A STUDY OF A FERRY TRANSPORTATION SYSTEM FOR AN ARCHIPELAGIC REGION: A CASE STUDY IN MALUKU

I.G.N. SUMANTA BUANA

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by

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Abstract

A ferry transportation system consists of many factors, which interact in a complex manner. Such a system is very difficult to analyze analytically. A computer simulation is thus an appropriate method to aid in understanding the system and its design.

The Province of Maluku, which consists of thousands of islands spread haphazardly, has suffered from having an ineffective sea transportation system. A good sea transportation system is essential for the development of this island province.

The purpose of this study is to analyze a ferry transportation system suitable for the Province of Maluku. As an initial step, the study proposes to model ferry traffic between a major port Ambon and nine outlying smaller communities on surrounding islands.

The performance of the ship to be measured is the time spent during its annual operation, that is, travelling/voyage time at sea, waiting time at the offing, and service time at a dock in a port. The other performance of the ships to be measured is the annual number of trip needed by a particular ship to carry the annual quantity of commodity. In doing so, a computer model written in MODSIM III is used to support decision-making.

Since the actual commodity data were inaccessible, a very general model was developed which can be utilized under any conditions, making the model very flexible to changing. The model will be run under some configurations, which includes the use of five different types of ship and its quantity in a particular route. A trial and error procedure will be carried out in order to obtain several optimum performances of ships in the whole system.

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Contents

List of Abbreviation and Symbols

μ	:	mean
α, β	:	beta distribution parameters
σ^2	:	variance
2_tT	:	2-ton trucks
4_tT	:	4-ton trucks
A	:	Car deck's area
a	:	optimistic estimate for beta distribution
B	:	Breadth
b	:	pessimistic estimate for beta distribution
C	:	Cargo
F	:	Fish
GRT	:	Gross Registered Tonnage
i	:	Trip
j	:	A, B, C, C', D (Ship types)
K_1	:	Constant for cars
K_2	:	Constant for 2-ton trucks
K_3	:	Constant for 4-ton trucks
L_{OA}	:	Length Overall
L_{pp}	:	Length Between Perpendicular

m	:	most likely estimate for beta distribution
o	:	Port of origin
P	:	Passengers
Q_1	:	Annual quantity of passengers
Q_2	:	Annual quantity of cars
Q_3	:	Annual quantity of cargo
Q_c	:	Annual quantity of commodity c
Q^R	:	Remaining quantity of commodity needed to be shipped
Q^R_{2i}	:	Remaining number of cars up to *ith* trip
Q^R_{1i}	:	Remaining number of passengers up to *ith* trip
Q^R_{3i}	:	Remaining quantity of cargo up-to *ith* trip
R	:	Rice
S	:	Ship/Ferry types
s_o	:	Route distance
T	:	Timber
t_l	:	Loading time
t_r	:	Returning time
t_t	:	Round trip time
T_t	:	Aggregate total round trip time
t_u	:	Unloading time
t_v	:	Voyage time

t_w	:	Waiting time
V	:	Cars (Sedan and alike)
v_j	:	*j*-type ship velocity
X_{1i}	:	Number of passengers on *ith* trip
$X_{2t,\,i}$	:	Number of 2-ton trucks on *ith* trip
$X_{4t,\,i}$	:	Number of 4-ton trucks on *ith* trip
X_{ci}	:	Quantity of the c-type commodity on *ith* trip
Y	:	Ship capacity
Y_1	:	Ship capacity for carrying passengers
Y_2	:	Ship capacity for carrying vehicles
Y_3	:	Ship capacity for carrying cargo
Z_{ci}	:	Quantity of commodity that has been transported up to *ith* trip

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1
Introduction

1.1. Background

Generally, Eastern Indonesia is less developed than the Western Indonesia. It can be observed that most of the low-growth provinces are situated in the Eastern zone (Soegijoko, 1992). Geographically this region is isolated and located on Indonesia's peripheral. Sea transportation system is the most effective means to hasten and to distribute the development equally in this region. Reasons for this are scarce and relatively expensive land transportation (Meyer et al., 1989) and islands which are scattered over a wide region of ocean.

Basically, the major problem in Eastern Indonesia is economical (both macro and micro) rather than technical. Low gross domestic product (GDP) makes it difficult for this region to support an effective transportation system which would connect and reach each part of the region. In other words, the region cannot provide itself with the main infrastructure, i.e., ports and ships. Thus, recently a pioneer or *Perintis* system of subsidizing passenger and cargo sea services has been introduced to isolated coastal areas and peripheral ports. However, these subsidized services overlapped with commercial services. Therefore, a sea transportation system has to be designed so that the maximum benefit to the society could be achieved. This system mainly consists of general cargo and/or ro-ro vessels as well as ports. Here, the system has to be able to link as many ports as possible using the available facilities, i.e., port and ship, which are limited and somewhat out-of-date.

1.2. Scope of Study

Due to the limitation of time and difficulties in finding data, the Province of Maluku (see Fig. 1.1.) is then chosen as a sample project. This province is assumed to be able to represent Indonesia in a small scale because of its geographic condition: wide spread archipelagos. The islands can be divided into two groups: developed islands with quite established infrastructures and the others, which have poor public facilities.

This province has a total area of 851,000 km^2: ocean 765,272 km^2 and land 85,728 km^2 (JICA, 1993 excerpted from "Dalam Angka 1990"). The population in Maluku Province was 1,857,970. Most of them live in central-to-north regions of the province.

Administratively, Maluku consist of four *kabupaten* (regency) and one *kotamadya* (municipality) which picture its global economic condition. While the Northern Region (Kabupaten Maluku Utara, Kabupaten Halmahera Tengah, Kabupaten Maluku Tengah and Kotamadya Ambon) is prosperous, the Southern Region (Kabupaten Maluku Tenggara) is considered underdeveloped. The Northern Region produces minerals and forestry products, which are highly valuable in trading and are able to establish the infrastructures. In contrast, the Southern Region needs to be subsidized due to its disabilities in exploring its potential resources, i.e., marine resources, which in turn could be used to upgrade the infrastructures.

Fig. 1.1.Map of Maluku

In addition to equalizing the development in the province, each region should distribute its products to other areas. As stated above, these imbalances could be resolved by creating a good sea transportation system as an effective-economical means of transportation.

However, the imbalances involve complex factors, both economic and technical, which cannot be easily reduced to a direct mathematical analysis. Therefore, simulation is the appropriate approach to model this complex problem (Pidd, 1992).

1.3. Objective of Study

The purpose of this research is to analyze using simulation a ferry transportation system suitable for an achipelagic region like the Province of Maluku. The result of this simulation will be used for developing a feasible sea transportation system by deploying the limited facilities and resources: the ports, the ships and the subsidization/financing support. To do so, several simulation results of several variables' and parameters' configuration which are called scenarios, will be compared. The results do not yield specific solutions, rather to design, implement and test a decision support tool for the ships' traffic (Darzentas et al., 1996).

The possible variables and parameters are those which are considered to have a great influence on the sea transportation activity. Those major variables and parameters consist of types of vessels, harbor layouts, weather conditions, passenger and vehicle demand, types of vehicles, as well as loading-unloading times. Because of difficulties in obtaining the real data, most data are assumed but are treated so that they will be able to represent the actual conditions, e.g., using certain distribution for weather condition which would affect ship sailing times. In case of unavailable data, some components might be assumed as dummy variables that can follow any criteria.

In this study, several performances of the ship will be measured. They are the time spent during its annual operation, that is, travelling/voyage time at sea, waiting time at the offing, and service time at a dock in a port. The other performance of the ships to be measured is the annual number of trips needed by a particular ship to carry the annual quantity of commodity. In doing so, a computer model written in MODSIM III is used as a decision support tool.

In order to simplify the simulation, Maluku is divided into three regions, according to its traditional inter-insular constellation, that is, Northern, Central and Southern Region. Here, *Kabupaten* Maluku Utara and *Kabupaten* Halmahera Tengah is grouped as the Northern Region; *Kabupaten* Maluku Tengah and *Kotamadya* Ambon is as the Central Region; and *Kabupaten* Maluku Tenggara alone is as the Southern Region.

Each region has one centre which accommodates several sub-centres. In this case, the centre is the central of most activities in the region, whereas the sub-centre is the small area surrounding the centre. Both centre and sub-centre are seaports. The centre of the Northern Region is either Ternate or Soa Siu, of the Central is Ambon, and the centre of the Southern Region is Tual.

1.4. Data Acquisitions

In this study, traffic can be divided into three categories, that is, passengers, cargo and vehicles. Since it was not possible to obtain actual data for this study, a reasonable and an arbitrary estimate of the quantity of the traffic had to be made. This calculation, passenger's traffic, was based on a previous study (JICA, 1993) which dealt with the same problem: ferry service in Indonesia.

Since it is impossible to include all regions due to time constraints, only ten selected seaports will be considered. These are located mostly in the Central Region of the province, except for one in the Southern Region. However, the selected region and its components are assumed to reasonably represent the whole province. These ten seaports are arbitrarily selected, namely, Sanana, Namlea, Tulehu, Amahai, Saparua, Tehoru, Werinama, Saumlaki and Banda. Ambon as the provincial capital city is treated as the centre/main port.

1.5. Present Condition of the Ferry Lines in Maluku

At present, 14 subsidized ferry boats are in service (Kompas, 1996), five of which are in the Northern region, two are in the Southern and seven of the boats are in the Central region.

2

Literature Reviews

Traffic simulation has been used as a means in recent years for aiding decision makers in improving the performance of a system such as cargo terminals in a port. However, only a few simulation studies in ocean-related traffic have been conducted. In most cases, they only discussed partial aspects of the whole system of sea transportation, namely, activities in the port: both berthing and the loading-unloading process. Nevertheless, these studies have been found to be critical in providing a basic understanding of a ferry transportation system. In addition to these, several non-sea transportation studies have also been found to be useful. They focus mainly on vehicle routing with the objective of optimizing their deployment and the objects via geographical allocation and discharging. Some of the most significant studies related to ferry transportation will be reviewed next.

1. El Sheikh et al. (1987)

El Sheikh et al., in their paper, described a simulation model for investigating the number of berths that a third-world port will require in a few years time. Such a computer simulation is used for aiding the development of the future berth requirements in this region. Although this study is primarily for ports in a certain region, i.e., a third-world port, it may be applied to many ports throughout the world.

Here, the qualitative characteristics of the port were discussed, e.g., number of berths in a port, type of berth needed by certain ships and total length of ship-berth space required upon loading-unloading cargoes. In other words, port's utilization is simulated in order to maximize its operations. Of these issues, the purpose of the study was to estimate the number of berths required in the short and medium term, and to examine the impact of proposed handling improvements.

The number of the berths required, depends essentially on three factors, that is,

1. the demands on the port in terms of expected traffic;
2. the handling rates for the different commodities;
3. what is regarded as an acceptable level of service for the ships using the port.

The relationship between the required berth-days and the expected ship waiting-time is complex. It depends on the patterns of ship arrivals and service time, and the way in which ships are allocated to different berths. For these reasons, a simulation model was developed.

In this simulation, an acceptable ratio of ship-waiting time, W, was set up referring to the general approach of the United Nations Conference on Trade and Development

(UNCTAD): Port Development.

$$W = \frac{\text{average ship waiting time}}{\text{average ship service (working) time}}$$

The value of W cannot be determined as a fixed number but rather a range where values from 0.1 to 0.2 are generally considered to be tolerable. Although this ratio is not exact, it can be used for assessing the acceptability of the given combination of expected traffic. Thus, an acceptable combination can be made by adjusting each component: either increasing the handling rates or providing more berths.

Since the study was focused on 1990 traffic projections and handling rates, the W factor becomes

$$W = \frac{\text{annual traffic for 1990}}{\text{handling rate (tons per ship - day alongside)}}$$

Simulation was then used for assessing the expected ship waiting-time and estimating the ratio W. This is due to the complex allocation decisions at the port which makes a desired relationship between percentage berth-occupancy and average ship-waiting time difficult to be derived.

Next, the required berth-days have been assessed for three cases:

1. using current handling rates, as calculated on the basis of the ship sample;
2. including the effect of projects already under implementation or committed;
3. including the effect of the projects and other measures not yet committed.

In order to make a convenient measurement, the required berth-day may be expressed in terms of the percentage occupancy of the port rather than the number of the days, e.g., 95-

110% instead of 7,279-8,410 days.

Furthermore, the simulation model is based on an activity cycle diagram (ACD) procedure which is written using the three-phase approach to structuring models. The crucial part of this approach is the part in which the allocation rules operate. In this model, a set of priority allocations was specified. In addition to the simulation program, an interactive data-configuration was written. As recommended by the UNCTAD report, arrival and service times at ports may well be represented using Erlang distribution with the appropriate mean.

These results provide computer simulation of ship-waiting times for various levels of service and demand at the port, corresponding to different traffic levels.

2. Park et al. (1987)

A port simulation conducted by Park et al. (1987) was used for simulating the future economic port capacity to meet projected cargo demand. In their study, two types of the port-development were evaluated: the effects caused by the port capacity expansion and the port economics due to changes in the port capacity.

The main goal of using a simulation for the port operation in this study was to provide a planning/analysis tool for port operations which allows the user, e.g., port authorities, to create models interactively instead of concentrating on learning how to use a general software package. This will assist the user in designing and controlling a reliable and cost-effective port system.

For the purpose of simulation, the port operation process was divided into three major components: marine transport model operation, cargo handling operation and inland transport mode operation. This division was then implemented in a general structure which had six modules: data-base module, real module, resource change module, simulation module, operation control module, and economic-analysis module. This structure is arranged to allow the users to control or modify the model, particularly after the simulation is done. Thus, these implementation modules describe all activities in the port, i.e., integrating the port operations with several analyses and judgements subject to the operation having been carried out.

In developing the simulation program (using the SLAM Language), the discrete approach event was used. This illustrated all port operations as grouped into these modules. Here, the model was designed and programmed to be an interactive system. It included several aids to the user who has minimal knowledge in programming and computers, in the form of messages and instructions. In order to be able to control the simulation program, the modeling structure for the simulation was then divided into six major groups, that is, the SLAM subprogram, data generation, port operation event programs, resource status, economic impact simulation, and report generation.

To initiate the program, a primary input which consists of current condition of the ports, e.g., the port size and the ship control mechanism, was used to evaluate whether an expansion is needed to be introduced to the system. If bottlenecks were found, users proposed a scenario to the simulation model to evaluate whether this alteration could improve the port operation performance.

A crucial step in developing the simulation model was to make some considerations and assumptions, that is,

1. the ship's arrival pattern over the project years could be anticipated and expressed by means of a statistical distribution form;
2. the crane on a berth was not physically transferable to another berth;
3. twenty-four hours of daily operation;
4. each cargo unit is measured by "tons";
5. a bulk-cargo ship carries only one type of cargo at a time.

The three major components of port operations above are translated into three main port-operation-event sub-programs, each of which has several routines. In the marine-transport-mode operation, the first action is to schedule the next arrival to occur at the current time plus the time between arrivals. After that, the anchorage area is checked in which the ships wait for port service. If everything is clear, i.e., there is a space for the incoming ship, the next inspection goes to the physical characteristics of the arriving ship. Meanwhile, the port facility status is examined to locate free resources such as a tugboat, pilot and berth. On the other hand, if the channel is fully occupied, the ship is put into waiting mode.

When the first condition of the channel takes place, i.e., free space is available, the ship is then moved to a berth, when at the same time a berth operation is initiated. This begins with a task such as to provide a pilot and tugboat as well as to determine the number of cranes, total cargo-unloading capability and unload time. The opposite procedure is repeated for de-berthing operation.

The simulation model reads the channel passing time, travel time and berthing-time from the primary input data, while the time to unload cargo from a ship to a transit shed is determined by the state of the port system. After the number of cranes needed is defined, the unload-time can be calculated by dividing cargo tonnage loaded in a ship by the unloading capacity of cranes on the berth.

To simulate the unloading-loading process into the possibilities that may occur, two methods are used: single and two-way operation. The first is applied when loading and unloading activities can only be done sequentially, while the latter is for when they can be performed simultaneously. The cargo is stored temporarily in the transit shed before being moved to the warehouse, while the cargo to be loaded comes from the opposite direction. During this operation, the berth status remains busy; thus, no other ship could use the berth until both operations terminate.

The cargo stored in the shed moved to the warehouse is an import activity and cargo moved from the warehouse to the shed is an export process. The cargo handling operation is commenced by deploying cargo-handling equipment. Initially, the capability of the equipment has to be specified by manipulating the cargo flow from these two places. To do so, the statistics of the storage level of each cargo type has to be collected. This cargo handling operation is performed daily and from this activity, the utilization factor of each cargo type can be obtained by compounding the amount of the cargo moved in a specific day and the capability of the equipment.

The last stage of the simulation, inland-transport-mode operation, is to move the cargo from the warehouse to the destination or to receive it from outside the port area. Here, an inland carrier's arrival event is represented and the carrier attributes are determined before starting the operation of either loading or unloading cargo at the inland platform. These attributes are carrier type, cargo type (export versus import), cargo amount and time required to load (unload) cargo. Next, the storage level of the cargo is checked, followed by either a loading or unloading activity. At the end, as all inland transport operation modes are completed, the total number of carriers served by cargo type and carrier type, average cargo delivering capability, and average loading time are summed up.

As the simulation progresses, statistical information is collected such as, expected port revenues, queue waiting time, system time, and storage level. This is required to identify possible congestion. In order to be able to modify such circumstances, the model could be rerun by changing the current port facilities such as number of berths, transit shed area, warehouse area, number of cranes, channel depth, dry dock, crane at inland platform, pilot, and cargo handling rate. In addition, the proposed port investment scenario is introduced to the simulation model. With this introduction, the future expanded port scenario can be assessed and its economic viability can be evaluated. This can be performed by calculating the net cash flow associated with any given level port of capacity.

The simulation model finally provides the annual construction cost, i.e., the yearly operational cost, and calculates the capital cost associated with the scenario. Along with this, the future port revenues can also be computed from the services given. In order to compute the total port operation cost, the operation and maintenance cost must be included.

Several simulation procedures can be listed as follows:

1. Distribution of different incoming ships can be obtained from the historical data. Thus, each type of ships will have a single probability.
2. The expected number of the arriving ships was obtained by dividing the total tonnage by the average tonnage of the ship
3. The average inter-arrival time was computed by dividing 365 days by the expected number of the arriving ships.
4. To generate an arrival event for port service, an exponential distribution was used with the corresponding arrival time.
5. The number of the ships served in the port can be assumed as the total number of the ships which can be processed by the current port capacity. From this assumption, a maximum length of ships' queue can be determined.
6. Port service tariff to calculate the incoming cash flow, are based on the charge per gross registered tonnage (GRT) of a vessel docking.

In order to reduce the estimation error of an output variable for the model, two basic procedures are introduced. The first is to use the common random variable while the second is to replicate the simulation experiment to improve the accuracy of point estimators. In this simulation, the number of replications was determined after several observations of several running. Before starting the simulation, the initial storage level was determined with the results of test runs, while the system was assumed empty and idle.

The final step of the simulation is to verify whether the model could adequately represent the port operation. This can be done by comparing the statistical properties of the real system's output and those of the simulated ones.

3. Ash et al. (1991)

As in most papers about routing, where a fleet of vehicles delivers goods from a warehouse to a set of customers, Ash et al. described the strategic problem of moving coal from its origin to a place (i.e., power station) located thousands of miles away. This study was carried out in order to be able to reduce the transport cost which is accountable for over 60% of final selling price. For this reason, a transportation simulation model was built to assess alternative routes to move the coal. The alternatives involved many parties including different layers of government. Although the primary purpose of the study was to find the least expensive route, it also evaluated the interaction of a number of factors of proposed strategies. In other words, this study does not only focus on one alternative but rather on several feasible routes. This is important as a tool for the decision makers.

On account of this complexity, a different way of handling a wide range of transportation problems is then introduced. Such multi-faceted problems are called strategic. A strategic problem will involve:

- a long time horizon;
- considerable expense;
- multiple objectives;
- uncertainty in future operations (including demand);

- effects over a range of organizations;
- large amount of information;
- information which gets less reliable further in the future.

Traditionally, coal is transported from its mine in Western Canada to the destination in the East (the power station) by two modes: train and ship. The amount of the coal will increase as demand increases because of a growing number of power stations. Coal is still preferable due to its low level of damage to the environment.

On the contrary, this high future demands faces serious problems from the United States. From this country, a large amount of coal can be sold and transported to any place in Canada with a competitive price. Therefore, to maintain the use of Canadian coal, a major investigation was conducted which focused on transportation as a key factor.

The transport of coal is more complicated than other commodities. Before any simple policy can be introduced, consultation from a number of parties is required. In this case, the first concern goes to the government, both national and provincial, which has policies on infrastructures, employment, public grants, industrial development, diversification, etc. Other parties are the coal producers, the customers for coal, the transport operators, the Alberta Office of Coal Research and Technology, industry and government advisers and environmentalists. However, each party has different objectives some of which conflict with each other.

The investigation was designed to be more than a simple costing tool and to help with various aspects of strategic planning. In particular, it assessed the economic consequences of decisions to allow the following:

- identification of those factors that assist in the transport of coal;
- priorities to be set for research and development within the coal industry;
- assessment of impact on areas of public policy (such as employment, infrastructure development and investment in transport);
- development of investment strategies for coal production, processing and transportation;
- planning a stable environment for the transport of bulk materials across Canada.

The coal transport model developed in this study was based on a simulation of alternative transport links and it had the specific objective of identifying the cheapest route between mines in Alberta and customers in Ontario. For this purpose, the model considered all aspects of coal movement from its origin to the destination which included:

- mining, with excavation and separation of coal from overburden;
- transport from pit to washplant;
- processing, with separation of coal from waste materials and upgrading;
- loading and transport to customers;
- storage at various points in this journey;
- combustion by customers.

In order to simulate the uncertainty of the future markets, several scenarios with several level of demands were designed. For each of them, a range of economic calculations was done, such as the capital requirements by year, rates of return, operating cost and employment level. The first priority for the model was to reduce all possible transport routes to a reasonable number of feasible alternatives.

The main features of the alternative networks consist of:

- rail and ship;
- direct rail shipment;
- high-efficiency rail;
- west coast ports and Panama Canal;
- coal-oil agglomeration -eastbound;
- coal-oil agglomeration -westbound;
- energy bus.

When all feasible routes were agreed, all corresponding data were then collected about coal production, coal characteristics, bitumen enrichment, loading at mine, transportation data, terminal operations, preparation of slurries, de-oiling of coal slurry, arrive- blend-and-store at power station, and demands/market.

The simulation itself is written in APL, with all data input using LOTUS 1-2-3 templates. The simulation starts by generating a set of feasible routes through the network, described by a route matrix. To produce a set of feasible routes, all possible expansions were added. This was done by selecting those expansions which proved to be cheapest. The final objective was to find the routes that had the lowest total cost.

Although the simulation could be applied for a limitless number of scenarios, the possible routes were selected based on the amount of energy content of the coal rather than its weight. From the output of the simulation, the cost of each route was then ranked. The output of the simulation shows an interesting phenomenon: when reaching a certain amount of coal, the cost is relatively flat rather than decreasing gradually. This is as result of the limited capacity of the infrastructure, such as the mine washplant capacity. In other words, in order to increase the delivered amount of coal, a new investment must be introduced, which in turn, would increase the total cost.

Although it is impossible to draw a single suggestion of a feasible route, due to a wide range of interests involved, the strategic decisions resulting from the simulation can be used as a decision making tool.

4. Kern (1989)

Kern proposed a simulation model for allowing an administrator in a police station to study several complex-dispatching tactics. This study would assist the police patrol administrator in deploying the scarce available resources in the station, i.e., patrol cars and officers. Such deployment can be divided into three highly inter-related decisions: patrol sector design, initial patrol unit geographic location, and dispatching.

