPD: | 3009.6 | (Dollars/FEU) |
| from UPB to NPR: | 3856.32 | (Dollars/FEU) |
| from UPC to UPD: | 3138.32 | (Dollars/FEU) |
| from UPC to NPR: | 3372.48 | (Dollars/FEU) |
| from UPD to UPA: | 2259.84 | (Dollars/FEU) |
| from UPD to UPB: | 1918.08 | (Dollars/FEU) |
| from UPD to UPC: | 2146.56 | (Dollars/FEU) |
| from UPD to NPR: | 2784.0 | (Dollars/FEU) |
| from NPR to UPA: | 5054.4 | (Dollars/FEU) |
| from NPR to UPB: | 4187.52 | (Dollars/FEU) |
| from NPR to NPS/UPC: | 4419.84 | (Dollars/FEU) |
| S/C Revenue Firm B: | 713 | (Dollars/FEU) |
| S/C Revenue Firm A: | 1350 | (Dollars/FEU) |
| S/C Cost Firm B(NPS/UPC): | 548 | (Dollars/FEU) |
| S/C Cost Firm A: | 1085 | (Dollars/FEU) |

Increment Cargo Volume by 0 %
Increment Freight Rates by 0 %

Step I: Set Value Screen

You can use following steps to change the values. Possible actions include:

1. Click Set Default button, the cargo volume and freight rates from our previous model run will appear.

2. Click Clear Up button, all the values will become zero.

3. Type the percentage change in the Increment textboxes, and click OK. All cargo volume and freight rates except slot charter rates will increase or decrease by the certain percent.

4. Click Save button to confirm the change. (The values on the screen will be saved.)

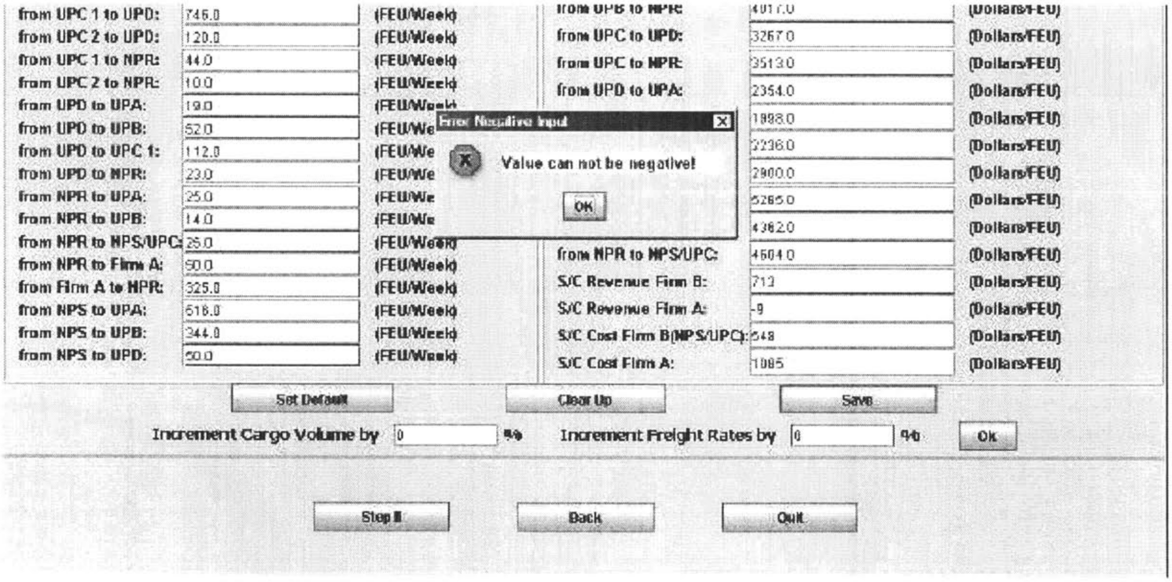
5. Click Step II to move to the next step.

6. Click Back to return to the Choose Trade Lane window.

7. Click Quit to quit the program.

A typical approach might be to start by clicking Set Default. From a general change modify all values by a certain percentage. For individual changes, modify just those text boxes. You could also combine these actions with a general percentage change followed by selective modifications. You must click OK to make the percentages changes appear on the screen. All changes are lost unless you click Save to save the numbers on the screen. (For any of the words in windows that you click on, a small shaded rectangle will appear around the word when it is clicked.)

If the user provides inputs as negative values, which are not allowed, then an error message window pops up. The user is expected to acknowledge the error by pressing ok and further correct the improper input.


| | | |
|---|---|---|
| from UPC 1 to UPD: | 746.0 | (FEU/Week) |
| from UPC 2 to UPD: | 120.0 | (FEU/Week) |
| from UPC 1 to NPR: | 44.0 | (FEU/Week) |
| from UPC 2 to NPR: | 10.0 | (FEU/Week) |
| from UPD to UPA: | 19.0 | (FEU/Week) |
| from UPD to UPB: | 52.0 | (FEU/We |
| from UPD to UPC 1: | 112.0 | (FEU/We |
| from UPD to NPR: | 23.0 | (FEU/We |
| from NPR to UPA: | 25.0 | (FEU/We |
| from NPR to UPB: | 14.0 | (FEU/We |
| from NPR to NPS/UPC: | 25.0 | (FEU/Week) |
| from NPR to Firm A: | 50.0 | (FEU/Week) |
| from Firm A to NPR: | 325.0 | (FEU/Week) |
| from NPS to UPA: | 516.0 | (FEU/Week) |
| from NPS to UPB: | 344.0 | (FEU/Week) |
| from NPS to UPD: | 50.0 | (FEU/Week) |

| | | |
|---|---|---|
| from UPB to NPR: | 4017.0 | (Dollars/FEU) |
| from UPC to UPD: | 3267.0 | (Dollars/FEU) |
| from UPC to NPR: | 3513.0 | (Dollars/FEU) |
| from UPD to UPA: | 2354.0 | (Dollars/FEU) |
| | 1888.0 | (Dollars/FEU) |
| | 2236.0 | (Dollars/FEU) |
| | 2900.0 | (Dollars/FEU) |
| | 5285.0 | (Dollars/FEU) |
| | 4382.0 | (Dollars/FEU) |
| from NPR to NPS/UPC: | 4604.0 | (Dollars/FEU) |
| S/C Revenue Firm B: | 713 | (Dollars/FEU) |
| S/C Revenue Firm A: | -9 | (Dollars/FEU) |
| S/C Cost Firm B(NPS/UPC): | 548 | (Dollars/FEU) |
| S/C Cost Firm A: | 1085 | (Dollars/FEU) |

Error Negative Input

Value can not be negative!

