Inland Container Transportation System Planning

with Reference to Korean Ports

BY

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China
North Korea
Seoul
Kangwon
Inch'on
Sudo
Chung
-buk
Chung
-nam
Kyongbuk
Chonbuk
Ulsan
Kyongnam
Masan
Pusan
Chonnam
Kwangyang
Gaduk
-do
Kyongbu
Railway
Kyongbu
Motorway
0
100 km
Chejudo

ABSTRACT

This study attempts to develop realistic and relevant investment planning models for inland container transportation systems. An inland container transport system model has been constructed consisting of three sub-models: forecasting future total export container demand, the inland container traffic allocation model and the optimum port capacity model.

The models may be utilised to identify the most effective investment plan for inland transportation infrastructure development and to evaluate the inland container transportation system. The procedure enables determination of the optimal locations, sizes and time of container port developments as well as the optimal container cargo flows through transportation networks.

A Heuristic algorithm was developed for the purpose of evaluating alternative investment plans. Dynamic and Linear programming methods are applied to each of the two planning problems: the former for the optimum container port capacity development problem and the latter for the optimal allocation of inland container traffic movements.

Finally, the model has been applied to concrete inland container transportation system problems in Korea. The results are reported and analysed. It is hoped that they may provide a guideline for actual development.

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Variables

Y_t = the total demand for container cargo at time t

E_t^i = the demand for region i at time t

F_{tk}^i = the modal split of each region's cargo at time t

D_t^j = the throughput in port j at time t

Q_{tk}^{ij} = the amount of container traffic shipped from region i to port j
using transportation mode k

K_t^i = the capacity of port j at time t

I_t = the configuration of the additional port development at time t

U_t^j = construction costs per terminal at port j

H_t^m = a dummy port for the extra traffic volume at time t

M_t^i = the area of the industrial complex in region i at time t

L_t^j = the amount of container traffic delayed at port j

P_i = the population of region i

A_{ij} = the distance between i and j

G_{ij} = the number of trips between i and j

Costs

T_{tk}^{ij} = the cost of transporting one unit between region i and port j
using transportation mode system k

U_t^j = construction costs per terminal at port j.

d^j = the additional costs in ports per TEU incurred
by insufficient handling capacity in port j .

$f(Q_t)$ = inland transportation costs at time t

$Z(K_t, I_t)$ = construction costs corresponding to the proposed port investment projects at time t

$C(K_t, Q_t)$ = terminal congestion costs at time t

$V_t(K_t, I_t)$ = system costs of alternative I_t at time t

$X_t^*(K_t)$ = the optimal total system costs to time t given the state K_t

B_t^j = stevedoring cost per ton at port j at time t

s_t^{fl} = shipping cost per ton between foreign port f and local port l at time t

R_t^j = the value of time at port j at time t

Parameters

r = interest rate

q = the rate of depreciation

$\delta^t = (1+r)^{-t}$

α = the maximum budget

λ_t^i = the un-normalised share of region i in total container volume at time t

β_t^j = weights for the additional costs in port j at time t

y = a proportionality factor

Notation

Subscripts

i : refers specifically to a region (1, 2, n, ... N)

j : refers specifically to a port (1, 2, p, ... P)

k : refers specifically to a transportation mode (Road, Rail, Coastal Shipping)

t : denotes time period (t = 1, 2 ...)

f : refers specifically to a foreign port

l : refers specifically to a local port

Superscript

T : the last year of the planning period

Abbreviations

TEU: Twenty foot Equivalent Units
O/D: Origin/Destination
EDI: Electronic Data Interchange
HSR: The Seoul-Pusan High Speed Rail System
ODCY: Off-Dock Container Yard
ICD: Inland Container Depot
KMI: Korea Maritime Institute
ROCO: average road transport cost per 40 foot container
RACO: average rail transport cost per 40 foot container
DIST: distance (Km) from point to port
QT: the delay time per TEU
EC: the excess level of handling capacity
RD: road transportation mode
RL: rail transportation mode
CS: coastal shipping transportation mode
TC: total inland transport costs
QC: terminal congestion costs
SC: construction costs
A0: Sudo region
B0: Pusan region
B1: Kyongnam region
B2: Kyongbuk region
C1: Chonnam region
C2: Chonbuk region
D1: Chungnam region
D2: Chungbuk region
E0: Kangwon region

Chapter 1

Introduction

1.1 Inland Container Transport as a Systems Problem

The continuum of possible national trade policy perspectives ranges from deciding on the balance between import and export orientation to the infrastructure development planning process. The inland container transport system can be considered as the transportation artery for international trade consisting of nodes and links with certain characteristics. When infrastructure development plans are considered, the policy-maker needs to balance each functional area and see to it that none is stressed to the point where it becomes detrimental to others. This may be identified with the concept of a systems approach which from the viewpoint of say, a firm, indicates that its objectives can be realised by only recognising the mutual interdependence of the basic functional areas of the firm. One definition of the systems approach is as follows: "The systems approach to a problem involves not only a recognition of the individual importance of the various elements of which it is composed but also an acknowledgement of their interrelationship. Whereas field specialists concentrate restrictively on their own particular bailiwick, the more versatile systems people, in their capacity as generalists, seek the optimum blend of many of these individual operations in order to fulfil a broader objective ".[1] Logistics[2] has been

[1] Barrett, C., 1971, The Machine and Its Parts, *Transportation and Distribution Management*, p.3.
[2] Transportation - Logistics Dictionary (1989) defines logistics as the management of all inbound and outbound materials, parts, supplies, and finished goods. The term logistics is not specific to the business or public sector. The basic concepts of logistical management are applicable throughout private and public enterprise activities. Above all, a fundamental logistics objective is smooth product flow in a manner that facilitates efficient capacity utilisation.

a classic example of the systems approach applied to business problems[3] and similar reasoning can be applied to inland container transport problems.

There are a number of points to consider in implementing the system approach to container transport.