The model developed in his study included inter-sector dispatching and preemptive to low priority calls. The method of simulation used in the model is a discrete-event simulation model. This model was able to assign calls for service (CFS) to more than one patrol unit and also capable of simulating sophisticated dispatching rules.

During the simulation, the administrator can define her/his patrol environment. After specifying the environment, the administrator then enters deployment, which, in turn, will be simulated by the model which provides a performance report. The language used is SLAM. It can incorporate FORTRAN subroutines.

The duties of the police-patrol forces are to investigate criminal incidents, intercede in civil disputes, and to prevent the occurrence of the future incidents. Next, four basic events, based on the patrol duties, can be determined, that is,

1. arrival of a CFS;
2. arrival of an assigned patrol unit at the CFS location;
3. completion of service of a CFS;
4. return of patrol unit to patrol area.

Four consecutive actions of the CFS, which would be used in designing the model, are as follows:

- initialization of the CFS, which is started when the call arrives, followed by choosing the selected dispatching logic to assign patrol unit(s);
- completion of service of a CFS;
- returning to the patrolling area to which the task was given;
- arrival of the patrol unit to its patrol area.

The process is then repeated again for the next call. Several sets of decisions rules supplied by the user (researcher or patrol administrator) are available upon completion of any of these four major events. These rules govern dispatching and the assessment of patrol unit availability.

For the purpose of the model, deployment was divided into five components, i.e., sector design, initial allocation, queued call selection, inter-sector dispatching, and preemption. The first two components are static decisions, because they are made once per decision period. The last three are of dynamic nature because they are selected depending upon the nature of the calls.

The next stage of the simulation is to describe the nature of the deployment as input as it can be described in the five features above. The input are demand, arrival rate of the incidents, service rate, distribution of incident location, sector design, travel time, initial allocation, and dispatching type. All random input values are assumed to be exponentially distributed which can be simply adjusted if the assumption changes.

In order to provide output for each of the patrol duties, the simulation model was designed to allow for variable replication lengths and number of replications. The output gives the overall performance of the deployment, namely, the efficiency with which the patrol is delivered. Two types of efficiency measures are reported: response time and dispatch delay. The first is the amount of time that elapses between when CFS arrives and when the dispatcher assigns the CFS to patrol units, while the latter is the length of time that a citizen must wait before service of their incidents begins. The last one is considered to be an important measure because a deployment may not only affect dispatch delay but also the patrol unit selected to serve a given call, i.e., the CFS. These two factors, dispatch delay and response time, measure how quickly the patrol system reacts to CFS.

The other factor that has to be taken into account is the possible inclusion of an inter-sector dispatching rule. This could affect the performance. Thus a patrol administrator may be concerned with the amount of time a given patrol unit spends working outside the sector to which it has been allocated. In other words, this intrusion, that is, the inter-sector dispatching, might improve the initial allocation or even delay the first deployment.

Because of the nature of the deployment, some assumptions need to be included in the model. The user must recognize these assumptions when interpreting the results. Several assumptions are applied:

- dispatchers are perfect and make their decisions instantaneously;
- all patrol units are composed of one patrol car and one patrol officer (this can be modified so that at least two patrol units are assigned to high-priority calls);
- patrol units are not considered available during travel times when preemption is not allowed by the dispatching rule;
- when allowed, preemption is capable of suspending service of lesser-priority calls during the delivery of the service as well as while the patrol unit is still traveling to the location.

The final stage of the simulation was to verify the output using two techniques. The first one was to construct a special subroutine that can report the content of all files, all variables and the event calendar. The other was to apply an M/M/S queueing system. The result of the queue, the average wait in the queue and the average length of the queue, were then statistically compared with the analytical values calculated using standard formulas.

5. Kondratowicz (1990)

In his paper, Kondratowicz outlined a general methodology for modeling and simulation of seaport and inland terminals in intermodal freight transportation systems. An object-oriented process simulation was constructed called TRANSNODE (the Simulator of Intermodal Transportation Terminals).

He recommended that a truly logistic approach in transportation requires the use of computer models which are capable of grasping the whole transportation system with sufficient detail. In other words, the decision-making should be supported by computer models which comprise more components and complex relations. Next, it is necessary to develop a generalized modeling capability to provide strategic and tactical decision support for transportation logistic and intermodal terminals.

In the simulation, both structural properties (description of objects and relation between them) and quantitative properties (model parameters) of the simulated objects are treated as a flexible input. Thus, a general simulation modeling language must be compatible with general simulation algorithms. In order to follow this purpose, two main parts of the transportation terminal modeling and simulation are:

1. a knowledge of transportation terminal(s) and its environment;
2. a general algorithm for control and guidance of simulation processes of

vehicles' movements, cargo handling and storage, and simulation of discrete time advance from event to event.

The new concept of simulation of intermodal terminals has several features that bring about dynamics to every model. In the conventional transportation simulation, any structural change requires amendment of model described in the computer program. On the other hand, using the new concept, any changes required in the model structure amount simply to changes in input data to the general processor which remains constant. To formulate general algorithms, common properties of various objects observed in the terminal and functional relations between them are divided into five classifications:

1. terminal resources (service equipment);
2. storage facilities;
3. cargoes;
4. means of transportation;
5. rules of system functioning.

The first four items, referred to as objects, are terminal properties, while the last one is an essential feature because it represents dynamic interdependencies among objects.

Some approaches in representing rules of terminal functioning must be set in order to be able to provide maximum flexibility of the model. The factors that have to be considered are types of transshipment technologies and the nature of the commodities which might be related. Next, it is necessary to classify the means of transportation. This is specified by the modelers. However, vehicle type descriptions that must be listed are as follows:

1. unique identification of vehicle type;

2. arrival frequency: method of calculation and its parameters;

3. time of the first arrival;

4. economic data: cost associated with one time unit of vehicle stay in the system;

5. information about required operations in the format: $\{o, t, c, m, p\}$, where

   o = operational number

   t = type of operation o: discharging or loading

   c = cargo name

   m = method of calculation of volume of cargo c to be discharged or loaded

   p = set of parameters used for calculation of cargo c volume according to method m

Vehicle arrival frequency may be determined as a fixed value or an interval period between consecutive arrivals. The last one can be either deterministic or probabilistic.

Total number of cargo handling operations for the chosen vehicle mostly are connected with the chosen scale of cargo handling simulation in the model. Here, the total number of cargo handling operations can be defined as either parallel or sequential loading and discharging operations for vehicles. The volume of cargoes during the operations either fixed or probabilistic depends on the type of the vehicle arrival. For instance, the volume of a certain type of cargo at each arrival will be random if the interarrival times are sampled from a probability distribution. A vehicle's servicing activities in the model can be assumed to be a sequential operation since a vehicle operation mainly depends on other activities before it can be initiated.

In some cases, a non-cargo handling operation has also to be considered because this will influence the availability of the cargo handling equipment and other terminal resources. Mainly this is due to random breakdowns, fixed maintenance schedules or other types of withdrawals or additions. Because of this, the arrival frequency in such circumstances may be equivalent to each type of changing, e.g., breakdown frequency.

Before the simulation model is created, modeling rules of terminal system functioning must be defined. This will include all possible functional interactions between modeled terminal objects such as vehicles and cargoes. Here, a set of processes relating to the objects would identify principles according to which the tasks required for specified vehicles and cargoes are to be carried out subject to current availability. This then determines possible behavior of the simulated terminal. In order to ensure the universality of the proposed simulation, it is assumed that the formal semantics in each process is always the same. Each process has four basic components, that is,

(1) cargo transfer direction

(2) cargo name

(3) definition of process efficiency

(4) resources required to carry out the process

In general, the process structure determines the configuration of the objects which interact for a given period of time.

The above process P has a general semantic structure that can be written as follows:

$$\{d.od \text{ -> } r.or;\ c;\ e;\ m; f\}$$

where *d*	:	deliverer from which cargo type *c* is to be transferred
od	:	operation number for *d*
r	:	receiver to which cargo type *c* is to be transferred from deliverer *d*
or	:	operation number for receiver *r*
c	:	cargo that is to be transferred from deliverer (or place) type *d* to receiver (or place) type *r*
e	:	general principle for definition of process *P* efficiency
m	:	method of calculation of process *P* efficiency rate
f	:	set of resources required to carry out process *P*

This process *P* encodes the information if deliverer type *d* of cargo type *c* is ready for operation *od*, and receiver type *r* of cargo type *c* is ready for operation *or*, then the process can be initiated subject to availability of relevant resources *f*, existence of the cargo *c* at the place *d*, and sufficient free space at the location *r*.

In this process, the number of time units (or optionally, cargo units-depending on the chosen principle e) may be sampled from an empirical or theoretical probability distribution or treated as a fixed value. In addition, the servicing priorities can be determined by the users.

If cargo handling does not take place, i.e., only loading and discharging, a general process occurs. In this case the formal structure becomes

$$\{d.od;\, e, m, f\}$$

This means that if object d (vehicle or storage) is ready for operation od then process P will be initiated for the period of time calculated according to method m and subject to availability of indicated resources f.

The above structures will allow us to proceed to the next step: simulation modeling of the transportation terminal operations. The simulation model in this study, TRANSNODE, is written in MS-FORTRAN under XENIX/UNIX and MS-DOS operating systems for IBM PC/AT type microcomputers. Using this program, the users are able to simulate any single freight transportation terminal or a group of terminals. In other words, some portions of the terminal subsystems or flow of cargoes or vehicles can be studied at any level. This simulator is easy to use, flexible and user-friendly. The use of the program requires only an understanding of the terminal under study.

Two main groups of algorithms are used in the simulation, that is,

(1) algorithms that simulate terminal operations and movement of vehicles to and from the terminal according to the model used as input;

(2) algorithms that control the simulation process as a whole.

These algorithms work on the assumption that the simulated system behavior is described according to the semantic convention above. The first algorithms cover the following events:

(1) arrival of vehicles to terminal;

(2) initiation (or activation) of processes according to given rules of system

functioning;

(3) interruption of processes;

(4) interruption and initiation of all terminal processes according to assumed daily and weekly work schedules and determination of occurrence times of the next events;

(5) arrival of vehicles to terminal;

(6) end of currently initiated processes;

(7) end of stoppage in terminal activities (end of daily break of work and free of work weekend period).

The second group deals with higher level of simulation guidance and general utility routines, namely,

(1) length of simulation control;

(2) simulation of real time flow;

(3) procedures for sampling from probability distributions;

(4) collecting observation on terminal system behavior.

The most comprehensive part of these algorithms is that which deals with the initiation of the processes. All groups are translated into a module which is numbered according to its sequence, e.g., arrival of the vehicles to terminal is represented by Module 1.

The main output of the simulation is the vehicle movement and time spent in the simulated system, which indicate the unacceptable queues and waiting times in real life. As predicted, the shortage of cargo handling capacity for unloading ships and loading barges will lead to the vehicle waiting times.

6. Hoare et al. (1992)

In their case study, it is shown that animated computer simulation was successfully employed to provide readily useful output for the management of ore mines. This, as a formal decision support model, promotes consistent decision making, which, in turn, prevents potential losses.

Two main problems that are usually faced by a big corporation such as an ore mine are the efficient management of the operation and the use of capital. Basically, both have a tight relationship because the inefficient operation will result in the misuse of the capital which is initially allocated. A computer simulation will help the management of the company to overcome these problems and aid them in making decisions.

Primarily, the case study was carried out in order to maintain a target total ore production while, on the other hand, the company faced problems in locating ore crushers. The main objective of locating the ore crush was to enable ore production from the upper level "stopes"[1]. It was necessary to relocate the crusher to a lower level at some future date in order to keep the production going on. These two tasks were not easy to be done because they could conflict with the movement of trucks. This could reduce the production rate, in this case, the amount of the ore hauled out by the trucks. The main problem was congestion

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[1] A "stope" is a vertical long open hole blasted in the orebody from which the ore is removed down through a drawpoint on the level below the stope.

if the number of the trucks increased. Thus, in order to meet the target ore production level, a computer model was proposed to simulate the compounded problem formed by crusher location, ever-increasing truck cycle distances, and choices in which sequence to mine the stopes.

The objectives of the computer model were:

1. to determine the long term effects on production of alternatives designs for crushing and rock handling facilities;
2. to provide a facility to test alternative stoping and development strategies (sequences) for the life of the mine with a view to making the best use of resources.

SLAM II was used for simulating the computer model. It was a powerful, fast, economical (low cost), and user-friendly tool, and can be modified as the model applied in an active production environment like ore mines. The SLAM II model was then translated to run under SIMAN and subsequently was animated using the CINEMA software.

The SLAM II computer model of the underground mining operations had up to six concurrently producing stopes, a decline development operation, two concurrent level development areas, a trucking system to service decline development, level development, stoping (if required), an ore-pass system, a crusher system, a hoisting system, a work-cycle control system, and a data collection system.

The outputs of the simulation are graphs that can be easily checked. These are graphs of cumulative production over a 12-month period, graphs of average number of idle trucks, and hoisting production histograms. From these outputs, the level of the performance of the production whether it increases or decreases the maximum number of idle trucks, and truck-demand change can be viewed.

The model has to be validated initially by using a 'base case' where the actual mine data was used for all input assumptions. The output from this base case study, after many replications, was then compared to actual production.

Finally, animation was then introduced to verify or to validate the model. Verification can be done easily because an animation output provided an informative tool as well as it is capable of following several entities at once as they traveled through the systems. Validation was useful for mine experts who inspected and evaluated the animated model. In addition, the animated version of the output was readily accepted by new and relatively inexperienced personnel.

7. Crookes et al. (1982)

They found a substantial benefit of using visual colour simulation when the first generation of microcomputers were introduced. Colour graphics, which were inexpensive and used carefully, could overcome communication problems both between analyst and machine, and between analyst and client. Although it was found that output of the simulation, sometimes, might not convince the client, the dynamic visual representation enabled the non-specialist to judge the correctness of the modelling visualization directly. Based on this, it was recommended to use this method for a wide range of simulation problems.

3

Simulation and Its Environment

3.1. General

Formulating and solving mathematical models that represent real systems can be done directly. However, many problems are so complex making them difficult to be solved analytically. In this case, simulation is the appropriate tool as it often provides practical approaches to complex problems. The main drawback of this approach might be the fact that it is time consuming and relatively expensive.

A simulation is an imitation of the operation of a real-world process or system over time. In other words, it mimics what happens in a real situation. Whether done by hand or on a computer, simulation involves the generation of an artificial history of a system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system (Banks et al., 1995). Some problems sometimes can be represented by only one or more parameters, so they can be solved by mathematical methods, e.g., by differential calculus and algebraic methods.

However, most real-life problems consist of many parameters. "Simulation typically involves the construction of a model that is also largely mathematical in nature. Rather than representing the overall behaviour of a system directly, a simulation model describes operations of the system in terms of individual events of individual components of the system. In particular, the system is divided into elements whose behaviour can be predicted, at least in terms of probability distributions, for each of the various possible states of the system and its input" (Hillier et al., 1986).

In addition to individual events, inherent interrelationships among the elements are also introduced into the proposed model. In other words, simulation breaks down a complex system into small representative elements having unique tasks which can be translated into less complicated formulas. These small elements are then rearranged to their original form according to their sequences.

After the simulation model has been constructed, it can be activated by using random numbers generated according to appropriate probability distributions. The result is a simulation of the actual operation of the system, mainly, over a period of time. In the output, several behaviours of the simulated components, known as objects, are recorded. Because so many parameters are involved in the simulation model, a computer-based simulation needs to be used for obtaining a fast output.

Although the simulation gives some outputs, it does not mean these outputs are the final solution. The output of a particular simulation has to be interpreted by users or experts to draw a conclusion. In other words, a simulation is just an aiding tool for the users.

3.2. When to Use Simulation

Although most problems can be translated into a simulation, not all cases would benefit from using this method. Generally, simulation can be used for the following purposes (Banks et al., 1995):

1. Simulation enables the study of, and experimentation with, the internal interactions of a complex system, or of a subsystem within a complex system.
2. Informational, organizational and environmental changes can be simulated and the effect of these alterations on the behaviour of the model can be observed.
3. The knowledge gained in designing a simulation model may be of great value toward suggesting improvement in the system under investigation.
4. By changing simulation inputs and observing the resulting outputs, valuable insight may be obtained into which variables are most important and how variables interact.
5. Simulation can be used as a pedagogical device to reinforce analytic solution methodologies.
6. Simulation can be used to experiment with new designs or policies prior to implementation, so as to prepare for what may happen.

7. Simulation can be used to verify analytic solutions.

3.3. Simulation Program Requirements

In order to obtain a valid result, the simulation model must be run for a number of replications. Mostly, various alternatives have to be repeated, allowing users to identify the optimal output. Therefore, the simulation program must be flexible enough to accommodate such alternatives. In addition to its flexibility, the simulation program has to be written in a specific purpose programming language rather than in a general one. This will result in selecting the appropriate simulation programming language.

However, some considerations, when selecting the simulation programming language, have to be taken into account. They relate to the objective of the simulation under study. Many criteria that are relevant when selecting the appropriate simulation language or simulation software, have to be taken into account. Such considerations can be listed as the following (Banks et al., 1995):

1. Consider the accuracy and detail required versus what can be achieved with the software being considered. Special purpose simulation software should be examined closely.
2. Select the greatest power that can be afforded. It is expensive to have simulation analysts wait.
3. Beware of fancy advertisements and demonstrations.
4. Beware of checklists with "yes" and "no" as the entries. Implementation and

capability are what is important. Yes and no answers do not indicate the degree of the features.

5. Ask the vendor to solve a small version of your problem.
6. Powerful simulation software can eliminate the need for a feature. This is better than checking for the presence or absence of that feature.

In addition, the simulation programming language selected has also to include several other considerations as the following (Hillier et al., 1986):

- It can provide a convenient means of describing the elements that commonly appear in the simulation model.
- It is capable of expediting changing the design and operating policies of the system being simulated.
- It has an internal time and control mechanism to assist in the kind of bookkeeping required when executing a simulation run.
- It can output a convenient aggregate behavoiur of the system being simulated.
- It provides simple operational procedures, such as introducing changes into the simulation model, initializing the state of the model, altering the kind of output data to be generated, and stacking a series of simulation runs.

3.4. Systems and Components of a System

It is necessary to understand the basic concept of a system before modeling it. A *system*[2] is defined as a group of objects that are joined together in some regular interaction or interdependence toward the accomplishment of some purpose.

Several terms used in a simulation model have to be defined, in order to synchronize the perception of both users and programmers. Most terms[3] that are usually used are as follows:

- *System state* is a collection of variables that contain all the information necessary to describe the system at any time.
- An *entity* is defined as any object or component in the system which requires explicit representation in the model, e.g., a ship.
- *Attributes* are the properties of a given entity, e.g., the priority of a waiting ship.
- A *list* is a collection of (permanent or temporarily) associated entities, ordered in some logical rules, such as all ships currently in a waiting line, ordered by first come, first served, or by priority.
- An *event* is defined as an instantaneous occurrence that may change the state of the system, e.g., an arrival of a new ship.

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[2] This concept, i.e., system, in discrete-event simulation is defined as a collection of entities (e.g., vehicles and ships) that interact together over time to accomplish one or more goals (Banks et al., 1995).

[3] Here are those that are usually used in discrete-event simulation (Banks et al., 1995).

- An *event notice* is a record of an event to occur at the current or some future time, along with any associated data necessary to execute the event; at a minimum, the record includes the event type and the event time.
- An *event list* is a list notices for future events, ordered by time of occurrence; also known as the future event list (FEL).
- An *activity* is a duration of time of specified length (e.g., a service time or inter-arrival time), which is known when it begins (although it may be defined in terms of a statistical distribution).
- A *delay* is a duration of time of unspecified indefinite length, which is not known until it ends (e.g., a vehicle delay in a last in, first out waiting line which, when it begins, depends on the future arrivals).
- A *clock* is a variable representing simulated time.

3.5. Model

The objective of a simulation is to understand relationships between components in a system or to foresee what would happen if a new policy is introduced. This can be done by analyzing the existing system. However, this would not always work. Reason for this is that a new system, in which the new policy will be applied, may not be employed. In other words, the study will be only hypothetical. Another reason is that it would be so impractical to study the existing by altering one or more components. For instance, in order to increase the number of passengers that can be carried in a period of time, it is not necessary to increase the number of ferries in a certain route. Therefore, in order to satisfy the objective of a simulation study, a model of system is then implemented.

Accordingly, a *model*[4] is defined as a representation of a system for the purpose of studying the system (Banks et al., 1995). Because of its complexity, only those factors which are considered to influence the system significantly are studied. In other words, factors that affect the system very much are included in the model. Thus, the model is a simplification of a system.

There are several classifications of models, according to time observation (static or dynamic), statistical contents (deterministic or stochastic), or time division (discrete or continuous). A *static* simulation model, well known as a Monte Carlo simulation, represents a system at a particular time, while a *dynamic* model represents a system from one point at a particular time to another point at a different time. A model is classified as a *deterministic* model if it does not contain any random variables. On the contrary, a stochastic model has one or more random variables as inputs. However, most simulation cannot be stochastic or deterministic alone: a combination has to be made. This is also applicable for other types of simulation models.

Because this study will use discrete-event simulation models, detail concepts about discrete and continuous models are discussed in the following section.

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[4] For discrete-event simulation purposes, a model can be defined as an abstract representation of a system, usually containing structural, logical or mathematical relationships which describe a system in terms of state, entities and their attributes, sets, processes, events, activities, and delays.

3.7. Continuous and Discrete-Event Simulation

There are two general categories of computer simulation: *continuous simulation* and *discrete-event simulation*. Continuous simulation describes events using sets of equations which are solved numerically with respect to time. Here, a time step is typically utilized. This means that the continuous simulation program then steps forward by the increment of time chosen for the time step and recalculates all equations which describe the model.

Discrete-event simulation describes a system in terms of logical relationships which cause changes of state at discrete points in time rather than continuously over time. Examples of problems in this area are most queuing situations: customers in a gas station, air-craft on a runway, jobs in a computer, and ships arrival/departure in a port. In this case, objects arrive and change the state of the system instantaneously. Varying amounts of time elapses between events.

In discrete-event simulation, large or small amounts of simulation time can pass between events, but the state of the system is only of interest when one of its component parts changes state (MODSIM III Tutorial, 1996).

3.8. Event and Process Simulation[5]

The classical approach to discrete-event simulation is event-oriented. In this approach, routines are written to describe discrete events in the operation of a system. For instance, in a simple seaport model the event routines might be:

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[5] MODSIM III Tutorial, 1996

– ship arrives;

– ship enters queue;

– ship engages services of a port;

– ship departs.

No time passes during any event routine. Instead, passage of time is handled by scheduling the next event for the object currently being manipulated. In this simple seaport model, the event "ship engages services of a port" would schedule the next event, "ship departs", at some future time.

This event-oriented approach is adequate for smaller models, but in larger models, it is often difficult to follow or modify the flow of logic which describes the behavior of an object, such as a ship.

In contrast to these circumstances, the process approach simplifies larger models by allowing many aspects of an object behavior in a model (e.g., ships) to be described in one method which allows for the passage of time at one or more points in its code.

There is a further advantage to the process technique. Once the actions of a class of objects (such as ships in a port) have been grouped together in an object, the simulation program can create multiple, concurrent instances of the object. In the above example, the simulation program would generate a new instance of the ship object each time a new ship arrived. It could also pass information about the ship in the parameter list of the object's initialization method. Perhaps it would pass in information about the type of the ship (ferry or general cargo) and the expected service time for the ship. While there would be multiple, distinct copies of the ship object operating simultaneously, each could have different values of their fields to describe the particular ship's properties.

Finally, objects can interact. For the seaport case above, an instance of the ship object with the *ferry* attribute might yield its place in the queue to a ship object with the *general cargo* attribute.

The advantages of processes are both conceptual and labour-saving. The process statements are expressed sequentially, in a manner which is analogous to the system being described. This practice is recommended by standard design methodologies.