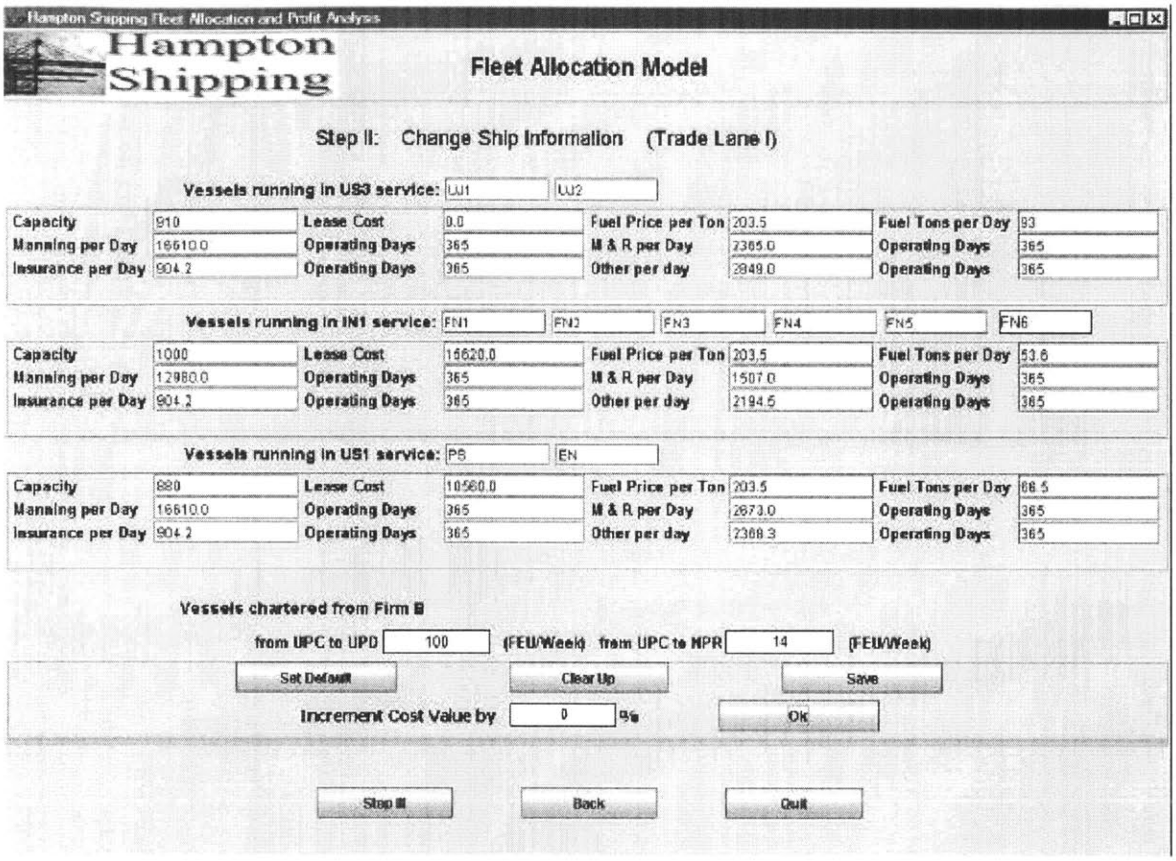
Increment Cargo Volume by 0 %

Increment Freight Rates by 0 %

Error Message

# Step II: Change Ship Information

## Change Input



Step II: Change Ship Information (Trade Lane I)

Vessels running in US3 service: LU1 LU2

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Capacity | 910 | Lease Cost | 0.0 | Fuel Price per Ton | 203.5 | Fuel Tons per Day | 93 |
| Manning per Day | 16610.0 | Operating Days | 365 | M & R per Day | 7365.0 | Operating Days | 365 |
| Insurance per Day | 904.2 | Operating Days | 365 | Other per day | 2849.0 | Operating Days | 365 |

Vessels running in IN1 service: FN1 FN2 FN3 FN4 FN5 FN6

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Capacity | 1000 | Lease Cost | 16620.0 | Fuel Price per Ton | 203,5 | Fuel Tons per Day | 53.6 |
| Manning per Day | 12980.0 | Operating Days | 365 | M & R per Day | 1507.0 | Operating Days | 365 |
| Insurance per Day | 904.2 | Operating Days | 365 | Other per day | 2194.5 | Operating Days | 365 |

Vessels running in US1 service: PS EN

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Capacity | 880 | Lease Cost | 10560.0 | Fuel Price per Ton | 203.5 | Fuel Tons per Day | 66.5 |
| Manning per Day | 16610.0 | Operating Days | 365 | M & R per Day | 2673.0 | Operating Days | 365 |
| Insurance per Day | 904.2 | Operating Days | 365 | Other per day | 2368.3 | Operating Days | 365 |