First, today's transport system problem has become more complicated than ever before so as to meet the needs of a more complex economic environment. It is obvious that the inland container transport system must be co-ordinated with container port development and at the same time, the role of container port development is critical to the system problem since port development significantly affects the inland container transport system. The port investment plan itself requires the commitment of much time and cost. Goss (1967) has pointed out that there is no commonly accepted method of appraising proposals for investment in port facilities. He makes the point that in some instances, this lack of systematic appraisal techniques appears to have led to either under-investment, over-investment or misplaced and mistimed investment. The overall problem of evaluating port investment covers a wide field ranging from forecasting traffic to modal split and to assignment of container traffic. Although the individual elements which make up the transport system are important, a more important point is how to integrate them. The systems approach mentioned above is one of the ways of giving some practical and systematic answers to these necessities. That is, the individual element is designed to be modular independently, but the whole system reaches an optimum by maintaining their interrelationship. One can distinguish between the classic four-stage-sequential model and a variety of newer approaches. Typically, in the latter, choices of trip frequency, destination and mode of travel are

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[3] Johnson, J. C. and D. F. Wood, 1996, *Contemporary Logistics* (6th ed.), New Jersey, Prentice Hall.

treated simultaneously in one single model[4]. The classic four-stage-sequential model is the preferred method here. As discussed later, the classic sequential model can help in coping with the complications of a problem by employing a step-by-step procedure.

Second, one of the recurring themes of transport modelling, such as in this study, is the distance between theoreticians and practitioners. A number of studies are theoretically sound but difficult to implement or to solve practically. For example we note that the model of Shneerson (1981) which was applied to a large-scale case study of the Nigerian port system to help to alleviate queuing in the port system and plan its country's future port requirements is nevertheless hard to implement. Successful applied research requires a satisfactory guide for action in a reasonable period of time. Thus, researchers occasionally use heuristic procedures to find a good sub-optimal or second-best solution. This may be supplemented by a number of "what if" questions concerning the effects of different parameter values on the measure of economic effectiveness of interest.

At present, there are a wealth of technical tools available to assist in the development of good solution algorithms for numerical models. These have been developed over the years by researchers working in many areas besides transportation. With the development of personal computers, it is possible to design a more pragmatic modelling approach reflecting the limitations of the data, time and resources available for a study.

[4] Ortuzar (1994) indicated that "the four-stage sequential model provides a point of reference to contrast alternative methods. For example, some contemporary approaches attempt to treat simultaneously the choices of trip frequency, destination and mode of travel, thus collapsing trip generation, distribution and mode choice in on single model. Other approaches emphasis the role of household activities and travel choices they entail: concepts like sojourns, circuits and time and money budgets are used in this context to model travel decisions and constraints. These modelling strategies are more difficult to cast in terms of the four main decisions or sub-models above. They have played more of a research role and their operational use is some time away yet."(p.25) He noted

Third, most port investment studies have focused on port development for distributing imports and exports of multi-commodity handling ports (De Weille and Ray,1974; Shneerson, 1981). Few studies have focused specifically on the movement of container traffic for international trade with the systems approach. There is a considerable difference between the operation of bulk cargo and that of container cargo. Dowd and Leschine (1990) noted "containerisation, the movement of cargo in containers, is a system with an ocean component and a land component. A container terminal is a facility which provides a package of activities and services to handle and control container flows from vessels to rail or road and vice versa."[5] A container cargo service uses various transport modes in handling a unit i.e. TEU (Twenty foot Equivalent Unit) which requires specialised container ports and specific handling facilities. The economics of container transport is such that typically deep-sea container ships concentrate upon main ports only as a scheduled service instead of calling at a large number of minor ports, while a dry bulk service ordinarily varies the calling ports according to the requirements of shippers and operators. Almost all countries have a limited number of main container ports for international deep-sea trade. The other, smaller, container ports within a country depend on the feeder services between them and the main container port. This results in a reduction in the number of alternatives to the choice of ports when a model is considered for a container transport system.

Fourth, in a number of counties such as Israel, Kenya, Singapore and Korea the port industry is organised by a central port authority, which in most cases regulates both investment and pricing in individual ports. Goss (1990) has emphasised the

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that the understanding of travel behaviour in terms of activity-based models is likely to enhance more conventional modelling approaches in the future.

importance and effectiveness of a port authority in the centralised planning of port development, illustrated with some examples of port development in the absence of a conventional port authority and of any conscious planning. The typical authority has faced an increase in the complexity of its infrastructure development. An important planning issue and question is how to determine the distribution system with the lowest total system costs and the most effective investment plan for the system in such a way that the investment plan can match or catch up with demands on the transport system over a given period. A typical question facing decision makers for national port developments, particularly in developing countries, involves the issue of centralisation versus devolution - i.e. one Mega port system or a Multi-port system for its international container port system. A further consideration concerns the role of the container port to the economy as a whole given its economic structure and its geographical position. That is, a container port may adopt the role of transit ports like Singapore, Rotterdam port or the role of gateway ports like the main container ports in Japan and the U.S. If the inland container transport problem is correctly specified, then the study can be used to yield a convincing answer to this issue including the question of how to evolve from (or to) one Mega port system to (or from) a Multi-port system.

In practice, complexity may be increased by the addition of non-economic factors such as the prejudices of policy-makers and the self-centred ambitions of local government. In the absence of consistent planning, there is a danger that infrastructure developments will change as regimes change. That is, regimes tend to make use of their infrastructure developments to maintain political support. In Korea both national

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[5] Dowd, T. J. and T. M. Leschine, 1990, Container Terminal Productivity: a Perspective, *Maritime Policy and Management*, Vol. 17, No.2, p.107-112.

and local governments have interests in infrastructure developments for their own political purposes and local governments may choose to develop their own infrastructure projects in disregard of the view-point of a national optimum. Local autonomy means that local governments can initiate their own port development plans even in the absence of sufficient capital to complete the project and which later may then become dependent on the national government's budget.

