# A FLEET DEPLOYMENT OPTIMIZATION MODEL FOR LINER SHIPPING

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to Professor Harry Benford
with appreciation.
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## Abstract

We use Linear Programming for solving the problem of the optimal deployment of an existing fleet of multipurpose or fully containerized ships, among a given set of routes, including information for lay-up time, if any, and type and number of extra ships to charter. A detailed and realistic model for the calculation of the operating costs of all the ship types in every route is developed. The optimization model is also applicable to the problem of finding the best fleet composition and deployment, in a given set of trade routes, which may be the case when a shipping company is considering new or modified services, or a renewal of the existing fleet. In addition, two promising mixed linear-integer programming formulations are suggested.

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## List of Symbols

$A^{p}_{irk}$ Operating costs per unit time for vessel k at the $i^{th}$ port of route r .

$A^{s}_{kr}$ Operating costs per unit time at sea for ship k on route r .

$a_k$ Coefficient in the speed-fuel consumption relationship for ship k.

$B_{rs}$ Zero-one variable indicating the speed s for the ships on route r.

$b_k$ Exponent in the speed-propulsion power relationship for ship k.

$C^{p}_{kr}$ Operating costs at ports per voyage for the ship k on route r.

$C^{s}_{kr}$ Operating costs at sea per voyage for ship k on route r.

$c_k$ Coefficient in the speed-propulsion power relationship for ship k.

$C_{kr}$ Operating costs per voyage of ship k on route r.

$C_{krs}$ Operating costs per voyage of ship k on route r at speed s.

$cd_r$ Length of the canal on route r.

$cf_r$ Canal fee on route r .

$cn_r$ Number of canal crossings /voyage on route r.

$cw_r$ Waiting time per canal crossing on route r .

$d^{m}_{ir}$ Distance of restricted waters associated with the $i^{th}$ port of route r.

$d^{m}_{r}$ Distance of restricted waters in route r .

$D_k$ Additional daily cost of ship k while laid-up, including anchorage charges, transportation for the crew in and out of the ship, etc.

$d_r$ Total sailing distance on route r .

$e_k$ Total lay-up costs per day for ship k .

$F_r$ Frequency of service in route r (an integer number).

$f_k$ Propulsion-fuel consumption per unit time of ship k .

$g^{p}_{k}$ Average electricity generation-fuel consumption per unit time, at ports, of ship k.

$g^{s}_{k}$ Electricity generation-fuel consumption per unit time, at sea, of ship k .

$g_{kl}$ Generator fuel consumption per unit time in lay-up condition .

$H_k$ Daily running costs in normal operation of ship k.

$h_k$ Daily running costs of the ship k while laid-up.

$I_r$ Number of ports on route r.

$L_{ijr}$ Amount of cargo onboard a ship sailing from port i to port j of route r, for a frequency of one voyage per year.

$L_r$ Maximum value of $L_{ijr}$ for all legs ij in route r.
$m_{kr}$ Canal fees per voyage for ship k on route r .
$M_r$ Number of voyages per year (a real number) on route r.
$n_{ir}$ Productivity or rate of loading and unloading cargo in port i of route r .
$N_k^{max}$ Number of ships type k available.
$P_k$ Brake power required to propel the vessel type k (at a given speed).
$p_r^f$ Price of propulsion-fuel on route r .
$p_r^g$ Price of fuel for electricity generation on route r .
$p_l$ Price of fuel for generation at the lay-up location .
$Q_{ijr}$ Amount of cargo to be carried per annum from port i to port j on route r.
$Q_{ir}$ Amount of cargo to be moved (loaded and unloaded) per annum at port i of route r by all ships.
$q_{ir}$ Amount of cargo to be unloaded and loaded per voyage at the $i^{th}$ port of route r.
$Q_{jir}$ Amount of cargo to be carried per annum from port j to port i on route r.
$RC_r$ Minimum required capacity of ships that are to operate on route r.
$RT_{kr}$ Register tonnage of ship k, for the canal in route r.
$RV_r$ Minimum required number of voyages per year on route r.
$S_k$ Service speed of vessel k .
$S_m$ Average speed in restricted waters for all ships .
$t_{kr}$ Voyage time of ship k on route r.
$t_r^m$ Total delay due to restricted waters operation for any ship on route r.
$t_{ir}^p$ Time spent per voyage (by any ship) at the $i^{th}$ port of route r.
$t_r^p$ Total time spent at ports, per voyage, on route r.
$t_{kr}^s$ Sailing time per voyage of ship k on route r.
$t_r^w$ Waiting time due to canal queues per voyage on route r, for any ship.
$t_{krs}$ Voyage time of ship k on route r at speed s.
$T_k$ Duration of shipping season for ship k.
$u_{irk}$ Fixed costs per call at port i of route r for ship k.
$v_{irk}$ Variable port fees (per unit time) for the ship k at port i of route r.
$V_k$ Cargo capacity of ship k.
$w_{ir}$ Allowance per call for inactive time at port i of route r.
$X_{kr}$ Number of voyages per year of ship k on route r.
$X_{krs}$ Number of voyages per year of ship k on route r at speed s.
$Y_k$ Number of lay-up days per year for ship k.

# 1.Introduction and Outline

Liner Shipping is the type of maritime transportation that has received the least attention by researchers, at least in the quantitative aspects of it. This is possibly due to the noncontrollable nature of some of the dominant variables and factors that affect the operation of this type of companies, like government regulations, subsidies, minimum required service frequencies, etc, which discourage any attempt for a systematic approach to the transportation system analysis and optimization.

Furthermore, the research that has been done so far in Liner Shipping operations has relied mainly on heuristics or simulation techniques, as opposed to other, more exact methods like non-linear, linear or integer programming, which have been extensively used for the optimization of fleets of tankers and bulk carriers. Such techniques can provide good practical solutions in many cases. It has to be born in mind that a simulation model can only help to choose the best from a limited group of alternatives submitted to it. We believe that techniques like Linear, Integer or Non-Linear programming can be successfully applied in Liner Shipping fleet deployment and scheduling problems, provided that the cargo forecasts are reliable.

Liner carriers specialize in the transport of high value goods and competition is often restricted to service rather than price; Liner Shipping companies are mainly committed to provide a regular and reliable service, in line with customers' requirements. In contrast, Tramp and Industrial shipping operations involve mainly dry bulk carriers and tankers. Tramp carriers specialize in the transportation of cargo that is irregularly generated and their rates are not subject to regulations from any conference. Most of the tramp operators are small independent owners, and although their number is large, little research has been done in their allocation, routing and scheduling.

"Industrial" carriers are also the owners of the cargo, and their operations have the objective of arranging the transportation of their goods at minimal cost. This type of operations have received more research attention than Tramp or Liner shipping.

In both Tramp and Industrial shipping, the operator's objective implies the maximization of the ship's cargo in the "loaded" leg of the voyage, and there are no strict timing requirements. In Liner Shipping timing is important, and in times of low cargo supply, the ships have to operate at low utilization levels, in order to comply with the schedules.

Operators of liner vessels are compelled in many instances to take ships in charter for one or more voyages in order to cover unexpected fluctuations in the demand; in other times, reductions in charter rates make it profitable to modify the deployment of the fleet by taking ships in long-term charter and slow-steaming or even laying-up part of the owned fleet.

The thesis is organized as follows:

In Chapter 2, the problem that motivated the present thesis is described; Chapter 3 is dedicated to a survey of past research in the area of Fleet Deployment.

The optimization model is described in Chapter 4; we first establish (Sections 4.1 and 4.2) the objectives and main assumptions of the model; Section 4.3 is dedicated to explain a method for calculating the amounts of cargo to be moved at different ports and amounts of cargo onboard the ships in the various sailing legs of a given route, and their relationship with the service frequency, with the goals of establishing a target value of frequency of service for each of the routes and/or determining the minimum required capacity of the ships that may be allocated in each route.

Section 4.4 is dedicated to the development of a mathematical model of the operating costs and voyage times of the different ship types while operating in every one of the possible routes. The results are the required coefficients for the linear programming formulation.

Section 4.5 focuses on the determination of the optimal speed for a ship operating in a given route, as an independent problem. In Section 4.6 a Linear Programming formulation is presented, which is the core of our Optimization Model.

In Section 4.7, the overall optimization procedure is outlined. It is important to note that the routing problem, i.e., the assignment of the sequence of ports that forms each route, is out of the scope of this thesis. It is assumed that the routes are already established. Justifications of this and other assumptions are given in Section 4.2. The scheduling situation is implied in the requirements of service frequency, which are considered given, but important considerations in this regard are discussed in Section 4.7.

In Chapter 5, an example is carried out, based on the information provided by *Flota Mercante Grancolombiana S.A.* (FMG), a large liner shipping company which operates in various trade routes between Colombia and Europe, the U.S. and the Far East. The results of this example show that substantial savings in the present operating costs can be achieved if the resultant deployment strategy is followed.

Finally in Chapter 6 the conclusions and suggested extensions of this work are presented. In this final part, two very appropriate mixed linear-integer programming formulations are explained.

# 2.Problem Description

## 2.1 General Aspects

Due to structural changes in their operating environment, caused by diverse factors such as changes in government regulations, dramatic changes in cargo forecasts, new competition or other pressure that forces freight rates up, etc, liner shipping companies are from time to time forced to make strategic decisions related to the deployment of their fleets. Examples of such decisions are the re-allocation of the existing owned fleet, what type of ships, how many and for how long, to take in charter to complement the operation of the owned fleet, and/or whether and for how long to lay-up the owned ships.

Managers of these companies rely mainly on the economic evaluation and comparison of a limited set of alternatives that are chosen by "common sense" and are based heavily on the experience of the operations personnel. Sometimes this task is not difficult, as when the number of ships in the fleet is small and/or their allocation to the routes is commanded by very specific ship characteristics, that leave on the table a very limited set of feasible allocation alternatives. However, when large fleets are involved, the number of feasible alternatives grows and it is not easy to pick the best of them for the analysis.

On the other hand, the companies have to decide what types of ships to build and their relevant characteristics like cargo carrying capacity, cargo moving equipment, hull form, engine type and power, crew size, etc; some of those factors interact to define the speed- fuel consumption relationship, the ship's operating costs, the life cycle costs, etc.

After defining the basic design characteristics and other operative requirements of the ships, there will be a number of alternatives of ship types from which the new fleet can be selected. A correct systematic approach for the selection of the new fleet or new set of ships is crucial for the future profitability of the shipping company. This approach has to take into account the existing fleet so that all the implications are considered in the economic analysis.

Tied to the allocation problem is the problem of determining the service speeds of the ships in the various routes, which for a given required service frequency, will determine the number of ships that has to be assigned to each route. A higher speed implies lower voyage time and therefore better utilization of the existing fleet. On the other hand a higher speed will increase more than proportionally the fuel costs per voyage. These interactions deserve a careful and comprehensive quantitative analysis.

Port constraints regarding maximum draft are not important in liner shipping, since the vessels are of moderate sizes (usually not bigger than 30,000 DWT); these relatively small sizes (compared with sizes of bulkers and tankers) are explained by the frequency requirements that constrain liner operations. However, port conditions regarding cargo handling equipment, days and hours at which stevedores work in a given port, stevedoring rates during weekends and night hours make timing an important consideration in liner operations. Consequently, the schedules are designed to take into account those port conditions.

## 2.2 Present Situation in *Flota Mercante Grancolombiana.*

### 2.2.1 Routing

The routing (set of routes and sequence of ports in each) is determined following obvious geographic considerations, cargo requirements and required transit times. In some of the routes double calls are necessary, one for unloading and another for loading, in order to keep transit times at a reasonable level (for the cargo that is loaded/unloaded in these double calls) and to ensure that there is enough capacity onboard for the available cargo.

There are in each of the routes "regular" and "optional" ports. When the amount of cargo to be loaded/unloaded in a regular port is low enough, and/or the ship is very delayed in its itinerary, a call to an optional or even a regular port may be canceled. In this case, the cargo that is on the ship addressed to that port may be unloaded in a nearby regular port and transported by truck to the final destination.

Some of the routes are composed of two or more "sub-routes" which are followed alternatively by the vessels assigned to the main route. This arrangement implies different service frequencies to the ports of the same main route.

### 2.2.2 Cargo Types

There are three basic categories of cargo carried by the company:

- General Cargo (about 60%)
- Refrigerated Cargo (about 10%)
- Containers (about 30%)

Some of the routes are almost 100% containerized. There is a trend towards more containerization, but this trend is slow, because of the limitation in equipment and opposition from stevedore unions in the home ports, which are owned and operated by a state-owned company.

As happens in other countries, there are government regulations in Colombia which require that a given percentage of the cargo in and out of the country, must be moved by national flag vessels or vessels chartered by national shipping companies. There are limitations however, to the number of ships that the company is allowed to charter.

### 2.2.3 Ship Allocation and Speed Assignment

In practice, the ships are assigned to the routes without any special technique or systematic method, the experience of the line managers plays a major role. Some of the major factors for determining the ships' allocation are the ships characteristics, especially their capacity and ability to carry each of the different types of cargo (including containers), and the types of cargo typically moved in a route.

The speed for the normal operation of the owned ships is fixed by the operations and engineering departments, within a feasible range, according to the ship's main engine manufacturer recommendations.

## 3.Literature Survey

Alexis [1] presents a comprehensive survey of the models in routing and scheduling in marine transportation, available until 1982; as this author points out, due to the complexity and the uncertainty of the operations of liner vessels, most models in liner operations consist of simulation and heuristic procedures emphasizing scheduling and routing.

For the present work, however, not only the research oriented towards liner operations, but also research for bulk and tanker shipping was reviewed. In fact, the formulations of some problems in bulk and tanker shipping (within tramp or industrial operations) are similar to the one in this thesis, with the main exeption of the service frequency requirement. For this reason, we will refer in the next paragraphs to such works in addition to the works specifically focused on liner shipping.

Datz et al. [2] developed a simulation approach for liner operations which generates a schedule based on the cargos offered and its profitability, including probability quantifications of the event of "promised" cargo disappearing.

In another research on liner shipping, Boffey et al. [3] developed an interactive computer program and an heuristic optimizing model, for scheduling containerships in the North Atlantic route. Several components of "level of service" were considered like the frequency of the service, the day the ships sail (it was argued that Friday sailings generate more cargo than sailings at other days of the week), the transit time of the ships between port pairs, and the reliability of the service provided. Both parts of the work were tried in actual operations of a carrier, the interactive computer program was better accepted/ understood by the management. This computer program was not a truly optimizing tool but instead a method that provided information on profitability, timing, transit times and total slack for different inputs of ship speeds and combinations of ports to be called.

Olson, Sorenson and Sullivan [9] used a deterministic simulation model to provide medium term regular schedules for a fleet of cargo ships involved in a liner trade. The model was also used to investigate the effects of factors like waiting in port for additional cargo or increasing competition.

In the present thesis the expression *Fleet Deployment* implies the allocation of ships to routes, their general scheduling (i.e., the assignment of service frequencies), and the chartering of vessels, if any, to complement the owned fleet in the fulfillment of the transportation mission. Very little has been written about Fleet Deployment, as we have defined it, for liner shipping. However, in the solution of a scheduling problem, a fleet deployment strategy may be implied, and vice versa. The most recent research dealing with fleet deployment applies to the transportation of bulk commodities in the framework of tramp and industrial shipping operations, i.e. not subject to frequency or timetable requirements. Some of such work is mentioned in the next paragraphs.

Benford in [4], formulates the problem of finding the best mix of ships (from an existing fleet) for the purpose of moving a given amount of bulk cargo in a period of time between two ports, and presents a simple solution procedure. Perakis [5] solved the same problem by mathematical and numerical methods obtaining appreciable improvement; the operating costs were modeled as a nonlinear function of the ship's speed and the nonlinear constrained optimization problem was solved with nonlinear optimization algorithms, and Lagrange multiplier techniques. Perakis and Papadakis [6] presented various, more detailed fleet deployment optimization models for the same problem. In all these cases both full load and ballast speeds were considered.

The authors of [6] also developed in a nonlinear approach [7], for the problem of minimum cost operation of a fleet of ships that has to carry a specific amount of cargo from a set of loading ports to a set of unloading ports. Here again the operating costs are nonlinear functions of the ships' full load and ballast speeds; the fuel consumption is the cause of the nonlinearity and a realistic speed-fuel consumption relationship is presented. An alternative linear approach for certain conditions is described; the linear objective function results after the ship's speed is fixed at its optimal value by an iterative approach. This optimal speed is found in an independent formulation to that of the main problem.

In few of the studies on fleet deployment/ ship scheduling for tramp or industrial shipping has the operating cost of the ships while in port, played a major role. Similarly, detailed models of the time spent in loading/ unloading and its associated costs are usually not presented. This situation can be explained by the fact that port costs are small as compared with the costs at sea in that type of shipping operations.

Other research deals with the tradeoffs implied in the slow steaming of ships independently of the allocation problem. Ronen [8] presents three methods to find the optimal speed of bulk carriers under each one of three operative states, which depend on the leg on which the ship is sailing.

Everet et al. [10], used linear programming to find the best fleet of large bulkers and tankers that was intended to carry 15% of the U.S. foreign trade in the major dry and liquid bulk commodities. The optimal fleet was chosen from a menu of ship types and in the same process ships were assigned to voyages. Four structural elements were considered; namely, commodity movements, voyages, a menu of ships, and port constraints. A sensitivity analysis was one of the important elements of the optimization, as the aim of the investigation was to produce a combination of ships and voyages that is optimum not only in the sense that it minimizes the life cycle cost of the fleet for a given distribution of demands, but which produces a minimum cost over as wide a range of probable demands as is possible. The results indicated that the fleet cost and composition are very sensitive to the opportunities for backhauls and to port constraints, but insensitive to small or medium changes in the mission.

Another linear programming approach was carried out by Conley et al. [11]; their objective was to minimize the total cost of moving an homogeneous product from overseas origins through United States ports to over 400 inland destinations. The formulation allocates a fleet of about 50 ships to routes between given groups of overseas and U.S. ports, it also assigns mainland destinations to ports and select inland modes of transportation. The size of the problem was reduced by introducing a fictitious port (the funnel) through which all the cargoes are moved. The model does not consider the return of the ships to the loading ports.

# 4 Optimization Model

## 4.1 Objectives

The model considered here is concerned with minimizing the annual operating costs of a fleet of liner ships. This minimization is equivalent to maximizing profits per unit time; the reason for this is that the cargo movement requirements are met, the freight rates are assumed fixed, and the revenue is therefore constant.

The costs referred in this work as "operating costs", are the following:

- Fuel Costs
  - Fuel for propulsion
  - Fuel for electricity generation
- "Daily Running Costs" (Explained in a following section)
- Port charges
  - Charges per call which do not depend on the time of stay (docking/undocking, pilotage, tugboat charges, port maintenance fees, etc)
  - Charges per unit of time of stay at port (wharfage, anchorage, etc)
- Canal fees

Several important costs are excluded from the model because they are effectively fixed, as per our assumptions. Those costs are:

- Stevedoring costs for loading/ unloading
- Agency fees
- Commissions to cargo brokers
- Communications billed by the agents; most of them are cargo related
- Container rental and maintenance.

All the above listed costs depend on the types, amounts, origins and destinations of the cargoes carried. All these factors are assumed given and constant in the present thesis; therefore, the costs depending on them are also constant. The overhead costs are also excluded, as they are independent of the fleet deployment.

It is pertinent to note that the stevedoring costs associated with each cargo shipment depend on the agreement made with the shipper; there are four basic types of agreements, depending on who pays the stevedoring charges:

- "liner terms": the shipping company pays both loading and unloading stevedoring charges.
- "free in, liner out": the shipper pays the loading charges and the shipping company pays the unloading ones
- "liner in, free out": the shipping company pays the loading charges and the shipper pays the unloading ones
- "free in and out": the shipper pays the stevedoring charges at both loading and unloading.

The first case, "liner terms" is the most common. The particular freight rate applied depends on which of the above mentioned types of agreement is chosen.

The model should include the costs at ports, as these are a major component of the operating costs of liner shipping companies. The port charges depend on the number of calls to the port, the time spent at port and the type of ship (wharfage and anchorage charges are usually classified according the ship's length or draft).

The output of the optimization model should include the following information:

- Allocation of the owned ships to the routes
- Number and type of ships to take in charter and for how long
- Whether to lay-up owned ships, of which type and for how long (in this point the possibility of chartering out or scrapping should be considered by the shipping company).

The problem of the optimal speed determination will be decoupled from the allocation problem. The most profitable speed *for each ship* should be found, and in this way the operating costs of the ships at sea for a given voyage will be fixed.

On the other hand, a minimum required frequency of service for each one of the routes is one of the most important inputs. Despite that, a method will be presented for assisting in the adjustment of such frequency, if that is allowed, and/or finding the minimum vessel size that can move the amount of cargo per voyage defined by a given service frequency. In practice, shipping companies do adjust the service frequencies, within small ranges. The customers of course, prefer a high frequency, but a higher frequency will normally result in a higher total operating cost.

The formulation should be applicable to the problem of the configuration of a fleet of ships (to be acquired), to comply with a given cargo movement requirement, in a set of given routes, or to the case of renovating part of the existing fleet. This thesis will not address the routing problem (defined as the determination of the set of routes, their ports and the port sequence). The goal of the optimization model is of a strategic nature, rather than oriented to the day-to-day decision process, which involves decisions about adjustment of schedules, slight routing modifications, etc, for which human intervention is essential.

In order to enable the application of linear programming, the speed of the ships has to be fixed. In this case, the determination of the best speed for each ship type has to be decoupled from the main problem. However, it is recognized that all the ships assigned to the same route should operate at the same speed, in order to keep a constant and stable frequency of service. Times at port per voyage in a given route are the same for all the ships. Delays caused by waiting and sailing in channels and restricted waters in general are also the same for all the ship types operating in the same route; consequently total voyage times are equal for all the ships in a given route. In this way, the intervals between arrivals of consecutive ships to a port are constant.

The delays due to restricted operation may be considerable in certain routes because of the amount of miles to be sailed in canals, rivers or other access to ports. Therefore the present model will consider those delays.

Finally, an important note about the notation used. Subscript k, as will be used in the present thesis, may denote either a single ship or a ship type, depending on the particular application. In this way the model can allow both the precise output due to including the singularities of ships (even among those of the same type), or to save formulation and computing time by dealing only with ship types.

This last alternative is most appropriate when the problem is the determination of the best ships to build or acquire among a menu of ship types available but not owned already by the shipping company. A parameter representing the number of ships of each type will be included in the model; in the case of k representing a single ship that variable will be assigned the value one.

## 4.2 Assumptions

### 4.2.1 Cargo Units

The cargo amounts are assumed to be the number of containers or units of weight of general (dry) cargo. We do not consider this a major source of difficulty, and for most companies carrying multiple types of cargo, the model shall be appropriate. Weight units are more suitable than volume ones for the general cargo case, since the stowage factor is less than one cubic meter per metric ton for the overwhelming majority of cargo types; therefore the active limit for a ship's loading is the cargo weight and not the cargo volume.

In line with this, a ship's cargo capacity as well as the data of the cargo to be carried between pairs of ports can be given in terms of metric tons, or number of TEU's (twety-foot equivalent container units).

### 4.2.2 Routing

As mentioned before, in the present thesis we will not address the routing problem. It is assumed that the routes have been already determined, taking into account factors as ports to be served, amounts of cargo to be carried between pairs of ports in a given period, distances between the ports, required transit times between port pairs, etc.

For the purpose of routing determination, well known models like the traveling salesman problem can be applied. However, it is often obvious which is the best sequence of ports in a given trade, because of geographic considerations alone; the set of routes may be also be obvious, when the trades are geographically separated; therefore, the routing problem may not be difficult.

As mentioned in Chapter I, double calls per voyage to a port are sometimes done, for carrying out the loading and unloading separately in order to overcome stowage difficulties. This case is covered in our model by assigning different port designations to each one of the port calls in the same route-voyage; for example in a given route a ship rotates:

port A(unloading) / port B(unloading & loading) / port A(loading)

In this case, port A(unloading) may be denoted as "port 1" and port A(loading) as "port 3" of that route. The notation of the ports in a route should represent the exact sequence in which the ports are called. This is essential for the correct computation of the amount of cargo on board in each leg of the voyage and the verification of capacity compatibility ship-route, for different values of the frequency of service.

### 4.2.3 Cargo Requirements and Frequency of Service

There is a fixed amount of cargo to be carried per year between a given pair of ports belonging to a given route. The ships must call the ports in regular intervals for loading/ unloading.

The term "frequency of service", or just "frequency", is often used in practice in the liner shipping business and especially in journal publications about liner services, for denoting the time between sailings from a port in a given route by a liner company. The time between sailings is equal to the time between arrivals of the ships to that port in that route (assuming that port stay is fixed).

In order to be consistent with this practice, the time between arrivals (or sailings) to (from) a port is called "Frequency of Service" in the present thesis. This Frequency of Service or port interarrival time defines a number of calls per year to that port, which is the service frequency rigorously speaking (365 divided by the value of Frequency of Service). In our model, it is assumed that there is exactly one call per voyage to each "port" , therefore the number of calls per voyage to a port is also the number of voyages per year in that route.

The cases of cargoes with origins and destinations other than the established ports of call, are included; in such cases, the cargoes are transported by feeder services from the origin to the nearest or most convenient regular port of call, and through the nearest or most convenient port to the cargo destination.

Inventory costs are excluded, as they do not play an important role in the actual operations of a liner shipping company.

### 4.2.4 Speed- Fuel Consumption for Different Loadings

One of the important assumptions in this thesis is that the relationship speed vs. resistance of the ships is basically the same for the typical (different) loading conditions that occur in liner operations. This implies the assumption that there are no long sailing legs where the ships are in a pure ballast condition, i.e., with no cargo or very small amount of cargo on board.

This is a realistic assumption in many cases. For the present thesis the data regarding speeds and specific fuel consumptions of the ships operated by FMG, in a period of moderate length and typical operation were analyzed. No clear relationship between the fuel consumption and the loading condition at a given speed was found. This may be explained by the number of factors that influence the performance of the ship in a given sea passage, like weather, currents, hull condition, etc., which make a precise analysis difficult.

On the other hand, we have to take into account that the DWT to total displacement ratio in medium or small ships (like most liner ships) is not as high as in larger ships (typically bulkers and tankers), and therefore in smaller ships the change in hydrodynamic conditions when the ship passes from loaded to ballast situations is not as dramatic. In addition, when the ship is in off-design conditions (like in the ballast case), its performance may not improve substantially, in spite of the significant reduction in displacement.

### 4.2.5 Other Assumptions

As the present model is intended to be a decision tool for the long-term operation of the fleet, the initial condition of the ships will not be included in the problem formulation.

The cargo (offered) is evenly generated throughout the year. In real life that is not exactly true, but the variations of cargo offerings from month to month are not large anyway.

There is a menu of ship types available for short or long term charter at given rates. A maximum number of ships of each type can be chartered; this is realistic, as there is always a limit in the number of ships of any type available in the market.

## 4.3. Frequency of Service and Cargo Movements

### 4.3.1 General Aspects

The model presented in this thesis requires a matrix of cargo movements per year from port to port in each route, as an input. Those values may be the typical cargo offerings for the company when operating in normal conditions, as per the company's statistics.

A method of analysis will be presented, for the determination of the minimum required size (capacity) of the ships allocated to that trade; we make the assumption that the total amount of cargo offered per year between pairs of ports is independent of the service frequency. Therefore, for frequencies different to the ones corresponding to the cargo statistics taken as input, the total amount of cargo to be carried per year remains constant. This assumption implies that the shipping company will neither lose nor gain customers if frequencies of service are modified; that is realistic for the case of moderate variations. The appropriate range of allowed frequency variations can only be determined by the liner shipping company.

Given the amounts of cargo to be moved between port pairs and the frequencies of service in each one of the routes, an amount of cargo to be moved at each call (i.e., per voyage) can be computed. We assume that the ship's stay at port is largely determined by that amount of cargo, given a standard "productivity" associated to that port; this productivity is given as a number of container units or weight units (loaded and/or unloaded) per unit time; most shipping companies keep records of that measure for the ports their ships call.

In the case of multiple types of cargo, it is obvious that a different productivity value is associated with every mix of commodity types that may be loaded/ unloaded in a port. However, it is assumed here that the values of productivity for each port (to be given as an input for our model), correspond to the mix of cargo types foreseen in the time horizon considered for the fleet deployment decision. This is not an unrealistic assumption, since liner companies usually maintain a stable/ loyal clientele, therefore the cargo mix to be moved at each port is not likely to change substantially.

The units for all the cargo data are given in TEU's or tons, depending on the type of cargo carried by the liner company.

### 4.3.2 Amounts of Cargo per Port

#### 4.3.2.1 Cargo Loaded/Unloaded Per Year

From a (given) three-dimensional matrix **Q** representing the amounts of cargo (tons or containers) to be moved per year from port i to port j on route r, the amounts of cargo to be loaded and unloaded in every port can be computed as follows:

$$Q_{ir} = \sum_{j=1}^{I_r} [\, Q_{ijr} + Q_{jir} ], \tag{1}$$

where:

$Q_{ir}$ = amount of cargo to be moved (loaded and unloaded) per annum, by all ships at port i of route r

$Q_{ijr}$ = amount of cargo to be carried per annum from port i to port j in route r

$Q_{jir}$ = amount of cargo to be carried per annum from port j to port i in route r

$I_r$ = number of ports in route r

#### 4.3.2.2 Cargo Loaded/Unloaded per Voyage

The targeted number of voyages per year define the amount of cargo that has to be loaded and unloaded per call (i.e. per voyage) at each port, as follows:

$$q_{ir} = Q_{ir} \, [\, F_r / 365 \,], \tag{2}$$

where:

$q_{ir}$ = amount of cargo to be unloaded and loaded at the ith port of route r

$F_r$ = Frequency of Service, as defined before; the term $[\, F_r / 365 \,]$ is the inverse of the number of voyages per year in route r.

### 4.3.3 Vessel Loading Levels

The present model assumes, that cargo may be carried between any couple of ports of a given route. Of course once a given port sequence in a route is established, the possible origin-destination couples are also defined; (on the other hand, that port sequence is established taking into consideration the normal flow of the cargo); for instance, if ports 1 and 2 are located in the U.S., ports 3 and 4 in Europe, and the port sequence is 1_2_3_4, the ships in this route should not pick cargo at port 2 for port 1 (assuming that the frequency may not be changed), because it will imply to carry that cargo to Europe and then back to the U.S., causing delays to the customers (excessive transit time), lost of cargo space and additional costs to the ship operator.

One important component of the present model is the calculation of the "loading level" of our ship for each one of the legs ij in a route, i.e, the amount of cargo remaining on board in those legs. These loading levels will suggest an optimal frequency of service, from the capacity utilization point of view only. This analysis, together with marketing considerations, will be the basic information that the shipping company shall use for the establishment of the service frequencies.

First, we assume that there is only one round voyage per year in each route and find the highest loading level in each one of them. With that information, we can find the optimal ship capacity for a given number of voyages per year or the optimal number of voyages per year for a given ship capacity. The number of voyages per year is just 365 divided by the value of Frequency of Service.

Let us define:

$L_{ijr}$ = amount of cargo onboard a ship sailing from port i to port j of route r, for the case of one voyage per year (a port is served every 365 days)

The above values can be computed as follows:

$$L_{ijr} = \sum_{f=1}^{i} \sum_{g=j}^{f} Q_{fgr}, \qquad \text{(for } i = I_r\text{)}$$

$$L_{ijr} = \sum_{f=j}^{I_r} \sum_{g=j}^{f} Q_{fgr} + \sum_{f=1}^{i} \sum_{g=j}^{f} Q_{fgr} + \sum_{f=1}^{i} \sum_{g=j}^{I_r} Q_{fgr}, \qquad \text{(for } i \neq I_r\text{)} \tag{3}$$

where $Q_{fgr}$ is the amount of cargo to be carried per year from port f to port g in route r

The above equations can be verified in the following example. Take a route r of five ports; the established sequence is:

port1 - port2 - port3 - port4 - port5, or just **1-2-3-4-5**

This sequence repeats itself as voyages complete. The amount of cargo on board for leg 51r ($i=I_r=5$), will be:

$$\begin{aligned} L_{51r} = {} & Q_{11r} + \\ & Q_{21r} + Q_{22r} + \\ & Q_{31r} + Q_{32r} + Q_{33r} + \end{aligned}$$

$$Q_{41r} + Q_{42r} + Q_{43r} + Q_{44r} +$$
$$Q_{51r} + Q_{52r} + Q_{53r} + Q_{54r} + Q_{55r}$$

The amount of cargo on board in the leg 23r ($i \neq I_r$, as $i=2$, $I_r=5$), will be:

$$\begin{aligned} L_{23r} = {} & Q_{33r} + Q_{43r} + Q_{44r} + Q_{53r} + Q_{54r} + Q_{55r} + \\ & Q_{13r} + Q_{14r} + Q_{15r} + Q_{23r} + Q_{24r} + Q_{25r} + \\ & Q_{11r} + Q_{21r} + Q_{22r} \end{aligned}$$

The amount of cargo in the most heavily loaded leg will be:

$L_r = \max L_{ijr}$, for all legs ij in route r

Now, the minimum required capacity of ships that are to operate in route r is:

$$RC_r = L_r \,/\, (365/F_r), \tag{4}$$

where $F_r$ is the established Frequency of Service

On the other hand, if ships of type k with given capacity $V_k$ are assigned to route r, then the minimum required number of voyages per year in that route is:

$$RV_r = L_r \,/\, V_k, \tag{5}$$

and the corresponding value of Frequency of Service is:

$$F_r = 365 \,/\, RV_r \tag{6}$$

## 4.4 Cost Estimation Model

### 4.4.1 Ship Daily Running Costs

#### 4.4.1.1. Daily Running Costs in Normal Operation

The concept of "daily running cost", or simply "daily cost" as will be called in the present thesis, will play a major role in our model. For the owned ships, this cost has typically the following components (approximate percentages are in brackets):

a- Equivalent daily cost of the ship; includes the payments for the ship's purchase minus the salvage value (45%)
b- Salaries and benefits of the crew (35%)
c- Maintenance and repair (labor and parts) (10.5%)
d- Insurance of hull and machinery (5.0%)
e- Lubricants (1.5%)
f- Supplies and miscellaneous (3%)

The equivalent daily cost of the ship can be computed from the cash flows related with the purchase of the ship and the salvage value. The Net Present Value (NPV) of those cash flows should be computed. In the case that favorable financing was obtained for the ship's acquisition, an "Adjusted Net Present Value" (APV) should be computed. This APV is the result of subtracting the present value of the "subsidized borrowing" to the NPV. Finally, the equivalent annual cost (EAC) can be computed as follows:

$$EAC = APV / AF(y,t), \tag{7}$$

where

$$AF(y,t) = y^{-1}(1+y)^{-t}[(1+y)^{t}-1] \tag{8}$$

is a factor converting to present value an annuity of t years at an annual interest rate of y.