Vessels chartered from Firm B

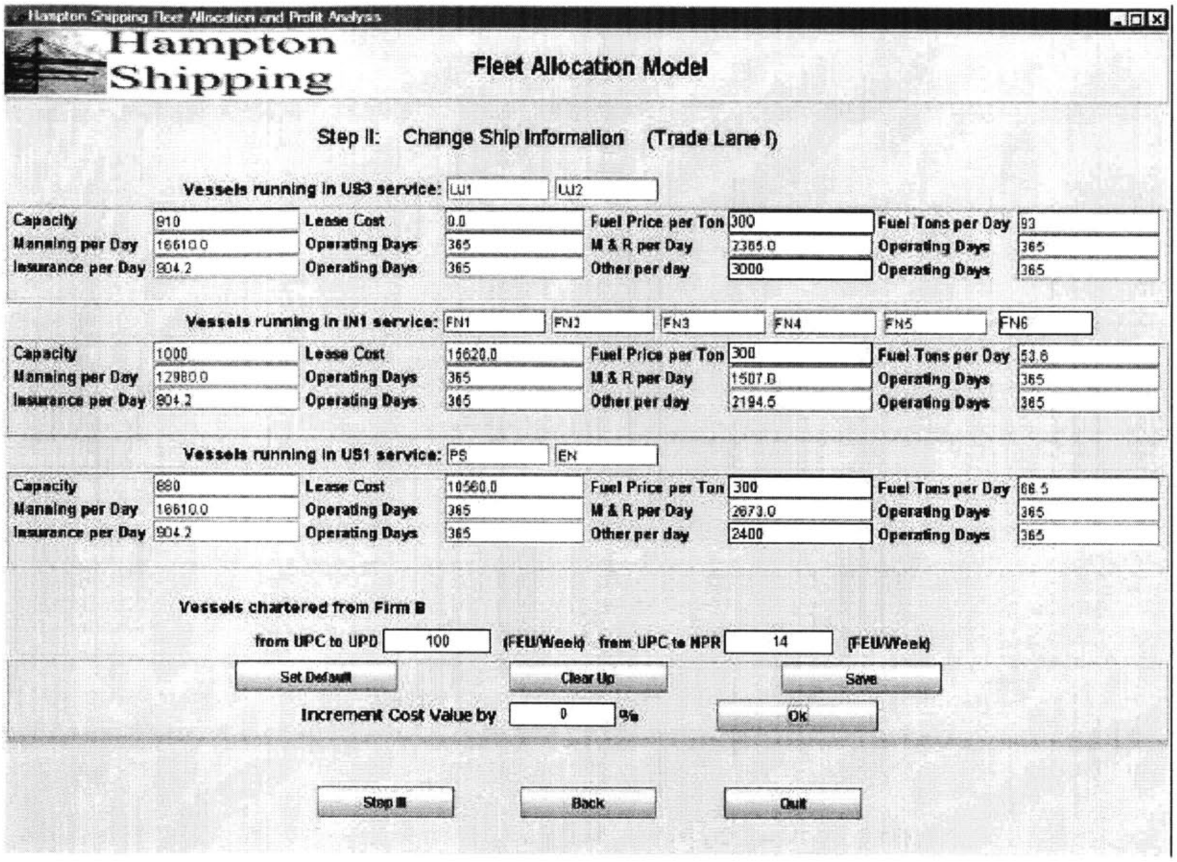
from UPC to UPD 100 (FEU/Week) from UPC to NPR 14 (FEU/Week)

Increment Cost Value by 0 %

Step II: Change Ship Information Screen

The vessels are listed by service. You can choose to change vessel name, set default value, increase variables by certain percentage, or type the value directly. The input includes vessel name, ship capacity, costs, and corresponding operating days. A percentage change only affects costs.

## Set value



Step II: Change Ship Information (Trade Lane I)

Vessels running in US3 service: LU1 LU2

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Capacity | 910 | Lease Cost | 0.0 | Fuel Price per Ton | 300 | Fuel Tons per Day | 93 |
| Manning per Day | 16610.0 | Operating Days | 365 | M & R per Day | 7365.0 | Operating Days | 365 |
| Insurance per Day | 904.2 | Operating Days | 365 | Other per day | 3000 | Operating Days | 365 |

Vessels running in IN1 service: FN1 FN2 FN3 FN4 FN5 FN6

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Capacity | 1000 | Lease Cost | 16620.0 | Fuel Price per Ton | 300 | Fuel Tons per Day | 53.8 |
| Manning per Day | 12980.0 | Operating Days | 365 | M & R per Day | 1507.0 | Operating Days | 365 |
| Insurance per Day | 904.2 | Operating Days | 365 | Other per day | 2194.5 | Operating Days | 365 |

Vessels running in US1 service: PS EN

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Capacity | 880 | Lease Cost | 10560.0 | Fuel Price per Ton | 300 | Fuel Tons per Day | 86.5 |
| Manning per Day | 16610.0 | Operating Days | 365 | M & R per Day | 2673.0 | Operating Days | 365 |
| Insurance per Day | 904.2 | Operating Days | 365 | Other per day | 2400 | Operating Days | 365 |

Vessels chartered from Firm B

from UPC to UPD 100 (FEU/Week) from UPC to NPR 14 (FEU/Week)