In attempting to develop transport systems for inland container distribution problems, it would be desirable to develop a model which has the capability to: 1) determine the optimal locations and sizes of new transportation facilities corresponding to alternative investment plans; 2) generate the optimal container flows over the transportation network.

It also requires that all activities are tied together in cause and effect relationships such that if one part of the system is changed it results in changes to the other parts of the system.

1.2 Theoretical and Historical Background

This section is aimed at describing how the inland container transport problem discussed in this thesis relates to the existing literature on this type of problem which originates mainly in passenger transportation problems, infrastructure planning techniques and mathematical programming problems. The classic transport model (the four-stage sequential model) is introduced briefly. The model provides a point of reference for modelling the inland container transport problem with the systems approach. The principal previous studies are, of course, mathematical programming problems. It will be convenient to start with partial equilibrium ideas from microeconomic location theory and then proceed to the mathematical formulation of commodity distribution problems at the macro-economic level.

1.2.1 Partial Equilibrium Location Theory

There are two main intellectual traditions that can be brought to bear on the empirical study of the spatial distribution of freight traffic and the associated question of regional comparative advantage. On the one hand, partial equilibrium location theory is a fairly well articulated body of concepts that can be made to yield some testable hypotheses. On the other, general equilibrium theory includes a number of feasible, or potentially feasible approaches to modelling the movement of goods.

The habitual starting point for location theory is the problem confronting a firm when making a decision as to the location of new investment. In the simplest version, this is conceived as the location of a plant (Weber,1929). This problem is formulated as an optimisation problem, with an objective function to be either maximised or minimised. Weber assumed that the choice of location would not affect either the volume of sales or the unit revenue and consequently initially postulated that the optimum location is that which minimised the cost of transport, summed for both inputs and outputs. For the purpose of forecasting trip or transport patterns, alternatives to system cost minimisation have been developed, including gravity models and entropy maximisation models.

The gravity model is based on an analogy with Newton's gravitational law. One of the earlier transport application of a gravity model was by Casey (1955) who used it to simulate shopping trips. In its simplest formulation the model has the following functional form:

$$G_{ij} = \frac{yP_iP_j}{A_{ij}^2} \tag{1.1}$$

where G_{ij} is the number of trips between i and j,
P_i and P_j = the populations of the towns of origin and destination,
A_{ij} = the distance between i and j,
y = a proportionality factor.

In some application population may be replaced by income as a measure of "positive attraction" and other functional forces may also be used.

While the gravity model has been regarded as quite successful as a forecasting tool e.g. in the forecasting of international trade flows, it has the drawback that it is not grounded in proper micro-foundations. A similar comment can be applied to the entropy-maximisation approach which may be used as a method to generate a variety of trip distribution models (including the gravity model itself)[6]. In this study the distribution of cargo by region (the equivalent of trip distribution) is in part based on a "mass" variable, namely the size of regional industrial complexes.

1.2.2 Commodity Distribution Models on a Network

Commodity distribution problems fall into a class of goods-oriented, location-allocation problems characterised by an economic criterion for performance. The goal of these problems, therefore, is to investigate the most economically efficient locations, sizes, and activity levels of facilities or commodity flows on a transportation network. Since mathematical programming techniques have the capability of determining optimal solutions simultaneously, they have been commonly applied to the model formulation of these problems.

[6] Ortuzar, J. d. D., and L. G. Willumsen, 1994, *Modelling Transport* (2nd ed.), Chichester, John Wiley & Sons, p.164.

The classic work in mathematical programming applied to transportation problems was introduced by Hitchcock (1941). The objective of a transportation problem is to determine the pattern of commodity flows from a set of supply nodes to a set of demand nodes which minimise the total transportation cost over the system, subject to the constraints of supply capacities and demand requirements.

According to Taha [Taha (1987)], in order to describe the general form of the transportation problem, we need to use terms that are considerably less specific than those of the components of the prototype example. In particular, the general transportation problem is concerned with distributing any commodity from any group of supply centres, called sources, to any group of receiving centres, called destinations, in such a way as to minimise the total distribution cost. Let Q_{ij} represent the amount transported from source i to destination j; then the linear programme representing the transportation problem is given as follows:

$$\text{Minimise } \sum_i \sum_j Q_{ij} T_{ij} \tag{1.3}$$

subject to

$$\sum_j Q_{ij} \leq E_i \qquad \forall i \in \mathrm{N} \tag{1.4}$$

$$\sum_j Q_{ij} \geq K_j \qquad \forall j \in \mathrm{P} \tag{1.5}$$

$$Q_{ij} \geq 0 \qquad \forall i, j \tag{1.6}$$

where Q_{ij} = amount of commodities transported from node i to node j,

T_{ij} = cost per unit commodity transport from node i to node j,

E_i = amount supplied at node i,

K_j = amount demanded at node j,

N = set of all supply nodes,

P = set of all demand nodes.

The first set of constraints stipulates that the sum of the shipments from a source cannot exceed its supply; similarly, the second set requires that the sum of the shipments to a destination must satisfy its demand. The constraints just described imply that the total supply must at least equal the total demand. When the total supply just equals the total demand, the resulting formulation is called a balanced transportation model. It differs from the model above only in the fact that all constraints are equations; that is,

$$\sum_j Q_{ij} = E_i \qquad \forall i \in \mathrm{N} \qquad (1.7)$$

$$\sum_j Q_{ij} = K_j \qquad \forall j \in \mathrm{P} \qquad (1.8)$$

In reality it is not necessarily true that supply equal demand or, for that matter, exceed it. However, a transportation model can always be made to be balanced. The balancing, in addition to its usefulness in modelling certain practical situations, is important for the development of a solution method that fully exploits the special structure of the transportation model.