The equivalent daily cost (EDC) is the EAC divided by 365. The EDC is added to the other costs per day summarized above in order to obtain the daily costs of the ship which will be denoted herein as $H_k$ for the kth. ship. This value will be extensively used for the cost computations in the following sections.

For chartered vessels, $H_k$ is simply the hire rate (for long term charter).

4.4.1.2. Daily Running Costs in Lay-up Condition

When the ship k is laid-up for medium periods of time, some of the cost components of $H_k$ reduce substantially ( e.g., maintenance and lubricants costs); others may also reduce depending on the particular case; the type of labor contract with the crew will define how much crew reduction can the company make, this is usually the most important input in deciding to lay-up a ship. If crew can be reduced, food and other provisions can also be reduced.

Insurance costs could be reduced, depending on the agreement between the shipping and the insurance companies; frequently the insurance policies require payments in advance covering long periods. In such cases, no cost reduction is obtained for laying up the ship, at least during the first year or semester after the lay-up takes place.

The daily cost for the ship k while laid-up will be denoted in the present thesis as $h_k$.

### 4.4.2 Voyage Costs

In the following sections, a model for the calculations of the coefficients to be input to the L.P. program is developed. Those coefficients are the operating costs of each ship type on each route.

The total costs will be divided into costs at sea and costs at port. A "voyage" in the present thesis is defined as one round trip in one of the established routes.

$$C_{kr} = C^{s}_{kr} + C^{p}_{kr}, \tag{9}$$

where:

$C_{kr}$ = operating costs per voyage for ship k in route r

$C^s_{kr}$ = operating costs at sea per voyage for ship k in route r

$C^p_{kr}$ = operating costs at port per voyage for ship k in route r

### 4.4.3 Costs at Sea

#### 4.4.3.1 General Formula

The costs incurred by the ship k while at sea operating in route r, denoted by $C^s_{kr}$, can be broken down as follows:

$$C^s_{kr} = t^s_{kr} A^s_{kr} + m_{kr} + t^m_r H_k, \tag{10}$$

where:

$t^s_{kr}$ = sailing time of ship k, per voyage on route r (days)

$A^s_{kr}$ = operating costs per unit time at sea for ship k on route r ($/day)

$m_{kr}$ = canal fees per voyage for ship k on route r ($/voyage).

$t^m_r$ = delay due to sailing in restricted waters, include waiting for passing canals (days)

#### 4.4.3.2 Sailing Time

The sailing time for ship k on route r can be calculated as follows:

$$t^s_{kr} = d_r / (24\, S_k), \tag{11}$$

where:

$d_r$ = total sailing distance in route r (nautical miles)

$S_k$ = service speed of vessel k (knots).

#### 4.4.3.3 Daily Costs at Sea

The costs per day for vessel k at sea in route r are:

$$A^s_{kr} = f_k\, p^f_r + g^s_k\, p^g_r + H_k, \tag{12}$$

where:

$f_k$ = consumption per unit time of propulsion fuel of ship k (ton/day)

$p_r^f$ = price of propulsion fuel on route r ($/ton)

$g_k^s$ = consumption per unit time of fuel for electricity generation at sea of ship k (ton/day)

$p_r^g$ = price of fuel for electricity generation on route r ($/ton)

4.4.4.4 Restricted Operation

i. Canal Fees

Canal fees are usually established per unit of the correspondent register ton. The costs due to canal fees are therefore calculated as follows:

$$m_{kr} = cf_r \, RT_{kr} \, nc_r \tag{13}$$

where:

$cf_r$ = canal fee in route r ($/register ton)
$RT_{kr}$ = register tonnage of ship k for the canal in route r
$cn_r$ = number of canal crossings /voyage in route r

Our model assumes only one canal (we refer here to the important canals costwise) is crossed in each of the routes; however with a slight change in notation the case of more than one canal can be adapted; $cn_r$ is usually two or zero, as the voyages in liner shipping are round trips.

ii. Delays due to Restricted Operation

In addition to canal costs we take into account the cost due to delays caused by sailing in restricted waters (including canals and entries/ departures to/from ports) and by waiting in queues before passing canals. This delays are calculated as follows:

$$t_r^m = (d_r^m/24)\,[(1/S_m) - (1/S_k)] + t_r^w \tag{14}$$

where:

$t_r^m$ = delay related to restricted waters operation (days)

$d_r^m$ = distance to be sailed in restricted waters in route r (nautical miles)

$S_m$ = average speed in restricted waters for all ships (knots).

$t_r^w$ = waiting time (at anchorage) due to canal queues per voyage in route r, for any ship (days)

$t_r^w$ can be estimated as a fixed amount of time per crossing times the number of crossings per voyage:

$$t_r^w = cn_r \, cw_r \tag{15}$$

where $cw_r$ = waiting time per canal crossing on route r (days)

$d_r^m$ is the sum of the restricted waters distance associated with every port in the route, plus the length of sailing in canals:

$$d_r^m = \sum_{i=1}^{I_r} d_{ir}^m + cn_r\, cd_r, \tag{16}$$

where:

$d_{ir}^m$ = distance of restricted waters sailing associated with port ir

$cd_r$ = length of the canal in route r

### 4.4.4 Costs at Ports

4.5.4.1 General Formula

Our model considers for the cost calculation at ports both fixed (per call basis) and variable (per day of port stay) costs:

$$C_{kr}^p = \sum_{i=1}^{I_r} [\, t_{ir}^p A_{irk}^p + u_{irk}], \tag{17}$$

where:

$C_{kr}^p$ = operating costs at ports per voyage for the ship k on route r,

$t_{ir}^p$ = time per call at port i of route r; can be called also time per voyage at that port, as we are denoting multiple calls per voyage to the same port as different ports,

$A_{irk}^p$ = operating costs per unit time for vessel k at port i of route r ($/day), and

$u_{irk}$ = fixed costs per call at port i of route r for ship k.

The fixed costs per call, $u_{irk}$, include typically the following:

- Docking/ Undocking
- Pilotage
- Tugboat fees
- Navigation aids maintenance fees (if any)

Depending on the port authority, there may be other costs to be included in this category. The rates are usually based on the ship's length, draft, deadweight tonnage (DWT), or register tonnage.

4.5.4.2 Time at Port

The time a ship spends in a port is proportional to the amount of cargo loaded and unloaded. We assume that there is only one type of cargo (for example, containers), therefore a single loading/unloading rate (here called "productivity") can be applied in order to find the time needed to move the cargo requirements. In addition, in order to be realistic, our model includes an allowance for inactive time at port; this is a time interval during which the ship is not performing its normal operations at port. Inactivities can be classified depending on their cause, as follows:

- Caused by the port authority
- Caused by the agent
- Caused by the shipper (as when waiting for a given cargo to arrive to the loading port)
- Caused by the shipping company
- Other, like bad weather

For control purposes the shipping company further classifies the above listed types. Inactive intervals may occur before, during or after the cargo operations.

The time at port is calculated as follows:

$$t^p_{ir} = q_{ir} / n_{ir} + w_{ir}, \tag{18}$$

where:

$n_{ir}$ = productivity or rate of loading and unloading cargo in port i of route r (tons or containers per day), and

$w_{ir}$ = allowance per call for inactive time at port i of route r (days), as defined above.

4.5.4.3 Daily Cost at Port

For the cost per unit time of the ship while at port, the model includes the fuel cost, the ship's daily running cost and the variable port fees. This cost is computed as follows:

$$A^p_{irk} = g^p_k \, p^g_r + H_k + v_{irk}, \tag{19}$$

where:

$g^p_k$ = average fuel consumption at ports (mainly for electricity generation)

$p^g_r$ = price of fuel for electricity generation in route r (\$/ton)

$v_{irk}$ = variable port fees (per unit time) for ship k at port i of route r

The variable port fees depend on the specific port; the most usual fees in this category are anchorage and wharfage charges. As with the fixed or per call fees, the level of the variable fees, is established depending on the ship's length, draft, DWT, or register tonnage.

### 4.4.5. Lay-up Daily Costs

Following the discussion about the daily running costs of the ship while laid-up, in Section 4.4.1.2, the laid-up costs per day are defined as follows:

$$e_k = h_k + g_{kl}\, p_l + D_k, \tag{20}$$

where:

$e_k$ = total lay-up costs per day for ship k in route r (\$),
$g_{kl}$ = generator fuel consumption in lay-up condition (ton/day),
$p_l$ = price of fuel for generation at the lay-up location (\$/ton), and
$D_k$ = additional daily cost of ship k while laid-up, including anchorage charges, transportation for the crew in and out of the ship, etc.

### 4.4.6 Total Time per Voyage

The total voyage time is the sum of the times at sea and at port plus the delay due to restricted operation:

$$t_{kr} = t_{kr}^{s} + t_{r}^{p} + t_{r}^{m} \tag{21}$$

where $t_r^p = \sum_{i=1}^{I_r} t_{ir}^p$ is the total time at port in route r (days), and the other terms have already been defined.

## 4.5 Optimal Speed Calculation

As mentioned before, the speed assignment problem will be decoupled from the main (deployment) problem. In the following paragraphs, we formulate the problem of finding the optimal speed as a non-linear constrained optimization problem that can be solved by standard mathematical procedures. The resulting speeds should normally not be too different among ships of similar size and power.

The power $P_k$ required to propel the vessel type k at speed S, may be expressed as:

$$P_k = c_k\, S^{b_k}, \tag{22}$$

where $c_k$ and $b_k$ are known coefficients, and $b_k$ is close to 3 for all ships over their usual speed range.

The specific fuel consumption (SFC) i.e., the fuel consumption per unit of power per unit of time, may be expressed as a second order polynomial of the engine power used. However, for a narrow speed range (close to the design speed) the SFC can be assumed to be constant for the different levels of engine power. In this case, the speed-fuel consumption per unit time relationship can be expressed as:

$$f_k = a_k\, S_k^3 \tag{23}$$

where:

$f_k$ = fuel consumption per unit time for the ship type k, and
$a_k$ is a known coefficient.

Recognizing the possibility that the optimal speeds in each route may be different for the same ship, we add the subscript r to $S_k$. Developing the expressions of our model and using the same notation defined before, the operating costs per voyage of ship type k in route r are:

$$C_{kr} = \frac{d_r}{24\, S_{kr}}\, [f_k\, p_r^f + g_k^s\, p_r^g + H_k] + m_{kr} + t_r^m\, H_k + C_{kr}^p \tag{24}$$

All the terms of the right hand side of this equation except the final one are the components of $C_{kr}^s$ which have been already described. Replacing $f_k$ by its expression (speed dependent) and rearranging, we have:

$$C_{kr} = (d_r / 24)\, [\, a_k\, p_r^f\, S_{kr}^2 \; + \; S_{kr}^{-1}\, (g_k^s\, p_r^g + H_k)\, ] \; + \; c_{kr}, \tag{25}$$

where:

$$c_{kr} = m_{kr} + t_r^m\, H_k + C_{kr}^p$$

Now, defining the following constants:

$$A_{kr} = d_r\, a_k\, p_r^f \,/\, 24 \tag{26}$$

$$B_{kr} = [d_r\, (g_k^s\, p_r^g + H_k)] \,/\, 24, \tag{27}$$

we have:

$$C_{kr} = A_{kr} S_{kr}^2 + B_{kr} S_{kr}^{-1} + c_{kr}, \tag{28}$$

expressing the operating costs per voyage as a nonlinear function of the service speed.

The first derivative of $C_{kr}$ with respect to $S_{kr}$ is;

$$d(C_{kr}) / dS_{kr} = 2A_{kr}S_{kr} - B_{kr}S_{kr}^{-2} \quad (29)$$

Setting (29) equal to zero, we have:

$$2A_{kr}S_{kr} = B_{kr}S_{kr}^{-2}, \quad (30)$$

therefore:

$$S_{kr}^{*} = [\ B_{kr} / 2A_{kr}\ ]^{(1/3)}, \quad (31)$$

where:

$S_{kr}^{*}$ = optimal speed of the ship k while operating in route r

We can check now whether this extremum is a maximum or a minimum by calculating the second derivative:

$$d^2C_{kr} / (dS_{kr})^2 = 2A_{kr} + 2B_{kr}\ S_k^{-3} \quad (32)$$

At the extremum found, our function has the following value (replacing $S_{kr}$ by $S_{kr}^{*}$ ):

$$2A_{kr} + 2B_{kr}\ 2A_{kr}/ B_{kr} = 6A_{kr},$$

as $A_{kr} > 0$, the extremum found is a minimum.

Replacing the components of $B_{kr}$ and $A_{kr}$, in (31), we obtain the optimum speed of ship k in route r:

$$S_{kr}^{*} = [\ (\ g_k^s\ p_r^g + H_k\ ) / (\ 2a_k\ p_r^f\ )\ ]^{(1/3)} \quad (33)$$

To be valid, the resultant speed must lie within the feasible range indicated by the minimum and maximum speed limits of the ship; if outside those limits, the assigned speed should take the value of the limit it has exceeded.

The method described assumes that the time saved because of the higher speed translates directly into savings in daily running costs, $H_k$, as is the case for short term chartered ships; however, this model is not realistic for the owned ships if their lay-up costs are high, because sailing faster may imply spending the sailing time saved in an expensive lay-up condition. We suggest two courses of action at this point :

i) the fleet of owned ships is sufficient to fulfil the transportation mission, i.e. no chartering is required.
ii) the fleet of owned ships is insufficient to fulfil the transportation mission and additional ships have to be chartered anyway.

For the first case, instead of $H_k$, the value of $[H_k - e_k]$ should be used, $e_k$ being the daily costs for the laid-up ship k.

For the second case, the value to be used instead of $H_k$ is the hire rate of a ship of similar type which would have eventually to be chartered as a direct consequence of the lower speed of owned ships. Long term chartered ships may be treated as owned ships.

## 4.6 Linear Programming Formulation

### 4.6.1 Decision Variables

The decision variables in our model are:

$X_{kr}$ = number of voyages per year of ship k in route r
$Y_k$ = number of lay-up days per year of ship k

for k=1,...,K and r=1,...,R

### 4.6.2 Objective Function

The total operating costs of the shipping company have to be minimized; they can be expressed in terms of the decision variables described above, as follows:

$$\sum_{k=1}^{K} \sum_{r=1}^{R} C_{kr} X_{kr} + \sum_{k=1}^{K} e_k Y_k \tag{34}$$

### 4.6.3 Constraints

4.6.3.1 Time Availability

The time used by the ship in all the assigned voyages and lay-up should equal one year. The time available (in one year, our time horizon) of all type k ships, is:

$$\sum_{r=1}^{R} t_{kr} X_{kr} + Y_k = 365 N_k^{max}, \quad \text{for all } k \tag{35}$$

where $N_k^{max}$ is the number of type k ships available.

4.6.3.2 Frequency of Service

$M_r$, the number of voyages per year (a real number) in route r should satisfy the inequality:

$$\sum_{k=1}^{K} X_{kr} \leq M_{kr}, \text{ for all r} \tag{36}$$

and,

$$M_r = 365 / F_r$$

4.6.3.3 Ship-Route Incompatibility

Due to various reasons, a ship may be unable to operate on a specific route, as in the following cases:

a. Insufficient (total) cargo capacity

b. Lack of capacity of a special cargo type that is usually carried in the route (in the case of general cargo ships) like refrigerated cargo.

c. Impossibility of carrying special types of cargo because of (ship's) limitations in cargo handling equipment (realistic consideration for the cases of routes calling ports of developing countries.

Our constraint here is:

$$X_{kr} = 0, \text{ for a given ship-route combination, (k,r).}$$

Constraints of this type can be used during the optimization procedure for dealing with special cases, like when there are governmental regulations about the number of ships of given flags in a route.

4.6.3.4 Shipping Season

In the present model, the case of a ship being scheduled for drydocking, or, in general, repairs, within the time horizon of the deployment problem, is dealt with by assigning a shorter shipping season. The time interval during which the ship is unable to operate for other reasons is treated similarly; whenever the ship is not operating, it is assumed to be laid-up. The constraints that establish shipping seasons are of the form:

$$Y_k \geq (365 - T_k)\, N_k^{max}, \tag{37}$$

where $T_k$ is the shipping season for type k ships, which takes into account the drydock/repair times programmed in the year.

4.6.3.5 Non-negativity

The decision variables should have values greater than, or equal to zero:

$$X_{kr},\ Y_k \geq 0 \tag{38}$$

## 4.7 Optimization Procedure

### 4.7.1 Basic Inputs

4.7.1.1 Cargo Data

Cargo Data refers to the amounts cargo to be moved between port pairs in all of the routes. It can be given as a three-dimensional matrix: route r, origin port i, destination port j (each element is denoted as $Q_{ijr}$). Information about special types of cargo to be carried in given routes is also necessary in order to establish later the ship-route incompatibilities.

4.7.1.2 Vessel Data

The vessel related information is the following (using the notation defined before):

a. The names of the ships or ship types and their corresponding ID's k, are defined.

b. $H_k$, $h_k$, $g_k^s$, $g_k^p$ $g_k^l$, $D_k$, $V_k$, $VR_k$, $N_k^{max}$, $TR_k$.

c. The speed vs. propulsion fuel consumption characteristics of the ship; these may be given as a discrete set of speed-consumption values (from which a regression can be obtained) or as a continuous function. This speed-consumption relationship can also be calculated from the following data:

-Curve of Delivered Power (power requirement after the stern tube) vs. Ship's speed; this curve is usually obtained in the ship trials by the shipyard.
-Information about the type of connection of the prime mover with the propeller, in order to calculate the efficiencies involved and use them in the calculation speed/ consumption.
-Curve of engine power vs. Specific Fuel Consumption (per unit power per unit time) vs engine RPM.

The parameters obtained here are: $S_k$, $f_k$ and $a_k$

d. General technical information about the ships in order to determine their suitability for operation in specific routes (especially concerning holds and handling equipment) like:

-Type, quantity and capacity of the cargo handling equipment
-Hold and hatch forms and dimensions
-Refrigerated capacity and equipment
-Container capacity
-Electric supply to refrigerated containers

4.7.1.3 Route Data

a. Name of the routes and their correspondent ID numbers r
b. Ports in the routes and routing sequence; a port is assigned its ID number (i) according to its position in the routing sequence.
c. $d_r$, $p_r^f$, $p_r^g$, $cn_r$, $d_r^m$, $t_r^w$, $cd_r$.

d. Desired values of $F_r$, as per marketing considerations.

4.7.1.4 Port Data

a. $n_{ir}$, $w_{ir}$, $d_{ir}^m$ (same for all ships)
b. $v_{irk}$, $u_{irk}$ (for every ship k at port ir)
c. Cargo handling equipment available (in order to establish ship-route incompatibilities )

### 4.7.2 Frequencies and Cargo Related Data

At this point, the following data regarding cargo is calculated as described in Section 4.3.3:

$L_{ijr}$, $L_r$, $Q_{ir}$, $RC_r$, $RV_r$

For the calculation of the last two, different values of Frequency of Service $F_r$, and Ship's Capacity $V_k$ are used in formula (3), (4), and (5).

For the calculation of $L_{ijr}$ and $L_r$, which is relatively complex, as well as for the computation of $Q_{ir}$, we have written a suitable Fortran code (see Appendix 1) which applies formula (3).

Graphs of required ship capacity, $RC_r$ vs. frequency of service, $F_r$ are very useful for visualizing the frequency-capacity tradeoff in the different routes (see Figure 1). Graphs showing the loading condition of the ships in the various legs of a specific route (load levels vs. cumulative distance) provide insight on the utilization of the ships and provide hints for minor routing or frequency of service modifications (see Figure 2).

The goal at this stage is to establish target values of $F_r$ (one for each route), based on the analysis of the frequency-capacity relationship mentioned above and on marketing considerations. At this point, the ship-route incompatibilities due to lack of cargo capacity are also determined. The incompatibilities due to special types of cargo and shipboard cargo handling equipment mentioned in Section 4.6.3.3 can also be established now.

**Figure 1**

**Typical Plot**
**Ship Capacity vs. Frequency of Service**

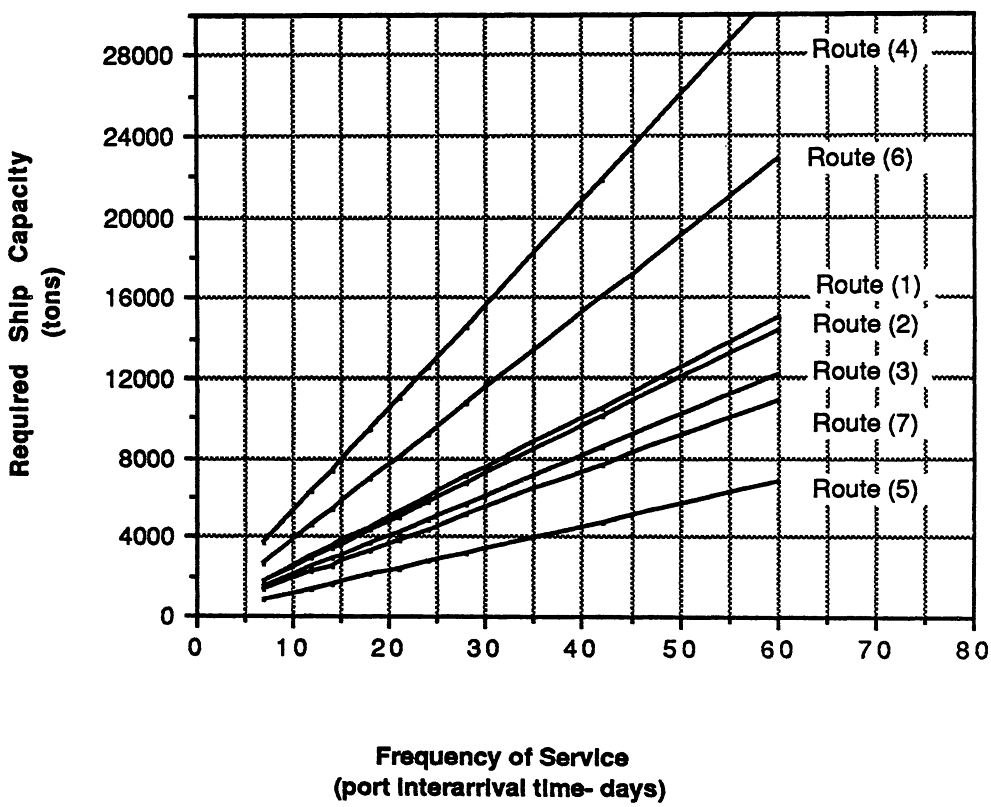
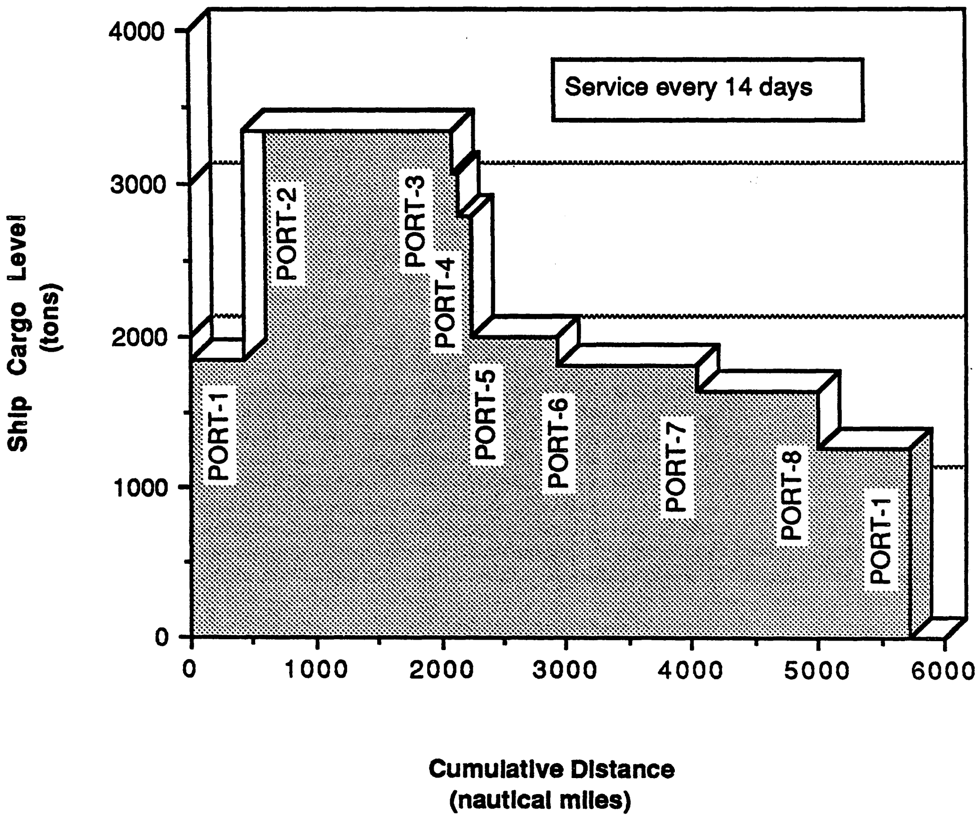


**Figure 2**

**Typical Plot
Ship Cargo Level vs. Distance**

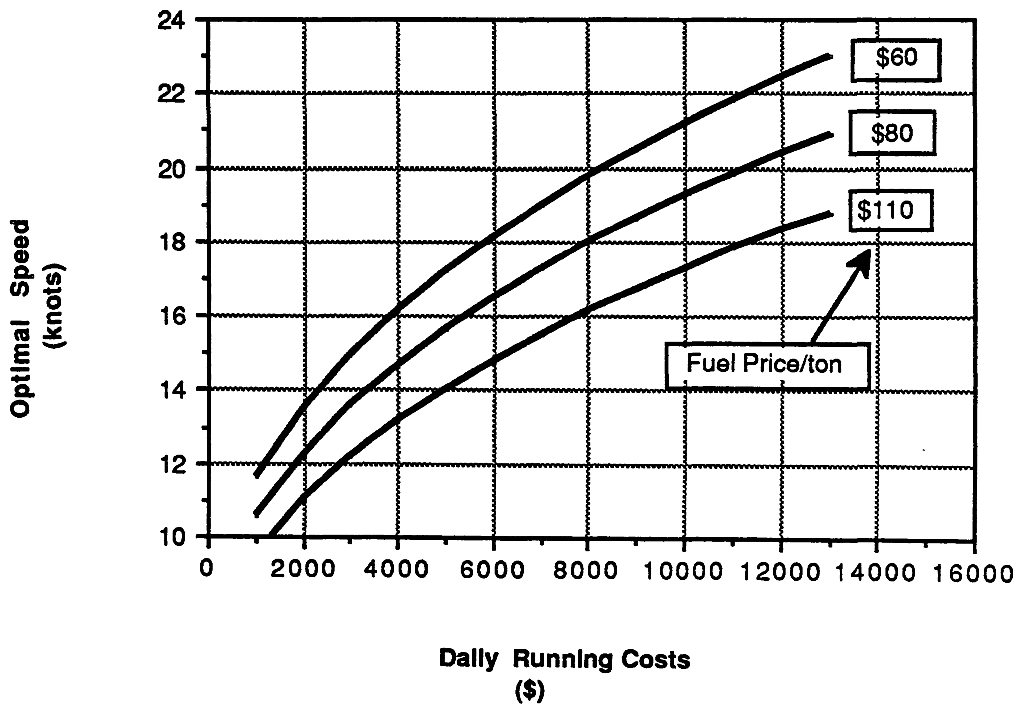


### 4.7.3 Speed Determination

Coefficients $a_k$ are calculated for all type k ships from a regression of the available speed-fuel consumption data as described in Section 4.5. Then (33) is applied with the fuel price data for every route, resulting in r values of $S_k^*$, (one for each route). If there are no big differences in fuel prices among routes, it is convenient to use only one set of fuel prices in order to obtain one speed value for a given ship.

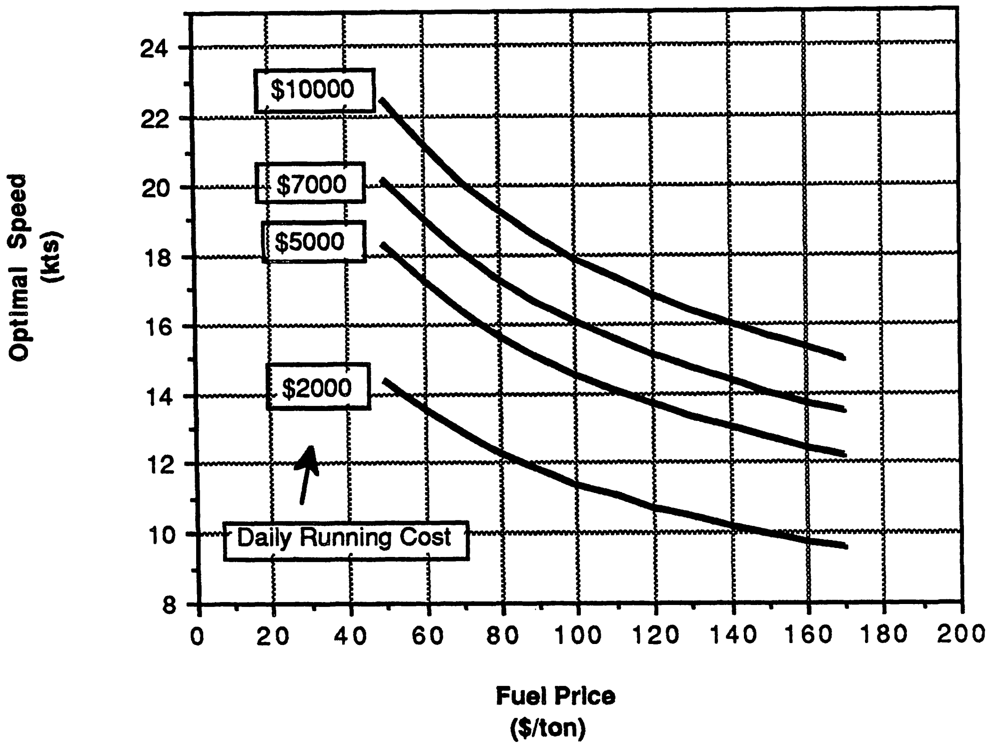
Graphs based on the relationships implied by (33) are very useful for visualizing the sensitivity of the optimal speed to variations in the parameters involved. The most important components of this formula are the fuel price, $p_r^f$, and the daily costs $H_k$; plots of optimal speed vs. daily costs for various fuel prices and of optimal speed vs fuel price for various daily costs are presented in Figures 3 and 4 respectively.

**Figure 3**
**Typical Plot**
**Optimal Speed vs. Daily Costs**




The key point in the speed determination is to find the correct value to use in place of daily cost as was discussed in Section 4.5. If the owned fleet is insufficient to fulfill the transportation mission ($H_k$ of a similar charter ship is used), or it is sufficient but the lay-up costs are low ($H_k$-$h_k$ is used, $h_k$ a small value), a relatively high speed will be better; if the owned fleet is sufficient and the lay-up costs are high ($H_k$-$h_k$ is used, $h_k$ a high value), a lower speed is more economical.

**Figure 4**
**Typical Plot**
**Optimal Speed vs. Fuel Price**




### 4.7.4 Cost and Time Coefficients for the L.P.

The next step is the calculation of coefficients $C_{kr}$, $e_k$ and $t_{kr}$ by means of (9), (20) and (21) respectively, which require also the application of (10) to (19). This calculation can be carried out by means of a computer program or a spreadsheet (commercial software) arrangement.

### 4.7.5 Input of the L.P. Program

The particular format of the input file for the LP computer application depends on the software used. In the present thesis we use the LINDO Fortran code (Linear, Integer and Discrete Optimizer) [12]; this program uses the simplex method. The input format for LINDO is basically the format of the mathematical formulation of the LP; for example:

Minimize
3 X + 4Y
Subject to
constr.1) 2X - Y < 6
constr.2) X - 3Y > 1
End

The non-negativity constraints need not be input as they are automatically taken into account by the program. The input file is created most conveniently by means of an editor program; in the same way the output can be diverted to an editor file, which is also convenient. LINDO allows a user subroutine that can interact with the main program, which is especially useful when the LP has to be run for a great number of times.

For running the program, the following (main) commands are required:

LINDO (opens the program)
TAKE
Filename (take the input file)
DIVERT
Filename (divert the output to this file)
GO (runs the program)
Do range (sensitivity) analysis?
Yes (do sensitivity analysis)
QUIT (quit the program)

A sample of the input file is provided in the next chapter

### 4.7.6 Output and Sensitivity Analysis

The output of LINDO gives the following basic information:

- Values of the controllable variables corresponding to the optimal solution
- Value of the objective function at the optimal solution,
- Number of steps before finding the optimal solution,
- "reduced cost" for each one the coefficients in the objective function; this term is defined as the amount by which the coefficient of the respective variable has to be reduced for the variable to appear in the optimal solution; if the variable already appears in the solution, its "reduced cost" is zero,
- Slack or surplus of each one of the constraints, i.e., the amount by which the right hand side (RHS) value of each constraint, must increase or decrease for the constraint to become active, and
- Dual prices of the constraints, i.e., the change in the objective function value due to an unitary relaxation (increase or decrease) in the right hand side (RHS) values of each constraint.