3.8. Steps in a Simulation Study

Any simulation study has the same set of stages as can be depicted in figure 3.1. These steps in a simulation study are as follows (Banks, et al., 1995):

1. Problem formulation

   A problem statement under study has to be clearly defined by those who have the problem and understood by the analyst. Reformulated the problem as the study progresses is also included in this stage.

2. Setting of objectives and overall project plan

   The objectives indicate the question to be answered by the simulation. The overall project plan should include a statement of the alternative systems to be considered, and a method for evaluating the effectiveness of these alternatives.

3. Model conceptualization

Because there is no formal instruction for model conceptualization, it can be developed by an ability to abstract the essential features of a problem, to select and modify basic assumptions that characterize the system, and then enrich the model, until a useful approximation is obtained. In other words, a simulation has to be started from a simple to a complex one, by modifying it continuously.

4. Data collection

There is a close relationship between the construction of the model and the collection of the needed input data: the more complex the model, the more variety of the data that to be collected. This collection has to be done as early as possible since it requires much time. Types of the data depend on the objectives of the study. Most of them will be used to depict the behaviour of an activity. This can be done by using an appropriate distribution for a particular activity.

5. Model translation

Since most real-world systems result in models that require a great deal of information storage and computation, a computer is required ti aid process. For this reason, the model must be entered into a computer recognizable format. In addition, care must be taken whether selecting a simulation language or using a special-purpose simulation software.

6. Verification

Verification pertains to the computer program prepared for the simulation model. The reason is to check whether the computer program is performing properly. With complex models, it is difficult, if not possible, to translate a model successfully in its entire without a good deal of debugging. If the input parameters and logical structure of a model are correctly represented in the computer, verification has been completed. For the most part, common sense is used in completing this step.

7. Validation

Validation is the determination that a model is an accurate representation of the real system. Validation is usually achieved through the calibration of the model, an iterative process of comparing the model to actual system behaviour and using the discrepancies between the two, and the insights gained, to improve the model. This process is repeated until model accuracy is judged acceptable.

Several techniques can be used (Hillier et al., 1986), depending on data availability of the system, namely,

- Outputs of the real system that has already been in operation are compared with that of the simulated one. This can be done by either using statistical tests or asking experts familiar with the behavoiur of the real system.

- When the model is intended to simulate several alternatives for a proposed system for which no actual data are available, a *field test* can be conducted by collecting some real data. This real data is then compared with the output of the proposed system. However, this technique, i.e., the field test, is too expensive and time consuming.
- If there is no real data available at all, the only way to validate the model is to have knowledgeable people carefully check the credibility of output data for various situations.

In order to continue the validation process, records of the model output have to be kept for future purposes.

8. Experimental design

The alternatives that are to be simulated must be determined. Often, the decision concerning which alternatives to simulate may be a function of runs that have been completed and analyzed. For each system design that is simulated, decisions need to be made concerning the length of the initialization period, the length of simulation runs, and the number of replications to be made of each run.

9. Production runs and analysis

Production runs, and their subsequent analysis, are used to estimate measures of performance for the system designs that are being simulated.

10. Rerun

Based on the analysis of the runs that have been completed, the analyst determines if additional runs are needed and what design those additional experiments should follow.

11. Documentation and reporting

Program documentation is necessary for numerous reasons. If the program is going to be used again by the same or different analysts, it may be necessary to understand how the program operates. This will enable confidence in the program so that model users and policymakers can make decisions based on the analysis. In addition, if the program is to be modified by the same or a different analyst, this can be greatly facilitated by adequate documentation. Another reason for documenting a model is that model users can change parameters of the model as the work progresses. On the report side, frequent refinement is suggested (after Musselman, 1994). This may or may not be the results of major accomplishments. Possibilities prior to the final report include a model specification, prototype demonstrations, animation, training results, intermediate analyses, program documentation, progress reports, and presentation.

12. Implementation

The success of the implementation phase depends on how well the previous 11 steps have been performed. It is also contingent upon how thoroughly the analyst has involved the ultimate model user during the entire simulation process. If the model user understands the nature of the model and its outputs, the likelihood of a vigorous implementation is enhanced (after Pritsker, 1995). Conversely, if the model and its underlying assumptions have not been properly communicated, implementation will probably suffer, regardless of the simulation model validity.

3.10. Object-Oriented Simulation

This type of simulation, as it is stated by its name, takes the advantages of an object-oriented programming, simplifying simulation procedures. It exploits object-oriented programming features to simplify both the original development and the subsequent maintenance of large models. Object oriented programming is a type of programming in which programmers define not only the data type of a data structure, but also the types of operations (functions) that can be applied to the data structure.

In this type of programming, there is a fundamental unit or concept called the *object*. An object is a self-contained entity that consists of both data and procedures to manipulate the data. Thus, by this concept, the data structure becomes an object that includes both data and functions. Programmers therefore can create relationships between one object and another. To do so, objects can inherit characteristics from other objects. Inheritance allows programmers to reuse existing objects, by adding some new attributes.

One of the principle advantages of object-oriented programming techniques over procedural programming techniques (conventional programming) is that they enable programmers to create modules. A module is a part of a program. Programs are composed of one or more independently developed modules that are not combined until the program is linked. A single module can contain one or several routines. These modules do not need to be changed when a new type of object is added. A programmer can simply create a new object that inherits many of its features from existing objects. This makes object-oriented programs easier to modify.

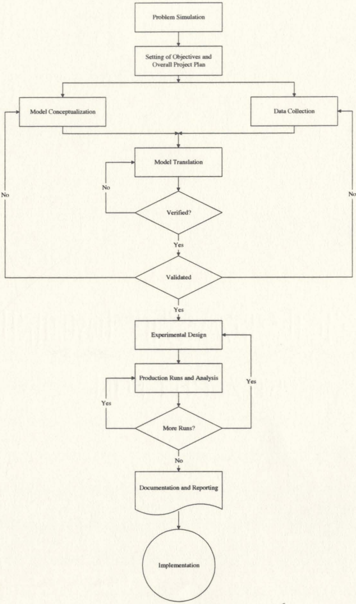

Fig. 3.1. Steps in a simulation study[6]

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[6] Banks et al., 1995

4

Problem Environment

4.1. Port Operation and Function

Park et al. (1987) considered that the primary function of a port is to transfer passengers, vehicles and raw commodities between island and marine modes of transportation. Depending on the state of congestion, the ship may have to wait in the offing. After berthing, passengers and vehicles can depart the ship directly while cargoes may be transported in several ways. The cargo is unloaded onto the quay. It can then be directly taken into the inland transport terminals (highway), or it can be removed to barges for further transport by waterway. If the route is indirect, the cargo is moved into the storage system and transferred at a later time to inland destinations. Departing commodities, of course, follow the reverse process. This procedure is also applicable for the ferry operation in a small to medium port, in which several activities can be omitted, such as unloading cargo to barges and use of cranes.

The sequence of operation and commodity movement in the port is as in Figure 4.1. The port operation process can be divided into two major components: marine transport mode operation and cargo handling operation. While cargo transportation procedure has to follow these two operations, two others, i.e., passengers and vehicles, only utilize the first mode of operation.

In this study, the cargo is carried by cargo vehicles[7], i.e., trucks. In other words, the cargo does not occupy any space on board, but rather on the vehicles. The quantity of the cargo carried by the ship will be proportionally related to the truck capacity (which will be discussed in detail in Database Section). Because of this, the cargo does not require cargo handling equipment, making the unloading/loading process simple and fast.

4.2. Multi-Port Modeling Concept

The use of object-oriented process simulation model is necessary to model not only the quantitative properties (Kondratowicz, 1990), as they appear in the conventional model, but also their structural properties. Thus, this study will apply this type of simulation.

In this study, the main port, i.e., port of Ambon, is the destination port of several outports: Sanana, Namlea, Tulehu, Saparua, Amahai, Tehoru, Werinama, Banda, and Saumlaki. Thus, the main port will function as a single server that serves many ships from a number of seaports. It can also be assumed that the main port works as a single terminal. Based on this assumption, a terminal simulation concept is then formalized. This simulation

[7] Trucks will be used instead of cargo vehicles, in order to differentiate these with non-cargo vehicles,

concept can be organized into two main parts:

1. Knowledge base on the terminal/port and its environment, i.e., description of simulated objects and interactions between them. These components are totally treated as variable input to the simulator.

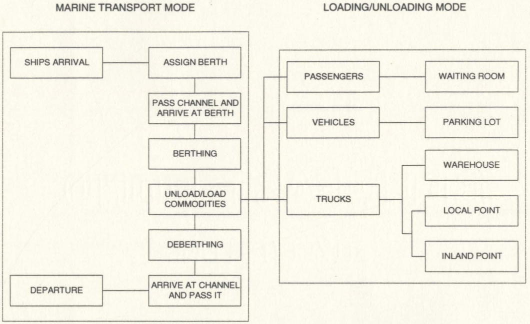

Fig. 4. 1. Modelling structure of a ferry simulator

2. Simulator: general algorithm for control and guidance of simulation processes of movement of passengers, and vehicles, as well as simulation of discrete advance from event to event. The simulator also contains supporting routines for data input (i.e., the input of information elements and decision elements of a concrete model), their formal and logical control, initiation of simulation process, standard procedure for

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which are then called cars.

sampling from various probability functions, editing outputting of simulation results.

4.3. Process of Simulation

Simulation is performed by two main groups of algorithms:

1. Algorithms that simulate ship operation, i.e., sailing at sea and waiting in the offing, and movement of vehicles to and from the ship according to the model used as input. This study will mainly evaluate the movement of the vehicles because vehicles are assumed to dominate the whole loading/unloading process in the port.
2. Algorithms that control the simulation process as a whole.

4.4. Port Simulation Study

This port simulation study has to consider several qualities of the port, from which the simulation model will be developed. This information is as follows:

- A port has its maximum number of vessels that can be accommodated at the same time, i.e, the capacity (Darzentas et al., 1996). This is determined by the number of berths or a total length of ship-berth space which can accommodate several ships at any one time, depending on the ships' length (El Sheikh, et al., 1987).
- A port operation process in a simulated port consists of two modes: marine transport mode (ships), commodity handling mode (Park et al., 1987).

4.5. Assumptions of a Port Model

1. A certain volume of traffic (of passengers, vehicles and cargo) is considered to be transported from the main port to a number of outlying ports. In the same manner, from these surrounding ports, almost the same volume of commodities is shipped to the main port.
2. The commodities (vehicles and cargo) are assumed to be mixed. In other words, several types of vehicles and cargoes can be unloaded/loaded at the same time.
3. Ships arrival and departure follow a fixed schedule, i.e., issuing by the port authority.

4.6. Objective of the Simulation

The objective is to determine the configuration of resources (ship types and numbers as well as the number of docks) in order to have feasible level of operating costs for a given volume of traffic (passengers, vehicles and cargo). Factors that should be considered are:

- Size of the port

  The size of the port will determine the port operation, reflected by its capacity to serve ships at one time. In this study, the size of the port is considered as a fixed entity.

- Weather conditions

  Weather conditions, winds and rain, will affect significantly both the port operation and the ship voyage: the operation may be delayed due to bad weather and the ship will travel not in its optimum speed. Because these factors are uncontrollable, a set of random numbers will be used to represent these natural phenomena.

- Geographical condition

  Each route has a different distance, making ship trips vary and creating delays in the main port

4.7. Attributes in Simulation

Before going further, attributes for all components, weather, commodities, port terminal and ships, have to be clearly defined. This is a crucial stage in object-oriented simulation.

1. Attributes for weather

   Weather mainly includes rain and winds. Thus, the attributes for weather could be a combination between both of them.

   Rain : heavy, medium or clear;

   Winds : speed and its directions.

   However, since no data about weather was available, this natural condition will be represented by a random distribution which can reasonably configure this phenomenon.

2. Attributes for commodities

Passengers are considered to have only one attribute, number of passengers, while two others have several.

Vehicle attributes:

- Type : two or four wheeler, minibus or truck, passenger or non passenger vehicles;
- Capacity : number of passengers on board or cargo volume/weight carried;
- Size : length and width.

In this study, only three types of vehicles will be utilized: cars, 2-ton trucks and 4-ton trucks. The last two types are for carrying cargo.

Cargo attributes:

- Type : vegetables, rice, wood, electronics, etc.;
- Weight : ton;
- Volume : m^3;

Here, only type of cargo and its weight will be accounted for.

3. Berth attributes

- Offing : distance from berths;
- Channel : length;
- Crane : number and its lifting capacity;
- Forklift : number of forklift and its carrying capacity;
- Warehouse : number of warehouses and its storing capacity;

- Waiting room for passengers : capacity;
- Parking lot for waiting vehicles : area, m^2.
- Berths : number of quays/docks

However, since data pertaining to most port information was unavailable, only the number of docks in can be used in the model building,

4. Attributes for ships

- Speed : knots;
- Size : length, breadth, draught;
- Type of loading and loading : end or side.
- Capacity : cargo carrying capacity, vehicle carrying capacity and passenger carrying capacity;

As such, type of loading/unloading of a particular ferryboat cannot be included in this study.

4.8. Model Rules

Out of three traffic components, passengers, vehicles and cargo, the model considers only two of them: vehicles and cargo. The reason for this is that passengers do not influence resources very much since their space requirements are not significant nor is the time needed for them to board or disembark the ferries significant. The number of the passengers that have to be transported is considered fixed and below the passenger carrying capacity. In addition, passenger loading and unloading process is much simpler than those of vehicles and cargo.

Thus, ship service provided by the port depends on two factors: type of cargo and type of vehicles. In general, the type of the cargo will determine the length of the service time because different type of cargo needs different type of cargo handling, which, in turn will qualify the service time. This is also applicable for the vehicles: large vehicles (e.g., trucks) need more time to get in to the vessel than the smaller ones (e.g., cars). However, in this study, the length of the ship service time will only be determined by vehicle types. The reason for this is that cargo will be carried in trucks.

For the model building purpose, types of the cargo will be selected and fixed for a particular outport. Thus, a ship would have a fixed type of cargo when it needs to be serviced in a port. On the contrary, vehicles composition carried by the ship will be specified randomly, following a certain rule. Such a rule may be that the number of large cars should not be more than four, while the quantity of the smaller cars does not exceed 10.

The other important factors that have to be taken into account are the cost of loading/unloading operations in port and expenses during the voyage of the ship. The first allocation will determine whether the service given by a port is feasible or not, while the latter is all expenses incurred during the ship operation at sea. Since most of the ship operation is at sea, the latter would be of greater portion (see Section 4.12.).

Regarding costs spent at port by a ship, there may be several types of costs such as berthing costs, lamp costs, fuel costs, and fresh water costs. The amount of the first two costs will vary based on the length of stays in a berth, while the last two would fluctuate depending on the ship's size.

Here, the main goal of a cost study is to obtain the optimum (minimum) level of daily total costs spent on a particular route. In doing so, several configurations or scenarios will be tried. Those that result in the lowest level of total costs will be considered as the optimum level in accordance with the service provided by the port. Generally, the service will be directly related to two factors: the number of berths in a port and the number of the ships to be served in a berth. Two cases might happen: the number of the berths is too many making the ships have to wait in the offing, or there are a lot of ships waiting outside the port area because of lack of berths. The former case might occur if there were not enough workers to unload/load a ship, which has berthed. Thus, it has to be decided how many berths have to be built in order to satisfy the ships.

4.9 Database

The simulation will be run based on the concept that the annual quantity of entities, i.e., passengers, cars and cargo, will be consumed by the ships through its annual operation. In other words, the ships will carry the passengers, vehicles, and the cargo from its origin ports to the main port gradually according to the ship capacity until the annual amount/number of each commodity expires. Each loading from any port for each transshipment will be based on a random number. Mathematically, this process is done by subtracting some amount (a number) of commodities (or passengers) from the annual total quantity.

For this purpose, a database containing a detail configuration of each commodity (and passengers) has to be set up. The database could comprise information as depicted in the Table 4.1. The annual number of passengers transported from a port of origin is obtained by using an estimate calculation from a previous study (JICA 1993)[8]. Since no information regarding the annual number of cars and the annual amount of cargo carried by a particular vessel from the outlying ports, these items are quantified arbitrarily. The other information is types of cargo from the ports of origin and its annual quantity. Along with this, ship type also needs to be defined in each route in order to model possible ferry operations in that route. Ship type is classified based on its capacity, speed, and its principal dimensions[9], as outlined in Table 4.2.

The ship type chosen for a particular route is influenced by the length of the route, the quantity of the commodity and number of passengers. This means that the longer the distance, the larger and the faster the ship needed. On the contrary, the number of the ships would increase as the routes are getting shorter. Reason for this is that the demand also increases. The number of the ships and its type in a particular route is then arbitrarily allocated based on these assumptions. More than one type of ferry, therefore, would serve the line. In this study, however, all types of ship will be applied in order to determine which one(s) would be suitable for a particular route.

In addition, when a ship travels back to a particular outport, it carries a commodity that is usually needed in the outport neighbourhood. Here, this type of commodity is assumed

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[8] See Appendix III.

[9] JICA 1993

to be the same for all outports: common manufactured goods. It is assumed (arbitrarily) that the quantity is 80% of the amount of cargo shipped from a particular outport.

Table 4.1 Quantities of commodities from ports of origin to the main port, Ambon, and common manufactured goods to be shipped to the minor ports

	Port of Origin	Sanana	Namlea	Tulehu	Saparua	Amahai	Tehoru	Werinama	Banda	Saumlaki
P	Qty.	6,081	17,999	65,514	26,173	29,511	17,618	11,699	2,590	13,066
V	Qty.	152	450	1,638	654	738	440	292	65	327
C	Type	T	T	0[10]	F	R	R	T	F	F
	Qty. (ton)	4,500	7,500	0	10,000	25,000	15,500	7,500	10,000	7,000
S	Type	C'	C'	C	C, D	A, B	B,C'	C	C'	B
	Qty.	1	2	2	2	2	2	2	1	2
G	Qty. (ton)	3,600	6,000	0	8,000	20,000	12,400	6,000	8,000	5,600

P	:	Passengers	R	:	Rice	S :	Ship/Ferry Types
V	:	Cars (Sedan and alike)	F	:	Fish	G :	Manufactured Goods
C	:	Cargo	T	:	Timber		

It is assumed that the cargo is transported by 2-ton or 4-ton trucks with its fully loading capacity, i.e., 100%. This means that each truck is assumed to carry exactly 2 tons and 4 tons cargo respectively. Thus, the amount of the cargo shipped by the ships will be reflected by the number of the trucks. Likewise, the ship also experiences fully loaded capacity, with any fluctuations according to random availability of the commodity to be shipped (See 4.11.).

Table 4.2 Ship types and capacity

Type	Speed (Knot)	GRT	LOA (m)	B (m)	A (m^2)	Capacity			
						Passenger	Cars	4^t-T	2^t-T
A	15.00	1,000	70	14.0	686	600	108	36	72
B	12.00	500	47	11.5	378	500	60	20	40
C	10.00	300	39	10.5	287	350	45	15	30
C'	12.50	300	39	10.0	273	300	42	14	28
D	9.50	150	30	8.0	168	100	27	9	18

GRT : Gross Registered Tonnage

LOA : Length Over All

B : Breadth

A : Car deck area

2^t T, 4^t T : 2-ton trucks, 4-ton trucks

Although the port plays an important role in this operation, i.e., loading/unloading, it is considered to have no effects during the operation. As a result, a fixed state is implied, making the loaded/unloaded commodities automatically leave the port area, i.e., the berth, without any influence from port facilities. In other words, all operations in the ports are self-activities without assisted by any means, e.g., cargo handling equipment, until each commodity expires.

[10] "0" means that it is assumed no commodities are carried because inland transportation modes are preferable.

4.10 Multi-Ports Simulation

This multi-ports simulation model works based on the assumption that a certain fixed amount of goods must be shipped from each outport to the main port. Ferry operation is assumed to begin at the main port. Here, ferryboats are located in a common pool, from which a ship is deployed, in this case, to sail to a particular outport. Before sailing, this ship has to load some amount of manufactured goods. In doing so, there will not always be a ship available, making the goods wait until a ship comes to the pool. In addition to this wait, a ship can be delayed when there is no space available for unloading/loading vehicles, that is, when all docks are in use. It is assumed that each quay in the berth can serve only one ship at one time.

The sailing time can be obtained by calculating the voyage time of each ship in a particular route (the routes are illustrated in Figure 4.2.). This type of time, i.e., voyage time, t_v, is then calculated using a velocity-distance relationship, as in the following.

$$t_v = \frac{s_o}{v_j} \tag{4.1}$$

o	=	port of origin
t_v	=	voyage time, hour
s_o	=	route distance, nautical mile
v_j	=	j-type ship velocity, knot
j	=	A, B, C, C', D

In order to find the actual voyage time, this theoretical voyage time will be assumed to vary randomly: up to 20% longer than its standard level.

The results of this calculation are listed in table 4.3. This table shows voyage time of every ship serving all routes from a number of outports to the Ambon as the main port.

When a ship arrives in the outport, it will be served in free berth space without waiting. Service time starts when the ship berths at any available quay. The length of the service time will vary depending on the size of the ship and the type of the cargo as well as its amount on board. Thus, in order to represent these circumstances, a random number, chosen from a beta distribution, will be applied.

Table 4.3 Voyage time

Port of Origin	Distance to Ambon (nautical miles)	Ship		Voyage Time (hour)
		Type	Speed (knot)	
Sanana	178	C'	12.50	14.24
Namlea	81	C'	12.50	6.48
Tulehu	32	C	10.00	3.20
Saparua	36	C	10.00	3.60
		D	9.50	3.79
Amahai	58	A	15.00	3.87
		B	12.00	4.83
Tehoru	94	B	12.00	7.83
		C'	12.50	7.52
Werinama	127	C	10.00	12.70
Banda	118	C'	12.50	9.44
Saumlaki	348	B	12.00	29.00

As discussed earlier, only vehicles will play a significant role in loading/unloading processes. In fact, there are two types of vehicles: cars (non-cargo vehicles) and trucks. Thus, service time for one ship will be determined by the total number of all vehicles going into and out of the ship.

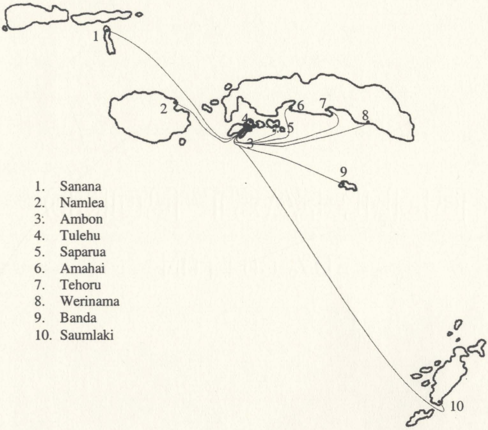

Fig. 4. 2. Routes

It is then assumed that each type of vehicle, i.e., cars, 2-ton trucks and 4-ton trucks, will have a range of loading/unloading time, (t_l / t_u). Each of them will have a single random number of loading/unloading time that would follow beta distribution. Since service time is an aggregate time of the loading and unloading operations, i.e., vehicle movement, this type of time will be counted with regard to these operations. Although each operation has the same property, that is, beta distributed and follows the same pathway in/out, both are somewhat different. Factors distinguishing both of them are merely the smoothness of the operations. It is considered that the loading operation will take more time than the opposite one. Here, it is assumed that the unloading operation would be 30% shorter than loading.

Since a beta distribution has two parameters, i.e., α and β, these parameters can be obtained by applying reasonably estimates of the loading time (Hillier et al., 1986). Three estimates will be used, that is, a most likely estimate (denoted by m), an optimistic estimate (a) and a pessimistic estimate (b). These estimates are then used for calculating the variance (σ^2) and the mean/expected value (μ) of the corresponding beta distribution. The variance and the expected value can be expressed as follows:

$$\sigma^2 = \left[\frac{1}{6}(b-a)\right]^2 \tag{4.2}$$

$$\mu = \frac{1}{3}\left[2m + \frac{1}{2}(a+b)\right] \tag{4.3}$$

where a, b and m values of beta distribution for each type of vehicle are listed in Table 4.4.