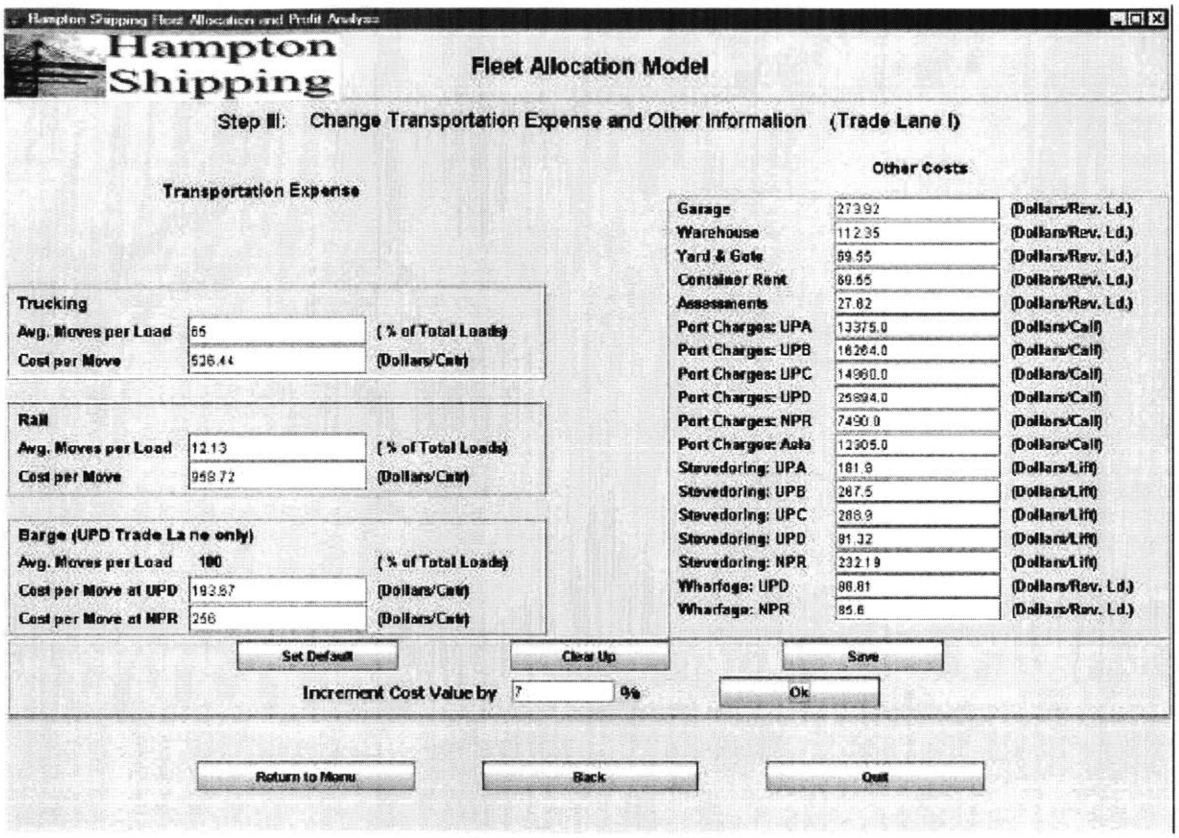
Increment Cost Value by 0 %

Step II: Set Value Screen

For this example, we change fuel price to 300, other cost for the vessels in US3 to 3000 per day, and 2400 per day for the vessels in US1 service. Then you need to press Save, and click Step III to move to the next step.

## Step III: Change Transportation Expense and Other Information

### Set Value



**Transportation Expense**

| | | |
|---|---|---|
| **Trucking** | | |
| Avg. Moves per Load | 65 | ( % of Total Loads) |
| Cost per Move | 536.44 | (Dollars/Cntr) |
| **Rail** | | |
| Avg. Moves per Load | 12.13 | ( % of Total Loads) |
| Cost per Move | 959.72 | (Dollars/Cntr) |
| **Barge (UPD Trade La ne only)** | | |
| Avg. Moves per Load | 100 | ( % of Total Loads) |
| Cost per Move at UPD | 193.87 | (Dollars/Cntr) |
| Cost per Move at NPR | 256 | (Dollars/Cntr) |

**Other Costs**

| | | |
|---|---|---|
| Garage | 273.92 | (Dollars/Rev. Ld.) |
| Warehouse | 112.35 | (Dollars/Rev. Ld.) |
| Yard & Gate | 69.55 | (Dollars/Rev. Ld.) |
| Container Rent | 89.65 | (Dollars/Rev. Ld.) |
| Assessments | 27.82 | (Dollars/Rev. Ld.) |
| Port Charges: UPA | 13375.0 | (Dollars/Call) |
| Port Charges: UPB | 16264.0 | (Dollars/Call) |
| Port Charges: UPC | 14980.0 | (Dollars/Call) |
| Port Charges: UPD | 25894.0 | (Dollars/Call) |
| Port Charges: NPR | 7490.0 | (Dollars/Call) |
| Port Charges: Asia | 12305.0 | (Dollars/Call) |
| Stevedoring: UPA | 181.8 | (Dollars/Lift) |
| Stevedoring: UPB | 287.5 | (Dollars/Lift) |
| Stevedoring: UPC | 288.9 | (Dollars/Lift) |
| Stevedoring: UPD | 81.32 | (Dollars/Lift) |
| Stevedoring: NPR | 232.19 | (Dollars/Lift) |
| Wharfage: UPD | 88.81 | (Dollars/Rev. Ld.) |
| Wharfage: NPR | 85.6 | (Dollars/Rev. Ld.) |