Additionally, under the optional sensitivity information, the following values are given:

- Allowable increase and decrease of the coefficients of the variables, i.e., the range of variation of those coefficients (one at a time) in which the optimal solution (mix of variables in the optimal solution) does not change; the objective function value, however, will normally change.
- Allowable increase and decrease of the RHS value of the constraints, i.e., the range in which the RHS values may vary without changing the dual prices reported

The values of variables $X_{kr}$ will tell us the allocation of the ships to the routes and the values of $Y_k$ will indicate the number of days for which ship k must be laid-up; these $Y_k$ values include the times of repair/ drydock and that have been given in the input (constraints in Section 4.6.3.4 )

The Reduced Cost will tell us how economical a particular type of ship is for a specific route (for ships other than the ones chosen in the optimal solution); for example, if the Reduced Cost of $X_{23}$ is close to zero (which implies that $X_{23}$'s value is zero in the optimal solution), it means that ship 3 could operate in route 2 without much additional cost.

If a constraint has slack or surplus, it indicates that the constraint is not active (its Dual Price is therefore zero). In practice, this suggests that the shipping company should not spend money to increase the resources regulated by this constraint. The Dual Price of a constraint tells about how rewarding is to increase one those resources.

Taking into account the allowable increase or decrease in the coefficients of the controllable variables or RHS values of the constraints, one can know the reach of the sensitivity information and make the correct computations in case that adjustments in the optimal mix must be made; those changes are generally required because the number of ships of a given type allocated to a given route must be an integer, as we describe in the following section. However, due to the fact that in most instances changes have to be made to various (not just one) values of the controllable variables, a recomputation of the total cost is normally required as it is described in the following section.

### 4.7.7 Calculation of Number of Ships Allocated to Routes

The output of the LP will give us the number of voyages per year of every ship in every route ($X_{kr}$), to find the number of ships k to be allocated in route r, the following relationship must be used:

$$N_{kr} = X_{kr}\, t_{kr} / T_k, \tag{39}$$

where $N_{kr}$ is the number of ships k assigned to route r.

The resultant $N_{kr}$ value will normally be non-integer; it therefore should be rounded to an integer number, verifying that the total number of ships available of each type, $N_k^{max}$ is not surpassed. This is easily accomplished with the help of spreadsheet software, as will be explained in the example of the next chapter. A spreadsheet or small computer program can be designed to derive the total number of ships per type and the total operating cost after each alternative "rounded" solution is entered. The process here is basically trial and error.

### 4.7.8 Speed and Coefficients Adjustment

It is required that all the ships assigned to the same route sail at the same speed in order to keep the frequency of service constant; however, since the speed for each ship was determined independently, the speeds of the various ships assigned to a route at the previous step will probably be different from each other. There are various approaches to this situation:

a. If the speed differences are not large (let us say, less than 1.5 knots), the speed to be assigned may be an intermediate value within the feasible range of speeds of every ship the costs coefficients $C_{kr}$ will change slightly. Although not exactly applicable in this case, the sensitivity information of the LP output can provide indication on the validity of the present solution with those changes. The voyage times will also change slightly and therefore the frequency of service will change. However this change is not important since the effects of increased speed in some ships and reduced in others will tend to cancel each other.

b. There are many other factors which cause delays/ advances in the schedules and are dealt in the day-to-day decision process by the operations department of a liner shipping company like bad weather (at sea and at port) cargo demand variations, etc. The small time differences due to small speed differences can be dealt in the same way in the day-to-day decision process. The decisions that we talk about are, for example, when must a ship sail (should it stop loading now and leave the rest of the cargo for the next ship?), how many stevedore gangs should work on a ship in particular day (this will determine the length of the port stay), etc. For example, the slower ships may be assigned (slightly) less cargo in ports or more stevedore gangs in order to reduce their port stay and compensate for the higher sailing time).

c. If the speed differences are big, i.e , if the LP output implies the allocation of "speed incompatible" ships in the same route, the ships may be reallocated using the sensitivity information; for this task, the information on Reduced Costs is very helpful, since it shows the best alternative routes for each particular ship. The inclusion of additional incompatibility constraints (in order to impede the assignment of incompatible ships to the same route) may be tried; in this case the LP should be run again, and a few iterations may be required before arriving at an acceptable solution.

d. Some applications may require more precision than others. If more precision is desired, the LP may be run iteratively with new, adjusted cost and time coefficients each time (correspondent to the new speeds and frequencies implied by the previous output), until a "good" solution is reached.

The alternatives described above may involve various iterations as the frequencies of service in each route and the voyage times change with every modification; however, those changes are usually not great and can be accepted and/or dealt with in the real operation. It is clear from our description above, that the knowledge of the particular situation (shipping company) is important for deciding the adjustments to be made and whether or not a particular solution is acceptable. The LP results are the foundation for that decision process.

Normally, ships of higher speeds will tend to be allocated to routes of relatively higher sailing distances and vice-versa; therefore, the assignment (by the LP) of ships of very different speeds to the same route is unlikely. This means that a "good" solution converges with no difficulty. In the example worked out in this thesis (described in the next chapter) a "good" solution was found after only one LP run with the appropriate constraints.

### 4.7.9 Operating Costs Recalculation

The rounding of the number of ships assigned to the routes and every modification of the original LP solution implies a change in the total operating costs. Therefore, after every modification, the operating costs must be recomputed and recorded. The monetary effects of each new constraint or adjustment can be assessed and consequently the impact of that constraint or adjustment of the costs can be assessed.

# 5 Optimization Example

## 5.1 Basic Data

The present example relates to the deployment of the liner fleet of FMG which operation was described in Section 2.2. A description of the aspects of the operation of this company related to the specific problem we are addressing, was provided in Chapter 2. There are 14 owned vessels of six types in the fleet and five types of ships that may be chartered. Their names and the basic input data for our model are presented in Appendix 2.

The company operates seven liner routes all of them involved in the transportation of Colombian imports and exports:

- U.S East Coast
- U.S. Gulf Coast
- U.S. West coast
- Europe-North
- Europe-Mediterraneum
- Japan
- South America West Coast

Most of the maritime (foreign) commerce of Colombia is performed by FMG. All but two of the routes require passing the Panama Canal twice per voyage. A description of the routes and the basic related inputs are shown in Appendix 3. The information concerned with the ports is included in Appendix 4. In this example, a port which is included in more than one route may have different productivity values ($n_{ir}$) in each of the routes because of the different cargo mix carried in each route.

The cargo information is displayed in Appendix 5 as origin-destination matrices for each route. The total quantities of cargo to be loaded/ unloaded at every port i ($Q_{ir}$) per year are displayed to the right of each matrix; these values are used to calculate the times at port.

## 5.2 Frequency Analysis

The computer program for calculating $L_{ijr}$ and $L_{ijr}$, which we mentioned in Section 4.7.2 (see Appendix 1), was run with the required inputs (quantities of cargo to carry from port to port in each route, number of routes and number of ports per route); the output of it was used as input for Figures 1, 2 and 5 through 11.

In Table 1 various values of $F_r$ (not all of them feasible in this case) are indicated for the seven routes and the correspondent values of ship maximum loading (or $RC_r$, required ship capacity, calculated with (4)) are shown. In Figure 1 (Section 4.7.2) a graph of the relationship $RC_r$ vs $F_r$ for every route in our example is shown.

**Table 1.**

Ship Maximum Loading vs. Frequency of Service

| | Mx.Load | Frequency of Service (port interarrival time), $F_r$ (days) | | | | | |
|---|---|---|---|---|---|---|---|
| Route, r | $L_r$ | 14 | 15 | 21 | 24 | 30 | 35 |
| | | | | | | | |
| 1 | 91076 | 3493 | 3743 | 5240 | 5989 | 7486 | 8733 |
| 2 | 87282 | 3348 | 3587 | 5022 | 5739 | 7174 | 8370 |
| 3 | 73597 | 2823 | 3025 | 4234 | 4839 | 6049 | 7057 |
| 4 | 189516 | 7269 | 7788 | 10904 | 12461 | 15577 | 18173 |
| 5 | 41108 | 1577 | 1689 | 2325 | 2703 | 3379 | 3942 |
| 6 | 138936 | 5329 | 5710 | 7994 | 9136 | 11419 | 13323 |
| 7 | 66160 | 2538 | 2719 | 3806 | 4350 | 5438 | 6344 |

If the company fixes the frequencies in the present levels and commits to satisfy the present cargo demand, the ship maximum load and the ship utilization factors at each route as per our model, are shown in Table 2.

**Table 2.**

Present Utilization Factors of FMG's ships

| Route, r | $F_r$ (days) | Ship Max. Load/voy, $L_rF_r/365$ (tons) | Ships k Presently Operating in the route | Ship Capacity, $V_k$ (tons) | Utilization Factor = $L_rF_r/365/V_k$ |
|---|---|---|---|---|---|
| 1 | 14 | 3500 | 1 | 14400 | 0.24 |
| 2 | 14 | 3400 | 5 | 11200 | 0.30 |
| | | | 8 | 11500 | 0.30 |
| 3 | 21 | 4300 | 6 | 15600 | 0.28 |
| | | | 8 | 11500 | 0.37 |
| 4 | 15 | 7800 | 1 | 14400 | 0.54 |
| | | | 3 | 13900 | 0.56 |
| 5 | 30 | 3400 | 11 | 15800 | 0.22 |
| 6 | 24 | 9200 | 2 | 14300 | 0.64 |
| | | | 3 | 13900 | 0.66 |
| | | | 7 | 14300 | 0.64 |
| 7 | 35 | 6400 | 4 | 10900 | 0.59 |

It is clear that the utilization of FMG's fleet (as we have defined it in the above table), is rather low. In any case,we have to take into account that if in the specific case quality of service is a priority (as it normally is in liner shipping), a margin or allowance must be included in order to account for the seasonal variations of the cargo demand; however, even if a reasonable margin is included, the utilization factors will still be low, therefore modifications of the frequencies or changes in the fleet composition should be considered.

Figures 5 to 11 show the loading levels of a ship operating in a route vs. cumulative distance sailed; here the utilization of the ships in the overall voyage (not only on the most loaded leg) can be visualized and low utilization levels (when the ship capacities - in the 11000 to 16000 ton range- are born in mind) are more evident. In the present example we will not change the frequencies at which FMG presently operates, in order to allow a suitable comparison of our results with the present fleet deployment situation of the company.

**Figure 5**
**Ship Cargo Levels**
**Route 1**

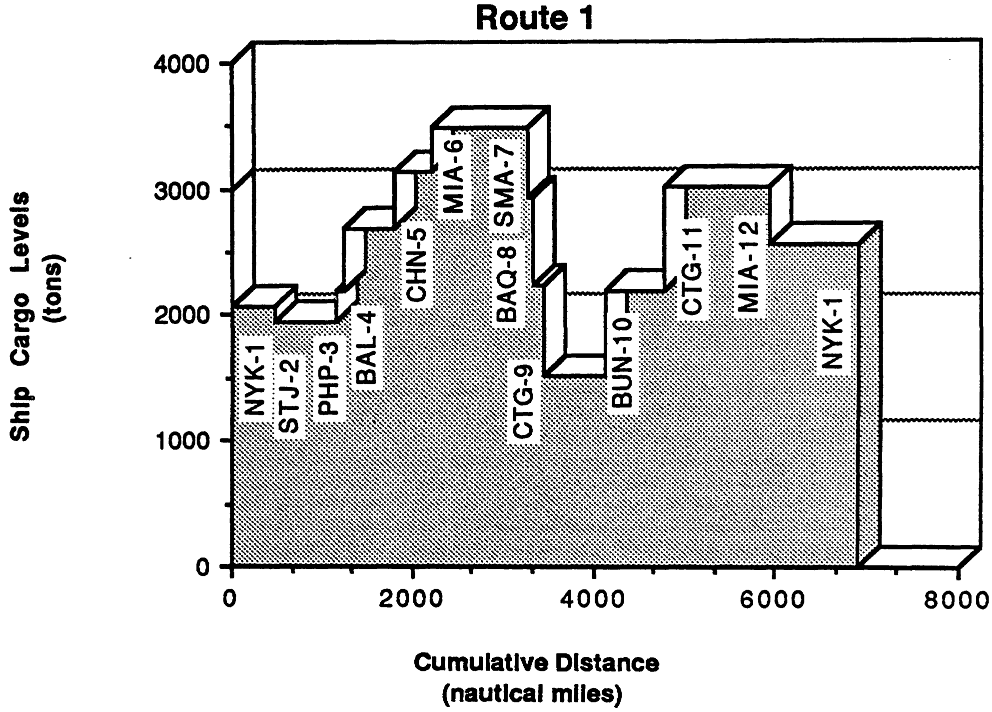


**Figure 6**
**Ship Cargo Levels**
**Route 2**

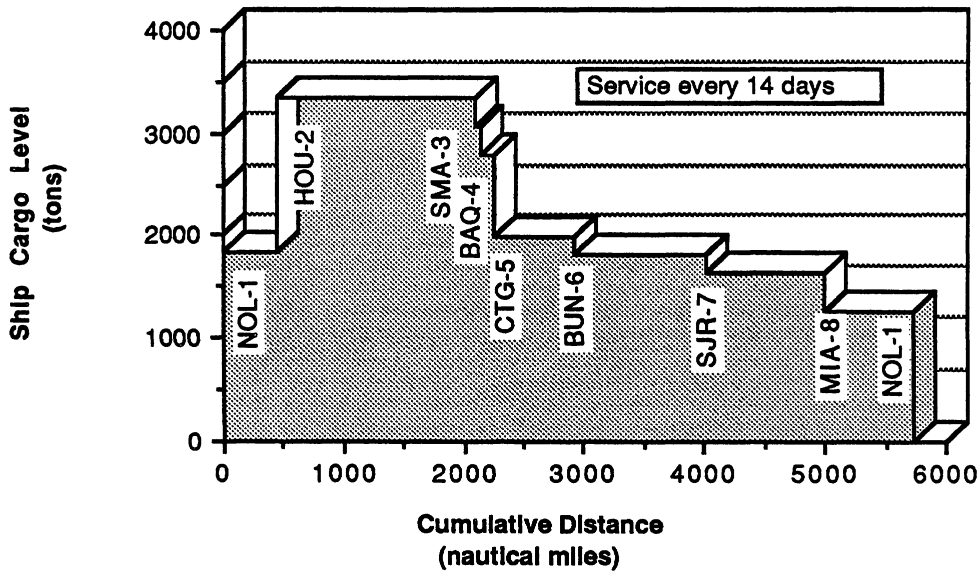



**Figure 7**
**Ship Cargo Levels**
**Route 3**

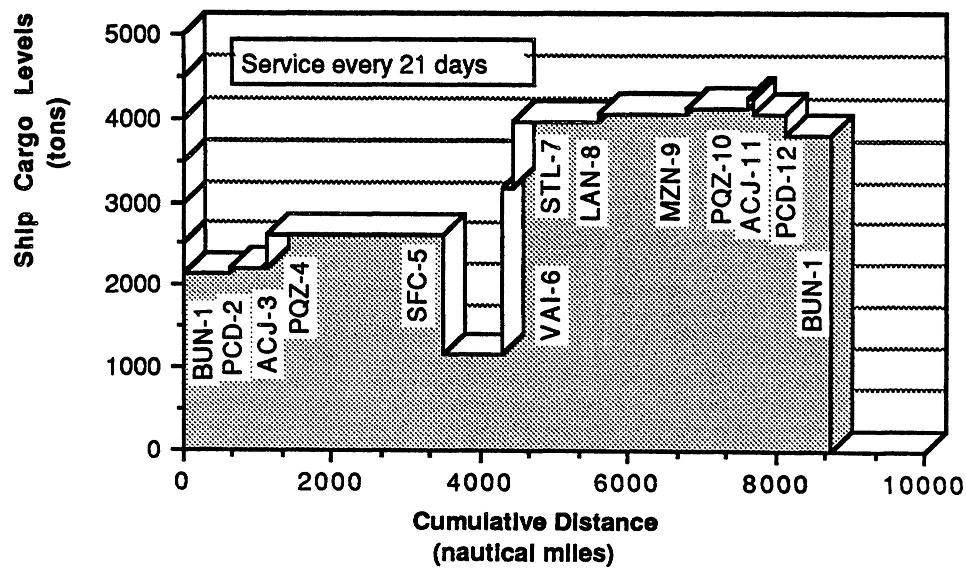


**Figure 8**
**Ship Cargo Levels**
**Route 4**

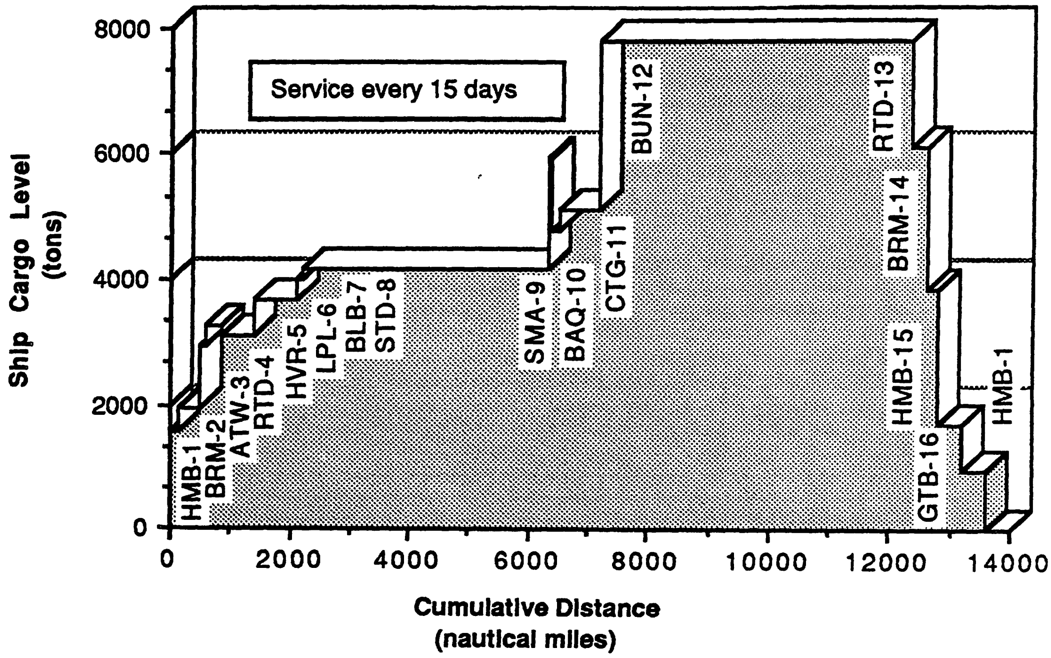



**Figure 9**
**Ship Cargo Levels**
**Route 5**

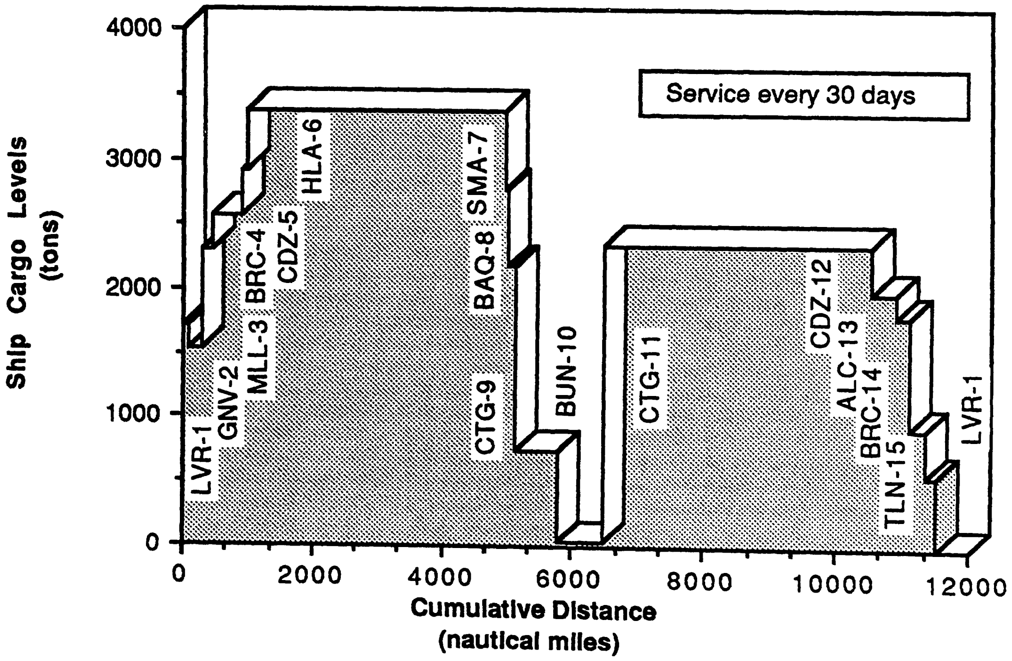


**Figure 10**
**Ship Cargo Levels**
**Route 6**

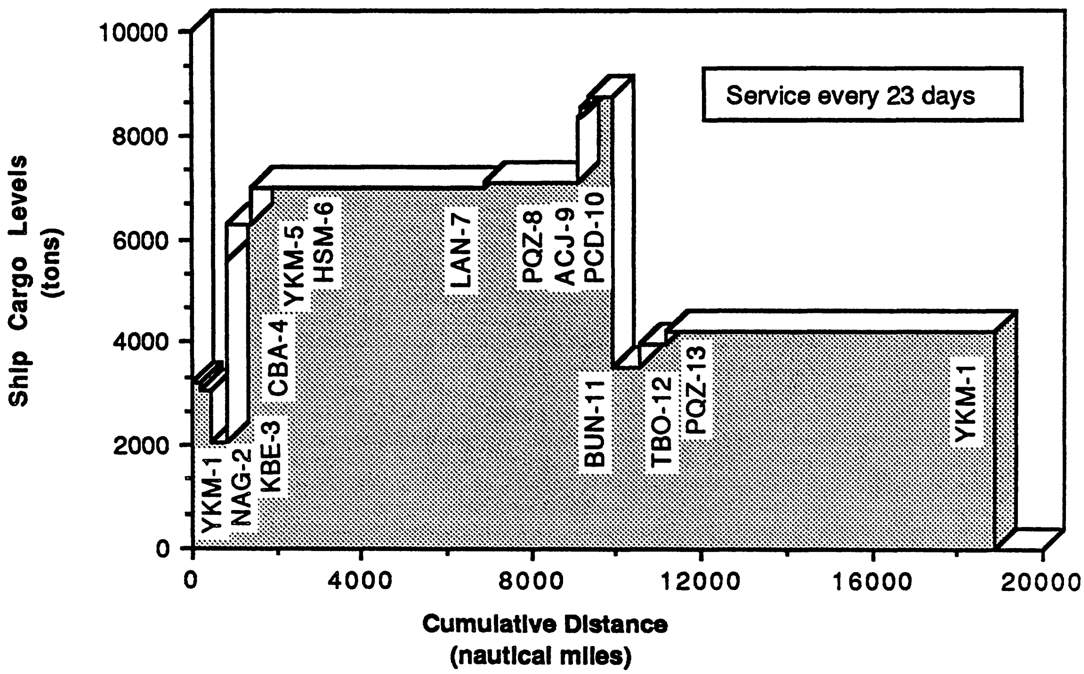
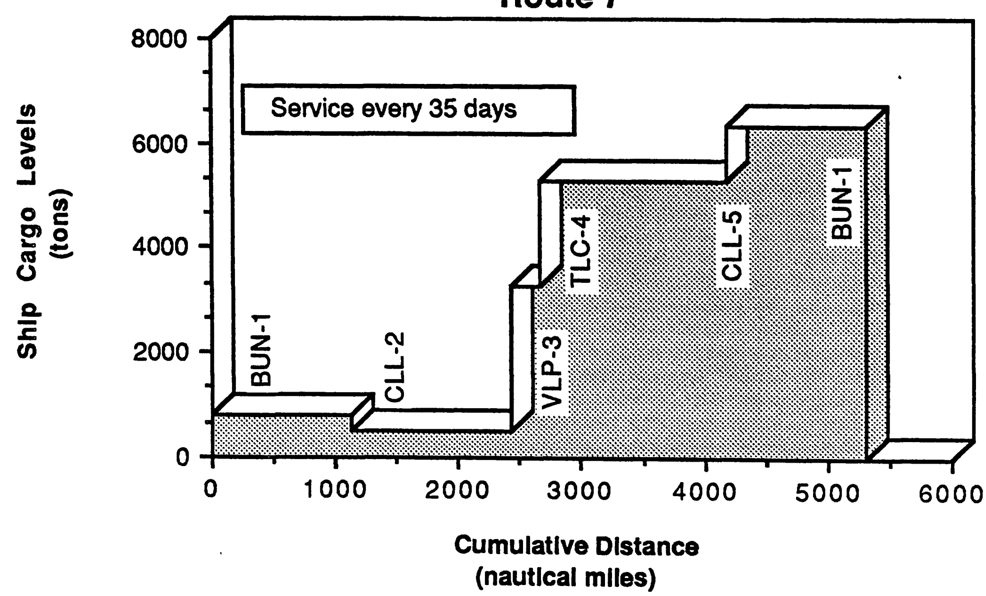


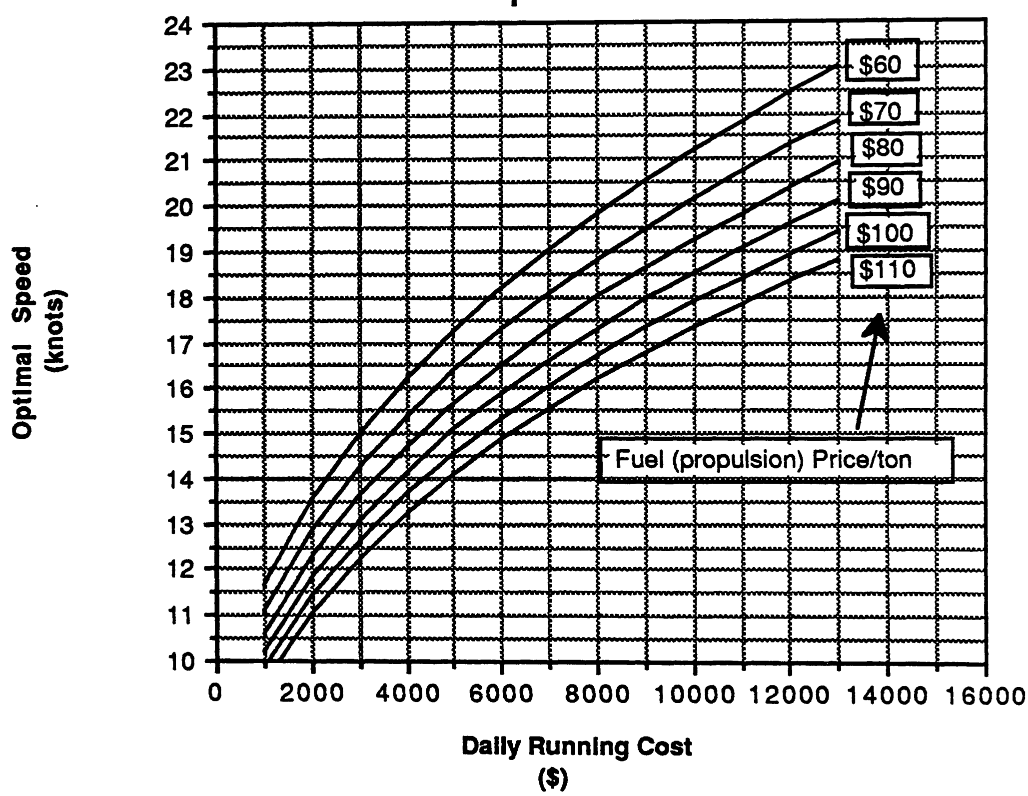

**Figure 11**
**Ship Cargo Levels**
**Route 7**



## 5.3 Speed Calculation

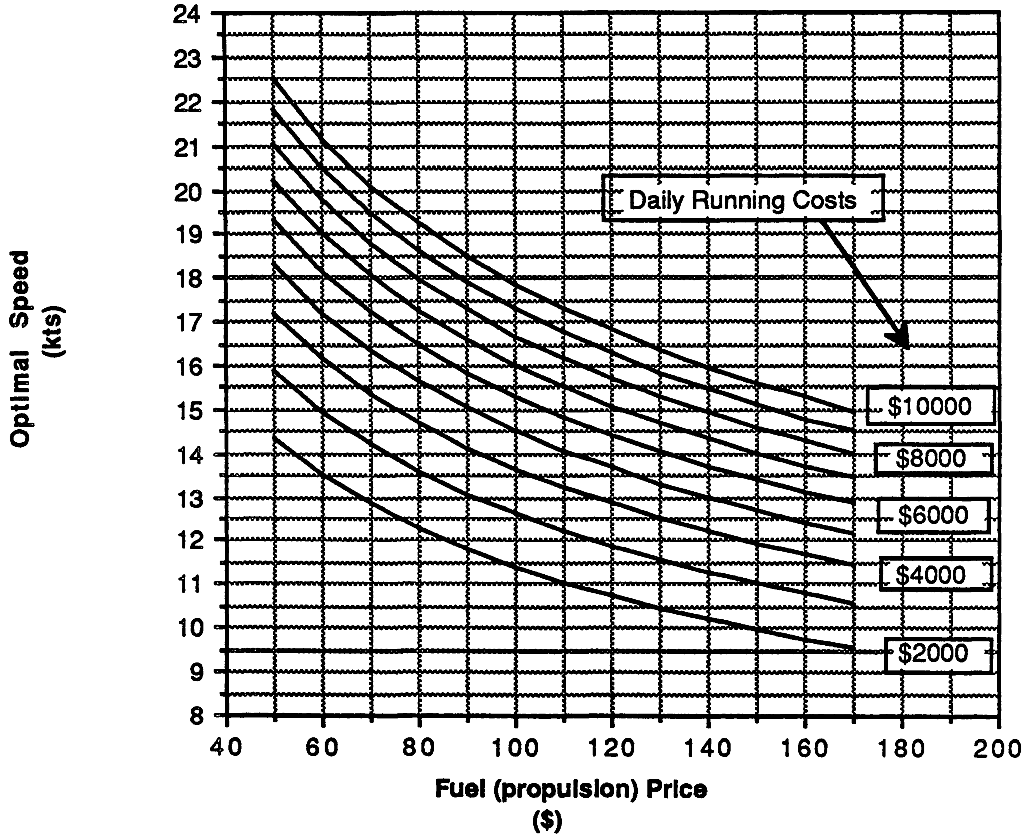
The speed for each ship speed was calculated with the method described before (Sections 4.5 and 4.7.3). Figure 12 shows a plot of the optimal speeds of the ships type 1, versus daily running costs, for different propulsion fuel prices. Figure 13 shows a different version of the same situation, the optimal speed is plotted against the fuel prices, for various values of the daily running costs. Both figures are based on (33).

**Figure 12**
**Optimal Speed vs. Daily Cost**
**Ship 1**




In this example the owned fleet is insufficient, and therefore, additional ships must be chartered. Following our method, a charter rate of ships of similar type to the type 1 (owned) ship was used; this rate was around $7000; for a fuel price of $80/ton, it can be seen in Figure 12 (or 13) that the optimal speed is around 17.2 knots (for ship 1), however the maximum (continuous) speed of ship 1 is 15 knots; therefore 15 knots was the preferred operating speed for that ship type. In the same way the speeds for the other ships were calculated, their values and correspondent fuel consumption per day are shown in Appendix 2.

**Figure 13**
**Optimal Speed vs. Fuel Price**
**Ship 1**




## 5.4 Cost and Time Coefficients

The cost and time coefficients were computed following our model. The calculations were developed by means of a spreadsheet arrangement; the software used for this purpose was *Microsoft EXCEL* for the *Macintosh* computer. The main spreadsheet is composed of four parts linked to each other. The first part summarizes the values of coefficients $C_{kr}$ (see Appendix 6). The second part contains ship related information (Appendix 2) and the calculations of the costs at sea and the total costs, (Appendix 7). The third part shows the route related information (Appendix 3), and the fourth component contains the information related to the ports (Appendix 4) and the calculations of the cost at ports (Appendix 8).

After the basic data of ships, ports and routes are introduced, the resultant $C_{kr}$ values are displayed and the values of $t_{kr}$ are summarized in another spreadsheet (see Appendix 9). The arrangement is such that any modification in the inputs produces the new coefficients $C_{kr}$ and $t_{kr}$, which are the ones required in the LP input, automatically.

The first part of the main spreadsheet (Appendix 6) also provides the fields for the input and modification of the main parameters of our model, the speed (for each ship) and the frequency of service (for each route).

## 5.5 Linear Programming Input

The coefficients $C_{kr}$ and $t_{kr}$ from the previous point were used for the LP input which is presented in Appendix 10. The values of coefficients $C_{kr}$ in the LP have been divided by $10^3$ and the variables $X_{kr}$ are written as X followed by three digits, the first two of which are the values of k and the last one is the value of r; for example, X012 indicates $X_{kr}$, where k=1 and r=2 (the zero is included for convenience in the input file presentation).

The first 11 constraints in the input file are the time constraints described in 4.6.3.1. The right hand side represents the number of ships available times the number of days of the year. The following seven are the frequency constraints of Section 4.6.3.2; the incompatibility constraints explained in 4.6.3.3 follow, and finally the constraints that establish shipping seasons and repair times as described in 4.6.3.4 appear in the input file.

The incompatibility constraints in the input file used for this example reflect the following cases:

- Ships unable to carry enough quantities of some types of cargo which are typical of some routes, mainly refrigerated cargo and/or containers.
- Lack of capacity of some ships to operate in some routes, as per the frequency-required ship capacity analysis of Section 5.2.
- Impossibility of operating chartered ships in one of the routes.

The shipping seasons were assumed as 345 days per year (for all ships), which include allowances for repair/drydock time and unexpected delays.

## 5.6 Results and Sensitivity Analysis

The output of the LP program for the input described in the previous point is presented in Appendix 11; as per the results, ship types 8 and 9 should not be taken in charter; this is explained by the fact that those ships have the highest daily cost (i.e., hire rate) among the chartered ships except for ship type 7 which has a high hire rate but also a high lay-up cost due to the long-term Charter. The owned ships must be operated continually (i.e., no lay-up time should be allocated apart from the repair/ drydocking time) this is explained by the high lay-up cost of these ships.