This simple transportation problem may be generalised to include many commodities and sectors and to allow for substitutability of inputs between various sectors. The transportation problem has often been used in a commercial context. Land (1957) applied the method to an analysis of coal movements in Britain and Henderson (1958) analysed coking coal movements in the United States in a similar manner. A more elaborate formulation was used by Heady and Skold (1966) to forecast an optimum pattern of location of agricultural production and trade for a number of crop combinations and products.[7] Chisholm and O'Sullivan (1973) published a distinguished study which modelled inter-regional freight flows in Britain. They applied both linear programming and the gravity distribution model to their problem with the data generated by combining a 1962 road freight survey with 1964 railway freight data. They pointed out that the gravity model approach in general performs less well than the linear programming solutions in describing the actually observed flows. The analysis was studied at a highly aggregate level in terms of commodities, with the consequence that their study was primarily relevant to the transport sector and for national policy relating to regional development rather than for specific industries or individual firms. Consequently, examination of the pattern of freight generation and attraction revealed that residential population and employment are moderately good predictors of zonal freight volumes at the aggregate level.

In general, the transportation of commodities requires the use of some kind of handling facilities, which incur an investment cost as well as operating costs. Therefore, the cost minimisation objective function should also include the investment costs associated with these facilities to determine the pattern that would yield the system-wide minimum cost. Balinski (1961) introduced a linear programming model for the warehouse location problem so as to properly assess the full investment cost of a facility in the cost minimisation objective function. He introduced an integer variable to represent the decision of whether or not to build a warehouse facility as a node. The objective function included investment cost as well as total transportation cost:

[7] Lee, K., 1987, Multiobjective Mathematical Programming Models of Intertemporal Multicommodity Distribution Problems. PhD Thesis, Geography, Boston, Boston Univ., p.10-16.

$$\text{Minimise} \sum_i \sum_j Q_{ij} T_{ij} + \sum_j Z_j O_j \qquad (1.9)$$

where Z_j = the investment cost of opening a facility at node j,

$O_j = 1$ if a facility is open at node j,
0 otherwise.

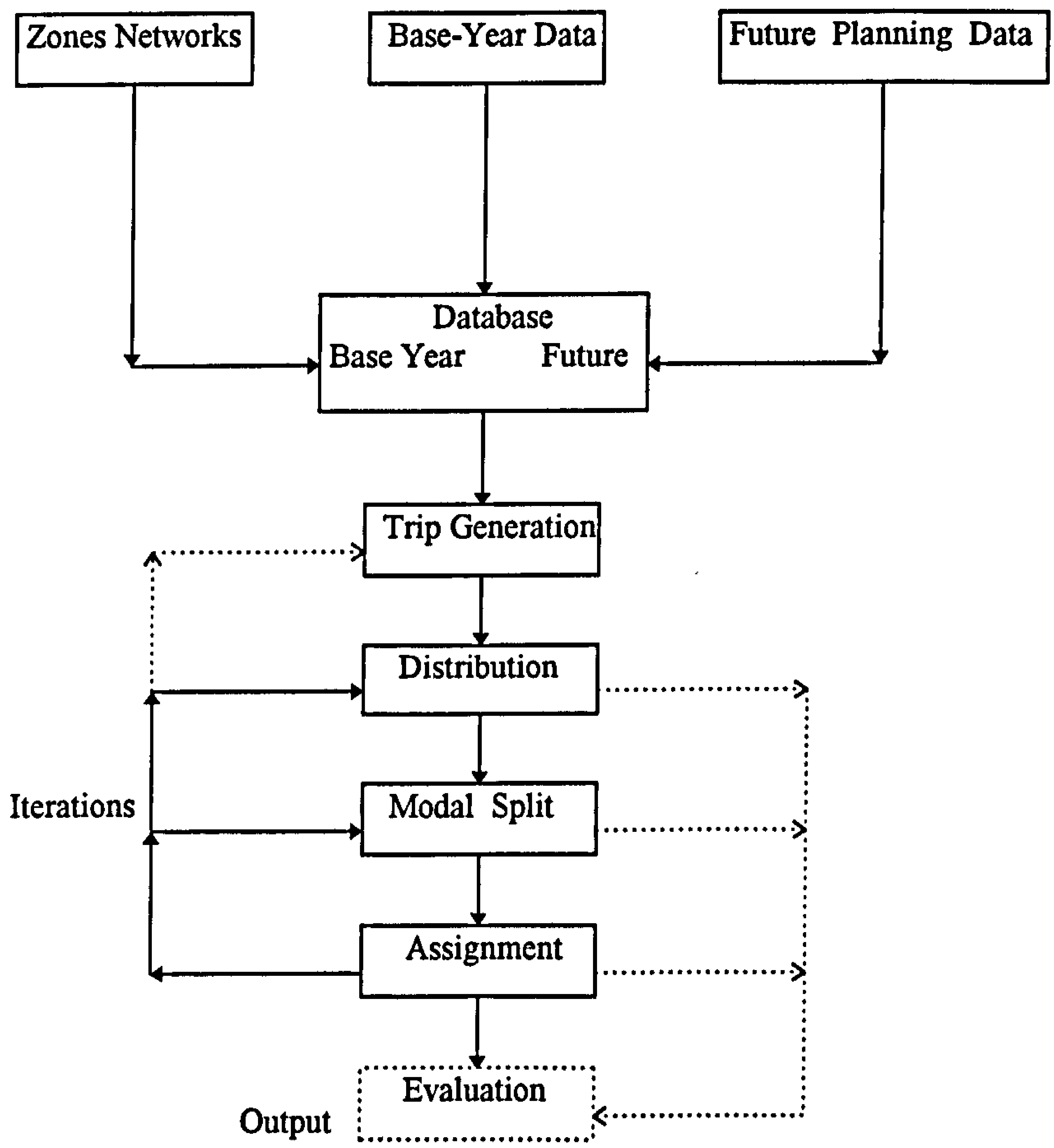
This model includes the possibility that certain warehouses should not be involved in an allocation which minimises total system costs.