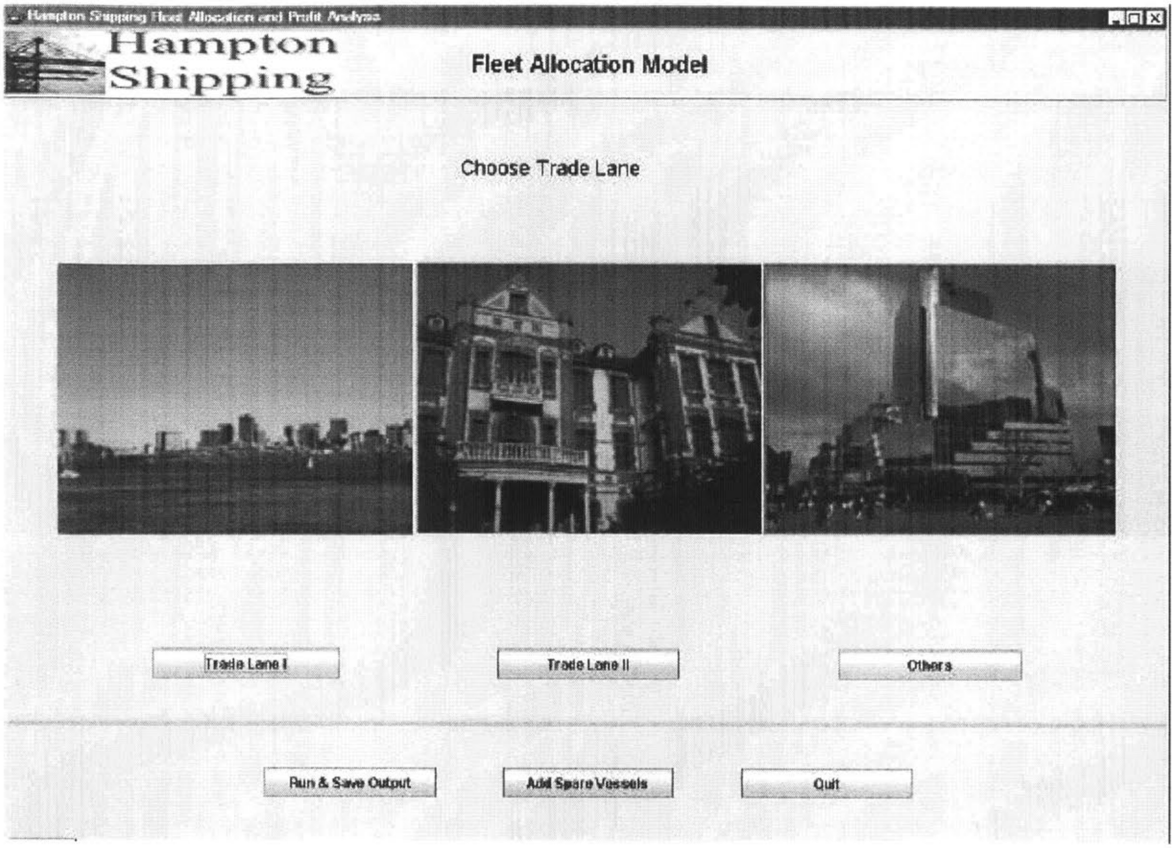
Increment Cost Value by 7 %

Step III: Change Transportation Expense and Other Information Screen

You can choose to set default value, increase variables by certain percentage, or type the value directly. Percentage changes only affect costs. For this example, we keep all the variables as proposed value. Please don't forget to press the Save button. If you forget to press the Save button, all the values will be saved as default.

Now you can press Change Other Trade Lanes to update the information of other trade lanes—the Trade Lane II and the Others. You can go back to any step by pressing Back.

## Change Other Trade Lanes

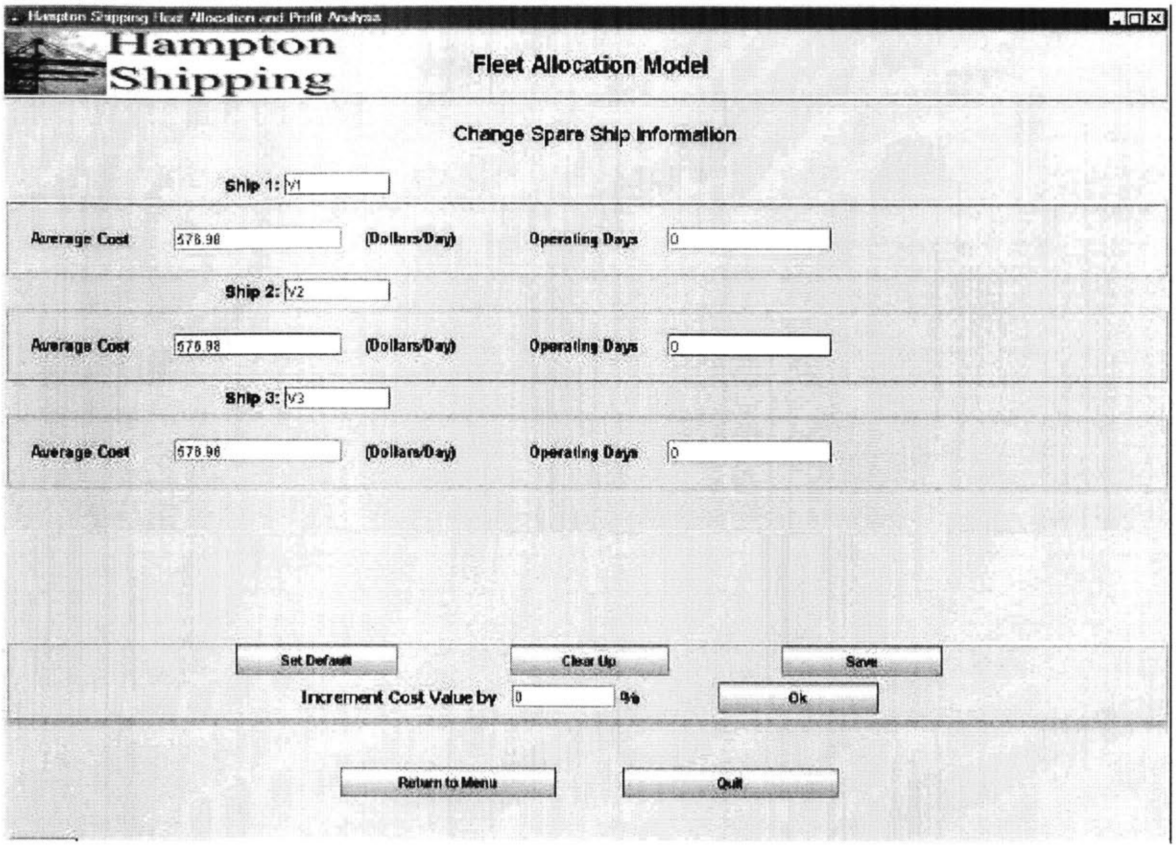


Choose Trade Lane Screen

You can press any button to change the input by following three steps—(1) Change cargo information, (2) Change ship information, and (3) Change transportation expense and other information. The operation of Trade Lane II and Others is very similar to that of Trade Lane I.

Meanwhile, you can press Add Spare Vessels to change the information of the spare ships.