The number of ships k allocated to route r, $N_{kr}$, was derived from the values of $X_{kr}$ given by the LP output (as described Section 4.7.7) by means of the spreadsheet shown in Appendix 12. Those values of $N_{kr}$ were rounded to integer numbers and the new (resultant) frequencies (and the changes with respect to the existing ones) were computed and displayed by means of the spreadsheet shown in Appendix 13; the procedure described in Section 4.7.8 was followed.

The operating costs with the new allocation were calculated as explained in Section 4.7.9 using the spreadsheet displayed in Appendix 14. The mentioned spreadsheets (Appendices 12, 13, 14) are suitably linked with each other and with the ones containing the values of the cost and time coefficients, $C_{kr}$ and $t_{kr}$, so that the information that has not changed is not unnecessarily entered again.

In order to appreciate the difference between the actual allocation situation and the results of our example, in the Tables 3 and 4, respectively, both situations are presented.The total operating costs (as defined in the present thesis) in the present operation situation applying our model for the calculation are $ 93,148,000.

The total operating costs for the fleet deployment suggested by the program output are $90,166,000, an improvement of 3.2% ( savings of $2,982,000 per year), keeping the existing frequencies in all the routes and complying with all the operating restrictions (which are reflected in the constraints of the LP); the speeds of the ships is assumed the same in both cases, in order to facilitate the comparison; in practice some of the FMG's ships sail at a slightly lower speed but on the other hand additional ships are chartered for single voyages in order to be able to comply with the cargo requirements. From our example it can be concluded that those occasional charterings can be avoided by sailing the ships at a higher speed.

**Table 3**

Present Ship Allocation

| | | Number of Ships, $N_{kr}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ship Type, k | Total Alloc. | Route 1 | Route 2 | Route 3 | Route 4 | Route 5 | Route 6 | Route 7 |
| 1 | 6 | 3 | | | 3 | | | |
| 2 | 2 | | | | | | 2 | |
| 3 | 3 | | | | 2 | | 1 | |
| 4 | 1 | | 1 | | | | | 1 |
| 5 | 1 | | | | | | | |
| 6 | 1 | | | 1 | | | | |
| 7 | 1 | | | | | | 1 | |
| 8 | 2 | | 1 | 1 | | | | |
| 9 | 0 | | | | | | | |
| 10 | 0 | | | | | | | |
| 11 | 2 | | | | | 2 | | |
| TOTAL | 19 | 3 | 2 | 2 | 5 | 2 | 4 | 1 |

**Table 4**

Resultant Allocation in Example

| | | Number of Ships, $N_{kr}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ship Type, k | Total Alloca. | Route 1 | Route 2 | Route 3 | Route 4 | Route 5 | Route 6 | Route 7 |
| 1 | 6 | 1 | | | 5 | | | |
| 2 | 2 | | | 1 | | | | 1 |
| 3 | 3 | | | | | | 3 | |
| 4 | 1 | | 1 | | | | | |
| 5 | 1 | | 1 | | | | | |
| 6 | 1 | | | | | | 1 | |
| 7 | 1 | | | 1 | | | | |
| 8 | 0 | | | | | | | |
| 9 | 0 | | | | | | | |
| 10 | 2 | | | | | 2 | | |
| 11 | 2 | 2 | | | | | | |
| TOTAL | 19 | 3 | 2 | 2 | 5 | 2 | 4 | 1 |

**Table 5**

Modified Target Frequencies

| Route, r | Existing $F_r$ (port interarrival time-days) | Modified $F_r$ | Existing $M_r$ (number of voyages/ year) | Modified $F_r$ |
|---|---|---|---|---|
| 1 | 14 | 21 | 26 | 17 |
| 2 | 14 | 21 | 26 | 17 |
| 3 | 21 | 28 | 17 | 13 |
| 4 | 15 | 18 | 24 | 20 |
| 5 | 30 | 35 | 12 | 10 |
| 6 | 23 | 23 | 16 | 16 |
| 7 | 35 | 45 | 10 | 8 |

We have carried out another example with some modifications to the frequencies of service in the less loaded routes especially, as per Table 5. With the new frequencies, there are new voyage cost coefficients $C_{kr}$, new values of $M_r$ (number of voyages per year in route r) and new ship-route incompatibilities due to the higher cargo capacity required with lower frequencies. With these adjusted values a new LP formulation was generated. In the rounding of the number of ships allocated to the routes (as per the LP output), changes to the targeted frequencies were necessary. Most of those changes were small; only in route 3 the change is substantial (the cargo requirements are still satisfied); however, it can be partially compensated by increasing the speed of the only ship assigned to that route. The corresponding allocation appears in Table 6.

**Table 6**

Allocation of Ships for Modified Frequency

| | | Number of Ships, $N_{kr}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ship Type, k | Total Alloca. | Route 1 | Route 2 | Route 3 | Route 4 | Route 5 | Route 6 | Route 7 |
| 1 | 6 | 3 | | | 1 | | 2 | |
| 2 | 2 | | | | 1 | | | 1 |
| 3 | 3 | | | | 3 | | | |
| 4 | 1 | | 1 | | | | | |
| 5 | 1 | | 1 | | | | | |
| 6 | 1 | | | | | | 1 | |
| 7 | 1 | | | 1 | | | | |
| 8 | 0 | | | | | | | |
| 9 | 0 | | | | | | | |
| 10 | 2 | | | | | 2 | | |
| 11 | 0 | | | | | | | |
| TOTAL | 17 | 3 | 2 | 1 | 5 | 2 | 3 | 1 |

In this case the total operating costs are $ 81,398,000 per year, a reduction of 12.6% ($11,750,000 per year) respect to the present fleet deployment situation. The most notable changes in the solution due to this reduction in required frequencies apart from the different allocation, are the lower amount of required chartered ships (before five, now three) which is accompanied by a reduction of the number of ships allocated in some of the routes.

Although not strictly applicable in our case due to the rounding of the number of ships allocated to each route, the sensitivity analysis give us the following guidances:

a. The dual price of the time constraints indicate that if the number of owned (k=1 to 6) or long-term chartered ships (k=7) in the fleet increase, the operating costs increase by an average of $3000 per day-ship . This means that if (with the present fleet) a new ship is aquired, (which means an increase of 365 days-ship) that will increase the annual operating costs by 365 x 3000 = $1,095,000. This effect is linear for an increase of up to two ships (as per the sensitivity information of the LP output.

b. An increase of one voyage/ year in the frequency requirements increases the operating costs in amounts that go from $355,000/ year in route 2 to $852,000 in route 6. This rate of change is valid for a wide range of increase/

decrease of frequency requirements. For example in route 4 the dual price of the frequency constraints is \$843,460; the present value of $F_4$ is 15 (corresponding to a $M_4$=24,33 voyages/ year), if it is reduced to 13 ($M_4$ = 28,07), the operating costs increase by 28.07-24.33 = 3.74, times 843,460, or \$3,160,455 per year. The same amount would be the decrease in costs if $F_4$ is reduced by two days.

c. As per the "allowable decrease" in the daily cost of the laid-up ship (coefficients $e_k$ of the objective function), the owned ships should not be laid-up unless the $e_k$ for these ships reduce substantially. In Table 7, these sensitivity results are summarized.

**Table 7**

Required Decrease in Lay-up Costs

| Ship k | $e_k$, Current Value (\$) | Required Decrease (\$) | $e_k$, Required Value (\$) |
|---|---|---|---|
| | | | |
| 1 | 9100 | 5676 | 3424 |
| 2 | 9000 | 5526 | 3474 |
| 3 | 9000 | 5554 | 3446 |
| 4 | 7400 | 6741 | 659 |
| 5 | 7300 | 7100 | 200 |
| 6 | 8900 | 6363 | 2537 |

Ship types 1,2 and 3 are the most expensive to operate, and therefore are the first candidates for lay-up (if $e_k$ reduces to below \$3400). These sensitivity results indicate that as long as ships 4 and 5 (the oldest owned ships of the fleet) remain with relatively low operating costs, with lay-up costs higher than \$7000/day (for instance because a high number of crew members while laid-up) and comply with the operative constraints like cargo capacities (for the different types of cargo), they should remain in operation.

The short term chartered ships have $e_k$ = 0, therefore in their case the lay-up decision is not an issue. The long term chartered ships are dealt with as owned ships, i.e. they have a high daily lay-up cost similar to the daily cost in normal operation.

d. The incompatibility constraints of ship 10 (the smallest of the chartered ships available as per our formulation) have high dual prices for all the routes, i.e. the increase of the RHS (maximum number of voyages allowed in each route, presently zero) of these constraints translates into high savings, this is not surprising as the voyage costs of this ship type are substantially smaller than the ones of the larger ships. The results of the sensitivity analysis here reveal potential savings in operating costs if the frequencies in some of the routes are adjusted (slightly increased) in such a way that the amount of cargoes per voyage reduce to the capacity levels that ship 10 is able to carry.

# 6 Conclusions and Extensions

## 6.1 General Model

We have successfully developed in this thesis á model for the optimum deployment of a liner fleet that may be composed by both owned and chartered ships subject to time, frequency and other realistic constraints. The problem is originally of non-linear nature; however fixing the two sources of non-linearity, namely the speed of the ships and the frequency of the service in each route, we arrive to a suitable Linear Programming formulation which allows the problem to be solved using LP codes of which there are a number in the market. We have used the Fortran program LINDO for the example presented in Chapter 5.

The LP formulation was used in our example with a procedure for adjusting the LP solution to comply with the integrality requirement of the number of ships of each type allocated to each route. The use of LP allows to use the detailed LP sensitivity analysis. This analysis is not exact because the original LP solution must be modified; however it allows to get insights into the effect of the various cost components and constraints in the profitability of the liner company. The sensitivity analysis showed here that the operating costs are very sensitive to the targeted frequency of service in each route and to the number of owned ships in the fleet (the more the owned ships the higher the operating costs).

The model developed here for the calculation of the costs is very useful not only for the purposes of calculating the cost and time coefficients for the LP formulation but also for analyzing the effects of the different cost components in the total operating costs. Our model also provides an appropriate degree of detail that makes it realistic and accurate and yet not too complicated.

## 6.2 Particular Example

The example of Chapter 5 shows that substantial savings may be achieved by applying our optimization model for the deployment of a liner fleet composed of owned and chartered vessels. The results of the example were compared against the present fleet deployment of a liner shipping company (FMG) showing a reduction of 3% of the operating costs without any modification in the service frequencies. When the frequencies were slightly reduced, the new deployment implied the reduction of two of the original five chartered ships and the reallocation of the remaining ones, resulting in savings of 13% of the operating costs ($11,750,000 per year).

The solution indicates that the ships that are already owned by the company should be used as much as possible because of their high lay-up costs, and that additional ships should be chartered only if the owned ones are insufficient to carry all the cargo and comply with the frequencies.

As mentioned before, the sensitivity analysis showed that the operating costs are very sensitive to changes in the frequency of service and also to changes in the number of owned ships. This last result is due to the high costs (at both lay-up and normal operation) of the owned ships of FMG. It is therefore recommended to consider the possibility of selling or scrapping some of those ships, and charter ships instead if the present cost structure is not going to change in the short/ medium term.

The analysis of frequency vs ship capacity shows that FMG's ships are operating at low utilization factors in most of the routes which (if is going to continue) suggest two actions: reduce the frequencies of service or change the ships presently operating in those routes for smaller ships. It may not be advisable to reduce the service frequencies because, as we discussed in Chapter 1, the level of service is very important in liner shipping as the competition is centered mainly on that aspect of the operation (freight rates are usually fixed by the conference). Therefore, to use smaller owned ships (changing them for some of the existing big ones) may be a more appropriate solution. A study focusing specifically on that possibility, which considers all the aspects involved like specific selling/ scrapping and purchasing prices/ conditions, is required for that decision.

## 6.3 Extensions of this Thesis

### 6.3.1 Mixed Linear-Integer Programming

One of the shortcomings of the LP formulation is that the number of ships of each type, allocated to each of the routes is non-integer and in the rounding of it some variations to the targeted frequencies of service are implied. A mixed linear-integer programming (LP-IP) formulation will avoid this inconvenience; however, transforming/ modifying our LP formulation into an LP-IP formulation is not a straightforward task.

An LP-IP formulation suppressing variables $Y_k$ is described in the following paragraphs. The *integer* variable $N_{kr}$, defining the number of ships k allocated to route r, and modifications to the previous formulation are introduced:

a. <u>Objective Function</u>

Minimize $\sum_{k=1}^{K} \sum_{r=1}^{R} C_{kr} X_{kr}$ [over $X_{kr}$, the decision variables]

b. <u>Constraints</u>

1. (Time availability) $X_{kr}\, t_{kr} - T_k\, N_{kr} = 0$, for all (k,r)

2. (Frequency) $\sum_{k=1}^{K} X_{kr} \leq M_r$, for all r

3. (Incompatibility ship-route) $X_{kr} = 0$, for given (k,r)

4. (Ships available) $\sum_{r=1}^{R} N_{kr} \leq N_k^{max}$, for all chartered ships

$\sum_{r=1}^{R} N_{kr} = N_k^{max}$, for all owned ships

5. (Non-negativity) $X_{kr}, N_{kr} \geq 0$

where $N_{kr}$, the number of ships k allocated to route r are integer variables and the other parameters and variables have the same meaning described before.

In this formulation, the alternative of laying-up the owned ships does not exist; this may not be an inconvenience as in many real life cases (like the example developed here) the high lay-up cost of those ships practically exclude that possibility. The constraint 4 guarantees that all owned ships are in operation at all times and that the chartered ones are employed only as much as they are needed.

### 6.3.2 A LP-IP Formulation with Speed as Discrete Variable

The problem of the speed assignment to the ships with the restriction that all the ships in the same route must sail at the same speed (for all the ships in a route to have the same voyage times and maintain therefore a constant frequency in the routes) may be addressed and solved with a more comprehensive LP-IP formulation:

a. Objective Function

Minimize $\sum_{k=1}^{K} \sum_{r=1}^{R} \sum_{s=1}^{S} C_{krs} X_{krs}$ [over $X_{krs}$, the decision variables]

b. Constraints

1. (Time availability) $\sum_{s=1}^{S} X_{krs} t_{krs} - T_k N_{kr} = 0$, for all (k,r)

2. (Frequency) $\sum_{k=1}^{K} \sum_{s=1}^{S} X_{krs} \leq M_r$, for all r

3. (Ship-route-speed incompatibility) $X_{krs} = 0$, for given (k,r,s)

4. (Ships available) $\sum_{r=1}^{R} N_{kr} \leq N_k^{max}$, for all chartered ships

$\sum_{r=1}^{R} N_{kr} = N_k^{max}$, for all owned ships

5. (Speed homogeneity a) $\sum_{k=1}^{K} X_{krs} - 100\ B_{rs} = 0$, for all (r,s)

6. (Speed homogeneity b) $\sum_{s=1}^{S} B_{rs} = 1$, for all r

7. (Non-negativity) $X_{krs}, N_{kr} \geq 0$,

where:

$X_{krs}$ = number of voyages of ship k in route r at speed s
$C_{krs}$ = operating costs per voyage of ship k in route r at speed s
$t_{krs}$ = voyage time of ship k in route r at speed s

$B_{rs}$ are zero-one variables indicating the best speed for the ships in route r; when $B_{rs} = 1$, all the ships in route r should sail at speed s

S = number of speed values considered

$N_{kr}$, the number of ships k allocated to route r are integer variables and the other parameters and variables are as defined before.

The coefficient of $B_{rs}$ in constraint 5 can be any number larger than the maximum possible number of voyages in route r; there can be only one variable $B_{rs}$ with value one, as per constraint 6, therefore if $B_{rs} = 1$, constraint 5 guarantees that all ships assigned to route r sail at speed s.

A finite number of possible speeds is considered within a reasonable range, the same values for all ships; a reasonable set of speed values in knots could be {14, 15, 16, 17} assuming that the possible (upper range) speeds of the ships considered fall within this range, as happens in the case of our example.

Assuming S = 4, R = 7, K = 11, there would be 4x7x11 = 308 variables $X_{krs}$, and 7x11 = 77 variables $N_{kr}$, 77 time constraints, seven frequency constraints, four ship availability constraints, 35 constraints 5 and seven constraints 6, i.e., at least 137 constraints. The new size of the problem depends very much on the number of speed values chosen.

The output of the LP-IP program with this new formulation will be final (and optimal), not requiring the adjustments needed for the case of the LP formulation we have developed in the present thesis. The integer variables $N_{kr}$ will tell directly the number of ships k to be allocated in route r and the zero-one variables $B_{rs}$ will point the speed at which all the ships assigned to route r must sail.

It does not, however, allow the possibility of laying-up owned ships; In many applications, like the one of our example, this is not a difficulty, since the lay-up costs of the owned ships are so high that the optimal solution would never suggest the lay-up of those ships. The lay-up possibility for owned ships could be included if their lay-up costs were zero, by modifying constraint 4 as follows:

$$\sum_{r=1}^{R} N_{kr} \leq N_k^{max}, \textit{ for all } \text{ships } k$$

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# Appendices

## Appendix 1

Computer Program for Calculation of $L_r$ and $L_{ijr}$

```
C       program to find L(r)
        real Lr, Lijr
        dimension Qijr(16,16,7), Qir(16,7), Ir(7), AQ(16,16,7),
     +  BQ(16,16,7), CQ(16,16,7), DQ(16,16,7), Lijr(16,16,7), Lr(7),
     +  legx(7)
        open(6,file='cargo.out',status='new')
        open (5, file='cargo.dat')
        read (5, *)nr
C Read data for matrices Ir and Qijr
        do 100 k=1,nr
        read(5,*)Ir(k)
        do 100 i=1,Ir(k)
        read (5,*)(Qijr(i,j,k), j=1,Ir(k))
100     continue
C Computations of the elements of Qijr
C  k is used instead of r for counting as r is real
        do 120 k=1,nr
        do 120 i=1,Ir(k)
        sumq=0
        do 110 j=1,Ir(k)
        sumq = sumq + Qijr(i,j,k) + Qijr(j,i,k)
110     continue
        Qir(i,k) = sumq
        write(6,301)i,k,Qir(i,k)
120     continue
C  computations for Lr, maximum amount of cargo onboard any ship in
C  in all the legs ij of route r if only one voyage per year is done
        do 135 k=1,nr
        Lr(k)=0
        do 130 i=1,Ir(k)
        do 125 j=1,Ir(k)
        if (j .ne. i+1) then
                        goto 330
        end if
C  calculation of first sumatory
        aq(i,j,k)=0
        do 150 m=j,Ir(k)
        do 150 n=j,m
        aq(i,j,k) = aq(i,j,k) + Qijr(m,n,k)
150     continue
C  calculation of the second sumatory
        bq(i,j,k)=0
        do 160 m=1,i
        do 160 n=1,m
        bq(i,j,k) = bq(i,j,k) + Qijr(m,n,k)
160     continue
```

```
C  calculation of the third sumatory
        cq(i,j,k)=0
        do 170 m=1,i
        do 170 n=j,Ir(k)
        cq(i,j,k)= cq(i,j,k) + Qijr(m,n,k)
170     continue
C  calc. of the elements of Lijr, amount of cargo on board in leg ij
C  of route r, (case j=i+1)
        Lijr(i,j,k) = aq(i,j,k) + bq(i,j,k) + cq(i,j,k)
        goto 390
C  verification that leg is in the route, for j not equal to i+1
330     if (i .ne. Ir(k)) then
                        go to 125
        end if
        if (j .ne. 1) then
                        go to 125
        end if
C  calculation of the fourth sumatory (for the case i=Ir)
        dq(i,j,k)=0
        do 180 m=1,i
        do 180 n=j,m
        dq(i,j,k) = dq(i,j,k) + Qijr(m,n,k)
180     continue
C  assign value to elements of Lijr for case j not equal to i+1
        Lijr(i,j,k) = dq(i,j,k)
C  find Lr for each route r. Lr has been defined above
390     if ( Lijr(i,j,k) .gt. Lr(k)) then
                Lr(k)=Lijr(i,j,k)
                legx(k)=i
        end if
C  close the loop opened far above
125     continue
130     continue
135     continue
C  print the array Lr(k)
        do 500 k=1,nr
500     write (6,101) k,Lr(k),legx(k)
C     print array Lijr
        do 600 k=1,nr
        do 600 i=1,Ir(k)
600     write(6,401)(i,j,k,Lijr(i,j,k),j=1,Ir(k))
101     format(' Lr(',I2,')=',F9.2,' on departure of port',i2)
301     format(' Qir(',2i2,')=',f10.2)
401   format(' Lijr('3i2,')=',f9.2)
        stop
        end
```

## Appendix 2

Ship Basic Information

| | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | MENU OF SHIPS | | | | | | | | | | | | |
| 23 | | | | | | | | LAID-UP | LAID-UP | LAY-UP | | | |
| 24 | NAME | | ID. NBR. | SPEED | PRO.FUEL | GEN.FUEL | DAILY C. | DAILY C. | GEN FUEL CON | TOTAL COST | DWT | CAPACITY | REGISTER TONN |
| 25 | | | | (kts) | (ton/day) | (ton/day) | ($/day) | ($/day) | (ton/day) | ($/day) | (ton) | (ton) | PANAMA CAN. |
| 26 | | | k | Sk | fk | gk | Hk | Hkl | gkl | ek | | Vk | TRk |
| 27 | | | | | | | | | | 150 | | | |
| 28 | | | | | | | | 0.8 | 0.8 | 500 | | | |
| 29 | OWNED | | | | | | | | | | | 0.9 | |
| 30 | TYPE "ALPAD" | | 1 | 15 | 32 | 5 | 10000 | 8000 | 4 | 9100 | 16010 | 14409 | 12520 |
| 31 | TYPE "CIARM" | | 2 | 16.5 | 45 | 4.5 | 10000 | 8000 | 3.6 | 9040 | 15912 | 14320.8 | 14088 |
| 32 | TYPE "CISAM" | | 3 | 16.5 | 45 | 4.5 | 10000 | 8000 | 3.6 | 9040 | 15450 | 13905 | 13622 |
| 33 | TYPE "CIMAN" | | 4 | 16 | 40 | 4 | 8000 | 6400 | 3.2 | 7380 | 12148 | 10933.2 | 7981 |
| 34 | TYPE "RIMAG" | | 5 | 16 | 35 | 3.5 | 8000 | 6400 | 2.8 | 7320 | 12450 | 11205 | 6809 |
| 35 | TYPE "CIBUN" | | 6 | 16.5 | 35 | 3 | 10000 | 8000 | 2.4 | 8860 | 17330 | 15597 | 11065 |
| 36 | CHARTERED | | | | | | | | | | | | |
| 37 | TYPE GOLFO DE CH. | | 7 | 16.5 | 45 | 4.5 | 10000 | 8000 | 3.6 | 9040 | 15912 | 14320.8 | 14088 |
| 38 | TYPE MEGHAN-A | | 8 | 16.5 | 35 | 3 | 8000 | 0 | 0 | 0 | 12720 | 11448 | 10303.2 |
| 39 | TYPE MONSUN | | 9 | 16.5 | 32 | 3 | 10500 | 0 | 0 | 0 | 15400 | 13860 | 12474 |
| 40 | TYPE METE SIF | | 10 | 14 | 13.5 | 1.5 | 6000 | 0 | 0 | 0 | 4482 | 4033.8 | 3884 |
| 41 | TYPE ANGELIKI | | 11 | 14 | 30 | 3 | 6500 | 0 | 0 | 0 | 17654 | 15888.6 | 14299.74 |

# Appendix 3

Route Basic Information

| | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | | | ROUTE | CHARACTERISTICS | | | | | | | | | |
| 43 | | | | | | | | | | | | | |
| 44 | NAME | | ID.NBR. | DISTANCE | No.PTS | P.FUEL PRIC | G.FUEL PRIC | FREQ SERV | PRESENT | NBR.CANAL | DIST.R.WAT | WAIT TIME | TOT.TIME |
| 45 | | | | (n.miles) | | ($/ton) | ($/ton) | (days) | No.SHIPS | PASG/VOY | (n. miles) | CAN. (days) | R.WAT (day) |
| 46 | | | r | dr | lr | pfr | pgr | Fr | | cnr | dmr | tcr | trm |
| 47 | | | | | | | | | | | | | |
| 48 | | | | | | | | | | | | 0.25 | 0.001 |
| 49 | U.S EAST COAST | | 1 | 6914 | 12 | 87 | 170 | 14 | 3 | 2 | 788 | 0.5 | 1.594 |
| 50 | U.S. GULF COAST | | 2 | 5727 | 8 | 80 | 166 | 14 | 3 | 2 | 498 | 0.5 | 1.192 |
| 51 | U.S.WEST COAST | | 3 | 8730 | 12 | 78 | 167 | 21 | 2 | 0 | 290 | 0 | 0.403 |
| 52 | EUROPE-NORTH | | 4 | 13586 | 16 | 80 | 138 | 15 | 5 | 2 | 1144 | 0.5 | 2.089 |
| 53 | EUROPE-MEDITERRANEUM | | 5 | 11505 | 15 | 87 | 164 | 30 | 2 | 2 | 280 | 0.5 | 0.889 |
| 54 | JAPAN | | 6 | 18853 | 14 | 81 | 164 | 23 | 4 | 2 | 640 | 0.5 | 1.389 |
| 55 | SOUTH AMERICA-WEST COAST | | 7 | 5307 | 5 | 107 | 192 | 35 | 1 | 0 | 58 | 0 | 0.081 |
| 56 | | | | | | | | | | | | | |
| 57 | | | PORTS | IN THE | ROUTES | | | | | | | | |
| 58 | | | | | | | | | | | | | |
| 59 | U.S EAST COAST | | 1 | (NYK)-STJ-PHP-BAL-CHN-MIA-SMA-BAQ-CTG-BUN-CTG-MIA | | | | | | | | | |
| 60 | | | | | | | | | | | | | |
| 61 | U.S. GULF COAST | | 2 | (NOL)-HOU-SMA-BAQ-CTG-BUN-SJR-MIA | | | | | | | | | |
| 62 | | | | | | | | | | | | | |
| 63 | U.S.WEST COAST | | 3 | (BUN)-PCD-ACJ-PQZ-SFC-VAI-STL-LAN-MZN-PQZ-ACJ-PCD | | | | | | | | | |
| 64 | | | | | | | | | | | | | |
| 65 | EUROPE-NORTH | | 4 | (HMB)-BRM-ATW-RTD-HVR-LPL-BLB-STD-SMA-BAQ-CTG-BUN-RTD-BRM-HMB-GTB | | | | | | | | | |
| 66 | | | | | | | | | | | | | |
| 67 | EUROPE-MEDITERRANEUM | | 5 | (LVR)-GNV-MLL-BRC-CDZ-HLV-SMA-BAQ-CTG-BUN-CTG-CDZ-ALC-BRC-TLN | | | | | | | | | |
| 68 | | | | | | | | | | | | | |
| 69 | JAPAN | | 6 | YKM-NAG-KBE-CBA-YKM-HSM-LAN-PQZ-ACJ-PCD-(BUN)-TBO-PQZ-YKM | | | | | | | | | |
| 70 | | | | | | | | | | | | | |
| 71 | SOUTH AMERICA-WEST COAST | | 7 | (BUN)-CLL-VLP-TLC-CLL | | | | | | | | | |

# Appendix 4

Port Basic Information

| | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | PORT RELATED INFORMATION | | | | | | | | | | | | | |
| 73 | | | | | | | | 0.5 | | | | | | |
| 74 | ROUTE/ | | TIME AT | PRODUCTIV | ALLOWANC | PAST TOT | PORT TIME | PORT | PORT | DIS.RESTR | CARGO | Bir=Qir/nir | FREQ | G.FUEL |
| 75 | PORT | | PORT | | INACT | PORT COST | 1988 | VAR.COST | FIX. COST | OPERATION | | ' /365 | | |
| 76 | | | (days) | (ton/day) | (days) | ($) | (days) | ($) | ($) | (n.miles) | (tons/year) | | (days) | ($) |
| 77 | US EC-1 | i,r | tpir | nir | wir | | | vir | uir | 100 | Qir | | Fr | prg |
| 78 | NYK | '1,1 | 1.665075 | 1206 | 0.25 | 6302 | 3 | 1050.333 | 3151 | 40 | 44493 | 0.101077 | 14 | 170 |
| 79 | STJ | '2,1 | 1.152325 | 1145 | 0.25 | 4518 | 2 | 1129.50 | 2259 | 10 | 26936 | 0.064452 | 14 | 170 |
| 80 | PHP | '3,1 | 0.898006 | 1080 | 0.25 | 4778 | 1 | 2389.00 | 2389 | 184 | 18246 | 0.046286 | 14 | 170 |
| 81 | BAL | '4,1 | 0.810026 | 1450 | 0.25 | 6407 | 1 | 3203.50 | 3203.5 | 304 | 21171 | 0.040002 | 14 | 170 |
| 82 | CHN | '5,1 | 1.729202 | 986 | 0.25 | 3550 | 3 | 591.67 | 1775 | 28 | 38025 | 0.105657 | 14 | 170 |
| 83 | MIA | '6,1 | 0.562768 | 1160 | 0.25 | 4533 | 1 | 2266.50 | 2266.5 | 10 | 9459 | 0.022341 | 14 | 170 |
| 84 | SMA | '7,1 | 1.325536 | 677 | 0.50 | 3012 | 2 | 753.00 | 1506 | 4 | 14571 | 0.058967 | 14 | 170 |
| 85 | BAQ | '8,1 | 1.539272 | 850 | 0.50 | 3026 | 2 | 756.50 | 1513 | 24 | 23031 | 0.074234 | 14 | 170 |
| 86 | CTG | '9,1 | 2.241454 | 731 | 0.50 | 3673 | 2 | 918.25 | 1836.5 | 20 | 33189 | 0.12439 | 14 | 170 |
| 87 | BUN | '10,1 | 5.663371 | 720 | 0.75 | 4422 | 3 | 737.00 | 2211 | 34 | 92231 | 0.350955 | 14 | 170 |
| 88 | CTG | '11,1 | 1.624082 | 731 | 0.50 | 3673 | 2 | 918.25 | 1836.5 | 20 | 21423 | 0.080292 | 14 | 170 |
| 89 | MIA | '12,1 | 0.634785 | 1160 | 0.25 | 4533 | 1 | 2266.50 | 2266.5 | 10 | 11637 | 0.027485 | 14 | 170 |
| 90 | | tpr= | 19.8459 | | | | | | dmr= | 788 | | | | |
| 91 | US GC-2 | | | | | | | | | 100 | | | | |
| 92 | NOL | '1,2 | 1.245478 | 1356 | 0.25 | 4256 | 1 | 2128.00 | 2128 | 206 | 35193 | 0.071106 | 14 | 166 |
| 93 | HOU | '2,2 | 2.742612 | 1281 | 0.25 | 4898 | 3 | 816.33 | 2449 | 98 | 83247 | 0.178044 | 14 | 166 |
| 94 | SMA | '3,2 | 0.906537 | 803 | 0.50 | 3430 | 2 | 857.50 | 1715 | 4 | 8511 | 0.029038 | 14 | 166 |
| 95 | BAQ | '4,2 | 2.051424 | 853 | 0.50 | 4009 | 3 | 668.17 | 2004.5 | 24 | 34502 | 0.110816 | 14 | 166 |
| 96 | CTG | '5,2 | 3.692832 | 662 | 0.50 | 5280 | 4 | 660.00 | 2640 | 20 | 55106 | 0.228059 | 14 | 166 |
| 97 | BUN | '6,2 | 2.35722 | 872 | 0.75 | 2005 | 3 | 334.17 | 1002.5 | 34 | 36539 | 0.114801 | 14 | 166 |
| 98 | SJR | '7,2 | 0.750267 | 947 | 0.50 | 5570 | 2 | 1392.50 | 2785 | 2 | 6179 | 0.017876 | 14 | 166 |
| 99 | MIA | '8,2 | 0.640486 | 986 | 0.25 | 5942 | 1 | 2971.00 | 2971 | 10 | 10038 | 0.027892 | 14 | 166 |
| 100 | | tpr= | 14.38686 | | | | | | dmr= | 498 | | | | |
| 101 | US WC-3 | | | | | | | | | 0 | | | | |
| 102 | BUN | '1,3 | 4.095381 | 1775 | 0.75 | 9643 | 9 | 535.72 | 4821.5 | 34 | 103209 | 0.159304 | 21 | 167 |
| 103 | PCD | '2,3 | 0.605358 | 865 | 0.50 | 7211 | 1 | 3605.50 | 3605.5 | 4 | 1584 | 0.005017 | 21 | 167 |
| 104 | ACJ | '3,3 | 0.743686 | 896 | 0.50 | 1255 | 1 | 627.50 | 627.5 | 4 | 3795 | 0.011604 | 21 | 167 |
| 105 | PQZ | '4,3 | 0.822821 | 1280 | 0.50 | 3948 | 1 | 1974.00 | 1974 | 4 | 7182 | 0.015372 | 21 | 167 |
| 106 | SFC | '5,3 | 0.643468 | 4809 | 0.25 | 8627 | 1 | 4313.50 | 4313.5 | 36 | 32888 | 0.018737 | 21 | 167 |
| 107 | VAI | '6,3 | 1.712296 | 2050 | 0.25 | 7396 | 2 | 1849.00 | 3698 | 174 | 52103 | 0.069633 | 21 | 167 |
| 108 | STL | '7,3 | 0.942587 | 1401 | 0.25 | 12910 | 1 | 6455.00 | 6455 | 8 | 16865 | 0.03298 | 21 | 167 |
| 109 | LAN | '8,3 | 0.586965 | 2332 | 0.25 | 8608 | 1 | 4304.00 | 4304 | 10 | 13658 | 0.016046 | 21 | 167 |
| 110 | MZN | '9,3 | 0.951196 | 900 | 0.50 | 4000 | 1 | 2000.00 | 2000 | 4 | 7058 | 0.021486 | 21 | 167 |
| 111 | PQZ | '10,3 | 0.650623 | 1280 | 0.50 | 3948 | 1 | 1974.00 | 1974 | 4 | 3351 | 0.007173 | 21 | 167 |
| 112 | ACJ | '11,3 | 0.68628 | 896 | 0.50 | 1255 | 1 | 627.50 | 627.5 | 4 | 2901 | 0.00887 | 21 | 167 |
| 113 | PCD | '12,3 | 0.823788 | 865 | 0.50 | 7211 | 1 | 3605.50 | 3605.5 | 4 | 4868 | 0.015418 | 21 | 167 |
| 114 | | tpr= | 13.26445 | | | | | | dmr= | 290 | | | | |

| | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | PORT RELATED INFORMATION | | | | | | | | | | | | | |
| 73 | | | | | | | | 0.5 | | | | | | |
| 74 | ROUTE/ | | TIME AT | PRODUCTIV | ALLOWANC | PAST TOT | PORT TIME | PORT | PORT | DIS.RESTR | CARGO | Bir=Qir/nir | FREQ | G.FUEL |
| 75 | PORT | | PORT | | INACT | PORT COST | 1988 | VAR.COST | FIX. COST | OPERATION | | ' /365 | | |
| 76 | | | (days) | (ton/day) | (days) | ($) | (days) | ($) | ($) | (n.miles) | (tons/year) | | (days) | ($) |
| 77 | US EC-1 | i,r | tpir | nir | wir | | | vir | uir | 100 | Qir | | Fr | prg |
| 115 | EUR.NORTH-4 | | | | | | | | | 100 | | | | |
| 116 | HMB | '1,4 | 0.737604 | 1230 | 0.25 | 16412 | 4 | 2051.50 | 8206 | 160 | 14594 | 0.032507 | 15 | 138 |
| 117 | BRM | '2,4 | 0.564841 | 1145 | 0.25 | 14977 | 5 | 1497.70 | 7488.5 | 136 | 8772 | 0.020989 | 15 | 138 |
| 118 | ATW | '3,4 | 1.80605 | 1080 | 0.25 | 16304 | 2 | 4076.00 | 8152 | 130 | 40893 | 0.103737 | 15 | 138 |
| 119 | RTD | '4,4 | 0.473505 | 1450 | 0.25 | 9425 | 3 | 1570.83 | 4712.5 | 42 | 7886 | 0.0149 | 15 | 138 |
| 120 | HVR | '5,4 | 0.458648 | 2685 | 0.25 | 7628 | 2 | 1907.00 | 3814 | 16 | 13632 | 0.01391 | 15 | 138 |
| 121 | LPL | '6,4 | 1.107467 | 652 | 0.25 | 25134 | 3 | 4189.00 | 12567 | 96 | 13604 | 0.057164 | 15 | 138 |
| 122 | BLB | '7,4 | 0.719532 | 736 | 0.25 | 5581 | 2 | 1395.25 | 2790.5 | 8 | 8409 | 0.031302 | 15 | 138 |
| 123 | STD | '8,4 | 0.391075 | 1206 | 0.25 | 5921 | 2 | 1480.25 | 2960.5 | 6 | 4140 | 0.009405 | 15 | 138 |
| 124 | SMA | '9,4 | 9.544056 | 361 | 0.50 | 6850 | 5 | 685.00 | 3425 | 4 | 79446 | 0.602937 | 15 | 138 |
| 125 | BAQ | '10,4 | 2.337076 | 685 | 0.50 | 4700 | 3 | 783.33 | 2350 | 24 | 30621 | 0.122472 | 15 | 138 |
| 126 | CTG | '11,4 | 4.82462 | 697 | 0.50 | 7694 | 6 | 641.17 | 3847 | 20 | 73347 | 0.288308 | 15 | 138 |
| 127 | BUN | '12,4 | 6.459459 | 802 | 0.75 | 15179 | 13 | 583.81 | 7589.5 | 34 | 111422 | 0.380631 | 15 | 138 |
| 128 | RTD | '13,4 | 1.403264 | 1450 | 0.25 | 9425 | 3 | 1570.83 | 4712.5 | 42 | 40691 | 0.076884 | 15 | 138 |
| 129 | BRM | '14,4 | 2.254798 | 1145 | 0.25 | 14977 | 5 | 1497.70 | 7488.5 | 136 | 55857 | 0.133653 | 15 | 138 |
| 130 | HMB | '15,4 | 1.972486 | 1230 | 0.25 | 16412 | 4 | 2051.50 | 8206 | 160 | 51554 | 0.114832 | 15 | 138 |
| 131 | GTB | '16,4 | 1.258156 | 1258 | 0.25 | 6545 | 7 | 467.50 | 3272.5 | 30 | 30861 | 0.06721 | 15 | 138 |
| 132 | | tpr= | 36.31264 | | | | | | dmr= | 1144 | | | | |
| 133 | EUR.MEDIT-5 | | | | | | | | | 100 | | | | |
| 134 | LVR | '1,5 | 1.785201 | 861 | 0.25 | 4176 | 1 | 2088.00 | 2088 | 6 | 16082 | 0.051173 | 30 | 164 |
| 135 | GNV | '2,5 | 0.873244 | 1256 | 0.25 | 4576 | 1 | 2288.00 | 2288 | 4 | 9524 | 0.020775 | 30 | 164 |
| 136 | MLL | '3,5 | 1.033906 | 986 | 0.25 | 3748 | 1 | 1874.00 | 1874 | 8 | 9404 | 0.02613 | 30 | 164 |
| 137 | BRC | '4,5 | 0.441801 | 1361 | 0.25 | 3111 | 1 | 1555.50 | 1555.5 | 8 | 3176 | 0.006393 | 30 | 164 |
| 138 | CDZ | '5,5 | 0.635376 | 906 | 0.25 | 4850 | 2 | 1212.50 | 2425 | 6 | 4248 | 0.012846 | 30 | 164 |
| 139 | HLA | '6,5 | 0.713315 | 1000 | 0.25 | 4423 | 1 | 2211.50 | 2211.5 | 16 | 5637 | 0.015444 | 30 | 164 |
| 140 | SMA | '7,5 | 1.150157 | 947 | 0.50 | 2709 | 1 | 1354.50 | 1354.5 | 4 | 7491 | 0.021672 | 30 | 164 |
| 141 | BAQ | '8,5 | 1.802967 | 489 | 0.50 | 3400 | 2 | 850.00 | 1700 | 24 | 7752 | 0.043432 | 30 | 164 |
| 142 | CTG | '9,5 | 2.93282 | 584 | 0.50 | 5684 | 4 | 710.50 | 2842 | 20 | 17286 | 0.081094 | 30 | 164 |
| 143 | BUN | '10,5 | 1.744861 | 749 | 0.75 | 3725 | 2 | 931.25 | 1862.5 | 34 | 9066 | 0.033162 | 30 | 164 |
| 144 | CTG | '11,5 | 4.448583 | 584 | 0.50 | 5684 | 4 | 710.50 | 2842 | 20 | 28056 | 0.131619 | 30 | 164 |
| 145 | CDZ | '12,5 | 0.647805 | 906 | 0.25 | 4850 | 2 | 1212.50 | 2425 | 6 | 4385 | 0.01326 | 30 | 164 |
| 146 | ALC | '13,5 | 0.438872 | 970 | 0.25 | 3065 | 2 | 766.25 | 1532.5 | 8 | 2229 | 0.006296 | 30 | 164 |
| 147 | BRC | '14,5 | 0.89298 | 1361 | 0.25 | 3111 | 1 | 1555.50 | 1555.5 | 8 | 10647 | 0.021433 | 30 | 164 |
| 148 | TLN | '15,5 | 0.522001 | 1306 | 0.25 | 4711 | 1 | 2355.50 | 2355.5 | 8 | 4322 | 0.009067 | 30 | 164 |
| 149 | | tpr= | 20.06389 | | | | | | dmr= | 280 | | | | |

| | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | PORT RELATED INFORMATION | | | | | | | | | | | | | |
| 73 | | | | | | | | 0.5 | | | | | | |
| 74 | ROUTE/ | | TIME AT | PRODUCTIV | ALLOWANC | PAST TOT | PORT TIME | PORT | PORT | DIS.RESTR | CARGO | Bir=Qir/nir | FREQ | G.FUEL |
| 75 | PORT | | PORT | | INACT | PORT COST | 1988 | VAR.COST | FIX. COST | OPERATION | | ' /365 | | |
| 76 | | | (days) | (ton/day) | (days) | ($) | (days) | ($) | ($) | (n.miles) | (tons/year) | | (days) | ($) |
| 77 | US EC-1 | i,r | tpir | nir | wir | | | vir | uir | 100 | Qir | | Fr | prg |
| 150 | JAPAN-6 | | | | | | | | | 100 | | | | |
| 151 | YKM | '1,6 | 0.845923 | 1350 | 0.25 | 12013 | 2 | 3003.25 | 6006.5 | 20 | 12767 | 0.02591 | 23 | 164 |
| 152 | NAG | '2,6 | 0.98406 | 1394 | 0.25 | 12791 | 3 | 2131.83 | 6395.5 | 76 | 16239 | 0.031916 | 23 | 164 |
| 153 | KBE | '3,6 | 2.649706 | 1118 | 0.25 | 12594 | 5 | 1259.40 | 6297 | 68 | 42576 | 0.104335 | 23 | 164 |
| 154 | CBA | '4,6 | 2.962431 | 1286 | 0.25 | 11631 | 4 | 1453.88 | 5815.5 | 68 | 55356 | 0.117932 | 23 | 164 |
| 155 | YKM | '5,6 | 1.473679 | 1350 | 0.25 | 12013 | 2 | 3003.25 | 6006.5 | 40 | 26216 | 0.053203 | 23 | 164 |
| 156 | HSM | '6,6 | 1.585362 | 1002 | 0.25 | 14316 | 2 | 3579.00 | 7158 | 190 | 21234 | 0.058059 | 23 | 164 |
| 157 | LAN | '7,6 | 0.332989 | 1000 | 0.25 | 2559 | 1 | 1279.50 | 1279.5 | 20 | 1317 | 0.003608 | 23 | 164 |
| 158 | PQZ | '8,6 | 2.000369 | 843 | 0.50 | 3982 | 1 | 1991.00 | 1991 | 4 | 20072 | 0.065233 | 23 | 164 |
| 159 | ACJ | '9,6 | 0.819563 | 743 | 0.50 | 1161 | 1 | 580.50 | 580.5 | 4 | 3768 | 0.013894 | 23 | 164 |
| 160 | PCD | '10,6 | 0.730257 | 821 | 0.50 | 9819 | 1 | 4909.50 | 4909.5 | 4 | 3000 | 0.010011 | 23 | 164 |
| 161 | BUN | '11,6 | 7.843643 | 1609 | 0.75 | 17885 | 15 | 596.17 | 8942.5 | 34 | 181130 | 0.308419 | 23 | 164 |
| 162 | TBO | '12,6 | 0.875678 | 1258 | 0.50 | 614 | 1 | 307.00 | 307 | 8 | 7500 | 0.016334 | 23 | 164 |
| 163 | PQZ | '13,6 | 0.528255 | 843 | 0.50 | 3982 | 1 | 1991.00 | 1991 | 4 | 378 | 0.001228 | 23 | 164 |
| 164 | | tpr= | 23.63192 | | | | | | dmr= | 640 | | | | |
| 165 | S.AMER.WC-7 | | | | | | | | | 0 | | | | |
| 166 | BUN | '1.7 | 9.060057 | 861 | 0.75 | 10931 | 9 | 607.28 | 5465.5 | 34 | 74616 | 0.23743 | 35 | 192 |
| 167 | CLL | '2,7 | 0.856648 | 1133 | 0.50 | 15169 | 2 | 3792.25 | 7584.5 | 8 | 4214 | 0.01019 | 35 | 192 |
| 168 | VLP | '3,7 | 5.048678 | 823 | 0.50 | 16240 | 3 | 2706.67 | 8120 | 4 | 39040 | 0.129962 | 35 | 192 |
| 169 | TLC | '4,7 | 1.957808 | 1400 | 0.50 | 13792 | 2 | 3448.00 | 6896 | 4 | 21284 | 0.041652 | 35 | 192 |
| 170 | CLL | '5,7 | 1.418026 | 1133 | 0.50 | 15169 | 2 | 3792.25 | 7584.5 | 8 | 10847 | 0.026229 | 35 | 192 |
| 171 | | tpr= | 18.34122 | | | | | | dmr= | 58 | | | | |

# Appendix 5

Cargo Matrices

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | | CARGO TO BE CARRIED PER YEAR BETWEEN PORTS IN ROUTE 1- EAST COAST U.S. (TONS) | | | | | | | | | | | | | | |
| 19 | | | | | | | | DESTINATION | | | | | | | UNLOAD | LOAD& |
| 20 | | | NYK-1 | STJ-2 | PHP-3 | BAL-4 | CHN-5 | MIA"-6 | SMA-7 | BAQ-8 | CTG'-9 | BUN-10 | CTG"-11 | MIA'-12 | TOTAL | UNLOAD |
| 21 | | NYK-1 | 0 | 0 | 0 | 0 | 0 | 0 | 2011.5 | 3759 | 5343 | 4783.5 | 0 | 0 | 15897 | 44943 |
| 22 | | STJ-2 | 0 | 0 | 0 | 0 | 0 | 0 | 6313.5 | 1624.5 | 181.5 | 3519 | 0 | 0 | 11639 | 26396 |
| 23 | | PHP-3 | 0 | 0 | 0 | 0 | 0 | 0 | 1735.5 | 2538 | 3463.5 | 4560 | 0 | 0 | 12297 | 18246 |
| 24 | | BAL-4 | 0 | 0 | 0 | 0 | 0 | 0 | 1587 | 6136.5 | 6483 | 2971.5 | 0 | 0 | 17178 | 21171 |
| 25 | ORIGIN | CHN-5 | 0 | 0 | 0 | 0 | 0 | 0 | 2433 | 2838 | 7972.5 | 11538 | 0 | 0 | 24782 | 38025 |
| 26 | | MIA"-6 | 0 | 0 | 0 | 0 | 0 | 0 | 490.5 | 3807 | 2461.5 | 2700 | 0 | 0 | 9459 | 9459 |
| 27 | | SMA-7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14571 |
| 28 | | BAQ-8 | 417 | 106.5 | 399 | 1381.5 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2328 | 23031 |
| 29 | | CTG'-9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7284 | 0 | 0 | 7284 | 33189 |
| 30 | | BUN-10 | 24711 | 8710.5 | 1960.5 | 840 | 12162 | 0 | 0 | 0 | 0 | 0 | 0 | 6490.5 | 54875 | 92231 |
| 31 | | CTG"-11 | 3918 | 5940 | 3589.5 | 1771.5 | 1057.5 | 0 | 0 | 0 | 0 | 0 | 0 | 5146.5 | 21423 | 21423 |
| 32 | | MIA'-12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11637 |
| 33 | | TOTAL | | | | | | | | | | | | | | |
| 34 | | UNLOAD | 29046 | 14757 | 5949 | 3993 | 13244 | 0 | 14571 | 20703 | 25905 | 37356 | 0 | 11637 | 177161 | 354321 |

| | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 48 | CARGO TO BE CARRIED PER YEAR BETWEEN PORTS IN ROUTE 2- GULF COAST U.S. (TONS) | | | | | | | | | | | LOAD & |
| 49 | | | | DESTINATION | | | | | | | | UNLOAD |
| 50 | | | NOL-1 | HOU-2 | SMA-3 | BAQ-4 | CTG-5 | BUN-6 | SJR-7 | MIA-8 | TOTAL | Qir |
| 51 | | NOL-1 | 0 | 0 | 2505 | 6927 | 11456 | 4458 | 0 | 0 | 25346 | 35193 |
| 52 | | HOU-2 | 0 | 0 | 5445 | 13211 | 26418 | 16086 | 0 | 0 | 61160 | 83247 |
| 53 | | SMA-3 | 0 | 528 | 0 | 0 | 0 | 0 | 0 | 33 | 561 | 8511 |
| 54 | ORIGIN | BAQ-4 | 691.5 | 8937 | 0 | 0 | 0 | 0 | 565.5 | 3409.5 | 13604 | 34502 |
| 55 | | CTG-5 | 1941 | 3843 | 0 | 0 | 0 | 0 | 4939.5 | 6493.5 | 17217 | 55106 |
| 56 | | BUN-6 | 7215 | 8779.5 | 0 | 0 | 0 | 0 | 0 | 0 | 15995 | 36539 |
| 57 | | SJR-7 | 0 | 0 | 0 | 658.5 | 15 | 0 | 0 | 0 | 673.5 | 6178.5 |
| 58 | | MIA-8 | 0 | 0 | 0 | 102 | 0 | 0 | 0 | 0 | 102 | 10038 |
| 59 | | TOTAL | 9847.5 | 22088 | 7950 | 20898 | 37889 | 20544 | 5505 | 9936 | 134657 | 269313 |
| 60 | | | | | | | | | | 134657 | | |

| | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 79 | CARGO TO BE CARRIED PER YEAR BETWEEN PORTS IN ROUTE 3- WEST COAST U.S. (TONS) | | | | | | | | | | | | | | | |
| 80 | | | | | | | | DESTINATION | | | | | | | TOTAL | LOAD & |
| 81 | | | BUN-1 | PCD'-2 | ACJ'-3 | PQZ'-4 | SFC-5 | VAI-6 | STL-7 | LAN-8 | MZN-9 | PQZ"-10 | ACJ"-11 | PCD"-12 | LOAD | UNLOAD |
| 82 | | BUN-1 | 0 | 354 | 1839 | 96 | 22104 | 6259.5 | 1365 | 5193 | 0 | 0 | 0 | 0 | 37211 | 103209 |
| 83 | | PCD'-2 | 0 | 0 | 0 | 0 | 1045.5 | 0 | 58.5 | 126 | 0 | 0 | 0 | 0 | 1230 | 1584 |
| 84 | | ACJ'-3 | 0 | 0 | 0 | 0 | 1425 | 438 | 52.5 | 40.5 | 0 | 0 | 0 | 0 | 1956 | 3795 |
| 85 | | PQZ'-4 | 0 | 0 | 0 | 0 | 4305 | 1807.5 | 345 | 628.5 | 0 | 0 | 0 | 0 | 7086 | 7182 |
| 86 | | SFC-5 | 3033 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 286.5 | 360 | 328.5 | 4008 | 32888 |
| 87 | ORIGIN | VAI-6 | 40380 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 304.5 | 30 | 2883 | 43598 | 52103 |
| 88 | | STL-7 | 13149 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 204 | 1425 | 265.5 | 15044 | 16865 |
| 89 | | LAN-8 | 2508 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2770.5 | 0 | 1086 | 1305 | 7669.5 | 13658 |
| 90 | | MZN-9 | 4287 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4287 | 7057.5 |
| 91 | | PQZ"-10 | 2556 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2556 | 3351 |
| 92 | | ACJ"-11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2901 |
| 93 | | PCD"-12 | 85.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 85.5 | 4867.5 |
| 94 | | TOTAL | 65999 | 354 | 1839 | 96 | 28880 | 8505 | 1821 | 5988 | 2770.5 | 795 | 2901 | 4782 | 124730 | |
| 95 | | LOAD | | | | | | | | | | | | 124730 | | 249459 |

| | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 119 | CARGO TO BE CARRIED PER YEAR BETWEEN PORTS IN ROUTE 4- EUROPE NORTH (TONS) | | | | | | | | | | | | | | | | | | | LOAD & |
| 120 | | | | | | | | DESTINATION | | | | | | | | | | | TOTAL | UNLOAD |
| 121 | | | HMB"-1 | BRM"-2 | ATW-3 | RTD"-4 | HVR-5 | LPL-6 | BLB-7 | STD-8 | SMA-9 | BAQ-10 | CTG-11 | BUN-12 | RTD'-13 | BRM'-14 | HMB'-15 | GTB-16 | LOAD | Qir |
| 122 | | HMB"-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 715.5 | 6489 | 5034 | 2355 | 0 | 0 | 0 | 0 | 14594 | 14594 |
| 123 | | BRM"-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 331.5 | 2847 | 2530.5 | 3063 | 0 | 0 | 0 | 0 | 8772 | 8772 |
| 124 | | ATW-3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7756.5 | 8295 | 8920.5 | 7693.5 | 0 | 0 | 0 | 0 | 32666 | 40893 |
| 125 | | RTD"-4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 288 | 2353.5 | 4224 | 1020 | 0 | 0 | 0 | 0 | 7885.5 | 7885.5 |
| 126 | | HVR-5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 267 | 79.5 | 4071 | 561 | 0 | 0 | 0 | 0 | 4978.5 | 13632 |
| 127 | | LPL-6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2382 | 2905.5 | 3597 | 4695 | 0 | 0 | 0 | 0 | 13580 | 13604 |
| 128 | | BLB-7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1938 | 3589.5 | 2184 | 697.5 | 0 | 0 | 0 | 0 | 8409 | 8409 |
| 129 | ORIGIN | STD-8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2838 | 18 | 1231.5 | 0 | 0 | 0 | 0 | 0 | 4087.5 | 4140 |
| 130 | | SMA-9 | 0 | 0 | 1368 | 0 | 5362.5 | 0 | 0 | 0 | 0 | 0 | 0 | 1498.5 | 7938 | 14921 | 7812 | 22610 | 61509 | 79446 |
| 131 | | BAQ-10 | 0 | 0 | 129 | 0 | 30 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 769.5 | 109.5 | 150 | 9 | 1209 | 30621 |
| 132 | | CTG-11 | 0 | 0 | 1174.5 | 0 | 1545 | 0 | 0 | 0 | 0 | 0 | 0 | 474 | 17795 | 14472 | 3237 | 1834.5 | 40532 | 73347 |
| 133 | | BUN-12 | 0 | 0 | 5556 | 0 | 1716 | 12 | 0 | 52.5 | 0 | 0 | 0 | 0 | 14189 | 26355 | 40355 | 0 | 88235 | 111422 |
| 134 | | RTD'-13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40691 |
| 135 | | BRM'-14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 55857 |
| 136 | | HMB'-15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 51554 |
| 137 | | GTB-16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1420.5 | 2835 | 1023 | 1129.5 | 0 | 0 | 0 | 0 | 6408 | 30861 |
| 138 | | TOTAL | | | | | | | | | | | | | | | | | | |
| 139 | | UNLOAD | 0 | 0 | 8227.5 | 0 | 8653.5 | 24 | 0 | 52.5 | 17937 | 29412 | 32816 | 23187 | 40691 | 55857 | 51554 | 24453 | 292863 | 585726 |
| 140 | | | | | | | | | | | | | | | | | | 292863 | | |

| | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 162 | CARGO TO BE CARRIED PER YEAR BETWEEN PORTS OF ROUTE 5- EUROPE MEDITERRANEUM (TONS) | | | | | | | | | | | | | | | | | | LOAD & |
| 163 | | | | | | | | | DESTINATION | | | | | | | | | TOTAL | UNLOAD |
| 164 | | | LVR-1 | GNV-2 | MLL-3 | BRC"-4 | CDZ"-5 | HLA-6 | SMA-7 | BAQ-8 | CTG'-9 | BUN-10 | CTG"-11 | CDZ'-12 | ALC-13 | BRC'-14 | TLN-15 | LOAD | Qir |
| 165 | | LVR-1 | 0 | 0 | 0 | 0 | 0 | 0 | 316.5 | 4437 | 9897 | 334.5 | 0 | 0 | 0 | 0 | 0 | 14985 | 16082 |
| 166 | | GNV-2 | 0 | 0 | 0 | 0 | 0 | 0 | 207 | 1321.5 | 1234.5 | 889.5 | 0 | 0 | 0 | 0 | 0 | 3652.5 | 9523.5 |
| 167 | | MLL-3 | 0 | 0 | 0 | 0 | 0 | 0 | 6934.5 | 141 | 604.5 | 1723.5 | 0 | 0 | 0 | 0 | 0 | 9403.5 | 9403.5 |
| 168 | | BRC"-4 | 0 | 0 | 0 | 0 | 0 | 0 | 33 | 1501.5 | 1327.5 | 313.5 | 0 | 0 | 0 | 0 | 0 | 3175.5 | 3175.5 |
| 169 | | CDZ"-5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33 | 4215 | 0 | 0 | 0 | 0 | 0 | 0 | 4248 | 4248 |
| 170 | | HLA-6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.5 | 5629.5 | 0 | 0 | 0 | 0 | 0 | 5637 | 5637 |
| 171 | | SMA-7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7491 |
| 172 | | BAQ-8 | 0 | 118.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 199.5 | 0 | 318 | 7752 |
| 173 | ORIGIN | CTG'-9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17286 |
| 174 | | BUN-10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 27 | 0 | 148.5 | 0 | 175.5 | 9066 |
| 175 | | CTG"-11 | 1096.5 | 5752.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4357.5 | 2229 | 10299 | 4321.5 | 28056 | 28056 |
| 176 | | CDZ'-12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4384.5 |
| 177 | | ALC-13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2229 |
| 178 | | BRC'-14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10647 |
| 179 | | TLN-15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4321.5 |
| 180 | | TOTAL | | | | | | | | | | | | | | | | | |
| 181 | | UNLOAD | 1096.5 | 5871 | 0 | 0 | 0 | 0 | 7491 | 7434 | 17286 | 8890.5 | 0 | 4384.5 | 2229 | 10647 | 4321.5 | 69651 | 139302 |
| 182 | | | | | | | | | | | | | | | | | 69651 | | |

| | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 203 | | CARGO TO BE CARRIED PER YEAR BETWEEN PORTS OF ROUTE 6-JAPAN (TONS) | | | | | | | | | | | | | | | LOAD & |
| 204 | | | | | | | | | DESTINATION | | | | | | | TOTAL | UNLOAD |
| 205 | | | YKM'-1 | NAG-2 | KBE-3 | CBA-4 | YKM"-5 | HSM-6 | LAN-7 | PQZ'-8 | ACJ-9 | PCD-10 | BUN-11 | TBO-12 | PQZ"-13 | LOAD | Qir |
| 206 | | YKM'-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12767 |
| 207 | | NAG-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6901.5 | 0 | 0 | 6901.5 | 16239 |
| 208 | | KBE-3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13491 | 0 | 0 | 13491 | 42576 |
| 209 | | CBA-4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 55356 | 0 | 0 | 55356 | 55356 |
| 210 | | YKM"-5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18716 | 0 | 0 | 18716 | 26216 |
| 211 | | HSM-6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16313 | 0 | 0 | 16313 | 21234 |
| 212 | ORIGIN | LAN-7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1317 | 0 | 0 | 1317 | 1317 |
| 213 | | PQZ'-8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20072 | 0 | 0 | 20072 | 20072 |
| 214 | | ACJ-9 | 0 | 100.5 | 3667.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3768 | 3768 |
| 215 | | PCD-10 | 0 | 0 | 3000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3000 | 3000 |
| 216 | | BUN-11 | 12567 | 9237 | 22239 | 0 | 0 | 4921.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 48965 | 181130 |
| 217 | | TBO-12 | 0 | 0 | 0 | 0 | 7500 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7500 | 7500 |
| 218 | | PQZ"-13 | 199.5 | 0 | 178.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 378 | 378 |
| 219 | | TOTAL | | | | | | | | | | | | | | | |
| 220 | | UNLOAD | 12767 | 9337.5 | 29085 | 0 | 7500 | 4921.5 | 0 | 0 | 0 | 0 | 132165 | 0 | 0 | 195776 | 391551 |
| 221 | | | | | | | | | | | | | | | 195776 | | |

| | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 |
|---|---|---|---|---|---|---|---|---|---|
| 236 | | CARGO TO BE CARRIED PER YEAR BETWEEN | | | | | | | |
| 237 | | PORTS OF ROUTE 7- SOUTH AMERICA WEST COAST (TONS) | | | | | | | |
| 238 | | | | | | | | | LOAD & |
| 239 | | | | DESTINATION | | | | TOTAL | UNLOAD |
| 240 | | | BUN-1 | CLL'-2 | VLP-3 | TLC-4 | CLL"-5 | LOAD | Qir |
| 241 | | BUN-1 | 0 | 3829.5 | 4627.5 | 0 | 0 | 8457 | 74616 |
| 242 | | CLL'-2 | 0 | 0 | 384 | 0 | 0 | 384 | 4213.5 |
| 243 | ORIGIN | VLP-3 | 34029 | 0 | 0 | 0 | 0 | 34029 | 39041 |
| 244 | | TLC-4 | 21284 | 0 | 0 | 0 | 0 | 21284 | 21284 |
| 245 | | CLL"-5 | 10847 | 0 | 0 | 0 | 0 | 10847 | 10847 |
| 246 | | TOTAL | | | | | | | |
| 247 | | UNLOAD | 66159 | 3829.5 | 5011.5 | 0 | 0 | 75000 | 150000 |
| 248 | | | | | | | 75000 | | |

# Appendix 6

Cost Coefficients $C_{kr}$

Appendix 6

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | |
| 2 | COEFFICIENTS Ckr, OPERATING COSTS PER VOYAGE FOR SHIP-ROUTE COMBINATIONS | | | | | | | | | | | | |
| 3 | FOR GIVEN SHIP SPEEDS AND SERVICE FREQUENCIES | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | |
| 5 | SHIP'S TYPE | | ID. NBR. | SPEED | FUEL CON | ***** Fr= VALUES OF SERVICE FREQUENCY FOR ROUTE r***** | | | | | | | LAY-UP |
| 6 | | | | (knots) | (ton/day) | F1= | F2= | F3= | F4= | F5= | F6= | F7= | ($/DAY) |
| 7 | | | k | Sk | fk | 14 | 14 | 21 | 15 | 30 | 23 | 35 | Ek |
| 8 | OWNED | | | | | | | | | | | | |
| 9 | TYPE "ALPAD" | | 1 | 15 | 32 | 591830.1 | 462725.4 | 536638.2 | 1103799 | 767132.7 | 1117575 | 484063.6 | 9100 |
| 10 | TYPE "CIARM" | | 2 | 16.5 | 45 | 591314.8 | 462404.2 | 526655.1 | 1096675 | 762837.8 | 1104410 | 480381.1 | 9040 |
| 11 | TYPE "CISAM" | | 3 | 16.5 | 45 | 589413.5 | 460502.9 | 526655.1 | 1094438 | 760936.5 | 1102509 | 480381.1 | 9040 |
| 12 | TYPE "CIMAN" | | 4 | 16 | 40 | 484151.4 | 374588.9 | 451804.7 | 915945.7 | 632262.4 | 926810.4 | 411981.9 | 7380 |
| 13 | TYPE "RIMAG" | | 5 | 16 | 35 | 468319.9 | 361409.5 | 439932.3 | 891221.2 | 610345.5 | 896180.8 | 401500.5 | 7320 |
| 14 | TYPE "CIBUN" | | 6 | 16.5 | 35 | 553962.4 | 431317.2 | 500614.5 | 1040099 | 713145 | 1035988 | 456899.5 | 8860 |
| 15 | CHARTERED | | | | | | | | | | | | |
| 16 | TYPE GOLFO DE CH. | | 7 | 16.5 | 45 | 590999 | 462404.2 | 526655.1 | 1096675 | 762837.8 | 1104410 | 480381.1 | 9040 |
| 17 | TYPE MEGHAN-A | | 8 | 16.5 | 35 | 473054.4 | 368127.8 | 429189.1 | 891023.7 | 610025.3 | 887621.5 | 393253 | 0 |
| 18 | TYPE MONSUN | | 9 | 16.5 | 32 | 574604.2 | 448615.4 | 513312.2 | 1074984 | 736313.8 | 1066483 | 468509.3 | 0 |
| 19 | TYPE METE SIF | | 10 | 14 | 13.5 | 350056.7 | 268725.3 | 340700.1 | 685807.4 | 455894.8 | 678134 | 308139.2 | 0 |
| 20 | TYPE ANGELIKI | | 11 | 14 | 30 | 453408.5 | 357858.4 | 403795 | 844481.1 | 588499.9 | 855803.2 | 362963.9 | 0 |