After unloading the commodities, the reversed operation takes place. When the loading is accomplished, the ship then returns to the main port. For doing so, it has to travel for a certain time, so-called returning time, t_r, which is about the same duration as the voyage time. The returning time is therefore assumed the same with its parallel time, unless natural phenomena, such as heavy rain and windstorm, occur. If such circumstances happen, each time, either voyage or returning time, has to be compensated by a certain portion of the normal time, say, ranging randomly from 0% to 20% of the time.

Table 4.4 Estimate values for beta distribution

	a (minutes)	m (minutes)	b (minutes)
Car	2	2.5	4
4-ton Trucks	4.5	5	7
2-ton Trucks	3	3.5	5.5

Upon arrival in the main port, the ship completes its round trip, t_t. Congestion may occur when a ship approaches the main port. Here, the ship has to wait in the offing because there is no free space available in the berths. For this reason, waiting time, t_w, has to be accounted for.

A round trip of the ship, t_t, will be obtained by summing up the voyage time, loading/unloading time, waiting time and returning time. Accordingly, a formula for this relationship can be written, viz.

$$t_t = 2(t_w + t_l + t_u) + t_r + t_v \tag{4.4}$$

4.11. Single Route Operations

Before a complete model is built, a single port-to-port model has to be established. This simplification, depicting time spent by a ship from a particular outport to the main port

, is done in order to observe a single route operation behaviour. The single operation can be depicted as a simple diagram as shown in Figure 4.3.

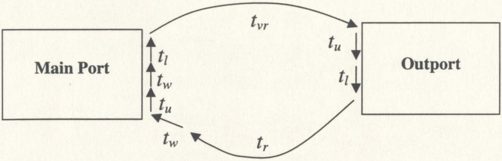

Fig. 4. 3. Single route diagram

As the ship moves back and forth between the main port and an outport, the commodities are transferred. The quantity of each item carried in each shipment will vary over time. As a result, the annual quantity, Q_c, where c is the type of a particular shipped item, i.e., passengers (Q_1), cars (Q_2) and cargo (Q_3), will decrease until it is completely shipped. The quantity of the item that has been transported up to the *ith* trip, Z_{ci}, can be defined using the following relationship,

$$Z_{ci} = \begin{cases} 0 & , i = 1 \\ \sum_{k=1}^{i-1} X_{ck} & , i \geq 2 \end{cases} \quad (4.5)$$

where X_{ck} is quantity of the c-type commodity carried on *ith* trip.

Thus, the quantity to be transported on the *ith* trip will be a random number such that, in general,

$$0 \quad \leq \quad X_{ci} \quad \leq \quad \mathrm{Min}\left(Y, Q^R\right) \tag{4.6}$$

where Y is the ship capacity for the commodity and Q^R is the remaining quantity needed to be shipped.

Each ship has its capacity for carrying commodities, that is, Y_1 is the passenger carrying capacity, Y_2, vehicle carrying capacity and Y_3, cargo carrying capacity. While passengers occupy a specific designated space on board, that is, passenger decks, vehicles and cargo share the same area, i.e., car decks. In this simulation, cargo will not use any space on board, since it will be assumed that it is carried by trucks. As a result, Y_3 is blended with Y_2.

Because cargo is carried by trucks, which are defined as a type of vehicle, a vehicle allocation rule on the car decks has to be applied. Such a rule is to determine how many vehicles of each type are to be loaded.

All trucks carried by the ship are assumed to deliver one type of cargo as defined previously (see Table 4.1) and will be fully loaded. Thus, the quantity of the cargo that will be shipped will be represented by the number of trucks on boards, for instance, 10 4 ton trucks on the ship means that 40 tons of cargo will be transported to the main port.

Since two types of trucks, 2-ton and 4-ton trucks, are used for carrying the cargo, a conversion has to be made. Reason for this is to obtain the total number of trucks (along with cars) that can be transported on one trip. Truck sizes are then converted into an equivalent number of cars. Thus, for instance, the equivalence between cars and trucks could be defined as: three cars = two 2-ton trucks = one 4-ton truck

Because of the vehicle allocation rule, equation (4.6) has to be modified. Since cargo will be carried by trucks, there is no necessity to use X_{3i}. The variable X_{1i} represents the number of passengers, X_{2i},the number of cars, $X_{4t,\,i}$, the number of 4-ton trucks and $X_{2t,\,i}$, the number of 2-ton trucks. Accordingly, four random numbers will be generated in the following manner:

$$0 \leq X_{1i} \leq \mathrm{Min}\left(Y_1, Q_{1i}^R\right) \tag{4.7}$$

$$0 \leq X_{2i} \leq \mathrm{Min}\left(K_1, Y_2, Q_{3i}^R\right) \tag{4.8}$$

$$0 \leq X_{4t,\,i} \leq \mathrm{Min}\left(K_{2,}\ \frac{Y_2 - X_{2i}}{3}, \frac{Q_{3i}^R}{4}\right) \tag{4.9}$$

$$0 \leq X_{2t,\,i} \leq \mathrm{Min}\left(K_{3,}\ 2\frac{Y_2 - X_{2i} - 3X_{4t,i}}{3}, \frac{Q_{3i}^R - 4X_{4t,i}}{2}\right) \tag{4.10}$$

The parameters K_1, K_2 and K_3 have been introduced since the other terms, such as Y_2, provide too large an upper bound. On site observations indicate that the amount of vehicular traffic is in general quite small. Without these terms, the simulation would conclude in a much shorter, and unrealistic time, by shipping large numbers of trucks. Previous surveys indicate that reasonable values for K_1, K_2 and K_3 would be around 15, 10 and 15 respectively. It also can be seen from equation (4.6) to (4.8) that the priority for loading is given to cars, then 4-ton trucks and lastly, 2-ton trucks. The reason for the latter preference is that 4-ton trucks (4-t) are more economical than 2-ton trucks (2-t). 2-ton trucks are still transported after a certain number of 4-ton trucks are selected.

However, these conditions need to be considered carefully when the annual quantities to be shipped are close to being filled. In these circumstances, X_{2i}, which is randomly generated, would most likely never equal the end value of Q_{2i}^R and as a consequence further trips might be necessary to transport what would be a small quantity of goods. For example, if Q_{2i}^R is less than K_1, to bring the simulation to a conclusion X_{2i} is set to be Q_{2i}^R. Similarly,

$$\text{if } \frac{Q_{3i}^R}{4} \le \frac{Y_2 - X_{car,i}}{3}, \text{ then } X_{4t,\,i} = \frac{Q_{3i}^R}{4} \tag{4.11}$$

and

$$\text{if } \frac{Q_{3i}^R - 4X_{4tr,i}}{2} \le 2\frac{Y_2 - X_{2i} - 3X_{4t,i}}{3}, \text{ then } X_{2t,\,i} = \frac{Q_{3i}^R - 4X_{4tr,i}}{2} \tag{4.12}$$

Q_{2i}^R, the remaining number of cars to be transported, can be expressed as the following:

$$Q_{2i}^R \quad = \quad Q_2 \quad - \quad Z_{2i} \tag{4.13}$$

where Z_{2i} is defined by (4.5).

Likewise, Q_{3i}^R, the remaining quantity of cargo to be shipped, is written as below:

$$Q_{3i}^R \quad = \quad \begin{cases} Q_3 & , i = 1 \\ Q_3 - \sum_{k=1}^{i-1} \left(4X_{4t,i} + 2X_{2t,i}\right) & , i \ge 2 \end{cases} \tag{4.14}$$

The condition to be met before a ship sails is that one of Q_{1i}^R, Q_{2i}^R or Q_{3i}^R must be non-zero, otherwise the ship operation is terminated. The following statement must be applied:

$$\text{If } \left\{Q_{1i}^R = Q_{2i}^R = Q_{3i}^R = 0\right\} \text{then} \begin{cases} \mathit{True} & \text{, Terminate the operation} \\ \mathit{False} & \text{, Load the remaining commodity} \end{cases} \tag{4.15}$$

In the same manner, total round-trip time, t_t, can also be aggregated for the whole operation of the ship until the quantity of the commodity in the port of origin expires.

$$T_t \quad = \quad \sum_{i=1}^{N} t_{ti} \qquad (4.16)$$

where t_{ti} = round-trip time of a ship on *ith* trip

4.12. Cost Classification

Costs are one of the most important factors, beside time allocation, for determining whether ship operations are profitable or have to be improved. Despite some differences in definition, costs are seen as expenditures by the producers to generate goods or services (Chrzanowski, 1985). Here, costs will be viewed from the ship operator's perspective.

Generally, the costs in shipping environment will be distinguished into three groups: vessel overhead expenses, voyage expenses and cargo or direct costs. Because of time considerations, this study will discuss the costs that are directly connected with the ship operations: voyage expenses and direct costs. The other reason for this is that the first expense is assumed fixed. In other words, they are allocated in advance before the ship runs. In a traditional fashion, those expenses are called fixed costs, whereas variable expenditures are variable costs.

Voyage costs will include those related with running the ship under normal operating conditions. These items are:

1. fuel costs: in transit and in port in tons per day per hour;
2. port dues and charges: harbour dues, wharf dues, lighthouse and buoys, port

authorities (police, sanitary, customs).

Direct costs vary as demand of the cargo, i.e., its quantity, handled to/from the ship fluctuates. Here, such costs will also be connected with passengers and vehicles carried. The following items are included in these type of costs:

1. cost connected with loading and discharging of cargo: stevedores, carriage from/to the ship, tallying, and measuring/weighing;
2. passenger costs: passenger related expenses incurred on board such as stewards' wages.

4.13. Cost Analysis

In order to find the optimum level of operation of the ship during its operation, i.e., the whole year, the above costs have to be further categorized in terms of the economist point of view. In this case, costs can also be grouped into four classifications: total, average, marginal, and opportunity costs. These will consider the ship's size, distance traveled, speed, etc. to determine the influenced factors that affect the ship operation.

Since the fixed costs are assumed to be constant, the variable costs will be used for analyzing the ship performance, that is, to obtain the optimum costs. Starting from this assumption, a cost analysis will be carried out in order to obtain the performance of the ship on a particular route, i.e., whether its operation is profitable or needs subsidizes.

Types of costs that can be analyzed for the ferry operation are fuel costs and port dues. These costs are classified as running costs of the ship because they are spent as the ship sails. Fuel costs depend upon the size of the ship, speed and its type. In general, the larger and the faster the ship, the more fuel will be consumed. Port dues are fixed, however the amount is proportional to the time spent by the ship in a port. These two expenses must be paid generally on a daily basis during which a ship operates.

4.14. Calculation for Obtaining Direct Costs of Ships

Several calculations can be carried out in order to obtain several optimum performances of ships, i.e., the optimum size and speed of ships. This calculation can be used to find direct costs of the ships. The optimum size of ships is calculated by using the deadweight tonnage (DWT) of the existing ships and those under study. Based on the known DWTs, several components, such as ships capital costs, can be computed. This is done by applying several proportionality relationships. On the contrary, the optimum speed of ships is attained by using a formula.

For given DWTs[11], the initial capital cost of vessels, C; the speed, s; fuel consumption, f; and the running costs of vessels, C_R, can be calculated using several relationship as in the following:

$$C = C_2\left(\frac{W}{W_2}\right)^{2/3} \tag{4.17}$$

$$s = s_2\left(\frac{W}{W_2}\right)^{1/6} \tag{4.18}$$

[11] After Thorburn, T. (Evans et al., 1990)

$$f = f_2 \left(\frac{W}{W_2} \right)^{0.75} \tag{4.19}$$

$$C_R = C_{R(2)} \left(\frac{W}{W_2} \right)^{0.3} \tag{4.20}$$

where C_2, s_2, f_2, $C_{R(2)}$, and W_2, are capital cost, speed, fuel consumption, daily running costs, and deadweight tonnage of a reference ship, respectively. W, is the deadweight tonnage of a particular ship under study. Since only GRT of the ships under study is available, DWT can be obtained by the following procedures:

- 1 DWT = 1.6 NRT (net registered tonnage)[12];
- NRT = 0.8 GRT;
- One DWT = 1.28 GRT

Consequently, the results[13] of the above entities for several ferryboats can be seen in Table 4.5.

However, the calculated speed, s, is not close to the actual/design speed of the ships. Thus, for obtaining the optimum speed a different method is then proposed. Similarly, the fuel consumption, f, is also much higher than several actual specifications from a catalogue (World Marine Engines and Propulsion Systems, 1998). For this reason, fuel consumption

[12] Ibid.

[13] Calculated using 64,500 DWT ship as a reference ship, except for finding s (26,600 DWT)

will be obtained from a range of actual data of medium-speed diesel engines[14]. From this catalogue, specific fuel consumption is selected.

Table 4.5 Ship's performance

Type	Design Speed, s_o (knots)	GRT	W	C (US$)	s (knots)	f (tons/day)	C_R (US$)
A	15.00	1,000	1,280	2,272,280	8.74	2.59	1,737
B	12.00	500	640	1,431,447	7.79	1.54	1,411
C	10.00	300	384	1,018,301	7.15	1.05	1,210
C'	12.50	300	390[15]	1,028,881	7.17	1.06	1,216
D	9.50	150	192	641,489	6.37	0.62	983

where C_2 = US $ 31,000,000

s_2 = 14.5 knots

f_2 = 49 tons/day

$C_{R(2)}$ = US $ 5,629/day

In selecting the appropriate specific fuel consumption, shaft horse power (SHP) of the corresponding engines must be known. SHP can be obtained by using the Admiralty Number, A_n (Muckle, 1975).

$$A_n = \Delta^{2/3} V^3 \tag{4.21}$$

[14] Medium speed engines are those which have RPM (rotation per minute) between 500 to 1,000.

[15] One DWT is arbitrarily set to be 1.3 GRT because this ship (C'-type) has somewhat larger size than the C-type.

and

$$\Delta = 1.026\, L_{PP}\, .\, B\, .\, T.\, C_b \tag{4.22}$$

where Δ : displacement of a particular ship in longtons,

L_{PP} : length between perpendiculars ($\approx L_{OA}/110\%$),

c_b : block coefficient,

T : draft of the ship (m),

V : speed of the ship (knots).

Because the result, which is tabulated in Table 4.6, is in kilowatt; it has to be converted to horsepower (metric) by dividing it by 0.735.

Table 4.6 SHP

Ship Type	V	L_{OA}	L_{PP}	B	T	Δ	SHP
A	15	70	63.64	14	3.5	2,239.48	642.11
B	12	47	42.73	11.5	2.6	917.53	181.36
C	10	39	35.45	10.5	2.2	588.21	78.03
C"	12.5	39	35.45	10	2.75[16]	700.25	171.19
D	9.5	30	27.27	8	1.5	235.05	36.30

It is found that the specific fuel consumption is about the same for the medium speed of marine diesel engines, i.e., 149 $\frac{\text{gram}}{\text{HP}-\text{hour}}$ or 0.003583 $\frac{\text{ton}}{\text{HP}-\text{day}}$. Fuel consumption per day is then gained by multiplying the selected specific fuel consumption by the corresponding SHP of engines.

[16] This ($T_{C''}$) is arbitrarily selected since the actual data was unavailable.

Two states will be used for calculating the optimum speed of ships: when time in port is ignored and when it is included. For these reasons, a daily gross-profit formula, G_s, is applied. This relationship involves freight rate per ton of cargo, R; tonnage of the ship, W; running costs per day, C_R; price of fuel per ton, p; route distance, d; constant of proportionality, k, and the speed of the ship, s.

Constant of proportionality, k, can be calculated using a relationship between design speed of the ships, s_o and fuel consumption, f. This relationship is expressed as in the following:

$$k = \frac{f}{s_o^3} \tag{4.23}$$

f can be obtained by using the result from the engine catalogue.

Freight rate per ton of cargo, R, is arbitrarily set to be the same for all routes, that is, \$0.25 per ton cargo.[17] Similarly, price of fuel per ton, p, is also set to be \$100 per ton. Rate of cargo handling per day, r, is 150 ton per day.

When the time spent by the ship in a port is ignored, the daily gross profit is

$$G_s = \frac{RW}{d/s} - C_R - pks^3 \tag{4.24}$$

To find the optimum speed of ships, differentiate G_s with respect to s and equate the result

[17] In this study, freight rate is applicable only for cargo.

to zero, yielding:

$$s = \sqrt{\frac{RW}{3pkd}} \tag{4.25}$$

When time in port, t, and port dues, D, are considered, the daily gross surplus is given by

$$G_s = \frac{RW - D}{\frac{d}{s} + t} - C_R - \frac{pks^2 d}{\frac{d}{s} + t} \tag{4.26}$$

Similarly, to find the optimum speed, differentiate G_s with respect to s and equate to zero, giving:

$$2s^2 t + 3ds^2 + \frac{D - RW}{pk} = 0 \tag{4.27}$$

This equation must be solved numerically.

A ferryboat spends a short period of time in a port if compared to its voyage time at sea; it is thus assumed that time in port is ignored in finding optimum speed of the ship. As a result, based on this assumption, the optimum speed of the ships, s, is calculated using equation (4.25).

From this calculation, cost of time in port, C_p, and cost of time at sea, C_s, can be obtained:

$$C_p = \frac{2W}{r}(C_D + C_R), \tag{4.28}$$

$$C_s = \frac{d}{s}(C_D + C_R) + \frac{d}{s}pf, \tag{4.29}$$

where C_D is daily capital costs and C_R is running costs.

$$C_D = \frac{C \text{ x CRC}}{350}$$

$$= \frac{\frac{i(1+i)^n}{(1+i)^n - 1} C}{350} \tag{4.30}$$

Equation (4.30) is based on the assumption that a vessel life, n, is 18 years, interest rate, i, 5%, and its service time is 350 days per annum. C is obtained from Table 4.4.

Therefore, the total operating cost, C_T, for a ship travelling a distance d is

$$C_T = C_p + C_s$$

$$= \frac{2W}{r}(C_D + C_R) + \frac{d}{s}(C_D + C_R) + \frac{d}{s} pf \tag{4.31}$$

The results of the optimum speed, s, and costs, C_p, C_s, and, C_T, for each ship can be seen in Table 4.7 and Table 4.8.[18]

For a set of fixed values, i.e., R, p and r, the results shows two phenomena, that is:

1. The optimum speed of ship for a short distance route, such as Ambon-Tehoru, is far beyond its design speed.
2. The optimum speed of ship for a medium-to-long distance route, such as Ambon-Banda and Ambon-Saumlaki, is about the same as the design speed.

Reasons for the above phenomena might be due to the given fixed values of several expenditures such as freight rate, R, and rate of cargo handling, r. These two instances may

[18] See Appendix I for a complete list.

vary from one port of origin to another. In other words, these must be different according to the distance.

Table 4.7 Optimum speed of ships

Port of Origin	d (miles)	Ship Type	Design Speed, s_o (knots)	f[19] (tons/day)	DWT (tons)	Optimum Speed, s (knots)
Sanana	178	C"	12.5	0.7096	390	11.0
Namlea	81	C"	12.5	0.7096	390	16.3
Saparua	36	C	10	0.2874	384	27.2
	36	D	9.5	0.1613	192	23.8
Amahai	58	A	15	2.3518	1,280	25.2
	58	B	12	0.6772	640	23.7
Tehoru	94	B	12	0.6772	640	18.6
	94	C"	12.5	0.7096	390	15.1
Werinama	127	C	10	0.2874	384	14.5
Banda	118	C"	12.5	0.7096	390	13.5
Saumlaki	348	B	12	0.7096	640	9.7

Table 4.8 Costs (US$)

Port of Origin	Ship Type	C	C_D	C_R	C_p	C_{so}	C_s	C_{Tso}	C_{Ts}
Sanana	C'	1,028,881	251	1,216	7,630	21,904	24,932	29,534	32,561
Namlea	C'	1,028,881	251	1,216	7,630	9,968	7,653	17,597	15,283
Saparua	C	1,018,301	249	1,210	7,470	5,356	1,966	12,826	9,436
	D	641,489	157	983	2,918	4,380	1,747	7,298	4,665
Amahai	A	2,272,280	555	1,737	39,116	9,772	5,824	48,888	44,940
	B	1,431,447	350	1,411	15,022	8,836	4,468	23,858	19,490
Tehoru	B	1,431,447	350	1,411	15,022	14,320	9,219	29,342	24,241
	C'	1,028,881	251	1,216	7,630	11,567	9,568	19,197	17,197
Werinama	C	1,018,301	249	1,210	7,470	18,894	13,026	26,365	20,496
Banda	C'	1,028,881	251	1,216	7,630	14,521	13,457	22,150	21,086
Saumlaki	B	1,431,447	350	1,411	15,022	53,016	65,666	68,038	80,689
							Total:	305,093	290,084

C_{Tso} and C_{Ts} are total daily direct costs at design speed, s_o, and at optimum speed, s, respectively.

[19] Obtained from World Marine Engines and Propulsion Systems, 1998

5
Computer Simulation and Results

5.1. Simulation Language

The model defined in the previous chapter has been implemented in a computer simulation program using MODSIM III. MODSIM III is a general-purpose, modular, block structured language which provides support for object-oriented programming and discrete-event simulation (MODSIM Tutorial, 1996). This program language is designed for being able to handle a large-complex problem such as ferry system problem under study. The main feature of this language is the process-oriented approach which allows time to pass in concurrent instances of the objects.

5.2. Model Translation

In the computer program[20], the primary object is the ship object. There are, in fact, five different types of ship objects which are derived from five separate pools of ships, corresponding to the five types of ships. The ships characteristics are defined by `shipObj` which contains the related data and associated methods (see Table 5.1).

Table 5.1 `shipObj`

```
shipObj = OBJECT
        name              : STRING;
        count             : INTEGER;
        type              : INTEGER;
        size              : INTEGER;
        source            : STRING;
        cars              : INTEGER;
        trucks4t          : INTEGER;
        trucks2t          : INTEGER;
        cargo             : REAL;
        cargotype         : STRING;
        arrived           : INTEGER;
        MinTime           : REAL;
        sailingTimeOut    : REAL;
        sailingTimeBack   : REAL;
        loadingtime       : REAL;
        unloadingtime     : REAL;
        cargotime         : REAL;
        Cp                : REAL;
        Cs                : REAL;

        TELL METHOD Arrive(IN il   : INTEGER);
        ASK METHOD Loadcars (OUT ncars   : INTEGER);
        ASK METHOD Loadship (IN il   : INTEGER;OUT cargol     : REAL);
        ASK METHOD LoadshipM (IN il   : INTEGER;OUT cargol     : REAL);
        ASK METHOD Load4ttrucks (INOUT weight    : REAL);
        ASK METHOD Load2ttrucks (INOUT weight    : REAL);
        TELL METHOD Sail(IN il   : INTEGER);
        ASK METHOD Setsize (IN i,k,n      : INTEGER);
    END OBJECT;
```

The ship objects are descendants of `ResourceObj` which allows the user to limit the

[20] Computer program was developed in collaboration with Dr. G. C. W. Sabin, Faculty of Applied Science and Engineering, Memorial University of Newfoundland. The author mainly provided core ideas while he translated them into computer codes.

number of ships allowed in the (sea transportation) system under study (`METHOD SetNumberAllowed`). The dock is an object which is also of `ResourceObj` type which allows the number of docks to be limited.

The overall progress of the model is defined by the `METHOD Generate`. All input to the model is contained in the file "ship_data.txt" (see Table 5.2 for explanation) and output is written to "port_output.txt". A complete list of the computer program can be seen in Appendix II.