# Change Spare Ships



Change Spare Ship Information

Ship 1: V1
Average Cost 576.98 (Dollars/Day) Operating Days 0

Ship 2: V2
Average Cost 576.98 (Dollars/Day) Operating Days 0

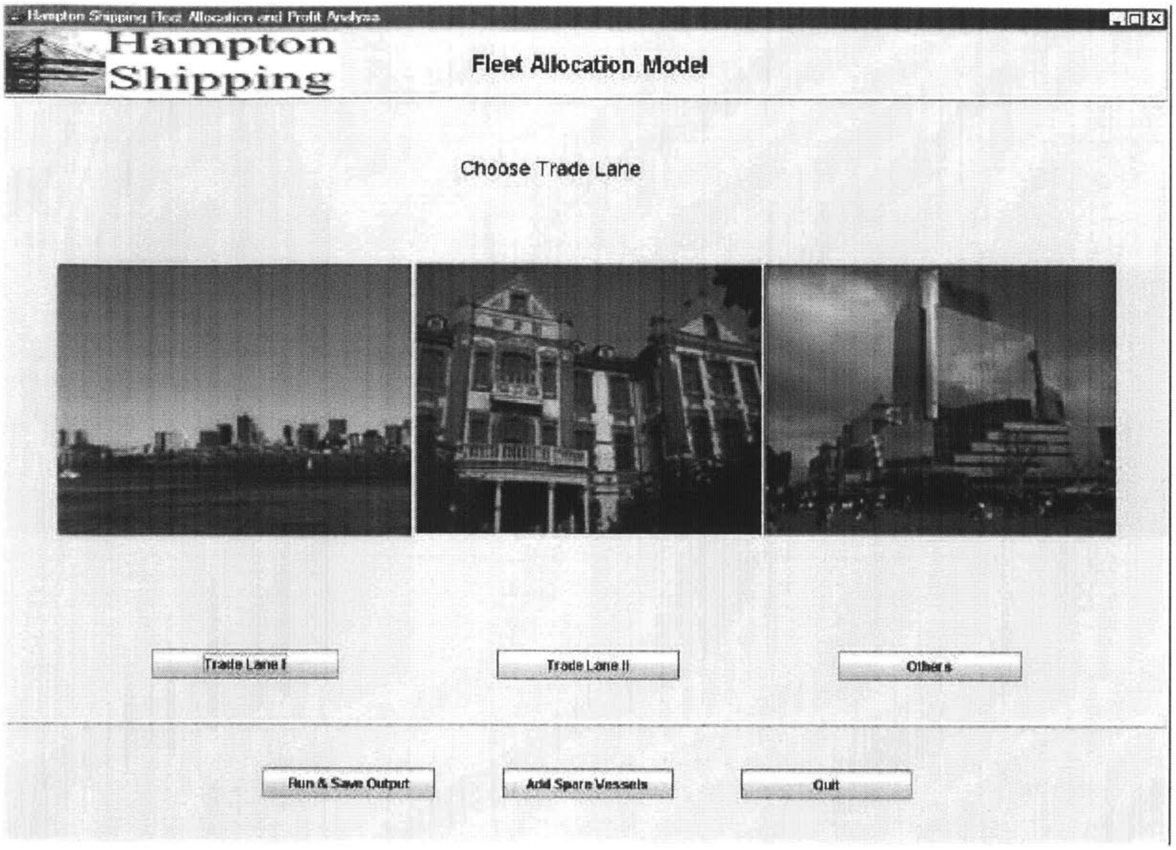
Ship 3: V3
Average Cost 576.98 (Dollars/Day) Operating Days 0

Increment Cost Value by 0 %

Change Spare Ship Information Screen

The default cost is USD$ 576.98 per day for each vessel. You can change the cost and the actual number of operating days. By pressing Save and Return to Menu, you can come back to the main menu.

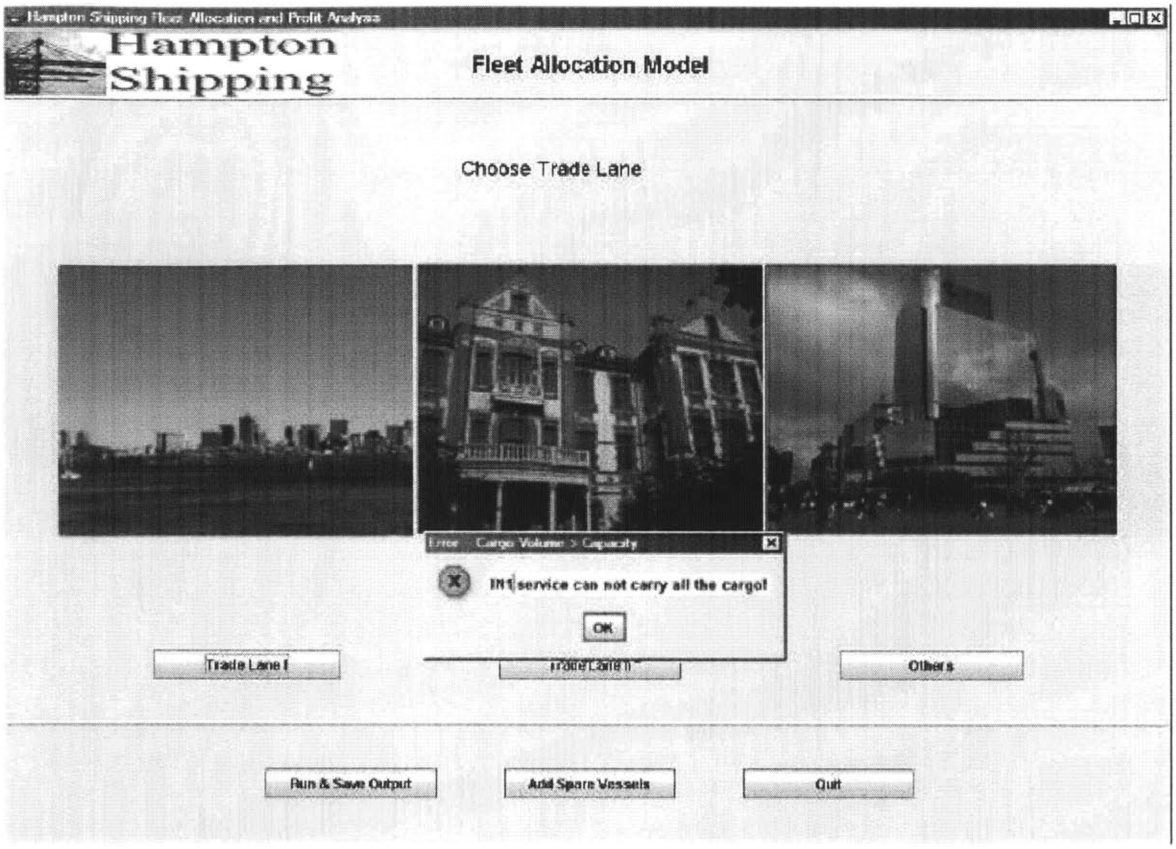
## Run the program and Output a Spreadsheet



Choose Trade Lane Screen

By pressing Run & Save Output, you can reach the output screen and obtain a spreadsheet on the detail information of the revenue, cost and the profit.