# Appendix 7

Calculation of Costs at Sea

| | 14 | 15 | 16 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | MENU | OF | SHIP | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | | | | |
| 24 | NAME | | ID. NBR. | ROUTE 1 (r=1)........................................................ | | | | | | ROUTE 2 (r=2)........................................................ | | | | | |
| 25 | | | | SAILING TIMI | VARIAB OPEI | CANAL | OPER COSTS | OPER COSTS | OPER COSTS | SAILING TIMI | VARIAB OPEI | CANAL | OPER COSTS | OPER COSTS | OPER COSTS |
| 26 | | | k | | COST AT SEA | COSTS | AT SEA | AT PORTS | TOTAL | | COST AT SEA | COSTS | AT SEA | AT PORTS | TOTAL |
| 29 | OWNED | | | | | | | | | | | | | | |
| 30 | TYPE "ALPAD" | | 1 | 19.205556 | 13634 | 51081.6 | 328874.51 | 262955.62 | 591830 | 15.908333 | 13390 | 51081.6 | 276010.8 | 186714.56 | 462725.36 |
| 31 | TYPE "CIARM" | | 2 | 17.459596 | 14680 | 57479.04 | 329730.28 | 261584.52 | 591315 | 14.462121 | 14347 | 57479.04 | 276883.71 | 185520.45 | 462404.17 |
| 32 | TYPE "CISAM" | | 3 | 17.459596 | 14680 | 55577.76 | 327829 | 261584.52 | 589414 | 14.462121 | 14347 | 55577.76 | 274982.43 | 185520.45 | 460502.89 |
| 33 | TYPE "CIMAN" | | 4 | 18.005208 | 12160.002 | 32562.48 | 264261.34 | 219890.01 | 484151 | 14.914063 | 11864.002 | 32562.48 | 219036.24 | 155552.63 | 374588.87 |
| 34 | TYPE "RIMAG" | | 5 | 18.005208 | 11639.999 | 27780.72 | 250116.83 | 218203.11 | 468320 | 14.914063 | 11380.999 | 27780.72 | 207050.95 | 154358.52 | 361409.48 |
| 35 | TYPE "CIBUN" | | 6 | 17.459596 | 13554.999 | 45145.2 | 297754.38 | 256208.01 | 553962 | 14.462121 | 13297.999 | 45145.2 | 249379.1 | 181938.13 | 431317.22 |
| 36 | CHARTERED | | | | | | | | | | | | | | |
| 37 | TYPE GOLFO DE CH. | | 7 | 17.459596 | 14680 | 57479.04 | 329730.28 | 261268.71 | 590999 | 14.462121 | 14347 | 57479.04 | 276883.71 | 185520.45 | 462404.17 |
| 38 | TYPE MEGHAN-A | | 8 | 17.459596 | 11554.999 | 42037.056 | 256538.17 | 216516.2 | 473054 | 14.462121 | 11297.999 | 42037.056 | 214963.39 | 153164.42 | 368127.8 |
| 39 | TYPE MONSUN | | 9 | 17.459596 | 13794.001 | 50893.92 | 308473.2 | 266130.96 | 574604 | 14.462121 | 13558.001 | 50893.92 | 259483.83 | 189131.55 | 448615.38 |
| 40 | TYPE METE SIF | | 10 | 20.577381 | 7429.5012 | 15846.72 | 178293.02 | 171763.7 | 350057 | 17.044643 | 7329.0011 | 15846.72 | 147916.9 | 120808.38 | 268725.28 |
| 41 | TYPE ANGELIKI | | 11 | 20.577381 | 9619.9989 | 58342.939 | 266661.16 | 186747.35 | 453409 | 17.044643 | 9397.999 | 58342.939 | 226274.28 | 131584.13 | 357858.41 |

| | 14 | 15 | 16 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | MENU | OF | SHIP | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | | | | |
| 24 | NAME | | ID. NBR. | ROUTE 3 (r=3)...................................................... | | | | | | ROUTE 4 (r=4)...................................................... | | | | | |
| 25 | | | | SAILING TIMI | VARIAB OPEI | CANAL | OPER COSTS | OPER COSTS | OPER COSTS | SAILING TIMI | VARIAB OPEI | CANAL | OPER COSTS | OPER COSTS | OPER COSTS |
| 26 | | | k | | COST AT SE/ | COSTS | AT SEA | AT PORTS | TOTAL | | COST AT SE/ | COSTS | AT SEA | AT PORTS | TOTAL |
| 29 | OWNED | | | | | | | | | | | | | | |
| 30 | TYPE "ALPAD" | | 1 | 24.25 | 13331 | 0 | 327304.49 | 209333.69 | 536638.18 | 37.738889 | 13250 | 60096 | 581025.05 | 522774.05 | 1103799.1 |
| 31 | TYPE "CIARM" | | 2 | 22.045455 | 14261.5 | 0 | 318429 | 208226.11 | 526655.1 | 34.308081 | 14221 | 67622.4 | 576406.4 | 520268.48 | 1096674.9 |
| 32 | TYPE "CISAM" | | 3 | 22.045455 | 14261.5 | 0 | 318429 | 208226.11 | 526655.1 | 34.308081 | 14221 | 65385.6 | 574169.6 | 520268.48 | 1094438.1 |
| 33 | TYPE "CIMAN" | | 4 | 22.734375 | 11788.002 | 0 | 271215.05 | 180589.63 | 451804.68 | 35.380208 | 11752.002 | 38308.8 | 470808.1 | 445137.63 | 915945.73 |
| 34 | TYPE "RIMAG" | | 5 | 22.734375 | 11314.499 | 0 | 260450.27 | 179482.05 | 439932.32 | 35.380208 | 11282.999 | 32683.2 | 448589.1 | 442632.06 | 891221.16 |
| 35 | TYPE "CIBUN" | | 6 | 22.045455 | 13230.999 | 0 | 295711.14 | 204903.36 | 500614.5 | 34.308081 | 13213.999 | 53112 | 527347.73 | 512751.76 | 1040099.5 |
| 36 | CHARTERED | | | | | | | | | | | | | | |
| 37 | TYPE GOLFO DE CH. | | 7 | 22.045455 | 14261.5 | 0 | 318429 | 208226.11 | 526655.1 | 34.308081 | 14221 | 67622.4 | 576406.4 | 520268.48 | 1096674.9 |
| 38 | TYPE MEGHAN-A | | 8 | 22.045455 | 11230.999 | 0 | 250814.68 | 178374.46 | 429189.14 | 34.308081 | 11213.999 | 49455.36 | 450897.17 | 440126.49 | 891023.66 |
| 39 | TYPE MONSUN | | 9 | 22.045455 | 13497.001 | 0 | 301776.66 | 211535.59 | 513312.25 | 34.308081 | 13474.001 | 59875.2 | 544075.54 | 530908.08 | 1074983.6 |
| 40 | TYPE METE SIF | | 10 | 25.982143 | 7303.5011 | 0 | 192177.26 | 148522.82 | 340700.08 | 40.434524 | 7287.0011 | 18643.2 | 325822.89 | 359984.5 | 685807.39 |
| 41 | TYPE ANGELIKI | | 11 | 25.982143 | 9340.999 | 0 | 245317.21 | 158477.79 | 403795 | 40.434524 | 9313.999 | 68638.752 | 458823.58 | 385657.53 | 844481.11 |

| | 14 | 15 | 16 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | MENU | OF | SHIP | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | | | | |
| 24 | NAME | | ID. NBR. | ROUTE 5 (r=5)........................................................ | | | | | | ROUTE 6 (r=6)........................................................ | | | | | |
| 25 | | | | SAILING TIM | VARIAB OPE | CANAL | OPER COSTS | OPER COSTS | OPER COSTS | SAILING TIM | VARIAB OPE | CANAL | OPER COSTS | OPER COSTS | OPER COSTS |
| 26 | | | k | | COST AT SE | COSTS | AT SEA | AT PORTS | TOTAL | | COST AT SE | COSTS | AT SEA | AT PORTS | TOTAL |
| 29 | OWNED | | | | | | | | | | | | | | |
| 30 | TYPE "ALPAD" | | 1 | 31.958333 | 13604 | 51081.6 | 494731.62 | 272401.06 | 767132.67 | 52.369444 | 13412 | 51081.6 | 767349.4 | 350226.03 | 1117575.4 |
| 31 | TYPE "CIARM" | | 2 | 29.05303 | 14653 | 57479.04 | 492081.95 | 270755.82 | 762837.77 | 47.608586 | 14383 | 57479.04 | 756122.15 | 348288.22 | 1104410.4 |
| 32 | TYPE "CISAM" | | 3 | 29.05303 | 14653 | 55577.76 | 490180.67 | 270755.82 | 760936.49 | 47.608586 | 14383 | 55577.76 | 754220.87 | 348288.22 | 1102509.1 |
| 33 | TYPE "CIMAN" | | 4 | 29.960938 | 12136.002 | 32562.48 | 403279.56 | 228982.8 | 632262.36 | 49.096354 | 11896.002 | 32562.48 | 627723.86 | 299086.57 | 926810.42 |
| 34 | TYPE "RIMAG" | | 5 | 29.960938 | 11618.999 | 27780.72 | 383007.92 | 227337.56 | 610345.49 | 49.096354 | 11408.999 | 27780.72 | 599032.06 | 297148.75 | 896180.81 |
| 35 | TYPE "CIBUN" | | 6 | 29.05303 | 13536.999 | 45145.2 | 447324.9 | 265820.1 | 713145 | 47.608586 | 13326.999 | 45145.2 | 693513.61 | 342474.77 | 1035988.4 |
| 36 | CHARTERED | | | | | | | | | | | | | | |
| 37 | TYPE GOLFO DE CH. | | 7 | 29.05303 | 14653 | 57479.04 | 492081.95 | 270755.82 | 762837.77 | 47.608586 | 14383 | 57479.04 | 756122.15 | 348288.22 | 1104410.4 |
| 38 | TYPE MEGHAN-A | | 8 | 29.05303 | 11536.999 | 42037.056 | 384332.93 | 225692.32 | 610025.25 | 47.608586 | 11326.999 | 42037.056 | 592410.53 | 295210.93 | 887621.46 |
| 39 | TYPE MONSUN | | 9 | 29.05303 | 13776.001 | 50893.92 | 460461.8 | 275852.04 | 736313.85 | 47.608586 | 13584.001 | 50893.92 | 712192.27 | 354290.72 | 1066483 |
| 40 | TYPE METE SIF | | 10 | 34.241071 | 7420.5012 | 15846.72 | 275265.95 | 180628.83 | 455894.78 | 56.110119 | 7339.5011 | 15846.72 | 436000.3 | 242133.65 | 678133.95 |
| 41 | TYPE ANGELIKI | | 11 | 34.241071 | 9601.9989 | 58342.939 | 392903.43 | 195596.49 | 588499.92 | 56.110119 | 9421.999 | 58342.939 | 596040.16 | 259763.06 | 855803.23 |

| | 14 | 15 | 16 | 64 | 65 | 66 | 67 | 68 | 69 |
|---|---|---|---|---|---|---|---|---|---|
| 22 | MENU | OF | SHIP | | | | | | |
| 23 | | | | | | | | | |
| 24 | NAME | | ID. NBR. | ROUTE 7 (r=7)........................................................ | | | | | |
| 25 | | | | SAILING TIMI | VARIAB OPEI | CANAL | OPER COSTS | OPER COSTS | OPER COSTS |
| 26 | | | k | | COST AT SE/ | COSTS | AT SEA | AT PORTS | TOTAL |
| 29 | OWNED | | | | | | | | |
| 30 | TYPE "ALPAD" | | 1 | 14.741667 | 14383.999 | 0 | 212849.68 | 271213.95 | 484063.62 |
| 31 | TYPE "CIARM" | | 2 | 13.401515 | 15679 | 0 | 210927.9 | 269453.19 | 480381.09 |
| 32 | TYPE "CISAM" | | 3 | 13.401515 | 15679 | 0 | 210927.9 | 269453.19 | 480381.09 |
| 33 | TYPE "CIMAN" | | 4 | 13.820313 | 13048.002 | 0 | 180971.91 | 231010 | 411981.91 |
| 34 | TYPE "RIMAG" | | 5 | 13.820313 | 12416.999 | 0 | 172251.25 | 229249.24 | 401500.49 |
| 35 | TYPE "CIBUN" | | 6 | 13.401515 | 14320.999 | 0 | 192728.63 | 264170.92 | 456899.55 |
| 36 | CHARTERED | | | | | | | | |
| 37 | TYPE GOLFO DE CH. | | 7 | 13.401515 | 15679 | 0 | 210927.9 | 269453.19 | 480381.09 |
| 38 | TYPE MEGHAN-A | | 8 | 13.401515 | 12320.999 | 0 | 165764.49 | 227488.49 | 393252.98 |
| 39 | TYPE MONSUN | | 9 | 13.401515 | 14500.001 | 0 | 195167.81 | 273341.53 | 468509.34 |
| 40 | TYPE METE SIF | | 10 | 15.794643 | 7732.5014 | 0 | 122615.43 | 185523.78 | 308139.21 |
| 41 | TYPE ANGELIKI | | 11 | 15.794643 | 10285.999 | 0 | 162987.28 | 199976.66 | 362963.94 |

## Appendix 8

Calculation of Cost at Port

| | 83 | 84 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | PORT RELATED INFO | | | | | | | | | | | | | | | | | | | | | |
| 73 | | | | | | | | | | | | | | | | | | | | | | |
| 74 | ROUTE/ | | | | | | | | | | | | | | | | | | | | | |
| 75 | PORT | | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk |
| 76 | | | K=1 | | | | k=2,3 | | | | k=4 | | | | k=5 | | | | k=6 | | | |
| 77 | US EC-1 | i,r | | | | | | | | | | | | | | | | | | | | |
| 78 | NYK | '1,1 | 5 | 10000 | 11900 | 22966 | 4.5 | 10000 | 11815 | 22966 | 4 | 8000 | 9730 | 19353 | 3.5 | 8000 | 9645 | 19211 | 3 | 10000 | 11560 | 22400 |
| 79 | STJ | '2,1 | 5 | 10000 | 11980 | 16063 | 4.5 | 10000 | 11895 | 16063 | 4 | 8000 | 9810 | 13563 | 3.5 | 8000 | 9725 | 13465 | 3 | 10000 | 11640 | 15671 |
| 80 | PHP | '3,1 | 5 | 10000 | 13239 | 14278 | 4.5 | 10000 | 13154 | 14278 | 4 | 8000 | 11069 | 12329 | 3.5 | 8000 | 10984 | 12253 | 3 | 10000 | 12899 | 13972 |
| 81 | BAL | '4,1 | 5 | 10000 | 14054 | 14587 | 4.5 | 10000 | 13969 | 14518 | 4 | 8000 | 11884 | 12829 | 3.5 | 8000 | 11799 | 12761 | 3 | 10000 | 13714 | 14312 |
| 82 | CHN | '5,1 | 5 | 10000 | 11442 | 21560 | 4.5 | 10000 | 11357 | 21413 | 4 | 8000 | 9272 | 17808 | 3.5 | 8000 | 9187 | 17661 | 3 | 10000 | 11102 | 20972 |
| 83 | MIA | '6,1 | 5 | 10000 | 13117 | 9648 | 4.5 | 10000 | 13032 | 9600.2 | 4 | 8000 | 10947 | 8426.8 | 3.5 | 8000 | 10862 | 8379 | 3 | 10000 | 12777 | 9456.7 |
| 84 | SMA | '7,1 | 5 | 10000 | 11603 | 16886 | 4.5 | 10000 | 11518 | 16774 | 4 | 8000 | 9433 | 14010 | 3.5 | 8000 | 9348 | 13897 | 3 | 10000 | 11263 | 16436 |
| 85 | BAQ | '8,1 | 5 | 10000 | 11607 | 19379 | 4.5 | 10000 | 11522 | 19248 | 4 | 8000 | 9437 | 16038 | 3.5 | 8000 | 9352 | 15907 | 3 | 10000 | 11267 | 18855 |
| 86 | CTG | '9,1 | 5 | 10000 | 11768 | 28214 | 4.5 | 10000 | 11683 | 28024 | 4 | 8000 | 9598 | 23351 | 3.5 | 8000 | 9513 | 23160 | 3 | 10000 | 11428 | 27452 |
| 87 | BUN | '10,1 | 5 | 10000 | 11587 | 67832 | 4.5 | 10000 | 11502 | 67351 | 4 | 8000 | 9417 | 55543 | 3.5 | 8000 | 9332 | 55062 | 3 | 10000 | 11247 | 65907 |
| 88 | CTG | '11,1 | 5 | 10000 | 11768 | 20949 | 4.5 | 10000 | 11683 | 20811 | 4 | 8000 | 9598 | 17425 | 3.5 | 8000 | 9513 | 17287 | 3 | 10000 | 11428 | 20397 |
| 89 | MIA | '12,1 | 5 | 10000 | 13117 | 10593 | 4.5 | 10000 | 13032 | 10539 | 4 | 8000 | 10947 | 9215.2 | 3.5 | 8000 | 10862 | 9161.2 | 3 | 10000 | 12777 | 10377 |
| 90 | | tpr= | | | Cpkr= | 262956 | | | Cpkr= | 261585 | | | Cpkr= | 219890 | | | Cpkr= | 218203 | | | Cpkr= | 256208 |
| 91 | US GC-2 | | | | | | | | | | | | | | | | | | | | | |
| 92 | NOL | '1,2 | 5 | 10000 | 12958 | 18267 | 4.5 | 10000 | 12875 | 18164 | 4 | 8000 | 10792 | 15569 | 3.5 | 8000 | 10709 | 15466 | 3 | 10000 | 12626 | 17853 |
| 93 | HOU | '2,2 | 5 | 10000 | 11646 | 34390 | 4.5 | 10000 | 11563 | 34163 | 4 | 8000 | 9480 | 28450 | 3.5 | 8000 | 9397 | 28222 | 3 | 10000 | 11314 | 33480 |
| 94 | SMA | '3,2 | 5 | 10000 | 11688 | 12310 | 4.5 | 10000 | 11605 | 12235 | 4 | 8000 | 9522 | 10347 | 3.5 | 8000 | 9439 | 10271 | 3 | 10000 | 11356 | 12009 |
| 95 | BAQ | '4,2 | 5 | 10000 | 11498 | 25592 | 4.5 | 10000 | 11415 | 25422 | 4 | 8000 | 9332 | 21149 | 3.5 | 8000 | 9249 | 20978 | 3 | 10000 | 11166 | 24911 |
| 96 | CTG | '5,2 | 5 | 10000 | 11490 | 45071 | 4.5 | 10000 | 11407 | 44764 | 4 | 8000 | 9324 | 37072 | 3.5 | 8000 | 9241 | 36765 | 3 | 10000 | 11158 | 43845 |
| 97 | BUN | '6,2 | 5 | 10000 | 11164 | 27319 | 4.5 | 10000 | 11081 | 27123 | 4 | 8000 | 8998 | 22213 | 3.5 | 8000 | 8915 | 22018 | 3 | 10000 | 10832 | 26536 |
| 98 | SJR | '7,2 | 5 | 10000 | 12223 | 11955 | 4.5 | 10000 | 12140 | 11893 | 4 | 8000 | 10057 | 10330 | 3.5 | 8000 | 9974 | 10268 | 3 | 10000 | 11891 | 11706 |
| 99 | MIA | '8,2 | 5 | 10000 | 13801 | 11810 | 4.5 | 10000 | 13718 | 11757 | 4 | 8000 | 11635 | 10423 | 3.5 | 8000 | 11552 | 10370 | 3 | 10000 | 13469 | 11598 |
| 100 | | tpr= | | | Cpkr= | 186715 | | | Cpkr= | 185520 | | | Cpkr= | 155553 | | | Cpkr= | 154359 | | | Cpkr= | 181938 |
| 101 | US WC-3 | | | | | | | | | | | | | | | | | | | | | |
| 102 | BUN | '1,3 | 5 | 10000 | 11371 | 51389 | 4.5 | 10000 | 11287 | 51047 | 4 | 8000 | 9204 | 42514 | 3.5 | 8000 | 9120 | 42172 | 3 | 10000 | 11037 | 50021 |
| 103 | PCD | '2,3 | 5 | 10000 | 14441 | 12347 | 4.5 | 10000 | 14357 | 12297 | 4 | 8000 | 12274 | 11035 | 3.5 | 8000 | 12190 | 10985 | 3 | 10000 | 14107 | 12145 |
| 104 | ACJ | '3,3 | 5 | 10000 | 11463 | 9152 | 4.5 | 10000 | 11379 | 9089.9 | 4 | 8000 | 9296 | 7540.4 | 3.5 | 8000 | 9212 | 7478.3 | 3 | 10000 | 11129 | 8903.6 |
| 105 | POZ | '4,3 | 5 | 10000 | 12809 | 12514 | 4.5 | 10000 | 12726 | 12445 | 4 | 8000 | 10642 | 10730 | 3.5 | 8000 | 10559 | 10662 | 3 | 10000 | 12475 | 12239 |
| 106 | SFC | '5,3 | 5 | 10000 | 15149 | 14061 | 4.5 | 10000 | 15065 | 14007 | 4 | 8000 | 12982 | 12667 | 3.5 | 8000 | 12898 | 12613 | 3 | 10000 | 14815 | 13846 |
| 107 | VAI | '6,3 | 5 | 10000 | 12684 | 25417 | 4.5 | 10000 | 12601 | 25274 | 4 | 8000 | 10517 | 21706 | 3.5 | 8000 | 10434 | 21563 | 3 | 10000 | 12350 | 24845 |
| 108 | STL | '7,3 | 5 | 10000 | 17290 | 22752 | 4.5 | 10000 | 17207 | 22674 | 4 | 8000 | 15123 | 20710 | 3.5 | 8000 | 15040 | 20631 | 3 | 10000 | 16956 | 22438 |
| 109 | LAN | '8,3 | 5 | 10000 | 15139 | 13190 | 4.5 | 10000 | 15056 | 13141 | 4 | 8000 | 12972 | 11918 | 3.5 | 8000 | 12889 | 11869 | 3 | 10000 | 14805 | 12994 |
| 110 | MZN | '9,3 | 5 | 10000 | 12835 | 14209 | 4.5 | 10000 | 12752 | 14129 | 4 | 8000 | 10668 | 12147 | 3.5 | 8000 | 10585 | 12068 | 3 | 10000 | 12501 | 13891 |
| 111 | POZ | '10,3 | 5 | 10000 | 12809 | 10308 | 4.5 | 10000 | 12726 | 10254 | 4 | 8000 | 10642 | 8897.9 | 3.5 | 8000 | 10559 | 8843.6 | 3 | 10000 | 12475 | 10091 |
| 112 | ACJ | '11,3 | 5 | 10000 | 11463 | 8494 | 4.5 | 10000 | 11379 | 8436.7 | 4 | 8000 | 9296 | 7006.8 | 3.5 | 8000 | 9212 | 6949.5 | 3 | 10000 | 11129 | 8264.8 |
| 113 | PCD | '12,3 | 5 | 10000 | 14441 | 15501 | 4.5 | 10000 | 14357 | 15433 | 4 | 8000 | 12274 | 13716 | 3.5 | 8000 | 12190 | 13647 | 3 | 10000 | 14107 | 15226 |
| 114 | | tpr= | | | Cpkr= | 209334 | | | Cpkr= | 208226 | | | Cpkr= | 180590 | | | Cpkr= | 179482 | | | Cpkr= | 204903 |

| | 83 | 84 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | PORT RELATED INFOF | | | | | | | | | | | | | | | | | | | | | |
| 73 | | | | | | | | | | | | | | | | | | | | | | |
| 74 | ROUTE/ | | | | | | | | | | | | | | | | | | | | | |
| 75 | PORT | | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk |
| 76 | | | k=7 | | | | k=8 | | | | k=9 | | | | k=10 | | | | k=11 | | | |
| 77 | US EC-1 | i,r | | | | | | | | | | | | | | | | | | | | |
| 78 | NYK | '1,1 | 4.5 | 10000 | 11815 | 22824 | 3 | 8000 | 9560 | 19070 | 3 | 10500 | 12060 | 23232 | 1.5 | 6000 | 7305 | 15315 | 3 | 6500 | 8060 | 16572 |
| 79 | STJ | '2,1 | 4.5 | 10000 | 11895 | 15965 | 3 | 8000 | 9640 | 13367 | 3 | 10500 | 12140 | 16248 | 1.5 | 6000 | 7385 | 10768 | 3 | 6500 | 8140 | 11638 |
| 80 | PHP | '3,1 | 4.5 | 10000 | 13154 | 14201 | 3 | 8000 | 10899 | 12176 | 3 | 10500 | 13399 | 14421 | 1.5 | 6000 | 8644 | 10151 | 3 | 6500 | 9399 | 10829 |
| 81 | BAL | '4,1 | 4.5 | 10000 | 13969 | 14518 | 3 | 8000 | 11714 | 12692 | 3 | 10500 | 14214 | 14717 | 1.5 | 6000 | 9459 | 10865 | 3 | 6500 | 10214 | 11477 |
| 82 | CHN | '5,1 | 4.5 | 10000 | 11357 | 21413 | 3 | 8000 | 9102 | 17514 | 3 | 10500 | 11602 | 21837 | 1.5 | 6000 | 6847 | 13614 | 3 | 6500 | 7602 | 14920 |
| 83 | MIA | '6,1 | 4.5 | 10000 | 13032 | 9600.2 | 3 | 8000 | 10777 | 8331.2 | 3 | 10500 | 13277 | 9738.1 | 1.5 | 6000 | 8522 | 7062.1 | 3 | 6500 | 9277 | 7487 |
| 84 | SMA | '7,1 | 4.5 | 10000 | 11518 | 16774 | 3 | 8000 | 9263 | 13784 | 3 | 10500 | 11763 | 17098 | 1.5 | 6000 | 7008 | 10795 | 3 | 6500 | 7763 | 11796 |
| 85 | BAQ | '8,1 | 4.5 | 10000 | 11522 | 19248 | 3 | 8000 | 9267 | 15777 | 3 | 10500 | 11767 | 19625 | 1.5 | 6000 | 7012 | 12306 | 3 | 6500 | 7767 | 13468 |
| 86 | CTG | '9,1 | 4.5 | 10000 | 11683 | 28024 | 3 | 8000 | 9428 | 22969 | 3 | 10500 | 11928 | 28573 | 1.5 | 6000 | 7173 | 17915 | 3 | 6500 | 7928 | 19607 |
| 87 | BUN | '10,1 | 4.5 | 10000 | 11502 | 67351 | 3 | 8000 | 9247 | 54580 | 3 | 10500 | 11747 | 68739 | 1.5 | 6000 | 6992 | 41809 | 3 | 6500 | 7747 | 46085 |
| 88 | CTG | '11,1 | 4.5 | 10000 | 11683 | 20811 | 3 | 8000 | 9428 | 17149 | 3 | 10500 | 11928 | 21209 | 1.5 | 6000 | 7173 | 13486 | 3 | 6500 | 7928 | 14713 |
| 89 | MIA | '12,1 | 4.5 | 10000 | 13032 | 10539 | 3 | 8000 | 10777 | 9107.3 | 3 | 10500 | 13277 | 10694 | 1.5 | 6000 | 8522 | 7675.8 | 3 | 6500 | 9277 | 8155.1 |
| 90 | | tpr= | | | Cpkr= | 261269 | | | Cpkr= | 216516 | | | Cpkr= | 266131 | | | Cpkr= | 171764 | | | Cpkr= | 186747 |
| 91 | US GC-2 | | | | | | | | | | | | | | | | | | | | | |
| 92 | NOL | '1,2 | 4.5 | 10000 | 12875 | 18164 | 3 | 8000 | 10626 | 15362 | 3 | 10500 | 13126 | 18476 | 1.5 | 6000 | 8377 | 12561 | 3 | 6500 | 9126 | 13494 |
| 93 | HOU | '2,2 | 4.5 | 10000 | 11563 | 34163 | 3 | 8000 | 9314 | 27995 | 3 | 10500 | 11814 | 34851 | 1.5 | 6000 | 7065 | 21826 | 3 | 6500 | 7814 | 23881 |
| 94 | SMA | '3,2 | 4.5 | 10000 | 11605 | 12235 | 3 | 8000 | 9356 | 10196 | 3 | 10500 | 11856 | 12462 | 1.5 | 6000 | 7107 | 8157.3 | 3 | 6500 | 7856 | 8836.3 |
| 95 | BAQ | '4,2 | 4.5 | 10000 | 11415 | 25422 | 3 | 8000 | 9166 | 20808 | 3 | 10500 | 11666 | 25937 | 1.5 | 6000 | 6917 | 16195 | 3 | 6500 | 7666 | 17731 |
| 96 | CTG | '5,2 | 4.5 | 10000 | 11407 | 44764 | 3 | 8000 | 9158 | 36459 | 3 | 10500 | 11658 | 45691 | 1.5 | 6000 | 6909 | 28154 | 3 | 6500 | 7658 | 30920 |
| 97 | BUN | '6,2 | 4.5 | 10000 | 11081 | 27123 | 3 | 8000 | 8832 | 21822 | 3 | 10500 | 11332 | 27715 | 1.5 | 6000 | 6583 | 16520 | 3 | 6500 | 7332 | 18286 |
| 98 | SJR | '7,2 | 4.5 | 10000 | 12140 | 11893 | 3 | 8000 | 9891 | 10206 | 3 | 10500 | 12391 | 12081 | 1.5 | 6000 | 7642 | 8518.2 | 3 | 6500 | 8391 | 9080.1 |
| 99 | MIA | '8,2 | 4.5 | 10000 | 13718 | 11757 | 3 | 8000 | 11469 | 10317 | 3 | 10500 | 13969 | 11918 | 1.5 | 6000 | 9220 | 8876.3 | 3 | 6500 | 9969 | 9356 |
| 100 | | tpr= | | | Cpkr= | 185520 | | | Cpkr= | 153164 | | | Cpkr= | 189132 | | | Cpkr= | 120808 | | | Cpkr= | 131584 |
| 101 | US WC-3 | | | | | | | | | | | | | | | | | | | | | |
| 102 | BUN | '1,3 | 4.5 | 10000 | 11287 | 51047 | 3 | 8000 | 9037 | 41830 | 3 | 10500 | 11537 | 52069 | 1.5 | 6000 | 6786 | 32614 | 3 | 6500 | 7537 | 35687 |
| 103 | PCD | '2,3 | 4.5 | 10000 | 14357 | 12297 | 3 | 8000 | 12107 | 10934 | 3 | 10500 | 14607 | 12448 | 1.5 | 6000 | 9856 | 9571.9 | 3 | 6500 | 10607 | 10026 |
| 104 | ACJ | '3,3 | 4.5 | 10000 | 11379 | 9089.9 | 3 | 8000 | 9129 | 7416.2 | 3 | 10500 | 11629 | 9275.5 | 1.5 | 6000 | 6878 | 5742.6 | 3 | 6500 | 7629 | 6300.7 |
| 105 | POZ | '4,3 | 4.5 | 10000 | 12726 | 12445 | 3 | 8000 | 10475 | 10593 | 3 | 10500 | 12975 | 12650 | 1.5 | 6000 | 8225 | 8741.3 | 3 | 6500 | 8975 | 9358.8 |
| 106 | SFC | '5,3 | 4.5 | 10000 | 15065 | 14007 | 3 | 8000 | 12815 | 12559 | 3 | 10500 | 15315 | 14168 | 1.5 | 6000 | 10564 | 11111 | 3 | 6500 | 11315 | 11594 |
| 107 | VAI | '6,3 | 4.5 | 10000 | 12601 | 25274 | 3 | 8000 | 10350 | 21420 | 3 | 10500 | 12850 | 25701 | 1.5 | 6000 | 8100 | 17567 | 3 | 6500 | 8850 | 18852 |
| 108 | STL | '7,3 | 4.5 | 10000 | 17207 | 22674 | 3 | 8000 | 14956 | 20552 | 3 | 10500 | 17456 | 22909 | 1.5 | 6000 | 12706 | 18431 | 3 | 6500 | 13456 | 19138 |
| 109 | LAN | '8,3 | 4.5 | 10000 | 15056 | 13141 | 3 | 8000 | 12805 | 11820 | 3 | 10500 | 15305 | 13288 | 1.5 | 6000 | 10555 | 10499 | 3 | 6500 | 11305 | 10940 |
| 110 | MZN | '9,3 | 4.5 | 10000 | 12752 | 14129 | 3 | 8000 | 10501 | 11989 | 3 | 10500 | 13001 | 14367 | 1.5 | 6000 | 8251 | 9847.8 | 3 | 6500 | 9001 | 10562 |
| 111 | POZ | '10,3 | 4.5 | 10000 | 12726 | 10254 | 3 | 8000 | 10475 | 8789.3 | 3 | 10500 | 12975 | 10416 | 1.5 | 6000 | 8225 | 7325 | 3 | 6500 | 8975 | 7813.3 |
| 112 | ACJ | '11,3 | 4.5 | 10000 | 11379 | 8436.7 | 3 | 8000 | 9129 | 6892.2 | 3 | 10500 | 11629 | 8607.9 | 1.5 | 6000 | 6878 | 5347.7 | 3 | 6500 | 7629 | 5862.8 |
| 113 | PCD | '12,3 | 4.5 | 10000 | 14357 | 15433 | 3 | 8000 | 12107 | 13579 | 3 | 10500 | 14607 | 15638 | 1.5 | 6000 | 9856 | 11725 | 3 | 6500 | 10607 | 12343 |
| 114 | | tpr= | | | Cpkr= | 208226 | | | Cpkr= | 178374 | | | Cpkr= | 211536 | | | Cpkr= | 148523 | | | Cpkr= | 158478 |