Table 5.2 Input Data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	1	1	1	0.01			
2	2.	2.5	4.				
3	4.5	5.	7.				
4	3.	3.5	5.5				
5	0.	7.	20.				
6	0.	6.	15.				
7	0.	4.	10.				
8	0.	6.	15.				
9	8						
10	Sanana	178	152	timber	4500	1	5
11	Namlea	81	450	timber	7500	1	5
12	Saparua	36	654	fish	10000	2	5, 3
13	Amahai	58	738	rice	25000	2	1, 2
14	Tehoru	94	440	rice	15500	2	3, 5
15	Werinama	127	292	timber	7500	1	3
16	Banda	118	65	fish	10000	1	4
17	Saumlaki	348	327	fish	7000	1	2
18	Shipdata						
19	5						
20	A	15.	108	1280	555	2.3518	2
21	B	12.	60	500	350	0.6772	2
22	C	10.	45	300	249	0.2874	4
23	CP	12.5	42	300	251	0.7096	3
24	D	9.5	27	150	157	0.1613	3
25	100						
26	64500						
27	5629						
28	49						

where:

Line 1 : - column 1 is number of replications;

- column 2 is minimum number of berths;

- column 3 is maximum number of berths;

- column 4 is increment for waiting ship in the main port to load commodity;

Line 2-4 : column 1, 2 and 3 are a, m and b of loading time for cars, 4 ton trucks and 2 ton trucks, respectively;

Line 5 : column 1, 2 and 3 are a, m and b for the actual voyage time (t_v), respectively;

Line 6-8 : column 1, 2 and 3 are a, m and b for K_1, K_2 and K_3, respectively;

Line 9 : the number of routes in accordance with a particular outport;

Line 10-17 : - column 1 is a corresponding outport;

- column 2 is a route distance;

- column 3 is annual number of cars to be shipped;

- column 4 is type of raw commodity;

- column 5 is annual quantity of raw commodity to be transported;

- column 6 is number of types of ships serving the route;

- column 7 is type of ship in the route;

Line 18 is comment for `Shipdata`

Line 19 is the number of ship types used in the model;

Line 19-24 : - column 1 is type of ships;

- column 2 is ship speeds;

- column 3 is ship car carrying capacity;

- column 4 is daily capital cost, C_D, of a particular ship;

- column 5 is daily operating costs, C_R, of the ship;

- column 6 is fuel consumption of the ship;

- column 7 is the number of a particular type of ship (as in column 1);

Line 25 is cost of fuel;

Line 26 is deadweight tonnage (DWT) of the reference ship;

Line 27 is daily running costs of the reference ship;

Line 28 is fuel consumption of the reference ship.

5.3. Results

Eight basic scenarios have been tried since two types of vessels in each route are used in three routes, that is, Saparua-Ambon, Amahai-Ambon and Tehoru-Ambon. However, in the model, more configurations could be examined. These configurations varied the number of docks utilized in the main port, type of ships and its number in each route. Other components that could be varied are constants K_1, K_2 and K_3 for cars, 4-ton trucks and 2-ton trucks respectively. The reason for this is that these constants were obtained empirically and this values could easily be questioned.

Tables 5.3 – 5.6 are representative scenarios. Note that each table includes all routes. Routes are numbered from 1 to 8, representing each route from a particular outport, that is, Sanana, Namlea, Saparua, Amahai, Tehoru, Werinama, Banda, and Saumlaki. A list of trial and error output of the computer program can be seen in Appendix IV.

Each component in a table can be classified as in the following:

- C_T (column 2) is daily total operating costs of a particular ship in a particular route;

- C_p (column 3) is costs spent by a ship in a port;
- C_s (column 4) is costs spent by a ship during its travel at sea;
- Column 5 is the number of trips needed to accomplish transporting annual quantity of raw commodity in a particular route;
- Column 6 is time (total number of days) for a vessel (vessels) to ship all raw commodities from an outport to the main port;
- Column 7 is the aggregate time needed by all ferryboats to transport the annual quantity of raw commodity. This means that each of them may be overlapped (operate at the same time) during the operation;
- Column 10 shows the number of each type of ship allocated in each pool.

Although the output of the computer program was obtained by using a trial and error method, which depends on the user discretion, the following comments can be used as guidance in understanding the system:

- Try the first input program (as shown in Table 5.3).
- Next, observe the time (column 6) in each route. If it exceeds 350 days, this means that the number of ships needed to serve a route (routes) is less than has been allocated. Change the number of ships allocated in the corresponding pool. Likewise, if it much less than 350 days, then reduce the number of ship in the associated pool. (see alteration made in Table 5.4). As a result, the total annual costs for the whole system is somewhat lower than of the previous scenario.

Table 5.3 Output 1a
Number of docks in the main port = 1

Ship		Ship Pool							
Route	Type	No.	# of Ships	K_1	K_2	K_3	μ_1	μ_2	μ_3
1	CP	Pool 1	1	15	10	15	6	4	6
2	CP	Pool 2	3						
3	D	Pool 3	2						
4	A	Pool 4	4						
5	B	Pool 5	1						
6	C								
7	CP								
8	B								

Route	C_T (US$)	C_p (US$)	C_s (US$)	**# of Trips**	**Time (days)**	**Operating Time (days)**	**Annual Quantity of Cargo**	**Ship Type**	**# of Ships**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	412,781	119,037	293,745	163	71	218.81	4,500	CP[21]	4
2	448,918	212,400	236,518	289	150	190.41	7,500	CP	4
3	390,106	175,689	214,416	596	249	233.63	10,000	D	1
4	5,557,253	4,776,134	781,119	915	414	398.61	25,000	A	1
5	1,547,596	858,650	688,946	582	213	454.32	15,500	B	3
6	657,160	211,630	445,530	286	177	344.54	7,500	C	2
7	741,135	281,714	459,421	385	197	353.25	10,000	CP	4
8	1,504,960	380,928	1,124,032	257	382	675.28	7,000	B	3
Total	11,259,910	7,016,181	4,243,729						

- After this, further changes could be made in order to improve calendar day in each route while still keeping the total costs reasonable (compared to previously proposed). Types of ships used in a particular route can be replaced with either a larger or a smaller one. It was hypothesized that the types of ships utilized in several routes (route 1, 2 and 5) are too large as shown in Table 5.4. Thus, smaller ships were then introduced. As a result, total annual costs spent in the

[21] CP = C'

whole system drop at a significant level (see Table 5.5). However, the calendar days increase extremely in many routes (routes 2, 3, 4, 5 and 7). This means that the selected ship was either too small.

Table 5.4 Output 1h
(The same configuration as in Output 1a, except pool 1 contains 2 of ship type A, pool 2 contains 4 of ship type B, pool 4 contains 3 of ship type CP and pool 5 contains 2 of ship type D).

Route	C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	442,742	127,381	315,361	175	124	234.45	4,500	CP	3
2	440,211	206,834	233,377	285	218	188.1	7,500	CP	3
3	388,243	174,657	213,586	594	131	233.01	10,000	D	2
4	5,527,726	4,752,251	775,475	908	213	395.34	25,000	A	2
5	1,522,004	844,978	677,026	572	172	446.72	15,500	B	4
6	653,466	209,259	444,207	286	179	344.1	7,500	C	2
7	734,236	278,747	455,489	382	266	350.72	10,000	CP	3
8	1,517,246	382,962	1,134,284	259	288	681.69	7,000	B	4
Total	11,225,874	6,977,068	4,248,806						

- At last, locate routes that experienced a significant increase in time and make a further alteration. Two possibilities may occur: the selected ships are too small or the number is insufficient. Here, the latter will be anticipated by increasing the pool size for the ship type on the route in question. The new configuration and the result can be seen in Table 5.6.
- Note that each configuration can be tried by changing K_1, K_2 and K_3, μ_1, μ_2 and μ_3 as well as the number of quays in the main port.

Table 5.5 Output 7i

(The same configuration as in Output 1h, except that the ship types in routes 1, 2 and 5 are changed to D, D and C, respectively as well as pool 2 is decreased to 2 ships and pool 3 is increased to 4 ships).

Route	C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	561,456	79,604	481,852	271	234	460.28	4,500	D	2
2	499,147	133,165	365,982	452	418	364.32	7,500	D	2
3	382,225	171,613	210,612	585	534	230.07	10,000	D	2
4	5,602,209	4,814,941	787,268	922	210	400.16	25,000	A	2
5	1,091,999	423,764	668,235	580	141	531.96	15,500	C	4
6	655,369	209,244	446,125	287	223	345.5	7,500	C	4
7	733,912	279,110	454,802	381	120	350.33	10,000	CP	3
8	1,501,677	379,637	1,122,040	256	339	674.2	7,000	B	2
Total	11,027,994	6,491,078	4,536,916						

Table 5.6 Output 7j

(The same configuration as in Output 7i, except pool 5 contains 3 of ship type D).

Route	C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	548,230	77,384	470,846	264	152	450.01	4,500	D	3
2	492,321	131,212	361,109	446	275	359.87	7,500	D	3
3	390,896	175,587	215,309	598	354	234.83	10,000	D	3
4	5,555,789	4,776,407	779,383	912	208	396.49	25,000	A	2
5	1,091,933	424,643	667,290	580	141	531.41	15,500	C	4
6	626,960	200,736	426,224	274	220	330.56	7,500	C	4
7	740,947	281,664	459,283	385	121	353.38	10,000	CP	3
8	1,535,747	387,116	1,148,630	262	347	690.07	7,000	B	2
Total	10,982,823	6,454,750	4,528,073						

5.4. Interpretation

Outputs of the computer simulation program can be interpreted in many ways. In this case, time will be discussed in detail since this factor shows the ship operation in the sea transportation system under study. In the output tables as shown above, two types of time appeared in column 6 and 7. The first one is a calendar time which reflects the actual operating time (days) in a year, while the latter is the total annual operating time (days) spent by several ships on a particular route.

Since the allocated operating days for a ship is considered 350 per annum, the calendar time (column 6) obtained from the computer program has to be less than 350 days. The total annual operating time is the real time for transporting all annual quantities of commodity from an outport to the main one. Accordingly, it sometimes could be more than 350 days. This could happen because this time is an aggregate amount of ships operating time in the route.

In selecting the appropriate scenarios, along with the annual allocated operating days (350 days), another concern has also to be mentioned. With this regard, the actual calendar days should not be far below this allocated time. In other words, the value must be close to 350. Regarding this matter, a subjective judgement may involve since it could be different depending on who interprets it. In general, when interpreting the actual operating time from the computer program, probable idle time has to be noted. This normally happens in the region where the traffic demand is not too high, such as in some routes in the region under study. Therefore, by using these criteria, appropriate scenarios for the whole transportation system can be obtained, for instance, as shown in Table 5.4 or Table 5.6.

Since the initial scenario (Table 5.3) is used as a reference, the output is then analyzed first. Time in each route is mostly less than 350 days as expected in the case of very short at routes in which traffic demand is very low. Here, route 1 shows a distinctive result because its annual time i.e., time needed by ships for carrying the annual quantity of a commodity, is extremely low. In fact, this could be understood that the annual quantity of commodity is also very low. On the contrary, the size of the ship served this route is considered too large.

These circumstances can be tolerable and interpreted that the ship in this route (type CP) may operate one or two days in a week with regard to the low level of demand. This could be improved by introducing less capacity ships. By doing so, it is expected that the time increases. In other words, the new type of ship can operate more frequently than the initial one. This would benefit those who use this ferry service (mainly communities nearby the outport) because more trips are available.

In other routes, although most times are not too short, the service can also be upgraded by the same approach. In addition, the number of ships in a route where time is more than 350 (route 8) could be increased. The reason for this is that the traffic demand is somewhat high, requiring more ships to be put in operation.

After trying a number of configurations (including variations of K_1, K_2 and K_3, μ_1, μ_2 and μ_3 as well as the number of quays in the main port), it was found that scenario as listed in Table 5.4 shows a significant improvement. Time in all routes increased, reaching a reasonable level (less than 350 days but not low). Although time is the main concern in improving the whole system, another consideration was also looked at: total annual direct costs. The total costs obtained falls somewhat lower than that obtained using the previous configuration.

It is assumed that when alteration is made, the total costs would increase particularly when larger ships are selected. It is also hypothesized that if the number of a particular type of ship is increased, the costs rise. However, the output in Table 5.4 shows different results (see route 5 and 8 which are served by B-type vessel). These are acceptable since the total trips (for transporting annual commodity) drops considerably.

On the contrary, when a smaller ship is introduced or when its number is reduced, the costs are expected to expand. However, the output shows otherwise (see route 1 and 2). As with the increasing number of ships, this can be accepted because the trips increase.

Although what was obtained using the scenario as shown in Table 5.4 is considered acceptable and reasonable, more scenarios could be tried. Other factors that can be used are ship configuration in the pools and types of ships utilized on each route. After trying several configurations, two results will be discussed as shown in Table 5.5 and Table 5.6.

Since the time in route 1 may be extended, a smaller ship (D type) was selected. Care must be taken when changing the type of ship that will be used. The main reason is the fact that the type of ship chosen may be used on other routes. Since ships are put into five common pools according to its type, some routes may share the same resources, i.e., ships, for instance.

In selecting a D type ship for replacing a CP type, it was assumed that the time span in route 1 could be extended to a certain level. There is only one way of doing so: operating D type ships since this is the smallest one available. It was also hypothesized that the number of the ships in the common pool for this ship type could be reduced. The reason was to find whether it affected the time in routes 2 and 3. In fact, it could be predicted that if the number (of the selected type) was reduced the time in both routes might increase significantly. The reason for this is that the annual commodity shipped from the corresponding outport is relatively high.

As predicted, the time in routes 2 and 3 after running the configuration defined in Table 5.5, inflate almost double what was obtained previously (Table 5.4). However, another configuration can be made in order to improve the time in these routes. This was done by simply increasing the number of ships since its number was reduced when selecting this type from CP. The result of this configuration can be seen in Table 5.6.

A substantial improvement was obtained in time and costs. The total costs of the whole system are much lower than that of the initial scenario, while the time in all routes are considered satisfactory. Although it was found that the time in route 4 slightly exceeds 350 days, i.e., 354, this value is tolerable.

The above example of suitable scenarios might not be the best result, since it was obtained by trial and error. By continuing this process, a better result may be achieved.

5.5. Result Implementation

The results of the computer simulation may be applied in several ways. Since the computer model simulates the system under study as one system, only the total costs of the whole system can be used for practical purposes. Here, the purpose is to allocate the total amount of budget for subsidizing the annual ferryboat operation.

The reason why it is difficult to implement the results of a particular route is merely due to the use of common pools. Since a pool can be shared by several routes, it is very difficult to distinguish exactly how many trips or days is spent by an associated ship on a particular route.

6 Conclusions and Recommendations

6.1. Conclusions

Simulation has been used as a tool for solving a complex and complicated system whose components interact in a complex manner. By using this method, a ferry transportation system in an archipelagic region as in the Province Maluku has been analyzed. Although it is difficult to build a realistic model, a reasonable approach has been introduced. Such an approach has been used in developing algorithms pertaining to the main elements of the ferry system operations: the loading/unloading process at a port and sailing at sea. In addition, total operating costs were also used for measuring the operation of ships in a particular route as well as the whole system. A computer program was then used to implement the model.

Before running the computer program, a preliminary calculation can be performed. This is to analyze the total operating costs of a particular ship operating on a particular route.

By doing so, it can be predicted whether the ship is oversized or undersized.

By analyzing the output of the computer model, it can be concluded that:

- time needed by a ship (ships) to transport a commodity on a particular route is proportional to its number in the corresponding pool and is reversibly related to the size/type;
- number of ships and its type determine the amount of the total costs of the whole system.

6.2. Recommendations

Since most data in this study was inaccessible, this study was done by assuming that a ship on particular route transports the annual amount of a raw commodity. Thus, this study can only analyze the annual operation of the ships in the system. Further studies for analyzing a shorter period of ship operations have to be carried out. The reason is that a detail (daily) observation may be necessary in order to analyze the longer one (annual operation).

Major weakness of this study is that operation of ships on a particular route half of the model, i.e., ports of origin activities, is ignored. Reason for this is that there would be a waiting time as two activities at both ports, i.e., the port of origin and the main port, occur.

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Appendix I
Optimum Speed of Ships and Costs

Table A.1 Optimum Speed of Ships

Port of Origin	Distance to Ambon, d (miles)	Ship Type	Design Speed, s_o (knots)	f[22] (tons/day)	DWT (tons)	Optimum Speed, s (knots)
Sanana	178	A	15	2.3518	1,280	14.4
		B	12	0.6772	640	13.5
		C	10	0.2874	384	12.3
		C"	12.5	0.7096	390	11.0
		D	9.5	0.1613	192	10.7
Namlea	81	A	15	2.3518	1,280	21.3
		B	12	0.6772	640	20.1
		C	10	0.2874	384	18.2
		C"	12.5	0.7096	390	16.3
		D	9.5	0.1613	192	15.9
Saparua	36	A	15	2.3518	1,280	31.9
		B	12	0.6772	640	30.1
		C	10	0.2874	384	27.2
		C"	12.5	0.7096	390	24.4
		D	9.5	0.1613	192	23.8
Amahai	58	A	15	2.3518	1,280	25.2
		B	12	0.6772	640	23.7
		C	10	0.2874	384	21.5
		C"	12.5	0.7096	390	19.2
		D	9.5	0.1613	192	18.8
Tehoru	94	A	15	2.3518	1,280	19.8
		B	12	0.6772	640	18.6
		C	10	0.2874	384	16.9
		C"	12.5	0.7096	390	15.1
		D	9.5	0.1613	192	14.7
Werinama	127	A	15	2.3518	1,280	17.0
		B	12	0.6772	640	16.0
		C	10	0.2874	384	14.5
		C"	12.5	0.7096	390	13.0
		D	9.5	0.1613	192	12.7
Banda	118	A	15	2.3518	1,280	17.6
		B	12	0.6772	640	16.6
		C	10	0.2874	384	15.0
		C"	12.5	0.7096	390	13.5
		D	9.5	0.1613	192	13.2
Saumlaki	348	A	15	2.3518	1,280	10.3
		B	12	0.6772	640	9.7
		C	10	0.2874	384	8.8
		C"	12.5	0.7096	390	7.9
		D	9.5	0.1613	192	7.7

[22] World Marine Engines and Propulsion Systems, 1998

Table A.2 Costs

Port of Origin	Ship Type	C	C_D	C_R	C_p	C_{so}	C_s	C_{Tso}	C_{Ts}
Sanana	A	2,272,280	555	1,737	39,116	29,989	31,311	69,105	70,427
	B	1,431,447	350	1,411	15,022	27,117	24,022	42,139	39,044
	C	1,018,301	249	1,210	7,470	26,482	21,613	33,952	29,084
	C"	1,028,881	251	1,216	7,630	21,904	24,932	29,534	32,561
	D	641,489	157	983	2,918	21,657	19,212	24,575	22,130
Namlea	A	2,272,280	555	1,737	39,116	13,647	9,612	52,763	48,728
	B	1,431,447	350	1,411	15,022	12,340	7,374	27,362	22,396
	C	1,018,301	249	1,210	7,470	12,051	6,635	19,521	14,105
	C"	1,028,881	251	1,216	7,630	9,968	7,653	17,597	15,283
	D	641,489	157	983	2,918	9,855	5,898	12,773	8,815
Saparua	A	2,272,280	555	1,737	39,116	6,065	2,848	45,181	41,964
	B	1,431,447	350	1,411	15,022	5,484	2,185	20,507	17,207
	C	1,018,301	249	1,210	7,470	5,356	1,966	12,826	9,436
	C"	1,028,881	251	1,216	7,630	4,430	2,268	12,060	9,897
	D	641,489	157	983	2,918	4,380	1,747	7,298	4,665
Amahai	A	2,272,280	555	1,737	39,116	9,772	5,824	48,888	44,940
	B	1,431,447	350	1,411	15,022	8,836	4,468	23,858	19,490
	C	1,018,301	249	1,210	7,470	8,629	4,020	16,099	11,490
	C"	1,028,881	251	1,216	7,630	7,137	4,637	14,767	12,267
	D	641,489	157	983	2,918	7,057	3,573	9,974	6,491
Tehoru	A	2,272,280	555	1,737	39,116	15,837	12,016	54,953	51,132
	B	1,431,447	350	1,411	15,022	14,320	9,219	29,342	24,241
	C	1,018,301	249	1,210	7,470	13,985	8,294	21,455	15,765
	C"	1,028,881	251	1,216	7,630	11,567	9,568	19,197	17,197
	D	641,489	157	983	2,918	11,437	7,373	14,354	10,291
Werinama	A	2,272,280	555	1,737	39,116	21,396	18,870	60,513	57,986
	B	1,431,447	350	1,411	15,022	19,348	14,477	34,370	29,499
	C	1,018,301	249	1,210	7,470	18,894	13,026	26,365	20,496
	C"	1,028,881	251	1,216	7,630	15,628	15,025	23,258	22,655
	D	641,489	157	983	2,918	15,452	11,578	18,370	14,496
Banda	A	2,272,280	555	1,737	39,116	19,880	16,900	58,996	56,016
	B	1,431,447	350	1,411	15,022	17,977	12,966	32,999	27,988
	C	1,018,301	249	1,210	7,470	17,555	11,666	25,026	19,136
	C"	1,028,881	251	1,216	7,630	14,521	13,457	22,150	21,086
	D	641,489	157	983	2,918	14,357	10,370	17,274	13,287
Saumlaki	A	2,272,280	555	1,737	39,116	58,630	85,593	97,746	124,709
	B	1,431,447	350	1,411	15,022	53,016	65,666	68,038	80,689
	C	1,018,301	249	1,210	7,470	51,774	59,083	59,244	66,553
	C"	1,028,881	251	1,216	7,630	42,824	68,153	50,453	75,783
	D	641,489	157	983	2,918	42,340	52,518	45,258	55,436