## Error Message: Cargo Volume > Capacity

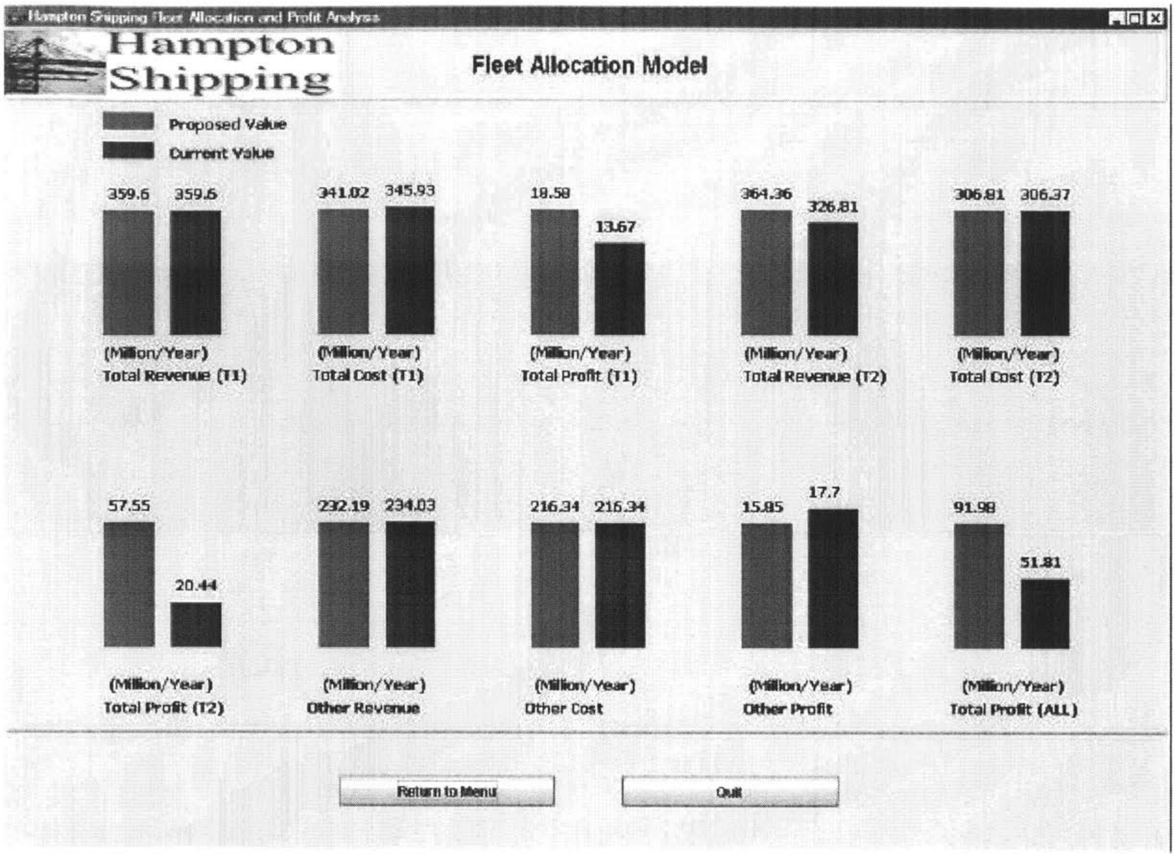


IN1 service can not carry all the cargo!

Error Message

If the program detects it is impossible to carry all the cargo volume by calculating the inputs provided by the user, an error message window pops up to show the service whose carrying capacity is less than the desired cargo volume. The user is expected to acknowledge the error by pressing ok and come back to the trade lane to change the vessel capacity or the cargo volume. However, if the user presses Run and Save Output instead, the model will run carrying cargo equal to the ship capacity. (Therefore, the surplus cargo will not be carried, while the user can still compare the revenue and costs.)