| | 83 | 84 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | PORT RELATED INFOI | | | | | | | | | | | | | | | | | | | | | |
| 73 | | | | | | | | | | | | | | | | | | | | | | |
| 74 | ROUTE/ | | | | | | | | | | | | | | | | | | | | | |
| 75 | PORT | | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk |
| 76 | | | K=1 | | | | k=2,3 | | | | k=4 | | | | k=5 | | | | k=6 | | | |
| 77 | US EC-1 | i,r | | | | | | | | | | | | | | | | | | | | |
| 115 | EUR.NORTH-4 | | | | | | | | | | | | | | | | | | | | | |
| 116 | HMB | '1,4 | 5 | 10000 | 12742 | 17604 | 4.5 | 10000 | 12673 | 17553 | 4 | 8000 | 10604 | 16027 | 3.5 | 8000 | 10535 | 15976 | 3 | 10000 | 12466 | 17401 |
| 117 | BRM | '2,4 | 5 | 10000 | 12188 | 14373 | 4.5 | 10000 | 12119 | 14334 | 4 | 8000 | 10050 | 13165 | 3.5 | 8000 | 9981 | 13126 | 3 | 10000 | 11912 | 14217 |
| 118 | ATW | '3,4 | 5 | 10000 | 14766 | 34820 | 4.5 | 10000 | 14697 | 34696 | 4 | 8000 | 12628 | 30959 | 3.5 | 8000 | 12559 | 30834 | 3 | 10000 | 14490 | 34322 |
| 119 | RTD | '4,4 | 5 | 10000 | 12261 | 10518 | 4.5 | 10000 | 12192 | 10485 | 4 | 8000 | 10123 | 9505.7 | 3.5 | 8000 | 10054 | 9473 | 3 | 10000 | 11985 | 10387 |
| 120 | HVR | '5,4 | 5 | 10000 | 12597 | 9591.6 | 4.5 | 10000 | 12528 | 9559.9 | 4 | 8000 | 10459 | 8611 | 3.5 | 8000 | 10390 | 8579.4 | 3 | 10000 | 12321 | 9465 |
| 121 | LPL | '6,4 | 5 | 10000 | 14879 | 29045 | 4.5 | 10000 | 14810 | 28969 | 4 | 8000 | 12741 | 26677 | 3.5 | 8000 | 12672 | 26601 | 3 | 10000 | 14603 | 28739 |
| 122 | BLB | '7,4 | 5 | 10000 | 12085 | 11486 | 4.5 | 10000 | 12016 | 11437 | 4 | 8000 | 9947 | 9947.9 | 3.5 | 8000 | 9878 | 9898.2 | 3 | 10000 | 11809 | 11288 |
| 123 | STD | '8,4 | 5 | 10000 | 12170 | 7720 | 4.5 | 10000 | 12101 | 7693 | 4 | 8000 | 10032 | 6883.9 | 3.5 | 8000 | 9963 | 6856.9 | 3 | 10000 | 11894 | 7612 |
| 124 | SMA | '9,4 | 5 | 10000 | 11375 | 111989 | 4.5 | 10000 | 11306 | 111330 | 4 | 8000 | 9237 | 91583 | 3.5 | 8000 | 9168 | 90925 | 3 | 10000 | 11099 | 109354 |
| 125 | BAQ | '10,4 | 5 | 10000 | 11473 | 29164 | 4.5 | 10000 | 11404 | 29003 | 4 | 8000 | 9335 | 24167 | 3.5 | 8000 | 9266 | 24006 | 3 | 10000 | 11197 | 28519 |
| 126 | CTG | '11,4 | 5 | 10000 | 11331 | 58516 | 4.5 | 10000 | 11262 | 58183 | 4 | 8000 | 9193 | 48201 | 3.5 | 8000 | 9124 | 47868 | 3 | 10000 | 11055 | 57184 |
| 127 | BUN | '12,4 | 5 | 10000 | 11274 | 80412 | 4.5 | 10000 | 11205 | 79966 | 4 | 8000 | 9136 | 66602 | 3.5 | 8000 | 9067 | 66156 | 3 | 10000 | 10998 | 78629 |
| 128 | RTD | '13,4 | 5 | 10000 | 12261 | 21918 | 4.5 | 10000 | 12192 | 21821 | 4 | 8000 | 10123 | 18918 | 3.5 | 8000 | 10054 | 18821 | 3 | 10000 | 11985 | 21530 |
| 129 | BRM | '14,4 | 5 | 10000 | 12188 | 34969 | 4.5 | 10000 | 12119 | 34814 | 4 | 8000 | 10050 | 30149 | 3.5 | 8000 | 9981 | 29993 | 3 | 10000 | 11912 | 34347 |
| 130 | HMB | '15,4 | 5 | 10000 | 12742 | 33338 | 4.5 | 10000 | 12673 | 33202 | 4 | 8000 | 10604 | 29121 | 3.5 | 8000 | 10535 | 28985 | 3 | 10000 | 12466 | 32794 |
| 131 | GTB | '16,4 | 5 | 10000 | 11158 | 17310 | 4.5 | 10000 | 11089 | 17224 | 4 | 8000 | 9020 | 14620 | 3.5 | 8000 | 8951 | 14534 | 3 | 10000 | 10882 | 16963 |
| 132 | | tpr= | | | Cpkr= | 522774 | | | Cpkr= | 520268 | | | Cpkr= | 445138 | | | Cpkr= | 442632 | | | Cpkr= | 512752 |
| 133 | EUR.MEDIT-5 | | | | | | | | | | | | | | | | | | | | | |
| 134 | LVR | '1,5 | 5 | 10000 | 12908 | 25131 | 4.5 | 10000 | 12826 | 24985 | 4 | 8000 | 10744 | 21268 | 3.5 | 8000 | 10662 | 21122 | 3 | 10000 | 12580 | 24546 |
| 135 | GNV | '2,5 | 5 | 10000 | 13108 | 13734 | 4.5 | 10000 | 13026 | 13663 | 4 | 8000 | 10944 | 11845 | 3.5 | 8000 | 10862 | 11773 | 3 | 10000 | 12780 | 13448 |
| 136 | MLL | '3,5 | 5 | 10000 | 12694 | 14998 | 4.5 | 10000 | 12612 | 14914 | 4 | 8000 | 10530 | 12761 | 3.5 | 8000 | 10448 | 12676 | 3 | 10000 | 12366 | 14659 |
| 137 | BRC | '4,5 | 5 | 10000 | 12376 | 7023 | 4.5 | 10000 | 12294 | 6986.8 | 4 | 8000 | 10212 | 6067 | 3.5 | 8000 | 10130 | 6030.7 | 3 | 10000 | 12048 | 6878.1 |
| 138 | CDZ | '5,5 | 5 | 10000 | 12033 | 10070 | 4.5 | 10000 | 11951 | 10018 | 4 | 8000 | 9869 | 8695.2 | 3.5 | 8000 | 9787 | 8643.1 | 3 | 10000 | 11705 | 9861.8 |
| 139 | HLA | '6,5 | 5 | 10000 | 13032 | 11507 | 4.5 | 10000 | 12950 | 11449 | 4 | 8000 | 10868 | 9963.5 | 3.5 | 8000 | 10786 | 9905 | 3 | 10000 | 12704 | 11273 |
| 140 | SMA | '7,5 | 5 | 10000 | 12175 | 15357 | 4.5 | 10000 | 12093 | 15263 | 4 | 8000 | 10011 | 12868 | 3.5 | 8000 | 9929 | 12774 | 3 | 10000 | 11847 | 14980 |
| 141 | BAQ | '8,5 | 5 | 10000 | 11670 | 22741 | 4.5 | 10000 | 11588 | 22593 | 4 | 8000 | 9506 | 18839 | 3.5 | 8000 | 9424 | 18691 | 3 | 10000 | 11342 | 22149 |
| 142 | CTG | '9,5 | 5 | 10000 | 11531 | 36659 | 4.5 | 10000 | 11449 | 36418 | 4 | 8000 | 9367 | 30312 | 3.5 | 8000 | 9285 | 30072 | 3 | 10000 | 11203 | 35697 |
| 143 | BUN | '10,5 | 5 | 10000 | 11751 | 22367 | 4.5 | 10000 | 11669 | 22224 | 4 | 8000 | 9587 | 18591 | 3.5 | 8000 | 9505 | 18448 | 3 | 10000 | 11423 | 21794 |
| 144 | CTG | '11,5 | 5 | 10000 | 11531 | 54136 | 4.5 | 10000 | 11449 | 53772 | 4 | 8000 | 9367 | 44510 | 3.5 | 8000 | 9285 | 44145 | 3 | 10000 | 11203 | 52677 |
| 145 | CDZ | '12,5 | 5 | 10000 | 12033 | 10220 | 4.5 | 10000 | 11951 | 10167 | 4 | 8000 | 9869 | 8817.9 | 3.5 | 8000 | 9787 | 8764.7 | 3 | 10000 | 11705 | 10007 |
| 146 | ALC | '13,5 | 5 | 10000 | 11586 | 6617.4 | 4.5 | 10000 | 11504 | 6581.4 | 4 | 8000 | 9422 | 5667.7 | 3.5 | 8000 | 9340 | 5631.7 | 3 | 10000 | 11258 | 6473.4 |
| 147 | BRC | '14,5 | 5 | 10000 | 12376 | 12607 | 4.5 | 10000 | 12294 | 12533 | 4 | 8000 | 10212 | 10674 | 3.5 | 8000 | 10130 | 10601 | 3 | 10000 | 12048 | 12314 |
| 148 | TLN | '15,5 | 5 | 10000 | 13176 | 9233.1 | 4.5 | 10000 | 13094 | 9190.3 | 4 | 8000 | 11012 | 8103.5 | 3.5 | 8000 | 10930 | 8060.7 | 3 | 10000 | 12848 | 9061.9 |
| 149 | | tpr= | | | Cpkr= | 272401 | | | Cpkr= | 270756 | | | Cpkr= | 228983 | | | Cpkr= | 227338 | | | Cpkr= | 265820 |

| | 83 | 84 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | PORT RELATED INFOF | | | | | | | | | | | | | | | | | | | | | |
| 73 | | | | | | | | | | | | | | | | | | | | | | |
| 74 | ROUTE/ | | | | | | | | | | | | | | | | | | | | | |
| 75 | PORT | | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk |
| 76 | | | k=7 | | | | k=8 | | | | k=9 | | | | k=10 | | | | k=11 | | | |
| 77 | US EC-1 | i,r | | | | | | | | | | | | | | | | | | | | |
| 115 | EUR.NORTH-4 | | ***** | | | | | | | | | | | | | | | | | | | |
| 116 | HMB | '1,4 | 4.5 | 10000 | 12673 | 17553 | 3 | 8000 | 10466 | 15925 | 3 | 10500 | 12966 | 17769 | 1.5 | 6000 | 8259 | 14298 | 3 | 6500 | 8966 | 14819 |
| 117 | BRM | '2,4 | 4.5 | 10000 | 12119 | 14334 | 3 | 8000 | 9912 | 13087 | 3 | 10500 | 12412 | 14499 | 1.5 | 6000 | 7705 | 11840 | 3 | 6500 | 8412 | 12240 |
| 118 | ATW | '3,4 | 4.5 | 10000 | 14697 | 34696 | 3 | 8000 | 12490 | 30710 | 3 | 10500 | 14990 | 35225 | 1.5 | 6000 | 10283 | 26724 | 3 | 6500 | 10990 | 28000 |
| 119 | RTD | '4,4 | 4.5 | 10000 | 12192 | 10485 | 3 | 8000 | 9985 | 9440.4 | 3 | 10500 | 12485 | 10624 | 1.5 | 6000 | 7778 | 8395.3 | 3 | 6500 | 8485 | 8730.1 |
| 120 | HVR | '5,4 | 4.5 | 10000 | 12528 | 9559.9 | 3 | 8000 | 10321 | 8547.7 | 3 | 10500 | 12821 | 9694.3 | 1.5 | 6000 | 8114 | 7535.5 | 3 | 6500 | 8821 | 7859.7 |
| 121 | LPL | '6,4 | 4.5 | 10000 | 14810 | 28969 | 3 | 8000 | 12603 | 26524 | 3 | 10500 | 15103 | 29293 | 1.5 | 6000 | 10396 | 24080 | 3 | 6500 | 11103 | 24863 |
| 122 | BLB | '7,4 | 4.5 | 10000 | 12016 | 11437 | 3 | 8000 | 9809 | 9848.6 | 3 | 10500 | 12309 | 11647 | 1.5 | 6000 | 7602 | 8260.6 | 3 | 6500 | 8309 | 8769.3 |
| 123 | STD | '8,4 | 4.5 | 10000 | 12101 | 7693 | 3 | 8000 | 9894 | 6829.9 | 3 | 10500 | 12394 | 7807.6 | 1.5 | 6000 | 7687 | 5966.8 | 3 | 6500 | 8394 | 6243.3 |
| 124 | SMA | '9,4 | 4.5 | 10000 | 11306 | 111330 | 3 | 8000 | 9099 | 90266 | 3 | 10500 | 11599 | 114127 | 1.5 | 6000 | 6892 | 69203 | 3 | 6500 | 7599 | 75950 |
| 125 | BAQ | '10,4 | 4.5 | 10000 | 11404 | 29003 | 3 | 8000 | 9197 | 23845 | 3 | 10500 | 11697 | 29688 | 1.5 | 6000 | 6990 | 18687 | 3 | 6500 | 7697 | 20339 |
| 126 | CTG | '11,4 | 4.5 | 10000 | 11262 | 58183 | 3 | 8000 | 9055 | 47535 | 3 | 10500 | 11555 | 59596 | 1.5 | 6000 | 6848 | 36887 | 3 | 6500 | 7555 | 40298 |
| 127 | BUN | '12,4 | 4.5 | 10000 | 11205 | 79966 | 3 | 8000 | 8998 | 65710 | 3 | 10500 | 11498 | 81859 | 1.5 | 6000 | 6791 | 51454 | 3 | 6500 | 7498 | 56021 |
| 128 | RTD | '13,4 | 4.5 | 10000 | 12192 | 21821 | 3 | 8000 | 9985 | 18724 | 3 | 10500 | 12485 | 22232 | 1.5 | 6000 | 7778 | 15627 | 3 | 6500 | 8485 | 16619 |
| 129 | BRM | '14,4 | 4.5 | 10000 | 12119 | 34814 | 3 | 8000 | 9912 | 29837 | 3 | 10500 | 12412 | 35474 | 1.5 | 6000 | 7705 | 24861 | 3 | 6500 | 8412 | 26455 |
| 130 | HMB | '15,4 | 4.5 | 10000 | 12673 | 33202 | 3 | 8000 | 10466 | 28849 | 3 | 10500 | 12966 | 33780 | 1.5 | 6000 | 8259 | 24496 | 3 | 6500 | 8966 | 25890 |
| 131 | GTB | '16,4 | 4.5 | 10000 | 11089 | 17224 | 3 | 8000 | 8882 | 14447 | 3 | 10500 | 11382 | 17592 | 1.5 | 6000 | 6675 | 11670 | 3 | 6500 | 7382 | 12560 |
| 132 | | tpr= | | | Cpkr= | 520268 | | | Cpkr= | 440126 | | | Cpkr= | 530908 | | | Cpkr= | 359984 | | | Cpkr= | 385658 |
| 133 | EUR.MEDIT-5 | | | | | | | | | | | | | | | | | | | | | |
| 134 | LVR | '1,5 | 4.5 | 10000 | 12826 | 24985 | 3 | 8000 | 10580 | 20975 | 3 | 10500 | 13080 | 25438 | 1.5 | 6000 | 8334 | 16966 | 3 | 6500 | 9080 | 18298 |
| 135 | GNV | '2,5 | 4.5 | 10000 | 13026 | 13663 | 3 | 8000 | 10780 | 11702 | 3 | 10500 | 13280 | 13885 | 1.5 | 6000 | 8534 | 9740.3 | 3 | 6500 | 9280 | 10392 |
| 136 | MLL | '3,5 | 4.5 | 10000 | 12612 | 14914 | 3 | 8000 | 10366 | 12591 | 3 | 10500 | 12866 | 15176 | 1.5 | 6000 | 8120 | 10269 | 3 | 6500 | 8866 | 11041 |
| 137 | BRC | '4,5 | 4.5 | 10000 | 12294 | 6986.8 | 3 | 8000 | 10048 | 5994.5 | 3 | 10500 | 12548 | 7099 | 1.5 | 6000 | 7802 | 5002.2 | 3 | 6500 | 8548 | 5331.8 |
| 138 | CDZ | '5,5 | 4.5 | 10000 | 11951 | 10018 | 3 | 8000 | 9705 | 8591 | 3 | 10500 | 12205 | 10179 | 1.5 | 6000 | 7459 | 7164 | 3 | 6500 | 8205 | 7637.9 |
| 139 | HLA | '6,5 | 4.5 | 10000 | 12950 | 11449 | 3 | 8000 | 10704 | 9846.5 | 3 | 10500 | 13204 | 11630 | 1.5 | 6000 | 8458 | 8244.4 | 3 | 6500 | 9204 | 8776.5 |
| 140 | SMA | '7,5 | 4.5 | 10000 | 12093 | 15263 | 3 | 8000 | 9847 | 12680 | 3 | 10500 | 12347 | 15555 | 1.5 | 6000 | 7601 | 10096 | 3 | 6500 | 8347 | 10954 |
| 141 | BAQ | '8,5 | 4.5 | 10000 | 11588 | 22593 | 3 | 8000 | 9342 | 18543 | 3 | 10500 | 11842 | 23051 | 1.5 | 6000 | 7096 | 14494 | 3 | 6500 | 7842 | 15839 |
| 142 | CTG | '9,5 | 4.5 | 10000 | 11449 | 36418 | 3 | 8000 | 9203 | 29831 | 3 | 10500 | 11703 | 37163 | 1.5 | 6000 | 6957 | 23244 | 3 | 6500 | 7703 | 25432 |
| 143 | BUN | '10,5 | 4.5 | 10000 | 11669 | 22224 | 3 | 8000 | 9423 | 18305 | 3 | 10500 | 11923 | 22667 | 1.5 | 6000 | 7177 | 14386 | 3 | 6500 | 7923 | 15687 |
| 144 | CTG | '11,5 | 4.5 | 10000 | 11449 | 53772 | 3 | 8000 | 9203 | 43780 | 3 | 10500 | 11703 | 54902 | 1.5 | 6000 | 6957 | 33789 | 3 | 6500 | 7703 | 37107 |
| 145 | CDZ | '12,5 | 4.5 | 10000 | 11951 | 10167 | 3 | 8000 | 9705 | 8711.6 | 3 | 10500 | 12205 | 10331 | 1.5 | 6000 | 7459 | 7256.7 | 3 | 6500 | 8205 | 7739.9 |
| 146 | ALC | '13,5 | 4.5 | 10000 | 11504 | 6581.4 | 3 | 8000 | 9258 | 5595.7 | 3 | 10500 | 11758 | 6692.9 | 1.5 | 6000 | 7012 | 4610 | 3 | 6500 | 7758 | 4937.4 |
| 147 | BRC | '14,5 | 4.5 | 10000 | 12294 | 12533 | 3 | 8000 | 10048 | 10528 | 3 | 10500 | 12548 | 12760 | 1.5 | 6000 | 7802 | 8522.1 | 3 | 6500 | 8548 | 9188.2 |
| 148 | TLN | '15,5 | 4.5 | 10000 | 13094 | 9190.3 | 3 | 8000 | 10848 | 8017.9 | 3 | 10500 | 13348 | 9322.9 | 1.5 | 6000 | 8602 | 6845.5 | 3 | 6500 | 9348 | 7234.9 |
| 149 | | tpr= | | | Cpkr= | 270756 | | | Cpkr= | 225692 | | | Cpkr= | 275852 | | | Cpkr= | 180629 | | | Cpkr= | 195596 |

| | 83 | 84 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | PORT RELATED INFO | | | | | | | | | | | | | | | | | | | | | |
| 73 | | | | | | | | | | | | | | | | | | | | | | |
| 74 | ROUTE/ | | | | | | | | | | | | | | | | | | | | | |
| 75 | PORT | | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk |
| 76 | | | K=1 | | | | k=2,3 | | | | k=4 | | | | k=5 | | | | k=6 | | | |
| 77 | US EC-1 | i,r | | | | | | | | | | | | | | | | | | | | |
| 150 | JAPAN-6 | | | | | | | | | | | | | | | | | | | | | |
| 151 | YKM | '1,6 | 5 | 10000 | 13823 | 17700 | 4.5 | 10000 | 13741 | 17631 | 4 | 8000 | 11659 | 15869 | 3.5 | 8000 | 11577 | 15800 | 3 | 10000 | 13495 | 17422 |
| 152 | NAG | '2,6 | 5 | 10000 | 12952 | 19141 | 4.5 | 10000 | 12870 | 19060 | 4 | 8000 | 10788 | 17011 | 3.5 | 8000 | 10706 | 16931 | 3 | 10000 | 12624 | 18818 |
| 153 | KBE | '3,6 | 5 | 10000 | 12079 | 38304 | 4.5 | 10000 | 11997 | 38087 | 4 | 8000 | 9915 | 32570 | 3.5 | 8000 | 9833 | 32353 | 3 | 10000 | 11751 | 37435 |
| 154 | CBA | '4,6 | 5 | 10000 | 12274 | 42176 | 4.5 | 10000 | 12192 | 41933 | 4 | 8000 | 10110 | 35765 | 3.5 | 8000 | 10028 | 35522 | 3 | 10000 | 11946 | 41204 |
| 155 | YKM | '5,6 | 5 | 10000 | 13823 | 26378 | 4.5 | 10000 | 13741 | 26257 | 4 | 8000 | 11659 | 23188 | 3.5 | 8000 | 11577 | 23068 | 3 | 10000 | 13495 | 25894 |
| 156 | HSM | '6,6 | 5 | 10000 | 14399 | 29986 | 4.5 | 10000 | 14317 | 29856 | 4 | 8000 | 12235 | 26555 | 3.5 | 8000 | 12153 | 26425 | 3 | 10000 | 14071 | 29466 |
| 157 | LAN | '7,6 | 5 | 10000 | 12100 | 5308.5 | 4.5 | 10000 | 12018 | 5281.2 | 4 | 8000 | 9936 | 4587.9 | 3.5 | 8000 | 9854 | 4560.6 | 3 | 10000 | 11772 | 5199.3 |
| 158 | POZ | '8,6 | 5 | 10000 | 12811 | 27618 | 4.5 | 10000 | 12729 | 27454 | 4 | 8000 | 10647 | 23289 | 3.5 | 8000 | 10565 | 23125 | 3 | 10000 | 12483 | 26962 |
| 159 | ACJ | '9,6 | 5 | 10000 | 11401 | 9923.9 | 4.5 | 10000 | 11319 | 9856.7 | 4 | 8000 | 9237 | 8150.4 | 3.5 | 8000 | 9155 | 8083.2 | 3 | 10000 | 11073 | 9655.1 |
| 160 | PCD | '10,6 | 5 | 10000 | 15730 | 16396 | 4.5 | 10000 | 15648 | 16336 | 4 | 8000 | 13566 | 14816 | 3.5 | 8000 | 13484 | 14756 | 3 | 10000 | 15402 | 16157 |
| 161 | BUN | '11,6 | 5 | 10000 | 11416 | 98487 | 4.5 | 10000 | 11334 | 97844 | 4 | 8000 | 9252 | 81513 | 3.5 | 8000 | 9170 | 80870 | 3 | 10000 | 11088 | 95914 |
| 162 | TBO | '12,6 | 5 | 10000 | 11127 | 10051 | 4.5 | 10000 | 11045 | 9978.9 | 4 | 8000 | 8963 | 8155.7 | 3.5 | 8000 | 8881 | 8083.9 | 3 | 10000 | 10799 | 9763.4 |
| 163 | POZ | '13,6 | 5 | 10000 | 12811 | 8758.5 | 4.5 | 10000 | 12729 | 8715.2 | 4 | 8000 | 10647 | 7615.3 | 3.5 | 8000 | 10565 | 7572 | 3 | 10000 | 12483 | 8585.2 |
| 164 | | tpr= | | | Cpkr= | 350226 | | | Cpkr= | 348288 | | | Cpkr= | 299087 | | | Cpkr= | 297149 | | | Cpkr= | 342475 |
| 165 | S.AMER.WC-7 | | | | | | | | | | | | | | | | | | | | | |
| 166 | BUN | '1.7 | 5 | 10000 | 11567 | 110266 | 4.5 | 10000 | 11471 | 109396 | 4 | 8000 | 9375 | 90406 | 3.5 | 8000 | 9279 | 89536 | 3 | 10000 | 11183 | 106787 |
| 167 | CLL | '2,7 | 5 | 10000 | 14752 | 20222 | 4.5 | 10000 | 14656 | 20140 | 4 | 8000 | 12560 | 18344 | 3.5 | 8000 | 12464 | 18262 | 3 | 10000 | 14368 | 19893 |
| 168 | VLP | '3,7 | 5 | 10000 | 13667 | 77119 | 4.5 | 10000 | 13571 | 76634 | 4 | 8000 | 11475 | 66052 | 3.5 | 8000 | 11379 | 65567 | 3 | 10000 | 13283 | 75180 |
| 169 | TLC | '4,7 | 5 | 10000 | 14408 | 35104 | 4.5 | 10000 | 14312 | 34916 | 4 | 8000 | 12216 | 30813 | 3.5 | 8000 | 12120 | 30625 | 3 | 10000 | 14024 | 34352 |
| 170 | CLL | '5,7 | 5 | 10000 | 14752 | 28504 | 4.5 | 10000 | 14656 | 28367 | 4 | 8000 | 12560 | 25395 | 3.5 | 8000 | 12464 | 25259 | 3 | 10000 | 14368 | 27959 |
| 171 | | tpr= | | | Cpkr= | 271214 | | | Cpkr= | 269453 | | | Cpkr= | 231010 | | | Cpkr= | 229249 | | | Cpkr= | 264171 |

| | 83 | 84 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | PORT RELATED INFOF | | | | | | | | | | | | | | | | | | | | | |
| 73 | | | | | | | | | | | | | | | | | | | | | | |
| 74 | ROUTE/ | | | | | | | | | | | | | | | | | | | | | |
| 75 | PORT | | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk | gpk | hk | Airk | Cpirk |
| 76 | | | k=7 | | | | k=8 | | | | k=9 | | | | k=10 | | | | k=11 | | | |
| 77 | US EC-1 | i,r | | | | | | | | | | | | | | | | | | | | |
| 150 | JAPAN-6 | | ***** | | | | | | | | | | | | | | | | | | | |
| 151 | YKM | '1,6 | 4.5 | 10000 | 13741 | 17631 | 3 | 8000 | 11495 | 15731 | 3 | 10500 | 13995 | 17845 | 1.5 | 6000 | 9249 | 13831 | 3 | 6500 | 9995 | 14462 |
| 152 | NAG | '2,6 | 4.5 | 10000 | 12870 | 19060 | 3 | 8000 | 10624 | 16850 | 3 | 10500 | 13124 | 19310 | 1.5 | 6000 | 8378 | 14640 | 3 | 6500 | 9124 | 15374 |
| 153 | KBE | '3,6 | 4.5 | 10000 | 11997 | 38087 | 3 | 8000 | 9751 | 32135 | 3 | 10500 | 12251 | 38760 | 1.5 | 6000 | 7505 | 26184 | 3 | 6500 | 8251 | 28161 |
| 154 | CBA | '4,6 | 4.5 | 10000 | 12192 | 41933 | 3 | 8000 | 9946 | 35279 | 3 | 10500 | 12446 | 42686 | 1.5 | 6000 | 7700 | 28626 | 3 | 6500 | 8446 | 30836 |
| 155 | YKM | '5,6 | 4.5 | 10000 | 13741 | 26257 | 3 | 8000 | 11495 | 22947 | 3 | 10500 | 13995 | 26631 | 1.5 | 6000 | 9249 | 19637 | 3 | 6500 | 9995 | 20736 |
| 156 | HSM | '6,6 | 4.5 | 10000 | 14317 | 29856 | 3 | 8000 | 12071 | 26295 | 3 | 10500 | 14571 | 30258 | 1.5 | 6000 | 9825 | 22734 | 3 | 6500 | 10571 | 23917 |
| 157 | LAN | '7,6 | 4.5 | 10000 | 12018 | 5281.2 | 3 | 8000 | 9772 | 4533.3 | 3 | 10500 | 12272 | 5365.8 | 1.5 | 6000 | 7526 | 3785.4 | 3 | 6500 | 8272 | 4033.8 |
| 158 | POZ | '8,6 | 4.5 | 10000 | 12729 | 27454 | 3 | 8000 | 10483 | 22961 | 3 | 10500 | 12983 | 27962 | 1.5 | 6000 | 8237 | 18468 | 3 | 6500 | 8983 | 19960 |
| 159 | ACJ | '9,6 | 4.5 | 10000 | 11319 | 9856.7 | 3 | 8000 | 9073 | 8016 | 3 | 10500 | 11573 | 10065 | 1.5 | 6000 | 6827 | 6175.2 | 3 | 6500 | 7573 | 6786.6 |
| 160 | PCD | '10,6 | 4.5 | 10000 | 15648 | 16336 | 3 | 8000 | 13402 | 14696 | 3 | 10500 | 15902 | 16522 | 1.5 | 6000 | 11156 | 13056 | 3 | 6500 | 11902 | 13601 |
| 161 | BUN | '11,6 | 4.5 | 10000 | 11334 | 97844 | 3 | 8000 | 9088 | 80227 | 3 | 10500 | 11588 | 99836 | 1.5 | 6000 | 6842 | 62610 | 3 | 6500 | 7588 | 68461 |
| 162 | TBO | '12,6 | 4.5 | 10000 | 11045 | 9978.9 | 3 | 8000 | 8799 | 8012.1 | 3 | 10500 | 11299 | 10201 | 1.5 | 6000 | 6553 | 6045.3 | 3 | 6500 | 7299 | 6698.6 |
| 163 | POZ | '13,6 | 4.5 | 10000 | 12729 | 8715.2 | 3 | 8000 | 10483 | 7528.7 | 3 | 10500 | 12983 | 8849.3 | 1.5 | 6000 | 8237 | 6342.2 | 3 | 6500 | 8983 | 6736.3 |
| 164 | | tpr= | | | Cpkr= | 348288 | | | Cpkr= | 295211 | | | Cpkr= | 354291 | | | Cpkr= | 242134 | | | Cpkr= | 259763 |
| 165 | S.AMER.WC-7 | | | | | | | | | | | | | | | | | | | | | |
| 166 | BUN | '1.7 | 4.5 | 10000 | 11471 | 109396 | 3 | 8000 | 9183 | 88667 | 3 | 10500 | 11683 | 111317 | 1.5 | 6000 | 6895 | 67937 | 3 | 6500 | 7683 | 75076 |
| 167 | CLL | '2,7 | 4.5 | 10000 | 14656 | 20140 | 3 | 8000 | 12368 | 18180 | 3 | 10500 | 14868 | 20321 | 1.5 | 6000 | 10080 | 16220 | 3 | 6500 | 10868 | 16895 |
| 168 | VLP | '3,7 | 4.5 | 10000 | 13571 | 76634 | 3 | 8000 | 11283 | 65083 | 3 | 10500 | 13783 | 77704 | 1.5 | 6000 | 8995 | 53531 | 3 | 6500 | 9783 | 57510 |
| 169 | TLC | '4,7 | 4.5 | 10000 | 14312 | 34916 | 3 | 8000 | 12024 | 30437 | 3 | 10500 | 14524 | 35331 | 1.5 | 6000 | 9736 | 25957 | 3 | 6500 | 10524 | 27500 |
| 170 | CLL | '5,7 | 4.5 | 10000 | 14656 | 28367 | 3 | 8000 | 12368 | 25123 | 3 | 10500 | 14868 | 28668 | 1.5 | 6000 | 10080 | 21879 | 3 | 6500 | 10868 | 22996 |
| 171 | | tpr= | | | Cpkr= | 269453 | | | Cpkr= | 227488 | | | Cpkr= | 273342 | | | Cpkr= | 185524 | | | Cpkr= | 199977 |

## Appendix 9

Time Coefficients $t_{kr}$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | |
| 2 | COEFFICIENTS tkr, AND ITS COMPONENTS (VOYAGE TIMES FOR SHIP-ROUTE COMBINATIONS) | | | | | | | | | | | | | | | | | |
| 3 | | | | | | ROUTES r | | | | | | | | | | | | |
| 4 | | | | | r=1 | | r=2 | | r=3 | | r=4 | | r=5 | | r=6 | | r=7 | |
| 5 | SHIP'S TYPE | | ID. NBR. | | tpr = | 19.8 | tpr = | 14.4 | tpr = | 13.3 | tpr = | 36.3 | tpr = | 20.1 | tpr = | 23.6 | tpr = | 18.3 |
| 6 | | | | | tmr = | 1.59 | tmr = | 1.19 | tmr = | 0.4 | tmr = | 2.09 | tmr = | 0.89 | tmr = | 1.39 | tmr = | 0.08 |
| 7 | | | (k) | | | | | | | | | | | | | | | |
| 8 | **OWNED** | | | | tkr | tskr | tkr | tskr | tkr | tskr | tkr | tskr | tkr | tskr | tkr | tskr | tkr | tskr |
| 9 | TYPE ALPAD | | 1 | | 40.6 | 19.2 | 31.5 | 15.9 | 37.9 | 24.3 | 76.1 | 37.7 | 52.9 | 32 | 77.4 | 52.4 | 33.2 | 14.7 |
| 10 | TYPE CIARM | | 2 | | 38.9 | 17.5 | 30 | 14.5 | 35.7 | 22 | 72.7 | 34.3 | 50 | 29.1 | 72.6 | 47.6 | 31.8 | 13.4 |
| 11 | TYPE CISAM | | 3 | | 38.9 | 17.5 | 30 | 14.5 | 35.7 | 22 | 72.7 | 34.3 | 50 | 29.1 | 72.6 | 47.6 | 31.8 | 13.4 |
| 12 | TYPE CIMAN | | 4 | | 39.4 | 18 | 30.5 | 14.9 | 36.4 | 22.7 | 73.8 | 35.4 | 50.9 | 30 | 74.1 | 49.1 | 32.2 | 13.8 |
| 13 | TYPE RIMAG | | 5 | | 39.4 | 18 | 30.5 | 14.9 | 36.4 | 22.7 | 73.8 | 35.4 | 50.9 | 30 | 74.1 | 49.1 | 32.2 | 13.8 |
| 14 | TYPE CIBUN | | 6 | | 38.9 | 17.5 | 30 | 14.5 | 35.7 | 22 | 72.7 | 34.3 | 50 | 29.1 | 72.6 | 47.6 | 31.8 | 13.4 |
| 15 | **CHARTERED** | | | | | | | | | | | | | | | | | |
| 16 | TYPE "GOLFO CHIRK | | 7 | | 38.9 | 17.5 | 30 | 14.5 | 35.7 | 22 | 72.7 | 34.3 | 50 | 29.1 | 72.6 | 47.6 | 31.8 | 13.4 |
| 17 | TYPE "MEGHAN A" | | 8 | | 38.9 | 17.5 | 30 | 14.5 | 35.7 | 22 | 72.7 | 34.3 | 50 | 29.1 | 72.6 | 47.6 | 31.8 | 13.4 |
| 18 | TYPE "MONSUN" | | 9 | | 38.9 | 17.5 | 30 | 14.5 | 35.7 | 22 | 72.7 | 34.3 | 50 | 29.1 | 72.6 | 47.6 | 31.8 | 13.4 |
| 19 | TYPE "METE SIF" | | 10 | | 42 | 20.6 | 32.6 | 17 | 39.6 | 26 | 78.8 | 40.4 | 55.2 | 34.2 | 81.1 | 56.1 | 34.2 | 15.8 |
| 20 | TYPE "ANGELIKI" | | 11 | | 42 | 20.6 | 32.6 | 17 | 39.6 | 26 | 78.8 | 40.4 | 55.2 | 34.2 | 81.1 | 56.1 | 34.2 | 15.8 |