Appendix II
Computer Program

```
(* Simulation model of a ferry transportation system between one main port and
   8 outports.

   Prepared by G. Sabin and S. Buana *)


MAIN MODULE port;

FROM IOMod IMPORT StreamObj, FileUseType(Input,Output);

FROM ResMod IMPORT
    ResourceObj;

FROM SimMod IMPORT
    StartSimulation, SimTime, ResetSimTime;

FROM RandMod IMPORT
    RandomObj, FetchSeed;

FROM IOMod IMPORT
    ReadKey;

FROM MathMod IMPORT POWER;


(**********************************************************************)
VAR


    numofIslands          : INTEGER;
    fileout               : StreamObj;
    filein                : StreamObj;
    mindocks              : INTEGER;
    maxdocks              : INTEGER;
    startTime             : REAL;
    numberReplications    : INTEGER;
    commodity             : STRING;
    waitduration          : REAL;
    K1                    : INTEGER;
    K2                    : INTEGER;
    K3                    : INTEGER;
    alpha                 : FIXED ARRAY [1..7] OF REAL;
    beta                  : FIXED ARRAY [1..7] OF REAL;
    poor                  : FIXED ARRAY [1..7] OF REAL
    likely                : FIXED ARRAY [1..7] OF REAL;
    best                  : FIXED ARRAY [1..7] OF REAL;

    random                : RandomObj;
    random2               : RandomObj;
    random3               : RandomObj;
    random4               : RandomObj;
    dock                  : ResourceObj;
    carsum                : INTEGER;
```

```
    carcount                : INTEGER;

(*************************************************************************)
TYPE
    IslandData = FIXED RECORD
        Name                : STRING;
        distance            : INTEGER;
        carquota            : INTEGER;
        carsShipped         : INTEGER;
        commodquota         : REAL;
        commoditytype       : STRING;
        QuantityShipped     : REAL ;
        numofships          : INTEGER;
        shiptypes           : FIXED ARRAY [1..2] OF INTEGER;
        quotasFilled        : BOOLEAN;
        Cscost              : REAL;
        Cpcost              : REAL;
        numofTrips          : INTEGER;
        TotalTime           : REAL;
        runtime             : REAL;

    END RECORD;

    FleetAObj = OBJECT(ResourceObj)
        OVERRIDE
            ASK METHOD ObjInit;
            ASK METHOD ObjTerminate;
        CLASS
            numberAllowed   :INTEGER;
            ASK METHOD  SetNumberAllowed(IN num : INTEGER);
    END OBJECT;

    OBJECT FleetAObj;
        ASK METHOD  ObjInit;
        BEGIN
            DEC(numberAllowed);
        END METHOD;

        ASK METHOD ObjTerminate;
        BEGIN
            INC(numberAllowed);
        END METHOD;

        ASK METHOD SetNumberAllowed(IN num  : INTEGER);
        BEGIN
            numberAllowed := num;
        END METHOD;
    END OBJECT;

    FleetBObj = OBJECT(ResourceObj)
        OVERRIDE
            ASK METHOD ObjInit;
            ASK METHOD ObjTerminate;
```

```
    CLASS
        numberAllowed    :INTEGER;
        ASK METHOD  SetNumberAllowed(IN num : INTEGER);
END OBJECT;

OBJECT FleetBObj;
    ASK METHOD  ObjInit;
    BEGIN
        DEC(numberAllowed);
    END METHOD;

    ASK METHOD ObjTerminate;
    BEGIN
        INC(numberAllowed);
    END METHOD;

    ASK METHOD SetNumberAllowed(IN num  : INTEGER);
    BEGIN
        numberAllowed := num;
    END METHOD;
END OBJECT;

FleetCObj = OBJECT(ResourceObj)
    OVERRIDE
        ASK METHOD ObjInit;
        ASK METHOD ObjTerminate;
    CLASS
        numberAllowed    :INTEGER;
        ASK METHOD  SetNumberAllowed(IN num : INTEGER);
END OBJECT;

OBJECT FleetCObj;
    ASK METHOD  ObjInit;
    BEGIN
        DEC(numberAllowed);
    END METHOD;

    ASK METHOD ObjTerminate;
    BEGIN
        INC(numberAllowed);
    END METHOD;

    ASK METHOD SetNumberAllowed(IN num  : INTEGER);
    BEGIN
        numberAllowed := num;
    END METHOD;
END OBJECT;

FleetCPObj = OBJECT(ResourceObj)
    OVERRIDE
        ASK METHOD ObjInit;
        ASK METHOD ObjTerminate;
    CLASS
```

```
        numberAllowed    :INTEGER;
        ASK METHOD  SetNumberAllowed(IN num : INTEGER);
END OBJECT;

OBJECT FleetCPObj;
    ASK METHOD  ObjInit;
    BEGIN
        DEC(numberAllowed);
    END METHOD;

    ASK METHOD ObjTerminate;
    BEGIN
        INC(numberAllowed);
    END METHOD;

    ASK METHOD SetNumberAllowed(IN num  : INTEGER);
    BEGIN
        numberAllowed := num;
    END METHOD;
END OBJECT;

FleetDObj = OBJECT(ResourceObj)
    OVERRIDE
        ASK METHOD ObjInit;
        ASK METHOD ObjTerminate;
    CLASS
        numberAllowed    :INTEGER;
        ASK METHOD  SetNumberAllowed(IN num : INTEGER);
END OBJECT;

OBJECT FleetDObj;
    ASK METHOD  ObjInit;
    BEGIN
        DEC(numberAllowed);
    END METHOD;

    ASK METHOD ObjTerminate;
    BEGIN
        INC(numberAllowed);
    END METHOD;

    ASK METHOD SetNumberAllowed(IN num  : INTEGER);
    BEGIN
        numberAllowed := num;
    END METHOD;
END OBJECT;

(*************************************************************************)
Shipdata = FIXED RECORD
    name              : STRING;
    speed             : REAL;
    size              : INTEGER;
    numberofships     : INTEGER;
```

```
      weight           : INTEGER;
      Cd               : INTEGER;
      Cscoeff          : REAL;
      Cpcoeff          : REAL;
      f                : REAL;

   END RECORD;
(**********************************************************************)

   GenObj = OBJECT
      TELL METHOD Generate;
   END OBJECT;
(**********************************************************************)
   shipObj = OBJECT
      name             : STRING;
      count            : INTEGER;
      type             : INTEGER;
      size             : INTEGER;
      source           : STRING;
      cars             : INTEGER;
      trucks4t         : INTEGER;
      trucks2t         : INTEGER;
      cargo            : REAL;
      cargotype        : STRING;
      arrived          : INTEGER;
      MinTime          : REAL;
      sailingTimeOut   : REAL;
      sailingTimeBack  : REAL;
      loadingtime      : REAL;
      unloadingtime    : REAL;
      cargotime        : REAL;
      Cp               : REAL;
      Cs               : REAL;

      TELL METHOD Arrive(IN il  : INTEGER);
      ASK METHOD Loadcars (OUT ncars  : INTEGER);
      ASK METHOD Loadship (IN il  : INTEGER;OUT cargo1    : REAL);
      ASK METHOD LoadshipM (IN il  : INTEGER;OUT cargo1    : REAL);
      ASK METHOD Load4ttrucks (INOUT weight   : REAL);
      ASK METHOD Load2ttrucks (INOUT weight   : REAL);
      TELL METHOD Sail(IN il  : INTEGER);
      ASK METHOD Setsize (IN i,k,n    : INTEGER);
   END OBJECT;

(**********************************************************************)
   shipAObj = OBJECT(FleetAObj,shipObj)
     (* speed   : REAL;
      size    : INTEGER;
      ASK METHOD setSpeedSize (IN speed1 : REAL, size1 INTEGER); *)
   END OBJECT;
(**********************************************************************)
   shipBObj = OBJECT(FleetBObj,shipObj)
     (* speed   : REAL;
```

```
      size     : INTEGER;
      ASK METHOD setSpeedSize (IN speed1 : REAL, size1 INTEGER); *)
   END OBJECT;
(*************************************************************************)
   shipCObj = OBJECT(FleetCObj,shipObj)
     (* speed   : REAL;
      size     : INTEGER;
      ASK METHOD setSpeedSize (IN speed1 : REAL, size1 INTEGER); *)
   END OBJECT;
(*************************************************************************)
   shipCPObj = OBJECT(FleetCPObj,shipObj)
     (* speed   : REAL;
      size     : INTEGER;
      ASK METHOD setSpeedSize (IN speed1 : REAL, size1 INTEGER); *)
   END OBJECT;
(*************************************************************************)
   shipDObj = OBJECT(FleetDObj,shipObj)
     (* speed   : REAL;
      size     : INTEGER;
      ASK METHOD setSpeedSize (IN speed1 : REAL, size1 INTEGER); *)
   END OBJECT;
(*************************************************************************)


VAR
   Islands               : FIXED ARRAY [1..9] OF IslandData;
   shiptable             : FIXED ARRAY [1..5] OF Shipdata;
(*************************************************************************)
OBJECT GenObj;
 TELL METHOD Generate;
   VAR

      shipA                : shipAObj;
      shipB                : shipBObj;
      shipC                : shipCObj;
      shipCP               : shipCPObj;
      shipD                : shipDObj;
      n                    : INTEGER;
      shipcount            : INTEGER;
      itemp                : INTEGER;
      timecount            : INTEGER;
      il                   : INTEGER;
      islandcount          : INTEGER;
      islandcheck          : BOOLEAN;
      loadtime             : REAL;
      outofships           : INTEGER;
      jj                   : INTEGER;
      time1                : REAL;

   BEGIN

     LOOP
```

```
    islandcheck := FALSE;

    FOR il := 1 TO numofIslands

     IF NOT Islands[il].quotasFilled
        islandcheck := TRUE;

(* The cycle begins in the main port and loads a ship with manufactured goods.
   It then sails from the main post to an outport.  When ship comes back to
   the main post it is unloaded.  It is assumed that the amount of
   manufactured goods is 80% of the raw commodity.  We will take 80% of the
   time it would take to load a ship with a raw commodity as the time needed
   to load the manufactured goods.*)

        timecount := 0;
        outofships := 0;
        itemp := 1;
        n := Islands[il].shiptypes[itemp];

        CASE n

        WHEN 1 :

            IF ASK FleetAObj numberAllowed > 0

                NEW(shipA);
                INC(shipcount);
                ASK shipA TO Setsize (il,shipcount,n);

                WAIT FOR dock TO Give(shipA, 1)
                END WAIT;

                TELL shipA TO Sail(il);

            ELSE

                outofships := 1;

            END IF;

        WHEN 2 :

            IF ASK FleetBObj numberAllowed > 0

                NEW(shipB);
                INC(shipcount);
                ASK shipB TO Setsize (il,shipcount,n);

                WAIT FOR dock TO Give(shipB, 1)
                END WAIT;

                TELL shipB TO Sail(il);
```

```
        ELSE

             outofships := 1;

        END IF;

    WHEN 3 :

        IF ASK FleetCObj numberAllowed > 0

            NEW(shipC);
            INC(shipcount);
            ASK shipC TO Setsize (il,shipcount,n);

            WAIT FOR dock TO Give(shipC, 1)
            END WAIT;

            TELL shipC TO Sail(il);

        ELSE

             outofships := 1;

        END IF;

    WHEN 4 :

        IF ASK FleetCPObj numberAllowed > 0

            NEW(shipCP);
            INC(shipcount);
            ASK shipCP TO Setsize (il,shipcount,n);

            WAIT FOR dock TO Give(shipCP, 1)
            END WAIT;

            TELL shipCP TO Sail(il);

        ELSE

             outofships := 1;

        END IF;

    WHEN 5 :

        IF ASK FleetDObj numberAllowed > 0

            NEW(shipD);
            INC(shipcount);
            ASK shipD TO Setsize (il,shipcount,n);
```

```
                WAIT FOR dock TO Give(shipD, 1)
                END WAIT;

                TELL shipD TO Sail(il);

            ELSE

                 outofships := 1;

            END IF;


        END CASE;

        IF (Islands[il].QuantityShipped >= Islands[il].commodquota)
            Islands[il].TotalTime := SimTime();
            Islands[il].quotasFilled := TRUE;
        END IF;

     END IF;

    END FOR;

    WAIT DURATION waitduration
    END WAIT;

    IF NOT islandcheck
        EXIT;
     ELSE
        islandcheck := FALSE;
     END IF;

  END LOOP

 END METHOD;


END OBJECT;
(**********************************************************************)

(**********************************************************************)
VAR
    Generator            : GenObj;

    numberdocks          : INTEGER;
    i                    : INTEGER;

(**********************************************************************)
OBJECT shipObj;

    ASK METHOD Setsize (IN i,k,n    : INTEGER);

    BEGIN
```

```
    type := n;
    size := shiptable[n].size;
    name := shiptable[n].name;
    MinTime := FLOAT(Islands[i].distance)/shiptable[n].speed;
    cargo := 0.;
    count := k

END  METHOD;

TELL METHOD Sail(IN il    :    INTEGER);

VAR
    ncars                  : INTEGER;
    weightlimit            : REAL;
    weight                 : REAL;
    shipcount              : INTEGER;
    itemp                  : INTEGER;
    randomtime             : REAL;
    z                      : REAL;
    cargo1                 : REAL;

BEGIN

     (* Load manufactured goods. *)

     ASK SELF TO LoadshipM(il,cargo1);

     loadingtime :=  loadingtime;

     WAIT DURATION  loadingtime
     END WAIT;

     cargotime := loadingtime;
     cargo  := cargo1;

     ASK dock TO TakeBack(SELF, 1);

     (* Sailing time is in days. *)

     z := best[4]*ASK random Beta(alpha[4],beta[4])/100.;
     sailingTimeOut := MinTime*(1. + z)/24.;

     WAIT DURATION sailingTimeOut
     END WAIT;

     (* Unload manufactured goods shipped from the main port *)

     unloadingtime := 0.7*loadingtime;

     WAIT DURATION unloadingtime
     END WAIT;
```

```
        cargotime := cargotime + unloadingtime;
        cargo    := cargo+ cargo1;

        (* Load raw goods from outport. *)

        ASK SELF TO Loadship(il,cargo1);

        WAIT DURATION  loadingtime
        END WAIT;

        cargotime := cargotime + loadingtime;
        cargo    := cargo+ 2.*cargo1;

        TELL SELF TO Arrive (il)

    END METHOD;
(*********************************************************************)

    ASK METHOD Loadship (IN il   :   INTEGER;OUT cargo1 : REAL);

    VAR
        ncars                    : INTEGER;
        weightlimit              : REAL;
        weight                   : REAL;
        shipcount                : INTEGER;
        itemp                    : INTEGER;
        randomtime               : REAL;
        z                        : REAL;


     BEGIN

        (* Load a random number of cars from the outport *)

        ASK SELF TO Loadcars (ncars);
        Islands[il].carsShipped := Islands[il].carsShipped + ncars;

        (* Load a random number of 4 ton trucks carrying a commodity *)

        weightlimit := 4.* FLOAT(MINOF(K2,size))/3.;

        IF Islands[il].commodquota - Islands[il].QuantityShipped < weightlimit
                 weight := Islands[il].commodquota - Islands[il].QuantityShipped;
                 ASK SELF TO Load4ttrucks (weight);
                 Islands[il].QuantityShipped := Islands[il].commodquota;
                 cargo1 := weight;
        ELSE
                weight := 0.;
                ASK SELF TO Load4ttrucks (weight);
                Islands[il].QuantityShipped := Islands[il].QuantityShipped + weight;
                cargo1 := weight;
```

```
            (* Load a random number of 2 ton trucks carrying a commodity *)

            weightlimit := 2.* FLOAT(MINOF(K3,size))/3.;

            IF Islands[il].commodquota - Islands[il].QuantityShipped < weightlimit
               weight := Islands[il].commodquota -
Islands[il].QuantityShipped;
               ASK SELF TO Load2ttrucks (weight);
               IF weight > 0.
                  Islands[il].QuantityShipped :=
Islands[il].commodquota;
               END IF;
            ELSE
                  weight :=0.;
                  ASK SELF TO Load2ttrucks (weight);
                  Islands[il].QuantityShipped :=
Islands[il].QuantityShipped + weight;
            END IF;
            cargo1 := cargo1+weight;
      END IF;

      loadingtime := loadingtime/60./24. (* Convert loading time to days. *)

      carsum:=carsum+cars;
      INC(carcount);

   END METHOD;
(***********************************************************************************************)
   ASK METHOD LoadshipM (IN il   :   INTEGER;OUT cargo1     : REAL);

   VAR
      ncars                : INTEGER;
      weightlimit          : REAL;
      weight               : REAL;
      shipcount            : INTEGER;
      itemp                : INTEGER;
      randomtime           : REAL;
      z                    : REAL;
      n                    : INTEGER;
      sizesave             : INTEGER;


    BEGIN

      (* Load a random number of cars from the outport *)
      sizesave := size;

      ASK SELF TO Loadcars (ncars);

      (* Load a random number of 4 ton trucks carrying a commodity *)
      z := MINOF(best[6],FLOAT(size)/3.)*ASK random Beta(alpha[6],beta[6]);
      trucks4t:=TRUNC(z);
```

```
    size := size - 3*trucks4t;

    (* Choose a random time to load each truck. *)

    FOR i:= 1 TO trucks4t;
        z := (best[2]-poor[2])*ASK random2 Beta(alpha[2],beta[2])+poor[2];
        loadingtime := loadingtime + 0.8*z;  (* Loading time is in minutes. *)
    END FOR;

    (* Load a random number of 2 ton trucks carrying a commodity *)
    n := size;

    IF n > 2
        (* Choose a random number of 2-ton trucks to load <= min(K3,2*size/3). *)
       z := MINOF(best[7],2.*FLOAT(size)/3.)*ASK random Beta(alpha[7],beta[7]);
        trucks2t:=TRUNC(z);

        (* Choose a random time to load each truck. *)

        FOR i:= 1 TO trucks2t;
            z := (best[3]-poor[3])*ASK random2 Beta(alpha[3],beta[3])+poor[3];
            loadingtime := loadingtime + 0.8*z;  (* Loading time is in minutes. *)
        END FOR;
    END IF;

    (* Convert the trucks into commodity weight *)

    cargo1 := 4.*FLOAT(trucks4t)+2.*FLOAT(trucks2t);
    size := sizesave;

    loadingtime := loadingtime/60./24. (* Convert loading time to days. *)

END METHOD;

(*******************************************************************************************)
ASK METHOD Loadcars (OUT ncars       : INTEGER);

VAR

    i        : INTEGER;
    z        : REAL;

BEGIN

    (* Choose a random number of cars to load <= K1. *)
    z        := best[5]*ASK random Beta(alpha[5],beta[5]);
    ncars    :=TRUNC(z);
    size     := size - ncars;
    cars     := ncars;

    (* Choose a random time to load each car. *)
```

```
    FOR i:= 1 TO ncars;
        z   := (best[1]-poor[1])*ASK random2 Beta(alpha[1],beta[1])+poor[1];
        loadingtime := z;    (* Loading time is in minutes. *)
    END FOR;

END METHOD;

ASK METHOD Load4ttrucks (INOUT weight : REAL);

VAR

    i        : INTEGER;
    z        : REAL;

BEGIN

    (* Load 4-ton trucks - there will always be room for some 4-ton
       trucks. Choose a random number of 4-ton trucks to load <=
       min(K2,size/3). *)
    IF weight = 0.
        z := MINOF(best[6],FLOAT(size)/3.)*ASK random Beta(alpha[6],beta[6]);
        trucks4t:=TRUNC(z);
    ELSE
        trucks4t := TRUNC(weight/4.)+1;
    END IF

    size := size - 3*trucks4t;

    (* Choose a random time to load each truck. *)

    FOR i:= 1 TO trucks4t;
        z := (best[2]-poor[2])*ASK random2 Beta(alpha[2],beta[2])+poor[2];
        loadingtime := loadingtime + z;   (* Loading time is in minutes. *)
    END FOR;

    IF weight = 0.
        weight := FLOAT(4*trucks4t);
    END IF


END METHOD;

ASK METHOD Load2ttrucks (INOUT weight : REAL);

VAR
    n        : INTEGER;
    i        : INTEGER;
    z        : REAL;

BEGIN


   (* Load 2-ton trucks if there is room. *)
```

```
        n := size;

        IF n > 2
            (* Choose a random number of 2-ton trucks to load <= min(K3,2*size/3). *)
            IF weight = 0.
                z := MINOF(best[7],2.*FLOAT(size)/3.)*ASK random
Beta(alpha[7],beta[7]);
                trucks2t:=TRUNC(z);
            ELSE
                trucks2t := TRUNC(weight/2.)+1;
            END IF

            (* Choose a random time to load each truck. *)

            FOR i:= 1 TO trucks2t;
                z := (best[3]-poor[3])*ASK random2
Beta(alpha[3],beta[3])+poor[3];
                loadingtime := loadingtime + z;   (* Loading time is in minutes. *)
            END FOR;
            IF weight = 0.
                weight := FLOAT(2*trucks2t);
            END IF;

        ELSE
            weight := 0.;
            trucks2t :=0;
        END IF

    END METHOD;

(**********************************************************************)
    TELL METHOD Arrive (IN il    :    INTEGER);

    VAR

        z   : REAL;
        tt  : REAL;

    BEGIN

        z := beta[4]*ASK random Beta(alpha[4],beta[4])/100.;
        sailingTimeBack := MinTime*(1. + z )/24.;

        WAIT DURATION sailingTimeBack
        END WAIT;

        WAIT FOR dock TO Give(SELF, 1)
        END WAIT;

        unloadingtime := .7*loadingtime;

        WAIT DURATION unloadingtime
```

```
        END WAIT;

        cargotime := cargotime + unloadingtime;
        Cp := cargotime/cargo*shiptable[type].Cpcoeff;
        Cs := (sailingTimeOut+sailingTimeBack)*shiptable[type].Cscoeff;
        Islands[il].Cscost := Islands[il].Cscost + Cs;
        Islands[il].Cpcost := Islands[il].Cpcost + Cp;
        tt := cargotime+sailingTimeOut+sailingTimeBack;
        Islands[il].runtime := Islands[il].runtime +  tt;
        INC(Islands[il].numofTrips);

        ASK dock TO TakeBack(SELF, 1);

        DISPOSE(SELF);

    END METHOD;


END OBJECT;

(***********************************************************************)


PROCEDURE Initialize;
VAR
    numberofships         : INTEGER;
    numberofshiptypes     : INTEGER;
    j                     : INTEGER;
    title                 : STRING;
    s2                    : REAL;
    mean                  : REAL;
    fuelcost              : INTEGER;
    weightRef             : INTEGER;
    runcostRef            : INTEGER;
    fuelconsumptionRef    : INTEGER;
    u                     : REAL;
    v                     : REAL;
    CR                    : REAL;
    Cp                    : REAL;
    Cs                    : REAL;



BEGIN

    NEW (filein);
    ASK filein TO Open ("ship_data.txt",Input);

    (* Enter data related to the model. *)

    ASK filein TO ReadInt(numberReplications);
    ASK filein TO ReadInt(mindocks);
    ASK filein TO ReadInt(maxdocks);
```

```
ASK filein TO ReadReal(waitduration);


FOR i:=1 TO 7;
    ASK filein TO ReadReal(poor[i]);
    ASK filein TO ReadReal(likely[i]);
    ASK filein TO ReadReal(best[i]);

    s2 := 1./36.;
    mean := ((2.*likely[i]+(best[i]+poor[i])/2.)/3. - poor[i])/(best[i]-poor[i]);
    beta[i] := (1.-mean)/s2*(mean*(1.-mean)-s2);
    alpha[i] := mean*beta[i]/(1.-mean);
END FOR;
K1 := TRUNC(best[5]);
K2 := TRUNC(best[6]);
K3 := TRUNC(best[7]);

    (* used to simulate loading and unloading times *)


(* Enter data related to the source islands. *)
ASK filein TO ReadInt (numofIslands);
FOR i := 1 TO numofIslands
    ASK filein TO ReadString(Islands[i].Name);
    ASK filein TO ReadInt (Islands[i].distance);
    ASK filein TO ReadInt (Islands[i].carquota);
    ASK filein TO ReadString (Islands[i].commoditytype);
    ASK filein TO ReadReal (Islands[i].commodquota);
    ASK filein TO ReadInt (Islands[i].numofships);
    FOR j:= 1 TO  Islands[i].numofships
        ASK filein TO ReadInt (Islands[i].shiptypes[j]);
    END FOR;
END FOR;

(* Enter data related to the types of ships *)
ASK filein TO ReadString (title);
ASK filein TO ReadInt (numberofshiptypes);

FOR i := 1 TO numberofshiptypes;
    ASK filein TO ReadString (shiptable[i].name);
    ASK filein TO ReadReal (shiptable[i].speed);
    ASK filein TO ReadInt (shiptable[i].size);
    ASK filein TO ReadInt (shiptable[i].weight);
    ASK filein TO ReadInt (shiptable[i].Cd);
    ASK filein TO ReadReal (shiptable[i].f);
    ASK filein TO ReadInt (shiptable[i].numberofships);


END FOR;


ASK filein TO ReadInt(fuelcost);   (* p *)
ASK filein TO ReadInt(weightRef);  (* W2 *)
```

```
    ASK filein TO ReadInt(runcostRef);        (* Cr2 *)
    ASK filein TO ReadInt(fuelconsumptionRef);  (* f2 *)

    (* Calculation of coefficients for Cp and Cs for each ship type. *)

    FOR i:=1 TO  numberofshiptypes;

        u := FLOAT(shiptable[i].weight)/FLOAT(weightRef);
        CR := FLOAT(runcostRef)*POWER(u,0.3);
        Cp := 2.*FLOAT(shiptable[i].weight)*(CR+FLOAT(shiptable[i].Cd));
        shiptable[i].Cpcoeff := Cp;
        v := shiptable[i].f;
        Cs := CR+FLOAT(shiptable[i].Cd) + FLOAT(fuelcost)*v;
        shiptable[i].Cscoeff := Cs;

    END FOR;

    ASK FleetAObj  TO SetNumberAllowed(shiptable[1].numberofships);
    ASK FleetBObj  TO SetNumberAllowed(shiptable[2].numberofships);
    ASK FleetCObj  TO SetNumberAllowed(shiptable[3].numberofships);
    ASK FleetCPObj TO SetNumberAllowed(shiptable[4].numberofships);
    ASK FleetDObj  TO SetNumberAllowed(shiptable[5].numberofships);

    DISPOSE (filein);

    NEW(fileout);
    ASK fileout TO Open ("port_output.txt",Output);

    ASK fileout TO WriteString(
      "       The number of docks ranges from");
    ASK fileout TO WriteInt(mindocks,4);
    ASK fileout TO WriteString (" to");
    ASK fileout TO WriteInt (maxdocks,4);
    ASK fileout TO WriteLn;
    ASK fileout TO WriteInt(numberReplications,4);
    ASK fileout TO WriteString (" replications for each number of docks");
    ASK fileout TO WriteLn;

END PROCEDURE;

(**********************************************************************)
(****************************** MAIN PROGRAM ******************************)

VAR

    ch: CHAR;
    sum : REAL;
    y  :  REAL;
    n   : INTEGER;

BEGIN

    Initialize;
```

```
NEW(Generator);

FOR numberdocks := mindocks TO maxdocks

    ResetSimTime(0.0);

    NEW(dock); (* allocate a dock ResourceObj and intialize *)

    NEW(random);
    NEW(random2);
    NEW(random3);
    NEW(random4);

    ASK random2 TO SetSeed(FetchSeed(2));
    ASK random3 TO SetSeed(FetchSeed(3));
    ASK random4 TO SetSeed(FetchSeed(4));

    ASK dock TO Create(numberdocks);

    FOR i := 1 TO numberReplications

        startTime := SimTime();

        ASK dock TO Reset;

        TELL Generator TO Generate;

        StartSimulation;

        ASK fileout TO WriteLn;
        ASK fileout TO WriteString(" # of docks: ");
        ASK fileout TO WriteInt(mindocks,5);

        FOR i := 1 TO numofIslands;

            ASK fileout TO WriteLn;
            y := Islands[i].Cpcost+Islands[i].Cscost;
            ASK fileout TO WriteString("* annual cost: ");
            ASK fileout TO WriteReal(y,10,2);
            ASK fileout TO WriteString(" Cp: ");
            ASK fileout TO WriteReal(Islands[i].Cpcost,10,5);
            ASK fileout TO WriteString(" Cs: ");
            ASK fileout TO WriteReal(Islands[i].Cscost,10,5);
            ASK fileout TO WriteString(" # of trips: ");
            ASK fileout TO WriteInt(Islands[i].numofTrips,5);
            ASK fileout TO WriteString(" Time: ");
            ASK fileout TO WriteReal(Islands[i].TotalTime,7,2);
            ASK fileout TO WriteString(" RTime: ");
            ASK fileout TO WriteReal(Islands[i].runtime,7,2);
            ASK fileout TO WriteString(" annual quota: ");
            ASK fileout TO WriteReal(Islands[i].commodquota,10,3);
            ASK fileout TO WriteString(" ship type: ");
```

```
            n := Islands[i].shiptypes[1];
            ASK fileout TO WriteString(shiptable[n].name+"  ");
            ASK fileout TO WriteInt(shiptable[n].numberofships,5);

        END FOR;

    END FOR;

    (* Check *)
    OUTPUT(carsum);
    OUTPUT(carcount);


DISPOSE(dock);
DISPOSE(random);
DISPOSE(random2);
DISPOSE(random3);
DISPOSE(random4);

END FOR;
DISPOSE(Generator);

OUTPUT("Finished, hit any key to quit...");
ch := ReadKey;

END MODULE.
```