## Output – Screen

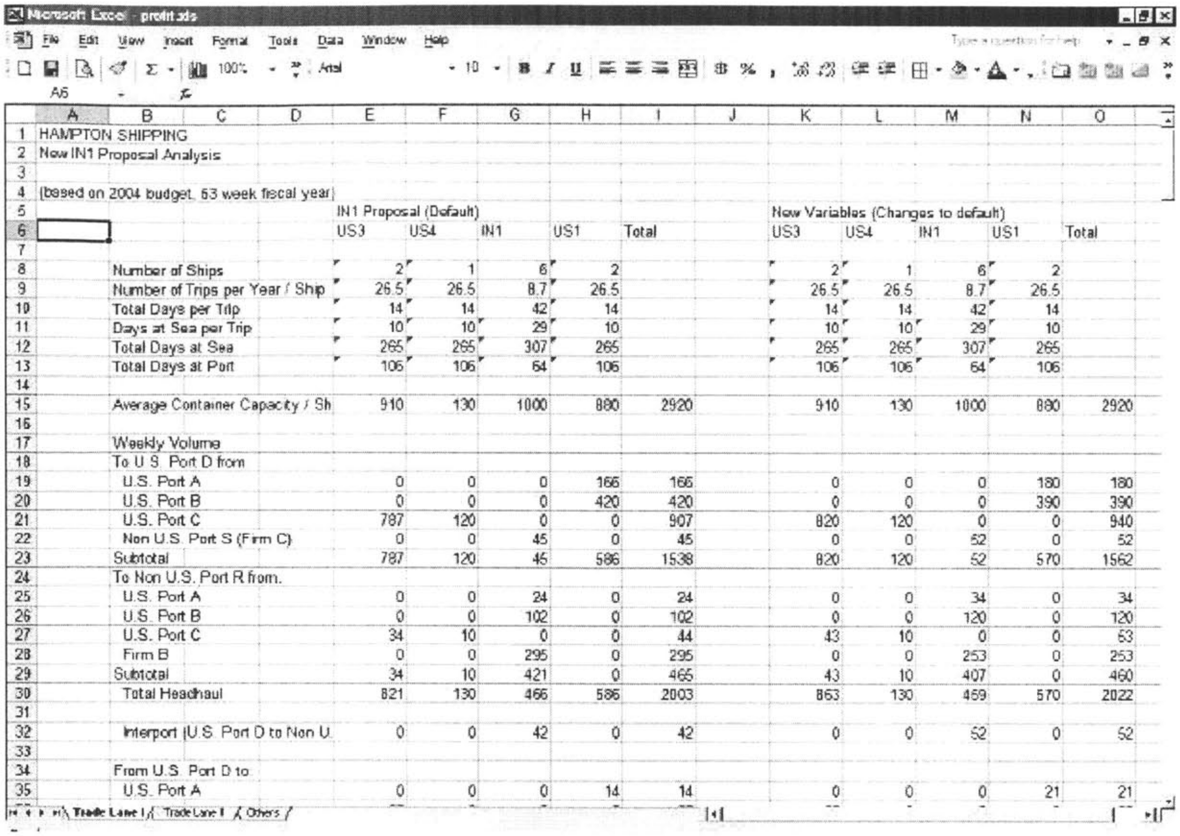


Output Screen

The output screen shows the revenue, cost, and profit of the proposed values and the new input.

You can also obtain a detailed printed summary of the profit results, similar to our output in the earlier model. The output is named as profit.xls, and is in the same package of the program itself. The user can save the detailed summary using the SAVE AS option to uniquely name each saved model run output.

# Output – Excerpt of Detailed Spreadsheet



| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | HAMPTON SHIPPING | | | | | | | | | | | | | | |
| 2 | New IN1 Proposal Analysis | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | |
| 4 | (based on 2004 budget, 53 week fiscal year) | | | | | | | | | | | | | | |
| 5 | | | | | IN1 Proposal (Default) | | | | | | New Variables (Changes to default) | | | | |
| 6 | | | | | US3 | US4 | IN1 | US1 | Total | | US3 | US4 | IN1 | US1 | Total |
| 7 | | | | | | | | | | | | | | | |
| 8 | | Number of Ships | | | 2 | 1 | 6 | 2 | | | 2 | 1 | 6 | 2 | |
| 9 | | Number of Trips per Year / Ship | | | 26.5 | 26.5 | 8.7 | 26.5 | | | 26.5 | 26.5 | 8.7 | 26.5 | |
| 10 | | Total Days per Trip | | | 14 | 14 | 42 | 14 | | | 14 | 14 | 42 | 14 | |
| 11 | | Days at Sea per Trip | | | 10 | 10 | 29 | 10 | | | 10 | 10 | 29 | 10 | |
| 12 | | Total Days at Sea | | | 265 | 265 | 307 | 265 | | | 265 | 265 | 307 | 265 | |
| 13 | | Total Days at Port | | | 106 | 106 | 64 | 106 | | | 106 | 106 | 64 | 106 | |
| 14 | | | | | | | | | | | | | | | |
| 15 | | Average Container Capacity / Sh | | | 910 | 130 | 1000 | 880 | 2920 | | 910 | 130 | 1000 | 880 | 2920 |
| 16 | | | | | | | | | | | | | | | |
| 17 | | Weekly Volume | | | | | | | | | | | | | |
| 18 | | To U.S. Port D from | | | | | | | | | | | | | |
| 19 | | U.S. Port A | | | 0 | 0 | 0 | 166 | 166 | | 0 | 0 | 0 | 180 | 180 |
| 20 | | U.S. Port B | | | 0 | 0 | 0 | 420 | 420 | | 0 | 0 | 0 | 390 | 390 |
| 21 | | U.S. Port C | | | 787 | 120 | 0 | 0 | 907 | | 820 | 120 | 0 | 0 | 940 |
| 22 | | Non U.S. Port S (Firm C) | | | 0 | 0 | 45 | 0 | 45 | | 0 | 0 | 52 | 0 | 52 |
| 23 | | Subtotal | | | 787 | 120 | 45 | 586 | 1538 | | 820 | 120 | 52 | 570 | 1562 |
| 24 | | To Non U.S. Port R from. | | | | | | | | | | | | | |
| 25 | | U.S. Port A | | | 0 | 0 | 24 | 0 | 24 | | 0 | 0 | 34 | 0 | 34 |
| 26 | | U.S. Port B | | | 0 | 0 | 102 | 0 | 102 | | 0 | 0 | 120 | 0 | 120 |
| 27 | | U.S. Port C | | | 34 | 10 | 0 | 0 | 44 | | 43 | 10 | 0 | 0 | 53 |
| 28 | | Firm B | | | 0 | 0 | 295 | 0 | 295 | | 0 | 0 | 253 | 0 | 253 |
| 29 | | Subtotal | | | 34 | 10 | 421 | 0 | 465 | | 43 | 10 | 407 | 0 | 460 |
| 30 | | Total Headhaul | | | 821 | 130 | 466 | 586 | 2003 | | 863 | 130 | 459 | 570 | 2022 |
| 31 | | | | | | | | | | | | | | | |
| 32 | | Interport (U.S. Port D to Non U. | | | 0 | 0 | 42 | 0 | 42 | | 0 | 0 | 52 | 0 | 52 |
| 33 | | | | | | | | | | | | | | | |
| 34 | | From U.S. Port D to | | | | | | | | | | | | | |
| 35 | | U.S. Port A | | | 0 | 0 | 0 | 14 | 14 | | 0 | 0 | 0 | 21 | 21 |

profit.xls

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