1.2.3 The Classic Transport Model

Years of experimentation and development of transport issues have resulted in a general structure which has been called the classic transport model. This structure is, in effect, a result of practice in the 1960s but has remained more or less unaltered despite major improvements in modelling techniques during the 1970s and 1980s[8].

The classic model is presented as a sequence of four sub-models: trip generation, distribution, modal split and assignment. The approach starts by considering a zoning and network system, and the collection and coding of planning, calibration and validation data. These data would include base-year levels for population of different types in each zone of the study area as well as levels of economic activity including employment, shopping space, educational and recreational facilities. These data are then used to estimate a model of the total number of trips generated and attracted by each zone of the study area (trip generation). The next step is the allocation of these trips to particular destinations, in other words, their distribution over space, thus producing a trip matrix. The following stage normally involves modelling the choice of mode and this results in modal split, i.e. the allocation of trips in the matrix to different modes. Finally, the last stage in the classic model requires the assignment of trips by each mode to their corresponding networks: typically private and public transport.

The trip generation-distribution-modal split and assignment sequence in figure 1.1 is the most commonly formed sequence but not the only possible one. Some past studies have put modal split before trip distribution and immediately after (or with) trip generation. This permits differing emphasis on decision variables depending on the trip generation unit i.e. the household.



<Fig. 1.1> The Classic Four-Stage Transport Model
Source: Adapted form Ortuzar, J. de D. and L. G. Willumsen, 1994, *Modelling Transport* (2nd ed.), Chichester, John Wiley & Sons.

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[8] Ortuzar, J. de D. and L. G. Willumsen, 1994, *Modelling Transport* (2nd ed.), Chichester, John Wiley & Sons.

Our model corresponds to the following sequence: the trip generation phase of the classic four-stage transport model may be identified with the container traffic projection of our model; the distribution phase of the classic model in turn corresponds to the determination of the distribution of regional traffic for our model; modal split then follows as in the classic transport model. The assignment phase of the classic model in our model takes the form of the transportation problem of linear programming.

1.2.4 Dynamic Location-Allocation Problems

Traditionally, the transportation problem has been treated in a static setting in which all parameters are assumed to be unchanging. In many real transportation problems however, some of the parameters may not remain at the same values through time. For example, supply and demand can change with time according to changes in investments and transportation costs. In such a dynamic environment, the optimal locations, sizes, and activity levels of facilities may differ in each time period in response to changes in parameters. In a dynamic location problem, flow and allocation variables are indexed by time so that there can be a different solution for each time period in response to changes in the environment. Wesolowsky (1973) developed a multiperiod location model, which was originally introduced by Ballou (1968), for single facility location problems. Tapiero (1971) considered a continuous space and time horizon for the capacity constructed transportation-location-allocation problem. Changes in demand have been the most prevalent problem handled in dynamic location-allocation problems. Wesolowsky and Truscott (1975), and Van Roy and Erlenkotter (1982), have developed mathematical programming models with predicted changes in the demand volume originating at demand points over a planning horizon of multiple time periods. The objective of their models was to select time-phasing decisions for the establishment of or closing of facilities at different locations in order to minimise the total discounted cost for meeting demand specified over time at various customer locations.[9]

1.2.5 Port System Investment Problems

Goss (1967) has emphasised that substantial economies in the cost of sea transport can be achieved by improvements in seaports and has discussed methods by which such proposals may be appraised. Criteria for port investment should include shipping considerations and specifically the type and size of ships. The extension from statics to dynamics was demonstrated by DeVanny (1972) who has argued that the size and timing of investment can be best determined by the application of dynamic programming. De Vanny illustrates this for a hypothetical case of a single port and a single commodity. De Wielle and Ray (1974) have attempted to identify the level of port capacity which maximises total net benefits, that is, net benefits to both ship owners and the port authority taken as a whole. This is equivalent to determining the minimum cost solution for alternative levels of given demand. The gross benefit of the investment is measured by adding the consumer surplus of the additional induced traffic to the reduction in queuing costs.

Finally, Shneerson (1981) has attempted to answer the questions of whether, when and where investment in port systems should be made. His model was applied to the planning of ports of Nigeria by using the technique of dynamic programming. The

[9] Lee, K., op.cit., 1987, p.16-17.

model determined simultaneously the optimal distribution of cargo among ports and the decisions of how much and where to invest. The objective function used within the model was the minimisation of the present value of total costs over the relevant period. Total costs to be minimised included the costs of investment in ports, the costs of queuing in ports, the costs of inland transport and the costs of shipping. It was subject to serving the forecast traffic flows for both imports and exports.

The model may be summarised as follows. There are N demand centres and P ports in the system.

Quantities from the set of demand centres to ports at time t are given by

$$Q_t = \{ Q_t^{np} \} \qquad n = 1, 2, \cdots N \text{ (Demand Centres)}$$

$$p = 1, 2, \cdots P \text{ (Ports)}$$

$$= (Q_t^{11} \cdots Q_t^{1P}; Q_t^{21} \cdots Q_t^{2P}; \cdots; Q_t^{N1} \cdots Q_t^{NP}) \tag{1.10}$$

Similarly, inland transport costs between demand centre n and port p at time t are denoted

$$T_t = (T_t^{11} \cdots T_t^{1P}; T_t^{21} \cdots T_t^{2P}; \cdots; T_t^{N1} \cdots T_t^{NP}) \tag{1.11}$$

The stock of port facilities, the number of berths, the number of cranes, storage facilities at time t is written

$$K_t = K_t^1 \cdots K_t^p \cdots K_t^P \tag{1.12}$$

where $1, \ldots p, \ldots P$ are the number of ports in the system and subscript t refers to time.