Appendix III
Passengers Demand Estimation

When actual data are unavailable, passenger demand can be obtained by the following procedures. This procedure[23] is based on an assumption that small islands and towns generally depend on nearby big cities for their daily need. Traffic demand to the big cities is proportional to the activities in the small island or towns. Passenger demand, therefore, principally depends on the population of small islands and towns, and not on those big cities.

There are two main types of traveling depending on the time of operations. These are **day trip routes** and **other routes, i.e., night trip routes**. Day trip routes are mainly for daily routine purposes, while the other routes will be for business trips and visiting relatives. These activities can be monthly, weekly or even daily basis.

Considering the possible differences in the characteristics between these types, the ship's routes can be divided into two groups depending upon the distance, that is:

- day trips whose distance is less than 50 miles;
- other routes whose distance is greater than (or equal to) 50 miles.

In this study, passenger demand from a port of origin *y* to the main port *z*, *Tyz*, can be obtained by using the following equation.

$$Tyz \quad = \quad k.P_y^a.P_z^b.E$$

where:

P_y : population of *y*-zone (small)

P_z : population of *z*-zone (large)

[23] JICA, 1993

E, k, a, b : parameters

$$E = (1 + G.E_1)$$

G : growth rate of GRDP (Gross Regional Domestic Product) per capita

E_1 : demand elasticity

The parameters are determined by recurrent analysis of the day routes, yielding the following:

- For the first group (day trip routes less than 50 miles), the parameters k, a, and b are calculated at 0.02294, 1.00983 and 0.14147 respectively.
- The second group has 0.02077, 1.32333 and 0.00367 for k, a, and b respectively.

This study will observe only those routes from several outports to the main port, i.e., Ambon. The population of Ambon and its suburban area is about 371,560, which becomes P_z. All ports of origin, including the surrounding area, are less populated than their port of destination, thus all of them are P_y. By assuming that the GRDP of the Province of Maluku is 6.7% per annum and the demand elasticity is 1.1, the result of the passenger demand can be obtained as tabulated in Table A.3.

Table A.3 Passenger demand from several port of origins to the main port, Ambon

Port of Origin	Population, P_y (Including its surrounding area)	Distance to Ambon (miles)	Passenger Demand
Sanana	36,280	178	6,081
Namlea	106,261	81	17,999
Tulehu	74,513	32	65,514
Saparua	37,249	36	26,173
Amahai	173,387	58	29,511
Tehoru	104,032	94	17,618
Werinama	69,355	127	11,699
Banda	15,582	118	2,590
Saumlaki	77,379	348	13,066

Appendix IV
Output Programs

Table A.4a Number of docks in the main port = 1

Output 1a

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

Route	C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
1	412,781	119,037	293,745	163	71	218.81	4,500	CP	4
2	448,918	212,400	236,518	289	150	190.41	7,500	CP	4
3	390,106	175,689	214,416	596	249	233.63	10,000	D	1
4	5,557,253	4,776,134	781,119	915	414	398.61	25,000	A	1
5	1,547,596	858,650	688,946	582	213	454.32	15,500	B	3
6	657,160	211,630	445,530	286	177	344.54	7,500	C	2
7	741,135	281,714	459,421	385	197	353.25	10,000	CP	4
8	1,504,960	380,928	1,124,032	257	382	675.28	7,000	B	3
Total	11,259,910	7,016,181	4,243,729						

Output 1b

i	1	2	3
K_i	12	10	12
μ_i	5	3	5

Route	C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
1	523,620	154,633	368,987	205	84	271.34	4,500	CP	4
2	524,219	249,810	274,409	335	166	216.87	7,500	CP	4
3	398,863	181,672	217,191	604	250	237.18	10,000	D	1
4	6,914,982	5,957,968	957,013	1120	484	468.39	25,000	A	1
5	1,881,688	1,052,645	829,042	700	246	535.35	15,500	B	3
6	791,493	256,157	535,336	344	208	409.13	7,500	C	2
7	875,499	335,322	540,178	453	229	409.71	10,000	CP	4
8	1,908,303	488,672	1,419,631	324	466	847.24	7,000	B	3
Total	13,818,667	8,676,879	5,141,788						

Table A.4b Number of docks in the main port = 1 (continued)

Output 1c

i	1	2	3
K_i	12	10	15
μ_i	5	3	4

Route	C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
1	532,360	156,159	376,200	209	84	276.63	4,500	CP	4
2	552,760	264,661	288,100	352	172	226.1	7,500	CP	4
3	445,309	202,045	243,263	676	275	261	10,000	D	1
4	6,970,316	6,002,117	968,199	1133	488	472.29	25,000	A	1
5	1,917,983	1,071,549	846,434	715	246	546.02	15,500	B	3
6	779,234	253,637	525,597	338	205	401.25	7,500	C	2
7	904,495	347,971	556,524	466	236	420.71	10,000	CP	4
8	1,896,629	481,420	1,415,209	323	469	844.66	7,000	B	3
Total	13,999,085	8,779,559	5,219,526						

Output 1d

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

Route	C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
1	422,635	122,141	300,494	167	96	223.56	4,500	CP	3
2	443,181	208,967	234,214	286	194	188.75	7,500	CP	3
3	387,918	174,567	213,351	593	249	232.78	10,000	D	1
4	5,502,718	4,727,756	774,962	907	410	395.05	25,000	A	1
5	1,532,262	849,481	682,781	577	198	450.8	15,500	B	3
6	622,123	198,834	423,289	272	168	328.34	7,500	C	2
7	726,557	275,794	450,764	378	259	347.01	10,000	CP	3
8	1,513,299	382,168	1,131,131	258	382	679.6	7,000	B	3
Total	11,150,693	6,939,707	4,210,986						

Table A.4c Number of docks in the main port = 1 (continued)

Output 1e

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

Route	C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
1	445,735	129,032	316,703	176	102	235.3	4,500	CP	3
2	428,502	202,188	226,314	276	194	182.5	7,500	CP	3
3	390,664	175,382	215,282	599	251	234.67	10,000	D	1
4	5,520,881	4,742,423	778,458	911	413	396.85	25,000	A	1
5	1,549,450	862,282	687,168	581	160	453.58	15,500	B	4
6	621,179	198,488	422,691	272	168	327.74	7,500	C	2
7	716,260	272,458	443,802	372	260	341.88	10,000	CP	3
8	1,530,817	387,878	1,142,939	261	290	686.63	7,000	B	4
Total	11,203,488	6,970,131	4,233,356						

Output 1f

i	1	2	3
K_i	12	10	12
μ_i	5	3	5

Route	C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
1	523,338	152,861	370,476	206	114	272.47	4,500	CP	3
2	564,275	268,812	295,463	361	223	232.35	7,500	CP	3
3	401,667	182,935	218,732	608	253	238.96	10,000	D	1
4	6,944,554	5,981,578	962,976	1127	487	471.09	25,000	A	1
5	1,816,933	1,016,101	800,832	677	168	518.35	15,500	B	4
6	787,931	254,584	533,346	343	207	407.56	7,500	C	2
7	883,679	340,271	543,407	456	312	411.93	10,000	CP	3
8	1,818,035	463,002	1,355,033	309	336	809.04	7,000	B	4
Total	13,740,411	8,660,144	5,080,266						

Table A.4d Number of docks in the main port = 1 (continued)

Output 1g

i	1	2	3
K_i	12	10	15
μ_i	5	3	4

Route	C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
1	544,108	158,386	385,722	214	115	282.82	4,500	CP	3
2	558,974	265,342	293,632	359	226	230.16	7,500	CP	3
3	432,144	196,442	235,702	655	266	254.05	10,000	D	1
4	7,385,655	6,358,715	1,026,940	1203	511	495.85	25,000	A	1
5	1,977,653	1,103,681	873,972	739	184	561.17	15,500	B	4
6	815,275	262,840	552,435	355	213	420.92	7,500	C	2
7	952,005	366,417	585,588	491	324	441.03	10,000	CP	3
8	1,981,268	506,020	1,475,248	337	364	878.96	7,000	B	4
Total	14,647,081	9,217,842	5,429,239						

Input 1h

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

Route	442,742	127,381	315,361	175	124	234.45	4,500	CP	3
1	440,211	206,834	233,377	285	218	188.1	7,500	CP	3
2	388,243	174,657	213,586	594	131	233.01	10,000	D	2
3	5,527,726	4,752,251	775,475	908	213	395.34	25,000	A	2
4	1,522,004	844,978	677,026	572	172	446.72	15,500	B	4
5	653,466	209,259	444,207	286	179	344.1	7,500	C	2
6	734,236	278,747	455,489	382	266	350.72	10,000	CP	3
7	1,517,246	382,962	1,134,284	259	288	681.69	7,000	B	4
8	11,225,874	6,977,068	4,248,806						
Total									

Table A.5a Number of docks in the main port = 2

Output 2a

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

Route	C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
1	435,720	125,975	309,745	172	60	230.44	4,500	CP	4
2	443,461	209,334	234,127	286	111	188.47	7,500	CP	4
3	383,781	172,196	211,586	588	235	230.86	10,000	D	1
4	5,574,360	4,791,759	782,601	916	404	398.2	25,000	A	1
5	1,518,775	844,387	674,388	570	165	445.35	15,500	B	3
6	622,326	199,066	423,260	272	165	328.57	7,500	C	2
7	731,084	277,903	453,182	380	193	348.99	10,000	CP	4
8	1,555,132	392,657	1,162,475	266	381	698.29	7,000	B	3
Total	11,264,641	7,013,276	4,251,364						

Output 2b

i	1	2	3
K_i	12	10	12
μ_i	5	3	5

Route	C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
1	524,894	154,234	370,660	206	69	272.69	4,500	CP	4
2	529,684	252,900	276,784	338	129	218.31	7,500	CP	4
3	398,541	181,915	216,625	602	240	236.72	10,000	D	1
4	6,970,327	6,006,810	963,517	1129	477	471.06	25,000	A	1
5	1,897,497	1,061,693	835,804	706	195	539.86	15,500	B	3
6	773,993	251,369	522,624	336	201	399.75	7,500	C	2
7	885,195	341,123	544,072	456	227	412.15	10,000	CP	4
8	1,859,046	477,989	1,381,057	315	456	824.4	7,000	B	3
Total	13,839,176	8,728,034	5,111,142						

Table A.5b Number of docks in the main port = 2 (continued)

Output 2c

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
441,899	127,117	314,782	175	82	233.57	4,500	CP	3
441,882	208,600	233,282	285	147	187.74	7,500	CP	3
389,734	175,588	214,146	595	238	233.89	10,000	D	1
5,598,798	4,809,358	789,441	924	407	401.72	25,000	A	1
1,521,244	844,897	676,347	571	162	445.86	15,500	B	3
626,147	200,300	425,848	274	166	330.44	7,500	C	2
708,580	269,266	439,314	368	254	338.32	10,000	CP	3
1,470,285	370,601	1,099,683	251	370	661.16	7,000	B	3
11,198,570	7,005,727	4,192,843						

Output 2d

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
450,353	129,854	320,499	178	83	237.92	4,500	CP	3
445,304	210,179	235,124	287	150	189.01	7,500	CP	3
381,297	171,293	210,003	584	233	229.28	10,000	D	1
5,584,052	4,801,395	782,657	917	404	398.8	25,000	A	1
1,497,759	830,432	667,327	564	124	441.01	15,500	B	4
635,593	202,096	433,497	278	168	335.79	7,500	C	2
726,554	276,580	449,974	377	259	346.32	10,000	CP	3
1,577,574	398,726	1,178,848	269	287	707.35	7,000	B	4
11,298,485	7,020,555	4,277,930						

Table A.5c Number of docks in the main port = 2 (continued)

Output 2e

i	1	2	3
K_i	12	10	12
μ_i	5	3	5

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
514,678	150,965	363,713	202	92	267.6	4,500	CP	3
507,158	241,778	265,380	324	165	210.11	7,500	CP	3
392,654	178,566	214,088	595	238	234.36	10,000	D	1
6,861,722	5,912,425	949,297	1111	470	463.97	25,000	A	1
1,835,096	1,026,624	808,472	684	145	523.19	15,500	B	4
755,565	245,500	510,064	328	196	390.09	7,500	C	2
870,853	334,828	536,025	449	296	406.55	10,000	CP	3
1,815,347	465,924	1,349,423	308	333	805.88	7,000	B	4
13,553,072	8,556,610	4,996,462						

Output 2g

i	1	2	3
K_i	12	10	15
μ_i	5	3	4

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
559,405	163,633	395,771	220	100	290	4,500	CP	3
583,478	277,897	305,582	373	184	238.28	7,500	CP	3
422,407	191,878	230,529	641	253	249.47	10,000	D	1
7,273,074	6,259,079	1,013,995	1187	497	490.44	25,000	A	1
1,959,278	1,095,320	863,958	730	152	555.16	15,500	B	4
826,491	265,817	560,673	360	214	426.83	7,500	C	2
935,691	360,939	574,753	481	322	432.95	10,000	CP	3
1,992,151	506,340	1,485,811	339	360	885.23	7,000	B	4
14,551,975	9,120,903	5,431,072						

Table A.5d Number of docks in the main port = 2 (continued)

Output 2h

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
427,271	123,137	304,135	169	81	226.08	4,500	CP	3
439,919	207,494	232,426	284	152	187.24	7,500	CP	3
388,517	174,569	213,947	595	119	233.34	10,000	D	2
5,549,730	4,769,745	779,986	913	202	396.93	25,000	A	2
1,520,674	844,997	675,678	571	126	446.04	15,500	B	4
631,575	202,671	428,904	276	167	331.91	7,500	C	2
726,955	275,466	451,489	378	255	347.64	10,000	CP	3
1,500,968	379,957	1,121,011	256	280	673.64	7,000	B	4
11,185,610	6,978,034	4,207,575						

Table A.6a Number of docks in the main port = 3

Output 3a

i	1	2	3
K_i	15	10	15
μ_t	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
422,618	121,908	300,710	167	56	223.69	4,500	CP	4
451,982	212,868	239,114	292	106	192.08	7,500	CP	4
385,097	173,334	211,763	589	234	231.43	10,000	D	1
5,548,622	4,765,763	782,859	916	403	398.57	25,000	A	1
1,519,523	845,361	674,162	570	154	444.88	15,500	B	3
636,395	204,046	432,349	278	168	335.21	7,500	C	2
706,056	268,696	437,361	367	189	337.13	10,000	CP	4
1,494,033	375,996	1,118,037	255	372	671.9	7,000	B	3
11,164,325	6,967,971	4,196,354						

Output 3b

i	1	2	3
K_i	12	10	12
μ_t	5	3	5

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
528,607	154,385	374,222	208	70	275.68	4,500	CP	4
516,364	246,125	270,239	330	124	213.5	7,500	CP	4
389,908	177,795	212,113	590	235	232.01	10,000	D	1
6,943,774	5,980,142	963,632	1128	477	471.3	25,000	A	1
1,877,865	1,052,263	825,603	698	188	533.71	15,500	B	3
768,442	248,449	519,993	334	200	397.84	7,500	C	2
881,437	338,719	542,719	455	226	411.14	10,000	CP	4
1,823,435	464,868	1,358,566	310	449	811.42	7,000	B	3
13,729,832	8,662,746	5,067,086						

Table A.6b Number of docks in the main port = 3 (continued)

Output 3c

i	1	2	3
K_i	12	10	15
μ_i	5	3	4

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
496,443	145,670	350,773	195	65	258.17	4,500	CP	4
573,993	273,572	300,421	367	127	235.26	7,500	CP	4
439,043	199,322	239,721	666	261	257.61	10,000	D	1
7,076,996	6,099,731	977,264	1144	482	476.42	25,000	A	1
1,867,365	1,045,050	822,315	695	186	530.76	15,500	B	3
782,578	253,952	528,626	340	202	403.53	7,500	C	2
883,273	339,421	543,852	456	227	411.92	10,000	CP	4
1,928,501	493,452	1,435,049	328	463	856.14	7,000	B	3
14,048,192	8,850,171	5,198,021						

Output 3d

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
405,728	117,471	288,257	160	72	214.61	4,500	CP	3
448,258	211,788	236,470	289	137	190.29	7,500	CP	3
383,173	172,383	210,790	586	233	230.38	10,000	D	1
5,528,746	4,751,243	777,504	910	401	396.42	25,000	A	1
1,566,715	870,548	696,167	588	160	458.48	15,500	B	3
641,519	204,993	436,527	281	169	337.91	7,500	C	2
745,982	283,390	462,592	388	254	355.43	10,000	CP	3
1,448,991	364,824	1,084,167	247	371	651.91	7,000	B	3
11,169,114	6,976,640	4,192,474						

Table A.6c Number of docks in the main port = 3 (continued)

Output 3e

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
445,735	129,032	316,703	176	102	235.3	4,500	CP	3
428,502	202,188	226,314	276	194	182.5	7,500	CP	3
390,664	175,382	215,282	599	251	234.67	10,000	D	1
5,520,881	4,742,423	778,458	911	413	396.85	25,000	A	1
1,549,450	862,282	687,168	581	160	453.58	15,500	B	4
621,179	198,488	422,691	272	168	327.74	7,500	C	2
716,260	272,458	443,802	372	260	341.88	10,000	CP	3
1,530,817	387,878	1,142,939	261	290	686.63	7,000	B	4
11,203,488	6,970,131	4,233,356						

Output 3f

i	1	2	3
K_i	12	10	12
μ_i	5	3	5

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
499,978	145,729	354,249	197	88	261.07	4,500	CP	3
542,688	258,969	283,720	346	164	223.45	7,500	CP	3
400,288	182,532	217,756	605	241	238.05	10,000	D	1
6,955,275	5,993,524	961,751	1126	476	470.72	25,000	A	1
1,886,848	1,055,094	831,754	703	142	537.89	15,500	B	4
766,181	249,069	517,111	332	198	395.7	7,500	C	2
858,904	329,957	528,947	443	297	402.24	10,000	CP	3
1,826,944	467,169	1,359,775	310	338	812.05	7,000	B	4
13,737,107	8,682,045	5,055,062						

Table A.6d Number of docks in the main port = 3 (continued)

Output 3g

i	1	2	3
K_i	12	10	15
μ_i	5	3	4

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
556,696	162,537	394,159	219	97	289.1	4,500	CP	3
564,774	269,483	295,291	360	176	230.97	7,500	CP	3
410,119	186,198	223,921	622	245	242.53	10,000	D	1
7,318,367	6,300,291	1,018,075	1192	498	491.98	25,000	A	1
1,936,295	1,079,319	856,976	724	145	550.85	15,500	B	4
840,107	270,292	569,815	366	217	433.33	7,500	C	2
920,952	353,068	567,885	476	317	428.27	10,000	CP	3
1,962,554	499,194	1,463,360	334	355	871.86	7,000	B	4
14,509,865	9,120,382	5,389,483						

Output 3h

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
419,970	121,026	298,944	166	74	222.41	4,500	CP	3
449,617	211,933	237,684	290	140	191.39	7,500	CP	3
387,110	174,087	213,023	592	118	232.73	10,000	D	2
5,611,671	4,822,368	789,303	924	203	401.58	25,000	A	2
1,514,733	840,606	674,127	569	122	445.5	15,500	B	4
646,115	207,690	438,425	282	170	339.49	7,500	C	2
723,113	275,095	448,018	375	254	344.98	10,000	CP	3
1,495,233	377,439	1,117,794	255	279	671.87	7,000	B	4
11,247,561	7,030,244	4,217,318						

Table A.7a Number of docks in the main port = 4

Output 4a

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
420,114	121,491	298,622	166	56	222.32	4,500	CP	4
447,110	211,288	235,822	288	105	189.65	7,500	CP	4
384,509	173,091	211,418	588	234	230.9	10,000	D	1
5,423,310	4,660,428	762,882	893	394	389.88	25,000	A	1
1,550,322	862,506	687,815	582	155	454.2	15,500	B	3
622,633	199,699	422,934	272	164	328.12	7,500	C	2
726,865	276,236	450,629	377	190	347.01	10,000	CP	4
1,511,848	380,933	1,130,916	258	378	679.64	7,000	B	3
11,086,710	6,885,673	4,201,037						

Output 4b

i	1	2	3
K_i	12	10	12
μ_i	5	3	5

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
514,348	150,831	363,517	202	67	267.4	4,500	CP	4
535,280	255,466	279,813	342	124	220.5	7,500	CP	4
407,823	185,549	222,274	618	245	242.23	10,000	D	1
6,910,283	5,951,508	958,775	1122	475	469.67	25,000	A	1
1,875,793	1,048,528	827,265	699	185	534.92	15,500	B	3
787,593	254,859	532,734	342	204	407.48	7,500	C	2
872,594	334,834	537,760	451	225	408.13	10,000	CP	4
1,861,731	475,230	1,386,501	316	455	827.73	7,000	B	3
13,765,444	8,656,806	5,108,638						