## Appendix 10

LP example input

```
MINIMIZE
592 X011 + 463 X012 + 537 X013 + 1104 X014 + 767 X015 + 1117 X016 +
484 X017 + 9.1 Y01 +
591 X021 + 462 X022 + 527 X023 + 1097 X024 + 763 X025 + 1104 X026 +
480 X027 + 9.0 Y02 +
589 X031 + 460 X032 + 527 X033 + 1094 X034 + 761 X035 + 1102 X036 +
480 X037 + 9.0 Y03 +
484 X041 + 375 X042 + 451 X043 + 0916 X044 + 632 X045 + 0927 X046 +
412 X047 + 7.4 Y04 +
468 X051 + 361 X052 + 440 X053 + 0891 X054 + 610 X055 + 0896 X056 +
402 X057 + 7.3 Y05 +
554 X061 + 431 X062 + 501 X063 + 1040 X064 + 713 X065 + 1036 X066 +
457 X067 + 8.9 Y06 +
591 X071 + 462 X072 + 527 X073 + 1097 X074 + 763 X075 + 1104 X076 +
480 X077 + 9.0 Y07 +
473 X081 + 368 X082 + 429 X083 + 0891 X084 + 610 X085 + 0888 X086 +
393 X087 + 0.0 Y08 +
575 X091 + 449 X092 + 513 X093 + 1075 X094 + 736 X095 + 1066 X096 +
468 X097 + 0.0 Y09 +
350 X101 + 269 X102 + 340 X103 + 0686 X104 + 456 X105 + 0678 X106 +
308 X107 + 0.0 Y10 +
453 X111 + 358 X112 + 404 X113 + 0844 X114 + 588 X115 + 0856 X116 +
363 X117 + 0.0 Y11
SUBJECT TO
1TIMEK) 40.6 X011 + 31.5 X012 + 37.9 X013 + 76.1 X014 + 52.9 X015 +
77.4 X016 + 33.2 X017 + Y01 = 2190
2TIMEK) 38.9 X021 + 30.0 X022 + 35.7 X023 + 72.7 X024 + 50.0 X025 +
72.6 X026 + 31.8 X027 + Y02 = 730
3TIMEK) 38.9 X031 + 30.0 X032 + 35.7 X033 + 72.7 X034 + 50.0 X035 +
72.6 X036 + 31.8 X037 + Y03 = 1095
4TIMEK) 39.4 X041 + 30.5 X042 + 36.4 X043 + 73.8 X044 + 50.9 X045 +
74.1 X046 + 32.2 X047 + Y04 = 365
5TIMEK) 39.4 X051 + 30.5 X052 + 36.4 X053 + 73.8 X054 + 50.9 X055 +
74.7 X056 + 32.2 X057 + Y05 = 365
6TIMEK) 38.9 X061 + 30.0 X062 + 35.7 X063 + 72.7 X064 + 50.0 X065 +
72.6 X066 + 31.8 X067 + Y06 = 365
7TIMEK) 38.9 X071 + 30.0 X072 + 35.7 X073 + 72.7 X074 + 50.0 X075 +
72.6 X076 + 31.8 X077 + Y07 = 365
8TIMEK) 38.9 X081 + 30.0 X082 + 35.7 X083 + 72.7 X084 + 50.0 X085 +
72.6 X086 + 31.8 X087 + Y08 = 1095
9TIMEK) 38.9 X091 + 30.0 X092 + 35.7 X093 + 72.7 X094 + 50.0 X095 +
72.6 X096 + 31.8 X097 + Y09 = 1095
10TIMEK) 42.0 X101 + 32.6 X102 + 39.6 X103 + 78.8 X104 + 55.2 X105 +
81.1 X106 + 34.2 X107 + Y10 = 1095
11TIMEK) 42.0 X111 + 32.6 X112 + 39.6 X113 + 78.8 X114 + 55.2 X115 +
81.1 X116 + 34.2 X117 + Y11 = 1095
1VOYAGES) X011 + X021 + X031 + X041 + X051 + X061 + X071 + X081 +
X091 + X101 + X111 > 26.071
2VOYAGES) X012 + X022 + X032 + X042 + X052 + X062 + X072 + X082 +
X092 + X102 + X112 > 26.071
3VOYAGES) X013 + X023 + X033 + X043 + X053 + X063 + X073 + X083 +
X093 + X103 + X113 > 17.381
4VOYAGES) X014 + X024 + X034 + X044 + X054 + X064 + X074 + X084 +
X094 + X104 + X114 > 24.333
5VOYAGES) X015 + X025 + X035 + X045 + X055 + X065 + X075 + X085 +
X095 + X105 + X115 > 12.167
6VOYAGES) X016 + X026 + X036 + X046 + X056 + X066 + X076 + X086 +
X096 + X106 + X116 > 15.870
7VOYAGES) X017 + X027 + X037 + X047 + X057 + X067 + X077 + X087 +
X097 + X107 + X117 > 10.42
41INCOMP) X041 = 0
43INCOMP) X043 = 0
44INCOMP) X044 = 0
46INCOMP) X046 = 0
```

```
51INCOMP) X051 = 0
53INCOMP) X053 = 0
54INCOMP) X054 = 0
56INCOMP) X056 = 0
101INCOM) X101 = 0
102INCOM) X102 = 0
103INCOM) X103 = 0
104INCOM) X104 = 0
106INCOM) X106 = 0
107INCOM) X107 = 0
77INCOMP) X077 = 0
87INCOMP) X087 = 0
97INCOMP) X097 = 0
117INCOM) X117 = 0
1ALLOW) Y01 > 120
2ALLOW) Y02 > 40
3ALLOW) Y03 > 60
4ALLOW) Y04 > 20
5ALLOW) Y05 > 20
6ALLOW) Y06 > 20
7ALLOW) Y07 > 20
8ALLOW) Y08 > 60
9ALLOW) Y09 > 60
10ALLOW) Y10 > 60
11ALLOW) Y11 > 60
END
LEAVE
```

# Appendix 11

LP example output

LP OPTIMUM FOUND AT STEP 44

OBJECTIVE FUNCTION VALUE

1) 89572.5800

| VARIABLE | VALUE | REDUCED COST |
|---|---|---|
| X011 | 10.726691 | .000000 |
| X012 | .000000 | .268738 |
| X013 | .000000 | 4.256989 |
| X014 | 21.478270 | .000000 |
| X015 | .000000 | 129.889200 |
| X016 | .000000 | .204651 |
| X017 | .000000 | .800476 |
| Y01 | 120.000000 | .000000 |
| X021 | .000000 | 2.870819 |
| X022 | .000000 | 2.900848 |
| X023 | 7.717135 | .000000 |
| X024 | .000000 | .997253 |
| X025 | .000000 | 133.312130 |
| X026 | 1.145210 | .000000 |
| X027 | 10.420000 | .000000 |
| Y02 | 40.000000 | .000000 |
| X031 | .000000 | 1.942444 |
| X032 | .000000 | 1.727295 |
| X033 | .000000 | .983459 |
| X034 | 2.854730 | .000000 |
| X035 | .000000 | 132.689510 |
| X036 | 11.397540 | .000000 |
| X037 | .000000 | .876038 |
| Y03 | 60.000000 | .000000 |
| X041 | .000000 | .000000 |
| X042 | 11.311480 | .000000 |
| X043 | .000000 | .000000 |
| X044 | .000000 | .000000 |
| X045 | .000000 | 142.433410 |
| X046 | .000000 | .000000 |
| X047 | .000000 | 21.230834 |
| Y04 | 20.000000 | .000000 |
| X051 | .000000 | .000000 |
| X052 | 11.311480 | .000000 |
| X053 | .000000 | .000000 |
| X054 | .000000 | .000000 |
| X055 | .000000 | 143.797300 |
| X056 | .000000 | .000000 |
| X057 | .000000 | 26.011170 |
| Y05 | 20.000000 | .000000 |
| X061 | .000000 | 2.306091 |
| X062 | 3.448048 | .000000 |
| X063 | .000000 | 7.438019 |
| X064 | .000000 | 12.090881 |
| X065 | .000000 | 130.144040 |
| X066 | 3.327253 | .000000 |
| X067 | .000000 | 6.785156 |
| Y06 | 20.000000 | .000000 |
| X071 | .000000 | 2.870850 |
| X072 | .000000 | 2.900848 |
| X073 | 9.663865 | .000000 |
| X074 | .000000 | .997253 |
| X075 | .000000 | 133.312130 |
| X076 | .000000 | .000000 |
| X077 | .000000 | .000000 |
| Y07 | 20.000000 | .000000 |
| X081 | .000000 | 20.000000 |

| | | |
|---|---|---|
| X082 | .000000 | 13.113590 |
| X083 | .000000 | 26.013153 |
| X084 | .000000 | 47.539430 |
| X085 | .000000 | 154.000000 |
| X086 | .000000 | 36.194824 |
| X087 | .000000 | .000000 |
| X091 | .000000 | 122.000000 |
| X092 | .000000 | 94.113590 |
| X093 | .000000 | 110.013200 |
| X094 | .000000 | 231.539420 |
| X095 | .000000 | 280.000000 |
| X096 | .000000 | 214.194820 |
| X097 | .000000 | .000000 |
| X101 | .000000 | .000000 |
| X102 | .000000 | .000000 |
| X103 | .000000 | .000000 |
| X104 | .000000 | .000000 |
| X105 | 12.167000 | .000000 |
| X106 | .000000 | .000000 |
| X107 | .000000 | .000000 |
| X111 | 15.344310 | .000000 |
| X112 | .000000 | 3.113586 |
| X113 | .000000 | 1.013153 |
| X114 | .000000 | .539429 |
| X115 | .000000 | 132.000000 |
| X116 | .000000 | 4.194824 |
| X117 | .000000 | .000000 |
| Y08 | 1095.000000 | .000000 |
| Y09 | 1095.000000 | .000000 |
| Y10 | 423.381600 | .000000 |
| Y11 | 450.539100 | .000000 |

| ROW | SLACK OR SURPLUS | DUAL PRICES |
|---|---|---|
| 1TIMEK) | .000000 | -3.423645 |
| 2TIMEK) | .000000 | -3.473758 |
| 3TIMEK) | .000000 | -3.446210 |
| 4TIMEK) | .000000 | -.659462 |
| 5TIMEK) | .000000 | -.200445 |
| 6TIMEK) | .000000 | -2.537119 |
| 7TIMEK) | .000000 | -3.473758 |
| 8TIMEK) | .000000 | .000000 |
| 9TIMEK) | .000000 | .000000 |
| 10TIMEK) | .000000 | .000000 |
| 11TIMEK) | .000000 | .000000 |
| 1VOYAGES) | .000000 | -453.000000 |
| 2VOYAGES) | .000000 | -354.886410 |
| 3VOYAGES) | .000000 | -402.986840 |
| 4VOYAGES) | .000000 | -843.460600 |
| 5VOYAGES) | .000000 | -456.000000 |
| 6VOYAGES) | .000000 | -851.805200 |
| 7VOYAGES) | .000000 | -369.534500 |
| 41INCOMP) | .000000 | -5.017212 |
| 43INCOMP) | .000000 | -24.008760 |
| 44INCOMP) | .000000 | -23.871154 |
| 46INCOMP) | .000000 | -26.328674 |
| 51INCOMP) | .000000 | -7.102448 |
| 53INCOMP) | .000000 | -29.716950 |
| 54INCOMP) | .000000 | -32.746582 |
| 56INCOMP) | .000000 | -29.221560 |
| 101INCOM) | .000000 | 103.000000 |
| 102INCOM) | .000000 | 85.886413 |
| 103INCOM) | .000000 | 62.986850 |
| 104INCOM) | .000000 | 157.460600 |

| | | |
|---|---|---|
| 106INCOM) | .000000 | 173.805200 |
| 107INCOM) | .000000 | 61.534484 |
| 77INCOMP) | .000000 | -.000031 |
| 87INCOMP) | .000000 | -23.465520 |
| 97INCOMP) | .000000 | -98.465520 |
| 117INCOM) | .000000 | 6.534485 |
| 1ALLOW) | .000000 | -5.676354 |
| 2ALLOW) | .000000 | -5.526242 |
| 3ALLOW) | .000000 | -5.553790 |
| 4ALLOW) | .000000 | -6.740538 |
| 5ALLOW) | .000000 | -7.099554 |
| 6ALLOW) | .000000 | -6.362881 |
| 7ALLOW) | .000000 | -5.526242 |
| 8ALLOW) | 1035.000000 | .000000 |
| 9ALLOW) | 1035.000000 | .000000 |
| 10ALLOW) | 363.381600 | .000000 |
| 11ALLOW) | 390.539100 | .000000 |

NO. ITERATIONS= 44

RANGES IN WHICH THE BASIS IS UNCHANGED:

| | | OBJ COEFFICIENT RANGES | |
|---|---|---|---|
| VARIABLE | CURRENT COEF | ALLOWABLE INCREASE | ALLOWABLE DECREASE |
| X011 | 592.000000 | 1.936755 | .287790 |
| X012 | 463.000000 | INFINITY | .268738 |
| X013 | 537.000000 | INFINITY | 4.256989 |
| X014 | 1104.000000 | .204933 | 3.630223 |
| X015 | 767.000000 | INFINITY | 129.889200 |
| X016 | 1117.000000 | INFINITY | .204651 |
| X017 | 484.000000 | INFINITY | .800476 |
| Y01 | 9.099999 | INFINITY | 5.676354 |
| X021 | 591.000000 | INFINITY | 2.870819 |
| X022 | 462.000000 | INFINITY | 2.900848 |
| X023 | 527.000000 | .983459 | .000000 |
| X024 | 1097.000000 | INFINITY | .997253 |
| X025 | 763.000000 | INFINITY | 133.312130 |
| X026 | 1104.000000 | .000000 | 1.827502 |
| X027 | 480.000000 | .800476 | 369.534500 |
| Y02 | 9.000000 | INFINITY | 5.526242 |
| X031 | 589.000000 | INFINITY | 1.942444 |
| X032 | 460.000000 | INFINITY | 1.727295 |
| X033 | 527.000000 | INFINITY | .983459 |
| X034 | 1094.000000 | .997254 | .204933 |
| X035 | 761.000000 | INFINITY | 132.689510 |
| X036 | 1102.000000 | .204651 | .995882 |
| X037 | 480.000000 | INFINITY | .876038 |
| Y03 | 9.000000 | INFINITY | 5.553790 |
| X041 | 484.000000 | INFINITY | INFINITY |
| X042 | 375.000000 | 20.109954 | INFINITY |
| X043 | 451.000000 | INFINITY | INFINITY |
| X044 | 916.000000 | INFINITY | INFINITY |
| X045 | 632.000000 | INFINITY | 142.433410 |
| X046 | 927.000000 | INFINITY | INFINITY |
| X047 | 412.000000 | INFINITY | 21.230834 |
| Y04 | 7.400000 | INFINITY | 6.740538 |
| X051 | 468.000000 | INFINITY | INFINITY |
| X052 | 361.000000 | 24.637910 | INFINITY |
| X053 | 440.000000 | INFINITY | INFINITY |
| X054 | 891.000000 | INFINITY | INFINITY |
| X055 | 610.000000 | INFINITY | 143.797300 |
| X056 | 896.000000 | INFINITY | INFINITY |
| X057 | 402.000000 | INFINITY | 26.011170 |

| | | | |
|---|---|---|---|
| Y05 | 7.300000 | INFINITY | 7.099554 |
| X061 | 554.000000 | INFINITY | 2.306091 |
| X062 | 431.000000 | .268738 | 20.109954 |
| X063 | 501.000000 | INFINITY | 7.438019 |
| X064 | 1040.000000 | INFINITY | 12.090881 |
| X065 | 713.000000 | INFINITY | 130.144040 |
| X066 | 1036.000000 | 4.303914 | .650345 |
| X067 | 457.000000 | INFINITY | 6.785156 |
| Y06 | 8.900000 | INFINITY | 6.362881 |
| X071 | 591.000000 | INFINITY | 2.870850 |
| X072 | 462.000000 | INFINITY | 2.900848 |
| X073 | 527.000000 | .000000 | INFINITY |
| X074 | 1097.000000 | INFINITY | .997253 |
| X075 | 763.000000 | INFINITY | 133.312130 |
| X076 | 1104.000000 | INFINITY | .000000 |
| X077 | 480.000000 | INFINITY | INFINITY |
| Y07 | 9.000000 | INFINITY | 5.526242 |
| X081 | 473.000000 | INFINITY | 20.000000 |
| X082 | 368.000000 | INFINITY | 13.113590 |
| X083 | 429.000000 | INFINITY | 26.013153 |
| X084 | 891.000000 | INFINITY | 47.539430 |
| X085 | 610.000000 | INFINITY | 154.000000 |
| X086 | 888.000000 | INFINITY | 36.194824 |
| X087 | 393.000000 | INFINITY | INFINITY |
| X091 | 575.000000 | INFINITY | 122.000000 |
| X092 | 449.000000 | INFINITY | 94.113590 |
| X093 | 513.000000 | INFINITY | 110.013200 |
| X094 | 1075.000000 | INFINITY | 231.539420 |
| X095 | 736.000000 | INFINITY | 280.000000 |
| X096 | 1066.000000 | INFINITY | 214.194820 |
| X097 | 468.000000 | INFINITY | INFINITY |
| X101 | 350.000000 | INFINITY | INFINITY |
| X102 | 269.000000 | INFINITY | INFINITY |
| X103 | 340.000000 | INFINITY | INFINITY |
| X104 | 686.000000 | INFINITY | INFINITY |
| X105 | 456.000000 | 129.889200 | 456.000000 |
| X106 | 678.000000 | INFINITY | INFINITY |
| X107 | 308.000000 | INFINITY | INFINITY |
| X111 | 453.000000 | .287790 | 5.915108 |
| X112 | 358.000000 | INFINITY | 3.113586 |
| X113 | 404.000000 | INFINITY | 1.013153 |
| X114 | 844.000000 | INFINITY | .539429 |
| X115 | 588.000000 | INFINITY | 132.000000 |
| X116 | 856.000000 | INFINITY | 4.194824 |
| X117 | 363.000000 | INFINITY | INFINITY |
| Y08 | .000000 | .437120 | INFINITY |
| Y09 | .000000 | 2.950342 | INFINITY |
| Y10 | .000000 | 8.260869 | 2.353065 |
| Y11 | .000000 | .140836 | .403670 |

RIGHTHAND SIDE RANGES

| ROW | CURRENT RHS | ALLOWABLE INCREASE | ALLOWABLE DECREASE |
|---|---|---|---|
| 1TIMEK | 2190.000000 | 622.978820 | 377.521110 |
| 2TIMEK | 730.000000 | 595.145320 | 83.142272 |
| 3TIMEK | 1095.000000 | 595.145320 | 207.538840 |
| 4TIMEK | 365.000000 | 105.165500 | 210.997830 |
| 5TIMEK | 365.000000 | 105.165500 | 210.997830 |
| 6TIMEK | 365.000000 | 595.145320 | 207.538840 |
| 7TIMEK | 365.000000 | 275.501730 | 83.142272 |
| 8TIMEK | 1095.000000 | INFINITY | 1035.000000 |
| 9TIMEK | 1095.000000 | INFINITY | 1035.000000 |
| 10TIMEK | 1095.000000 | INFINITY | 363.381600 |
| 11TIMEK | 1095.000000 | INFINITY | 390.539100 |

| | | | |
|---|---|---|---|
| 1VOYAGES | 26.071000 | 9.298550 | 15.344310 |
| 2VOYAGES | 26.071000 | 6.917962 | 3.448048 |
| 3VOYAGES | 17.381000 | 2.328915 | 7.717135 |
| 4VOYAGES | 24.333000 | 4.960856 | 8.186318 |
| 5VOYAGES | 12.167000 | 6.583000 | 12.167000 |
| 6VOYAGES | 15.870000 | 2.858662 | 8.197595 |
| 7VOYAGES | 10.420000 | 2.614537 | 10.420000 |
| 41INCOMP | .000000 | 5.355276 | .000000 |
| 43INCOMP | .000000 | 6.746828 | .000000 |
| 44INCOMP | .000000 | 2.859050 | .000000 |
| 46INCOMP | .000000 | 3.314231 | .000000 |
| 51INCOMP | .000000 | 5.355276 | .000000 |
| 53INCOMP | .000000 | 6.746828 | .000000 |
| 54INCOMP | .000000 | 2.859050 | .000000 |
| 56INCOMP | .000000 | 3.287611 | .000000 |
| 101INCOM | .000000 | 8.651942 | .000000 |
| 102INCOM | .000000 | 3.448048 | .000000 |
| 103INCOM | .000000 | 7.717135 | .000000 |
| 104INCOM | .000000 | 4.611442 | .000000 |
| 106INCOM | .000000 | 4.480661 | .000000 |
| 107INCOM | .000000 | 10.420000 | .000000 |
| 77INCOMP | .000000 | 10.420000 | .000000 |
| 87INCOMP | .000000 | 10.420000 | .000000 |
| 97INCOMP | .000000 | 10.420000 | .000000 |
| 117INCOM | .000000 | 10.420000 | .000000 |
| 1ALLOW | 120.000000 | 377.521110 | 120.000000 |
| 2ALLOW | 40.000000 | 83.142272 | 40.000000 |
| 3ALLOW | 60.000000 | 207.538840 | 60.000000 |
| 4ALLOW | 20.000000 | 210.997830 | 20.000000 |
| 5ALLOW | 20.000000 | 210.997830 | 20.000000 |
| 6ALLOW | 20.000000 | 207.538840 | 20.000000 |
| 7ALLOW | 20.000000 | 83.142272 | 20.000000 |
| 8ALLOW | 60.000000 | 1035.000000 | INFINITY |
| 9ALLOW | 60.000000 | 1035.000000 | INFINITY |
| 10ALLOW | 60.000000 | 363.381600 | INFINITY |
| 11ALLOW | 60.000000 | 390.539100 | INFINITY |

## Appendix 12

Number of Ships Allocated

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | NUMBER OF SHIPS ALLOCATED | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | SHIP'S TYPE | | ID. NBR | r=1 | | | r=2 | | | r=3 | | | r=4 | | | r=5 | | | r=6 | | | r=7 | | |
| 6 | | | | input | | | input | | | input | | | input | | | input | | | input | | | input | | |
| 7 | | | (k) | Xkr | tkr | Nkr | Xkr | tkr | Nkr | Xkr | tkr | Nkr | Xkr | tkr | Nkr | Xkr | tkr | Nkr | Xkr | tkr | Nkr | Xkr | tkr | Nkr |
| 8 | OWNED | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | TYPE ALPAD | | 1 | 10.7 | 40.6 | 1.26 | | 31.5 | 0 | | 37.9 | 0 | 21.5 | 76.1 | 4.74 | 0 | 52.9 | 0 | 0 | 77.4 | 0 | 0 | 33.2 | 0 |
| 10 | TYPE CIARM | | 2 | | 38.9 | 0 | | 30 | 0 | 7.72 | 35.7 | 0.8 | | 72.7 | 0 | | 50 | 0 | 1.15 | 72.6 | 0.24 | 10.4 | 31.8 | 0.96 |
| 11 | TYPE CISAM | | 3 | | 38.9 | 0 | | 30 | 0 | | 35.7 | 0 | 2.86 | 72.7 | 0.6 | | 50 | 0 | 11.4 | 72.6 | 2.4 | | 31.8 | 0 |
| 12 | TYPE CIMAN | | 4 | | 39.4 | 0 | 11.3 | 30.5 | 1 | | 36.4 | 0 | | 73.8 | 0 | | 50.9 | 0 | | 74.1 | 0 | | 32.2 | 0 |
| 13 | TYPE RIMAG | | 5 | | 39.4 | 0 | 11.3 | 30.5 | 1 | | 36.4 | 0 | | 73.8 | 0 | | 50.9 | 0 | | 74.1 | 0 | | 32.2 | 0 |
| 14 | TYPE CIBUN | | 6 | | 38.9 | 0 | 3.45 | 30 | 0.3 | | 35.7 | 0 | | 72.7 | 0 | | 50 | 0 | 3.33 | 72.6 | 0.7 | | 31.8 | 0 |
| 15 | CHARTERED | | | | | | | | | | | | | | | | | | | | | | | |
| 16 | TYPE "GOLFO | | 7 | | 38.9 | 0 | | 30 | 0 | 9.66 | 35.7 | 1 | | 72.7 | 0 | | 50 | 0 | | 72.6 | 0 | | 31.8 | 0 |
| 17 | TYPE "MEGHA | | 8 | | 38.9 | 0 | | 30 | 0 | | 35.7 | 0 | | 72.7 | 0 | | 50 | 0 | | 72.6 | 0 | | 31.8 | 0 |
| 18 | TYPE "MONSU | | 9 | | 38.9 | 0 | | 30 | 0 | | 35.7 | 0 | | 72.7 | 0 | | 50 | 0 | | 72.6 | 0 | | 31.8 | 0 |
| 19 | TYPE "METE S | | 10 | | 42 | 0 | | 32.6 | 0 | | 39.6 | 0 | | 78.8 | 0 | 12.2 | 55.2 | 1.95 | | 81.1 | 0 | | 34.2 | 0 |
| 20 | TYPE "ANGEL | | 11 | 15.3 | 42 | 1.87 | | 32.6 | 0 | | 39.6 | 0 | | 78.8 | 0 | | 55.2 | 0 | | 81.1 | 0 | | 34.2 | 0 |
| 21 | | | | | Nr= | 3.13 | | Nr= | 2.3 | | Nr= | 1.8 | | Nr= | 5.34 | | Nr= | 1.95 | | Nr= | 3.34 | | Nr= | 0.96 |

# Appendix 13

Rounding of Number of Ships Allocated

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | ROUNDING OF THE NUMBER OF SHIPS, Nkr AND RECALCULATION OF FREQUENCIES | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | SHIP'S TYPE | | ID. NBR | | r=1 | | | r=2 | | | r=3 | | | r=4 | | | r=5 | | | r=6 | | | r=7 | | TOT |
| 6 | | | | | | input | | | input | | | input | | | input | | | input | | | input | | | input | SHIPS |
| 7 | | | (k) | Xkr | tkr | Nkr | Xkr | tkr | Nkr | Xkr | tkr | Nkr | Xkr | tkr | Nkr | Xkr | tkr | Nkr | Xkr | tkr | Nkr | Xkr | tkr | Nkr | |
| 8 | OWNED | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | TYPE ALPAD | | 1 | 8.49 | 40.6 | 1 | 0 | 31.5 | 0 | 0 | 37.9 | 0 | 22.7 | 76.1 | 5 | 0 | 52.9 | 0 | 0 | 77.4 | 0 | 0 | 33.2 | 0 | 6 |
| 10 | TYPE CIARM | | 2 | 0 | 38.9 | 0 | 0 | 30 | 0 | 9.66 | 35.7 | 1 | 0 | 72.7 | 0 | 0 | 50 | 0 | 0 | 72.6 | 0 | 10.8 | 31.8 | 1 | 2 |
| 11 | TYPE CISAM | | 3 | 0 | 38.9 | 0 | 0 | 30 | 0 | 0 | 35.7 | 0 | 0 | 72.7 | 0 | 0 | 50 | 0 | 14.3 | 72.6 | 3 | 0 | 31.8 | 0 | 3 |
| 12 | TYPE CIMAN | | 4 | 0 | 39.4 | 0 | 11.3 | 30.5 | 1 | 0 | 36.4 | 0 | 0 | 73.8 | 0 | 0 | 50.9 | 0 | 0 | 74.1 | 0 | 0 | 32.2 | 0 | 1 |
| 13 | TYPE RIMAG | | 5 | 0 | 39.4 | 0 | 11.3 | 30.5 | 1 | 0 | 36.4 | 0 | 0 | 73.8 | 0 | 0 | 50.9 | 0 | 0 | 74.1 | 0 | 0 | 32.2 | 0 | 1 |
| 14 | TYPE CIBUN | | 6 | 0 | 38.9 | 0 | 0 | 30 | 0 | 0 | 35.7 | 0 | 0 | 72.7 | 0 | 0 | 50 | 0 | 4.75 | 72.6 | 1 | 0 | 31.8 | 0 | 1 |
| 15 | CHARTERED | | | | | | | | | | | | | | | | | | | | | | | | |
| 16 | TYPE "GOLFO | | 7 | 0 | 38.9 | 0 | 0 | 30 | 0 | 9.66 | 35.7 | 1 | 0 | 72.7 | 0 | 0 | 50 | 0 | 0 | 72.6 | 0 | 0 | 31.8 | 0 | 1 |
| 17 | TYPE "MEGHA | | 8 | 0 | 38.9 | 0 | 0 | 30 | 0 | 0 | 35.7 | 0 | 0 | 72.7 | 0 | 0 | 50 | 0 | 0 | 72.6 | 0 | 0 | 31.8 | 0 | 0 |
| 18 | TYPE "MONSU | | 9 | 0 | 38.9 | 0 | 0 | 30 | 0 | 0 | 35.7 | 0 | 0 | 72.7 | 0 | 0 | 50 | 0 | 0 | 72.6 | 0 | 0 | 31.8 | 0 | 0 |
| 19 | TYPE "METE S | | 10 | 0 | 38.9 | 0 | 0 | 30 | 0 | 0 | 39.6 | 0 | 0 | 78.8 | 0 | 12.5 | 55.2 | 2 | 0 | 81.1 | 0 | 0 | 34.2 | 0 | 2 |
| 20 | TYPE "ANGEL | | 11 | 16.4 | 42 | 2 | 0 | 32.6 | 0 | 0 | 39.6 | 0 | 0 | 78.8 | 0 | 0 | 55.2 | 0 | 0 | 81.1 | 0 | 0 | 34.2 | 0 | 2 |
| 21 | | ACTUAL VOY | | 24.9 | Nr= | 3 | 22.6 | Nr= | 2 | 19.3 | Nr= | 2 | 22.7 | Nr= | 5 | 12.5 | Nr= | 2 | 19 | Nr= | 4 | 10.8 | Nr= | 1 | |
| 22 | | REQD.VOY | | 26.1 | | | 26.1 | | | 17.4 | | | 24.3 | | | 12.2 | | | 15.9 | | | 10.4 | | | |
| 23 | | | DIFF | -1.2 | | | -3.4 | | | 1.94 | | | -1.7 | | | 0.33 | | | 3.13 | | | 0.41 | | | |
| 24 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | | ACTUAL FRE | | 14.7 | | | 16.1 | | | 18.9 | | | 16.1 | | | 29.2 | | | 19.2 | | | 33.7 | | | |
| 26 | | REQD.FREQ | | 14 | | | 14 | | | 21 | | | 15 | | | 30 | | | 23 | | | 35 | | | |
| 27 | | | DIFF | 0.65 | | | 2.13 | | | -2.1 | | | 1.11 | | | -0.8 | | | -3.8 | | | -1.3 | | | |

# Appendix 14

Operating Cost Recalculation

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | RECALCULATION OF OPERATING COSTS WITH THE ADJUSTED Xkr VALUES FOR ROUNDED NUMBER OF SHIPS | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | RESULT: TOTAL COS | | | 90166466 | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | SHIP'S TYPE | | ID. | r=1 | | | r=2 | | | r=3 | | | r=4 | | | r=5 | | | r=6 | | | r=7 | | | | | | |
| 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | | | (k) | Xkr | Ckr | tkr | Xkr | Ckr | tkr | Xkr | Ckr | tkr | Xkr | Ckr | tkr | Xkr | Ckr | tkr | Xkr | Ckr | tkr | Xkr | Ckr | tkr | Tk | Yk | Ek | Ck |
| 8 | OWNED | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | TYPE ALPAD | | 1 | 8.5 | 591830 | 41 | 0 | 462725 | 31 | 0 | 536638 | 38 | 23 | 1103799 | 76 | 0 | 767133 | 53 | 0 | 1117575 | 77 | 0 | 484064 | 33 | 2190 | 120 | 9100 | 31122556 |
| 10 | TYPE CIARM | | 2 | 0 | 591315 | 39 | 0 | 462404 | 30 | 9.7 | 526655 | 36 | 0 | 1096675 | 73 | 0 | 762838 | 50 | 0 | 1104410 | 73 | 11 | 480381 | 32 | 730 | 40 | 9040 | 10657185 |
| 11 | TYPE CISAM | | 3 | 0 | 589414 | 39 | 0 | 460503 | 30 | 0 | 526655 | 36 | 0 | 1094438 | 73 | 0 | 760936 | 50 | 14 | 1102509 | 73 | 0 | 480381 | 32 | 1095 | 60 | 9040 | 16253629 |
| 12 | TYPE CIMAN | | 4 | 0 | 484151 | 39 | 11 | 374589 | 30 | 0 | 451805 | 36 | 0 | 915946 | 74 | 0 | 632262 | 51 | 0 | 926810 | 74 | 0 | 411982 | 32 | 365 | 20 | 7380 | 4385784 |
| 13 | TYPE RIMAG | | 5 | 0 | 468320 | 39 | 11 | 361409 | 30 | 0 | 439932 | 36 | 0 | 891221 | 74 | 0 | 610345 | 51 | 0 | 896181 | 74 | 0 | 401500 | 32 | 365 | 20 | 7320 | 4235469 |
| 14 | TYPE CIBUN | | 6 | 0 | 553962 | 39 | 0 | 431317 | 30 | 0 | 500615 | 36 | 0 | 1040099 | 73 | 0 | 713145 | 50 | 4.8 | 1035988 | 73 | 0 | 456900 | 32 | 365 | 20 | 8860 | 5098293 |
| 15 | CHARTERED | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 16 | TYPE "GOLFO CHIRIQUI | | 7 | 0 | 590999 | 39 | 0 | 462404 | 30 | 9.7 | 526655 | 36 | 0 | 1096675 | 73 | 0 | 762838 | 50 | 0 | 1104410 | 73 | 0 | 480381 | 32 | 365 | 20 | 9040 | 5268517 |
| 17 | TYPE "MEGHAN A" | | 8 | 0 | 473054 | 39 | 0 | 368128 | 30 | 0 | 429189 | 36 | 0 | 891024 | 73 | 0 | 610025 | 50 | 0 | 887621 | 73 | 0 | 393253 | 32 | 1095 | 1095 | 0 | 0 |
| 18 | TYPE "MONSUN" | | 9 | 0 | 574604 | 39 | 0 | 448615 | 30 | 0 | 513312 | 36 | 0 | 1074984 | 73 | 0 | 736314 | 50 | 0 | 1066483 | 73 | 0 | 468509 | 32 | 1095 | 1095 | 0 | 0 |
| 19 | TYPE "METE SIF" | | 10 | 0 | 350057 | 42 | 0 | 268725 | 33 | 0 | 340700 | 40 | 0 | 685807 | 79 | 13 | 455895 | 55 | 0 | 678134 | 81 | 0 | 308139 | 34 | 1095 | 405 | 0 | 5699320 |
| 20 | TYPE "ANGELIKI" | | 11 | 16 | 453409 | 42 | 0 | 357858 | 33 | 0 | 403795 | 40 | 0 | 844481 | 79 | 0 | 588500 | 55 | 0 | 855803 | 81 | 0 | 362964 | 34 | 1095 | 405 | 0 | 7445713 |