Thus total inland transport cost is given by

$$\sum_n \sum_p Q_t^{np} T_t^{np} .$$

Stevedoring cost per ton at port p at time t is

$$B_t^p$$

and total stevedoring cost is

$$\sum_p B_t^p Q_t^p$$

where $Q_t^p = \sum_n Q_t^{np}$ and is total throughput at port p

The queuing costs at port p are denoted by

$$R_t^p \cdot L_t^p(Q_t^p, K_t^p).$$

Where the function $L_t^p(Q_t^p, K_t^p)$ denotes delay as a function of throughput and capacity at port p and R_t^p denotes the value of time

Shipping cost per ton between foreign port f and local port l at time t is given by

$$s_t^{fl},$$

and quantities from foreign port f and local port l at time t are given by

$$Q_t^{fl}$$

Thus, the total shipping cost between foreign ports and local ports at time t is denoted

$$\sum_f \sum_l s_t^{fl} Q_t^{fl}$$

The problem of distributing throughput among ports so that total costs are minimised is given by

$$\underset{Q_t}{Min} f(K_t, Q_t) = \{\sum_p V_t^p \cdot Z_t^p(Q_t^p, K_t^p) + \sum_p B_t^p Q_t^p +$$

$$\sum_n \sum_p Q_t^{np} T_t^{np} + \sum_f \sum_l s_t^{fl} Q_t^{fl}\} \qquad (1.13)$$

subject to

$$\sum_p Q_t^{np} = Q_t^n \qquad (1.14)$$

$$\sum_{f} Q_t^{fl} = Q_t^l \tag{1.15}$$

$$Q_t^{np},\ Q_t^{fl} \geq 0,$$

This problem takes K_t as given. In order to make the problem dynamic we need to consider investment in new port facilities. Annual investment cost Z_t is assumed to be a function of new investment (I_t) and the stock of inherited capital K_t :

$$Z_t = Z(K_t, I_t) \tag{1.16}$$

The stock of port facilities at t + 1 equals the stock at t plus investment minus depreciation. We have

$$K_{t+1} = K_t + I_t - qK_t \tag{1.17}$$

$$\text{or } K_{t+1} = (1 - q)\ K_t + I_t \tag{1.18}$$

where q is the rate of depreciation.

The problem can be reduced to a recursive one by using a value function. Define $X_t(K_t)$ as the present value discounted to the year t of the minimised total system costs from the year t until the end of the planning period, T. This may be decomposed into two sub-problems as illustrated below.

$$X_t(K_t) = \underset{Q_t}{Min}[\,f(K_t, Q_t)] + \underset{I_t}{Min}[\,Z(K_t, I_t) +$$

$$(1+r)^{-1} X_{t+1}\{(1-q)K_t + I_t\}] \tag{1.19}$$

Thus, in each year two sets of independent decisions have to be made:

(1) allocation of traffic among ports i.e. Q_t. This depends on the number of berths at each port at the beginning of the period i.e. on the inherited capital stock.

(2) investment in new port capacity i.e. I_t.

This model provides basic model framework for our model. In particular, the combination of dynamic programming and linear programming is crucial in developing our model.

1.3 The Aims and Outline of the Thesis

The primary aim of the thesis is to use a systems approach to jointly determine optimal inland container flows and optimal container port investment in the Korean context.

This thesis consists of six chapters.

Chapter 2 is devoted to the construction of the basic model. First, the Inland Container Traffic Allocation model is formulated in a static situation as a mathematical programming model. We next extend it to a multi-period situation and incorporate the Optimum Port Capacity model which provides the dynamic element of the problem and generates the capacity parameters of the static problem.

Chapter 3, offers an attempt of forecasting the future amount of container traffic originating in Korea over the period 1997 - 2020 both in the aggregate and disaggregated by region and by transport mode.

Chapter 4 applies the static part of the model developed in Chapter 2 to the inland container transport allocation problem in Korea and includes a description of how the data set was created.

In Chapter 5, the dynamic part of the model is applied to determine investment priorities. On the basis of these results, the optimum allocations of inland container traffic between the origins and the ports can be identified. Sensitivity analyses investigates the impact on the results when some factors are varied.

In Chapter 6, we summarise the main results and recommendations of the Korean case, together with some suggestions for future research.

Chapter 2

An Inland Container Transportation Development Planning Model

2.1 Introduction

In recent decades, developing countries have made considerable progress in developing infrastructure, such as their transportation networks. The construction of a new container port system represents a long term project which involves enormous expense. Determining the necessity, size, timing and location of investments in a container port system is a crucial element of such a task. Since many port authorities are public, we formulate the analysis from the viewpoint of a social planner whose aim is to optimise the performance of the system as a whole, rather than to optimise any individual component. In other words, planners are concerned not only with the proper distribution of scarce resources, but also with trade-offs between the development costs of certain ports and the various costs of providing access to them.

2.2 The Ports Systems Investment and Traffic Allocation Problem

An important problem in this field is the optimal design of systems involving new container port facilities, which is subject to certain operational constraints. The version of this problem considered in this thesis depends on the model created by Shneerson (1981) as follows:

A country consists of N regions to be serviced by M transport modes, and in each region there is a demand for container traffic to be transported to each of P container ports. The country is considering proposals from its existing ports for the possible expansion of its facilities in order to meet expected growth of demand. There are a number of alternative proposals and the goal of this project is to identify the investment programme which will minimise the total cost of meeting the expected demand. That is, the problem can be seen as the optimisation of the inland container transport system where the pattern of container port development project is the decision variable. Thus, the objective is to determine over the whole period:

(1) How much and where to invest in the development of container facilities.

Given a particular investment plan, another problem is to determine in each year of the whole period;

(2) The allocation of traffic between the regions and the ports;

so as to minimise the total costs which consist of three categories:

(1) Costs directly related to transportation;

(2) Costs related to use of the infrastructure;

(3) Costs related to the construction of infrastructure networks;

subject to constraints on

(1) The total sum of each region's export volume meeting the projected national total export volume;

(2) The total sum of each transport mode's export volume for a region meeting the sum of the region's export volume;

(3) The total sum of each port's export capacity at least being equal to the total projected national export volume.