Table A.7b Number of docks in the main port = 4 (continued)

Output 4c

i	1	2	3
K_i	12	10	15
μ_i	5	3	4

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
528,091	155,559	372,532	207	69	273.43	4,500	CP	4
544,376	258,678	285,697	349	126	224.65	7,500	CP	4
443,750	201,976	241,773	672	263	259.82	10,000	D	1
6,893,310	5,935,743	957,567	1122	474	468.21	25,000	A	1
1,880,052	1,051,620	828,432	700	182	534.33	15,500	B	3
783,101	253,288	529,812	340	203	405.22	7,500	C	2
890,114	341,956	548,158	459	229	414.84	10,000	CP	4
1,924,179	492,182	1,431,997	327	464	854.12	7,000	B	3
13,886,972	8,691,003	5,195,969						

Output 4d

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
417,696	120,997	296,698	165	74	221.08	4,500	CP	3
445,205	209,970	235,235	287	139	189.33	7,500	CP	3
382,952	172,606	210,347	585	232	229.69	10,000	D	1
5,541,657	4,761,897	779,761	913	401	397.12	25,000	A	1
1,507,047	837,837	669,210	565	152	442.03	15,500	B	3
646,147	206,728	439,418	282	170	339.97	7,500	C	2
743,765	283,206	460,559	386	256	354.15	10,000	CP	3
1,507,435	381,438	1,125,997	257	373	676.22	7,000	B	3
11,191,904	6,974,679	4,217,225						

Table A.7c Number of docks in the main port = 4 (continued)

Output 4e

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
448,747	130,091	318,656	177	79	236.49	4,500	CP	3
447,393	210,458	236,935	289	143	190.59	7,500	CP	3
391,313	175,947	215,366	599	238	235.03	10,000	D	1
5,551,870	4,771,297	780,573	914	402	398.18	25,000	A	1
1,475,944	818,988	656,956	555	113	434.73	15,500	B	4
650,082	207,915	442,167	284	171	342.26	7,500	C	2
741,703	282,355	459,348	385	261	353.16	10,000	CP	3
1,488,475	375,949	1,112,526	254	276	668.52	7,000	B	4
11,195,528	6,973,002	4,222,526						

Output 4f

i	1	2	3
K_i	12	10	12
μ_i	5	3	5

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
506,255	148,249	358,005	199	88	263.38	4,500	CP	3
534,223	255,035	279,188	341	163	220	7,500	CP	3
404,701	184,429	220,272	612	243	240.48	10,000	D	1
6,865,155	5,916,046	949,109	1110	470	464.13	25,000	A	1
1,858,341	1,037,680	820,661	693	139	530.53	15,500	B	4
787,992	255,536	532,456	342	204	407.55	7,500	C	2
863,238	332,247	530,991	445	297	402.97	10,000	CP	3
1,816,775	462,971	1,353,805	309	335	808.89	7,000	B	4
13,636,679	8,592,193	5,044,486						

Table A.7d Number of docks in the main port = 4 (continued)

Output 4g

i	1	2	3
K_i	12	10	15
μ_i	5	3	4

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
557,125	163,069	394,055	219	96	288.8	4,500	CP	3
562,118	266,967	295,151	360	175	231.05	7,500	CP	3
434,053	197,604	236,450	657	259	255.41	10,000	D	1
7,266,636	6,258,176	1,008,460	1181	493	487.08	25,000	A	1
1,973,273	1,101,638	871,635	737	149	559.49	15,500	B	4
780,416	251,566	528,850	340	202	403.48	7,500	C	2
925,550	355,083	570,467	478	318	430.17	10,000	CP	3
1,982,407	505,644	1,476,763	337	360	879.44	7,000	B	4
14,481,579	9,099,747	5,381,832						

Output 4h

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
421,509	120,978	300,531	167	75	223.59	4,500	CP	3
431,419	203,498	227,921	278	138	184.14	7,500	CP	3
384,691	173,133	211,558	588	117	231.15	10,000	D	2
5,546,906	4,769,729	777,178	910	200	395.47	25,000	A	2
1,485,155	825,170	659,985	558	115	436.28	15,500	B	4
626,523	199,948	426,574	274	166	330.89	7,500	C	2
742,033	283,318	458,714	385	254	352.8	10,000	CP	3
1,475,600	371,134	1,104,466	252	275	664.12	7,000	B	4
11,113,837	6,946,908	4,166,929						

Table A.8a Number of docks in the main port = 5

Output 5a

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
431,572	123,841	307,731	171	57	229.05	4,500	CP	4
451,352	213,371	237,981	291	106	191.32	7,500	CP	4
380,822	170,884	209,938	584	233	229.75	10,000	D	1
5,618,578	4,830,443	788,135	923	405	400.61	25,000	A	1
1,513,268	840,621	672,647	568	154	444.17	15,500	B	3
650,735	208,561	442,174	284	171	342.12	7,500	C	2
725,220	275,696	449,524	377	192	346.16	10,000	CP	4
1,510,332	378,412	1,131,920	258	376	680.48	7,000	B	3
11,281,879	7,041,829	4,240,050						

Output 5b

i	1	2	3
K_i	12	10	12
μ_i	5	3	5

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
520,144	152,263	367,880	204	68	270.76	4,500	CP	4
512,275	243,663	268,612	328	123	212.14	7,500	CP	4
394,621	180,377	214,243	595	237	234.67	10,000	D	1
6,921,108	5,961,488	959,620	1124	475	469.84	25,000	A	1
1,844,156	1,033,122	811,034	686	179	524.99	15,500	B	3
790,927	256,905	534,022	343	204	407.93	7,500	C	2
859,003	330,955	528,047	443	222	400.75	10,000	CP	4
1,837,143	469,342	1,367,801	313	448	817	7,000	B	3
13,679,375	8,628,115	5,051,260						

Table A.8b Number of docks in the main port = 5 (continued)

Output 5c

i	1	2	3
K_i	12	10	15
μ_i	5	3	4

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
517,768	150,606	367,163	204	68	270.04	4,500	CP	4
535,808	254,728	281,080	343	124	221.02	7,500	CP	4
448,713	203,920	244,793	680	266	262.81	10,000	D	1
6,985,849	6,016,896	968,954	1135	479	473.34	25,000	A	1
1,876,864	1,049,191	827,673	700	187	535	15,500	B	3
750,321	242,291	508,030	326	195	388.82	7,500	C	2
881,991	338,884	543,107	455	226	411.36	10,000	CP	4
1,978,685	507,279	1,471,406	336	471	877.12	7,000	B	3
13,976,000	8,763,794	5,212,205						

Output 5d

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
429,760	123,760	306,000	170	76	227.82	4,500	CP	3
444,951	210,120	234,831	287	140	188.87	7,500	CP	3
388,873	175,160	213,713	595	236	233.26	10,000	D	1
5,489,767	4,717,146	772,620	905	399	394.49	25,000	A	1
1,524,622	847,084	677,538	573	153	447.51	15,500	B	3
632,009	202,423	429,586	276	167	332.89	7,500	C	2
726,079	276,109	449,970	378	255	346.46	10,000	CP	3
1,486,183	375,958	1,110,225	253	372	667.14	7,000	B	3
11,122,244	6,927,760	4,194,483						

Table A.8c Number of docks in the main port = 5 (continued)

Output 5e

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
436,179	126,193	309,986	172	77	230.33	4,500	CP	3
445,517	210,084	235,433	287	142	189.27	7,500	CP	3
383,201	172,272	210,929	587	233	230.19	10,000	D	1
5,561,881	4,778,924	782,957	916	404	399.05	25,000	A	1
1,513,683	839,924	673,759	569	118	444.72	15,500	B	4
626,580	200,679	425,901	274	165	329.94	7,500	C	2
741,733	281,914	459,819	385	259	354.1	10,000	CP	3
1,538,611	389,298	1,149,314	262	283	690.31	7,000	B	4
11,247,386	6,999,286	4,248,100						

Output 5f

i	1	2	3
K_i	12	10	12
μ_i	5	3	5

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
522,535	152,844	369,691	205	91	271.9	4,500	CP	3
520,443	247,624	272,819	333	164	215.4	7,500	CP	3
390,003	177,865	212,138	589	235	231.97	10,000	D	1
6,958,761	5,996,100	962,661	1127	476	470.57	25,000	A	1
1,877,167	1,048,915	828,252	700	138	535.63	15,500	B	4
781,893	252,596	529,297	340	202	404.65	7,500	C	2
863,379	332,022	531,357	445	298	403.35	10,000	CP	3
1,897,211	486,178	1,411,033	322	345	841.92	7,000	B	4
13,811,391	8,694,143	5,117,248						

Table A.8d Number of docks in the main port = 5 (continued)

Output 5g

i	1	2	3
K_i	12	10	15
μ_i	5	3	4

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
573,424	167,240	406,184	226	100	297.45	4,500	CP	3
564,146	267,234	296,912	363	178	232.33	7,500	CP	3
421,598	192,407	229,191	637	251	247.7	10,000	D	1
7,330,914	6,312,144	1,018,770	1193	498	491.91	25,000	A	1
1,977,192	1,104,993	872,200	737	145	559.79	15,500	B	4
807,792	260,387	547,406	352	209	417.23	7,500	C	2
963,255	368,954	594,301	498	327	447.45	10,000	CP	3
1,994,499	509,223	1,485,276	339	362	884.64	7,000	B	4
14,632,820	9,182,581	5,450,239						

Output 5h

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
430,219	123,989	306,229	170	76	227.8	4,500	CP	3
453,451	213,936	239,515	292	141	192.47	7,500	CP	3
385,497	173,164	212,332	590	117	231.65	10,000	D	2
5,578,703	4,794,156	784,547	919	202	399.45	25,000	A	2
1,559,001	865,825	693,176	586	121	457.34	15,500	B	4
632,507	201,318	431,189	277	167	334.06	7,500	C	2
714,813	271,419	443,394	372	255	341.69	10,000	CP	3
1,537,202	387,217	1,149,985	262	287	690.45	7,000	B	4
11,291,393	7,031,025	4,260,369						

Table A.9a Number of docks in the main port = 6

Number of docks in the main ports = 6

Output 6a

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
435,369	125,556	309,813	172	58	230.29	4,500	CP	4
440,389	207,600	232,789	284	106	187.34	7,500	CP	4
393,454	176,805	216,649	603	239	236.05	10,000	D	1
5,581,727	4,797,961	783,766	918	404	399.33	25,000	A	1
1,547,564	859,606	687,958	581	158	454	15,500	B	3
622,484	198,795	423,689	272	165	328.44	7,500	C	2
708,855	269,640	439,216	368	190	338.67	10,000	CP	4
1,478,847	370,852	1,107,995	253	373	666.37	7,000	B	3
11,208,689	7,006,815	4,201,874						

Output 6b

i	1	2	3
K_i	12	10	12
μ_i	5	3	5

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
532,319	156,153	376,166	209	69	276.65	4,500	CP	4
526,268	250,140	276,128	337	125	217.86	7,500	CP	4
386,970	176,146	210,824	586	234	230.93	10,000	D	1
6,917,843	5,960,792	957,051	1120	474	468.59	25,000	A	1
1,888,561	1,058,054	830,507	702	185	536.03	15,500	B	3
781,579	252,455	529,125	340	203	404.6	7,500	C	2
869,354	335,011	534,344	448	226	405.12	10,000	CP	4
1,823,031	467,834	1,355,197	310	449	809.28	7,000	B	3
13,725,925	8,656,585	5,069,340						

Table A.9b Number of docks in the main port = 6 (continued)

Output 6c

i	1	2	3
K_i	12	10	15
μ_i	5	3	4

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
521,711	152,477	369,234	205	68	271.67	4,500	CP	4
553,055	263,061	289,994	354	127	228.35	7,500	CP	4
450,941	205,221	245,720	683	267	263.5	10,000	D	1
7,015,979	6,038,911	977,068	1144	482	476.85	25,000	A	1
1,878,217	1,049,224	828,992	701	185	535.13	15,500	B	3
802,527	260,383	542,145	348	207	413.55	7,500	C	2
887,686	341,683	546,004	458	229	413.23	10,000	CP	4
1,922,883	489,248	1,433,634	327	464	855.52	7,000	B	3
14,032,999	8,800,208	5,232,791						

Output 6d

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
428,612	123,714	304,898	169	76	226.9	4,500	CP	3
452,300	213,397	238,903	292	141	191.98	7,500	CP	3
382,572	171,982	210,591	585	232	229.57	10,000	D	1
5,499,544	4,726,162	773,382	905	399	394.4	25,000	A	1
1,493,599	829,513	664,086	561	153	438.62	15,500	B	3
635,198	203,419	431,779	278	168	334.46	7,500	C	2
724,930	275,812	449,118	377	256	345.85	10,000	CP	3
1,479,513	371,790	1,107,723	253	368	666.04	7,000	B	3
11,096,269	6,915,789	4,180,480						

Table A.9c Number of docks in the main port = 6 (continued)

Output 6e

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
438,251	126,450	311,801	173	77	231.46	4,500	CP	3
438,781	206,962	231,819	283	141	186.63	7,500	CP	3
383,534	172,398	211,136	587	234	230.98	10,000	D	1
5,511,881	4,738,390	773,490	906	398	393.98	25,000	A	1
1,519,083	844,348	674,735	570	117	445.35	15,500	B	4
636,338	203,596	432,742	278	167	335.07	7,500	C	2
744,808	282,627	462,181	387	259	355.37	10,000	CP	3
1,476,857	373,958	1,102,899	252	277	662.87	7,000	B	4
11,149,534	6,948,730	4,200,804						

Output 6f

i	1	2	3
K_i	12	10	12
μ_i	5	3	5

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
520,797	152,987	367,810	204	90	270.66	4,500	CP	3
536,830	255,870	280,960	343	165	221.39	7,500	CP	3
403,504	184,032	219,472	610	243	240.04	10,000	D	1
6,798,719	5,855,482	943,238	1103	468	462.25	25,000	A	1
1,885,322	1,053,614	831,708	703	142	537.48	15,500	B	4
754,842	244,245	510,597	328	196	391.17	7,500	C	2
853,485	328,552	524,932	440	298	398.43	10,000	CP	3
1,829,859	467,747	1,362,113	311	338	812.97	7,000	B	4
13,583,358	8,542,529	5,040,829						

Table A.9d Number of docks in the main port = 6 (continued)

Output 6g

i	1	2	3
K_i	12	10	15
μ_i	5	3	4

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
545,277	159,805	385,473	214	94	282.69	4,500	CP	3
570,873	270,974	299,900	366	175	234.43	7,500	CP	3
415,728	189,148	226,581	630	249	245.52	10,000	D	1
7,292,901	6,277,304	1,015,596	1189	497	491.36	25,000	A	1
1,954,485	1,088,362	866,123	732	147	556.51	15,500	B	4
849,985	274,273	575,712	370	219	437.87	7,500	C	2
946,660	363,289	583,371	489	320	439.36	10,000	CP	3
1,993,253	508,731	1,484,522	339	360	884.46	7,000	B	4
14,569,163	9,131,886	5,437,278						

Output 6h

i	1	2	3
K_i	15	10	15
μ_i	6	4	6

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
435,730	125,738	309,992	172	77	230.44	4,500	CP	3
454,048	213,915	240,134	293	143	193.21	7,500	CP	3
386,540	173,549	212,991	592	118	232.31	10,000	D	2
5,694,818	4,894,324	800,494	937	205	406.2	25,000	A	2
1,503,677	834,162	669,514	566	118	442.32	15,500	B	4
645,526	206,853	438,674	282	170	339.64	7,500	C	2
713,408	270,562	442,846	371	256	341.36	10,000	CP	3
1,514,420	383,052	1,131,368	258	280	679.58	7,000	B	4
11,348,168	7,102,155	4,246,013						

Table A.10a Pools and types of ship alterations

Number of docks in the main port = 1

Ships in each route			Ship pools	K_1	K_2	K_3	μ_1	μ_2	μ_3
Route	Quantity	Type							
1	1	C	Pool 1: 2 of type A	15	10	15	6	4	6
2	1	C	Pool 2: 4 of type B						
3	2	D	Pool 3: 2 of type C						
4	2	A	Pool 4: 3 of type CP;						
5	2	C	Pool 5: 1 of type D						
6	1	D							
7	1	CP							
8	1	B							

Output 7a

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
484,254	121,736	362,517	166	157	274.16	4,500	C	2
473,046	201,122	271,924	274	279	219.94	7,500	C	2
391,481	175,753	215,728	599	331	235.05	10,000	D	1
5,595,679	4,808,627	787,052	921	209	400.41	25,000	A	2
1,075,600	418,935	656,664	570	514	522.85	15,500	C	2
689,813	129,743	560,070	441	791	542.95	7,500	D	1
733,851	278,283	455,568	382	120	350.71	10,000	CP	3
1,574,752	397,968	1,176,784	269	177	706.31	7,000	B	4
11,018,475	6,532,167	4,486,308						

Output 7b

(The same configuration as in Output 7a, except pool 3 contains 3 of ship type C and pool 5, 2 of type D).

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
501,703	126,144	375,559	172	115	283.93	4,500	C	3
479,936	203,994	275,942	278	215	223.44	7,500	C	3
393,991	177,056	216,935	603	205	236.64	10,000	D	2
5,467,281	4,698,246	769,036	901	207	392.62	25,000	A	2
1,049,109	407,352	641,757	557	346	512.1	15,500	C	3
681,998	128,068	553,931	436	398	537.25	7,500	D	2
721,977	274,753	447,224	375	118	344.43	10,000	CP	3
1,522,858	383,443	1,139,415	260	173	684.63	7,000	B	4
10,818,854	6,399,056	4,419,798						

Table A.10b Pools and types of ship alterations (continued)

Output 7c

(The same as in Output 7b, except route 6 utilizes 1 C type ship)

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
486,834	122,542	364,292	167	121	275.84	4,500	C	3
479,218	203,198	276,020	278	210	223.63	7,500	C	3
386,440	173,444	212,996	592	128	232.78	10,000	D	2
5,476,076	4,706,632	769,444	901	206	391.94	25,000	A	2
1,086,079	421,721	664,358	577	354	529.72	15,500	C	3
644,746	206,723	438,023	282	462	339.64	7,500	C	3
722,351	274,316	448,034	375	120	344.69	10,000	CP	3
1,500,209	379,791	1,120,418	256	170	673.35	7,000	B	4
10,781,952	6,488,366	4,293,586						

Output 7d

(The same configuration as in Output 7c, except pool 3 contains 4 C type ship).

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
481,081	120,857	360,224	165	89	273.18	4,500	C	4
488,942	207,067	281,875	284	171	227.83	7,500	C	4
378,439	169,916	208,523	580	127	227.82	10,000	D	2
5,636,582	4,842,902	793,680	929	214	403.52	25,000	A	2
1,081,593	420,205	661,387	574	270	527.26	15,500	C	4
655,658	210,678	444,980	286	350	344.06	7,500	C	4
722,435	274,041	448,394	376	121	345.7	10,000	CP	3
1,540,197	386,772	1,153,425	263	175	693	7,000	B	4
10,984,927	6,632,440	4,352,487						

Output 7e

(The same configuration as in Output 7d, except pool 2 contains 3 B type ships).

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
480,651	120,694	359,956	165	90	272.57	4,500	C	4
476,615	203,311	273,304	276	172	221.12	7,500	C	4
387,074	174,365	212,709	591	129	232.57	10,000	D	2
5,606,697	4,818,429	788,268	923	213	400.89	25,000	A	2
1,083,446	421,266	662,181	575	266	527.2	15,500	C	4
624,606	200,163	424,442	273	344	329.19	7,500	C	4
745,576	283,531	462,045	387	123	355.44	10,000	CP	3
1,513,776	382,781	1,130,995	258	228	679.22	7,000	B	3
10,918,440	6,604,539	4,313,901						

Table A.10c Pools and types of ship alterations (continued)

Output 7f

(The same configuration as in Output 7e, except pool 3 contains 3 C type ships).

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
495,016	124,347	370,668	170	114	280.82	4,500	C	3
475,610	201,659	273,952	276	205	221.87	7,500	C	3
386,020	173,511	212,509	591	126	231.91	10,000	D	2
5,593,062	4,805,000	788,061	922	211	400.73	25,000	A	2
1,055,288	409,613	645,675	560	348	514.65	15,500	C	3
644,510	205,089	439,421	282	459	340.61	7,500	C	3
737,723	280,979	456,743	383	121	351.19	10,000	CP	3
1,529,165	385,647	1,143,518	261	231	686.84	7,000	B	3
10,916,393	6,585,845	4,330,548						

Output 7g

(The same configuration as in Output 7f, except pool 2 contains 2 of ship type B and pool 3, 4 of type C).

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
500,658	125,521	375,137	172	89	283.85	4,500	C	4
479,590	203,040	276,550	279	169	223.88	7,500	C	4
387,581	174,333	213,248	593	128	232.98	10,000	D	2
5,568,185	4,786,270	781,915	915	211	397.95	25,000	A	2
1,075,168	418,036	657,132	571	270	523.62	15,500	C	4
627,813	200,295	427,518	275	347	331.43	7,500	C	4
705,409	268,085	437,324	367	116	337.69	10,000	CP	3
1,492,474	376,416	1,116,058	255	337	670.67	7,000	B	2
10,836,878	6,551,996	4,284,882						

Output 7h

(The same as in Output 7g, except route 1 utilizes 1 D type ship)

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
543,820	77,679	466,142	262	228	445.4	4,500	D	2
481,204	203,873	277,331	279	78	224.88	7,500	C	4
388,878	175,185	213,693	594	345	233.19	10,000	D	2
5,615,025	4,825,863	789,162	924	211	401.71	25,000	A	2
1,081,318	419,742	661,576	574	197	526.49	15,500	C	4
638,416	203,564	434,851	279	278	336.61	7,500	C	4
719,532	272,852	446,680	374	118	344.04	10,000	CP	3
1,500,096	377,702	1,122,394	256	339	674.57	7,000	B	2
10,968,289	6,556,460	4,411,829						

Table A.10d Pools and types of ship alterations (continued)

Output 7i

(The same as in Output 7h, except route 2 utilizes 2 D type ships)

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
561,456	79,604	481,852	271	234	460.28	4,500	D	2
499,147	133,165	365,982	452	418	364.32	7,500	D	2
382,225	171,613	210,612	585	534	230.07	10,000	D	2
5,602,209	4,814,941	787,268	922	210	400.16	25,000	A	2
1,091,999	423,764	668,235	580	141	531.96	15,500	C	4
655,369	209,244	446,125	287	223	345.5	7,500	C	4
733,912	279,110	454,802	381	120	350.33	10,000	CP	3
1,501,677	379,637	1,122,040	256	339	674.2	7,000	B	2
11,027,994	6,491,078	4,536,916						

Output 7j

(The same configuration as in Output 7i, except pool 5 contains 3 D type ships).

C_T (US$)	C_p (US$)	C_s (US$)	# of Trips	Time (days)	Operating Time (days)	Annual Quantity of Cargo	Ship Type	# of Ships
548,230	77,384	470,846	264	152	450.01	4,500	D	3
492,321	131,212	361,109	446	275	359.87	7,500	D	3
390,896	175,587	215,309	598	354	234.83	10,000	D	3
5,555,789	4,776,407	779,383	912	208	396.49	25,000	A	2
1,091,933	424,643	667,290	580	141	531.41	15,500	C	4
626,960	200,736	426,224	274	220	330.56	7,500	C	4
740,947	281,664	459,283	385	121	353.38	10,000	CP	3
1,535,747	387,116	1,148,630	262	347	690.07	7,000	B	2
10,982,823	6,454,750	4,528,073						