2.3 Construction of the Model

The procedure involves three tasks:

(1) Forecasting future total export container demand;

(2) Defining the amount and timing of investment;

(3) Allocating the predicted total export container volume by determining the direction and amount of the container transport flow between regions and container ports.

The last two objectives may be tackled by means of an integrated model which consists of two stages and which minimises total costs over a given time horizon. The first stage of the model is termed the Optimum Port Capacity Model. This is a long term model whose purpose is to estimate the optimum capacity additions to the container port system. Its outputs i.e. new container capacity, are used as input data in the second stage of the model, termed the Inland Container Traffic Allocation Model. This is a short run model which is used to achieve optimal allocation of traffic in each year.

First, some basic notation is introduced.

A nation consists of N regions, and the total demand for container cargo over time is given at time t by:

$$Y = (Y_1 \cdots Y_t \cdots) \tag{2.1}$$

The national demands for container cargo at time t, Y_t , are exogenous and are derived from the first task as mentioned above.

The demands for region i at time t, E_t^i, are derived from a function for the distribution of regional container traffic as described in Eq (2.27).

$$E_t = (E_t^1 \cdots E_t^N) \tag{2.2}$$

The modal split of each region's cargo at time t, F^{i}_{tk}, is based on a function for the modal split described in Eq (2.28).

$$F_t = (F^1_{t,Road}, F^1_{t,Rail}, F^1_{t,CoastalShipping}; F^2_{t,Road}; \cdots; \cdots F^N_{t,CoastalShipping}) \quad (2.3)$$

Also, there are P ports, where D^j_t, is the throughput in port j at time t.

$$D_t = (D^1_t \cdots D^p_t \cdots D^P_t) \quad (2.4)$$

Port capacities at time t are given by:

$$K_t = (K^1_t \cdots K^p_t \cdots K^P_t) \quad (2.5)$$

The configuration of the new port development at time t is:

$$I_t = (I^1_t \cdots I^p_t \cdots I^P_t) \quad (2.6)$$

That is, $I_t = \Delta K_t$

It is assumed that the decision-making on port development is made at certain intervals which are normally in excess of a year. Port developments typically have a large budget and are undertaken from a long-term perspective. For this model, we divide the whole period concerned into a number of stages. The investment at each stage is constrained by budget, i.e.

$$0 \leq I_t \leq \alpha, \quad \forall\, t \in [0, \mathrm{T}] \quad (2.7)$$

where, α is the maximum budget allowed for a given interval and T is the last year of the planning period.

Once a number of feasible alternative investment proposals have been made, these must be evaluated. Ideally, one would wish to undertake full cost-benefit analysis, but it is especially difficult to define and measure the social benefits and costs generated by large infrastructure developments. Here we confine attention to the more limited objective of identifying the investment programme which minimises total system costs.

The objective function consists of the sum of the following categories of costs[10]:

(i) construction costs,

(ii) transportation costs, that is, costs directly related to transportation and

(iii) costs related to the infrastructure or the use of it, such as congestion costs.

Transportation costs (ii) may also include additional costs due to congestion.

The first step in the overall procedure is to calculate the transportation costs per year as a function of the container traffic flow for a given level of port capacity. The optimal container traffic allocation between regions and ports is determined by minimising total transport costs. The mathematical formulation becomes as follows:

$$Minimise\, f(Q_t) = \sum_{i=1}^{N}\sum_{j=1}^{P}\sum_{k=1}^{M} T_{tk}^{ij} Q_{tk}^{ij} \tag{2.8}$$

Subject to

$$Y_t = \sum_{i=1}^{N} E_t^i \qquad \text{for} \quad i = 1, 2, \cdots N$$

(Regional Demands) (2.9)

$$E_t^i = \sum_{k=1}^{M} F_{tk}^i \qquad k = 1, 2, \cdots M$$

(Modal Split for traffic originating in region i) (2.10)

$$F_{tk}^i = \sum_{j=1}^{P} Q_{tk}^{ij} \qquad j = 1, 2, \cdots P$$

(Flow from region i to port j by mode k) (2.11)

[10] Button (1982) noted that "shippers are concerned not simply with the financial costs of carriage but also the speed, reliability and time-tabling of the service. As a pragmatic device to reduce the wide range of costs which influence travel, a single index expressing 'generalised cost' has evolved. The characteristic of generalised cost is, therefore, that it reduces all cost items to a single index and this index may be used in the same way as simple money costs are in standard economic analysis. While in simple indices, generalised cost is formed as a linear combination of time and money (or distance) costs in most applied analysis the time and money components are divided into a number of elements."(p.98) In this study the sum of inland transport costs and congestion costs may be thought to correspond to generalised transport cost.

$$D_t^j = \sum_{i=1}^{N}\sum_{k=1}^{M} Q_{tk}^{ij}$$

(Throughput at port j) (2.12)

$$Q_{tk}^{ij} \geq 0 \quad (2.13)$$

where

T_{tk}^{ij} = the cost of transporting one unit between region i and port j using transportation mode system k, which may include an element of congestion cost in the case of the "Road" transport mode.

Q_{tk}^{ij} = the amount of container traffic shipped from region i to port j using transportation mode k and $Q_t = \{ Q_{tk}^{ij} \}$

Secondly, additional costs may be incurred because of over-burdened container traffic allocated to each port:

$$C(K_t, Q_t) = \sum_{j=1}^{P} d_t^j (D_t^j, K_t^j) \quad (2.14)$$

where

d^j = the additional costs in ports per TEU incurred by insufficient handling capacity in port j .

An example for the function in Eq (2.14) might be:

$$d_t^j = \beta(D_t^j \,/\, K_t^j) \quad \text{and} \quad \beta' > 0 \quad (2.15)$$

Lastly, we include the construction costs corresponding to the proposed port investment projects:

$$Z(K_t, I_t) = \sum_{j=1}^{P} U_t^j (K_t, I_t) \quad (2.16)$$

where

U_t^j = construction costs per terminal at port j.

Thus, the overall problem may be defined as choosing an investment programme $\{I_t\}$ and traffic allocation $\{Q_t\}$ so as to minimise;

$$\sum_{t=0}^{T}\delta^t[f(Q_t)+C(K_t,Q_t)+Z(K_t,I_t)] \tag{2.17}$$

where $\delta^t=(1+r)^{-t}$ and r is the interest rate.

or we may write this as

$$Min\sum_{t=0}^{T}\delta^t V_t(Q_t,K_t,I_t) \tag{2.18}$$

where $V_t=[f(Q_t)+C(K_t,Q_t)+Z(K_t,I_t)]$

The planning period ends at time T and all feasible investment is assumed to take place before that year. Hence;

$$V_T=f(Q_T)+C(K_T,Q_T) \tag{2.19}$$

we also have

$$K_1=\overline{K}_1, \quad I_t\geq 0 \tag{2.20}$$

This is a dynamic optimisation problem. Dynamic programming techniques may be used to determine the amount and the priority of investment. The computations are carried out in the order from the first to the last year. This method of computations is known as the forward procedure. However, many dynamic programming studies are constructed with a recursive equation which is such that the computations start at the last period and then "proceed" backward to the first one. This is called the backward procedure. In fact, the forward and backward formulations are computationally equivalent. There are situations, however, where it would make a difference, from the standpoint of computational efficiency, which formulation is used[11]. The computations for our model are carried out with the forward procedure as follows.

Define

$$X_1^*(K_1) = \underset{I_1}{Min}\{V_1(Q_1, K_1, I_1)\} \qquad (2.21)$$

$$X_t^*(K_t) = \underset{I_t}{Min}\{V_t(Q_t, K_t, I_t) + X_{t-1}^*(K_{t-1})\} \qquad (2.22)$$

where $V_t(K_t, I_t)$ = system costs of alternative I_t at time t

$X_t^*(K_t)$ = the optimal total system costs to time t given the state K_t

There is an important point that we need to clarify regarding the mathematical definition of this recursive equation. First, note that $X_t^*(K_t)$ is a function of the argument K_t only. This requires the right side of the recursive equation to be expressed in terms of K_t rather than K_{t-1}. This is accomplished by recalling that

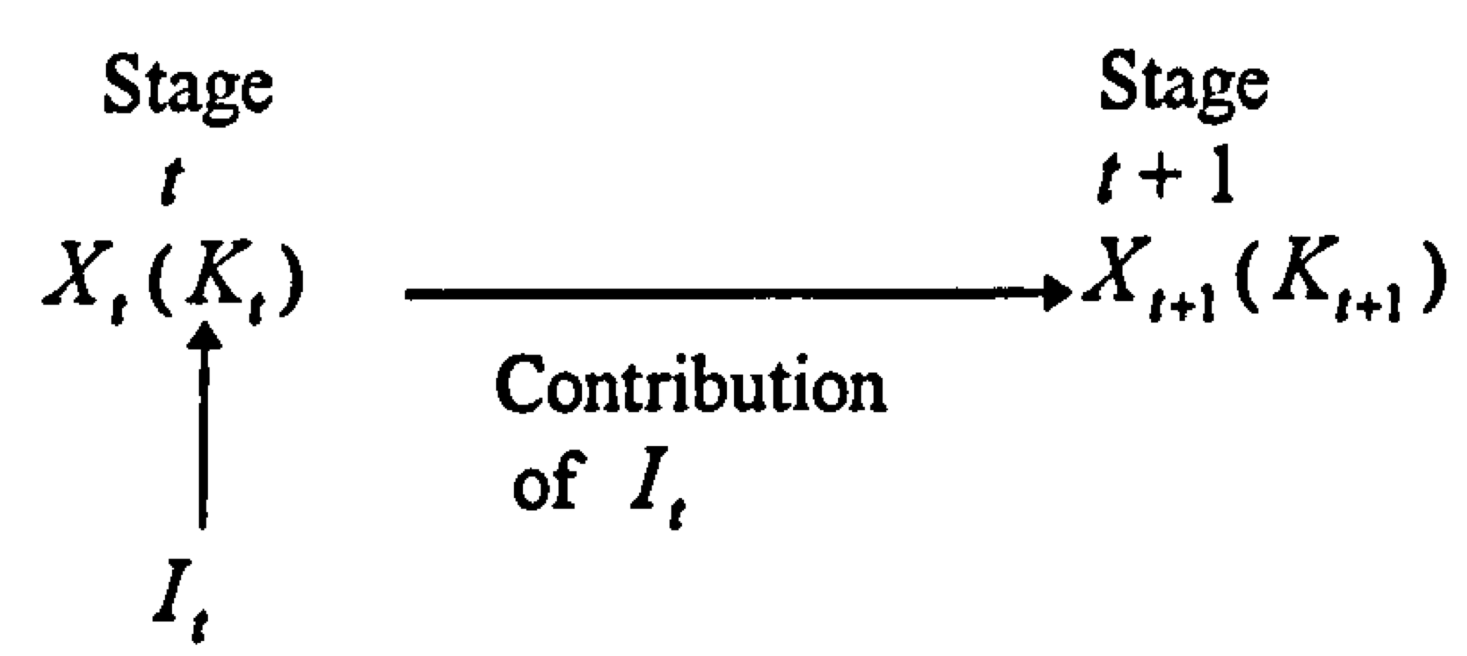
$$K_t - I_t = K_{t-1} \qquad (2.23)$$

we can write the dynamic programming recursive equations by substituting Eq (2.23) into Eq (2. 22) as

$$X_1^*(K_1) = \underset{I_1}{Min}\{V_1(K_1, I_1)\} \qquad (2.24)$$

$$X_t^*(K_t) = \underset{I_t}{Min}\{V_t(K_t, I_t) + X_{t-1}^*(K_t - I_t)\} \qquad (2.25)$$

The recursive sequence of deterministic dynamic programming can be illustrated diagrammatically as shown in Fig.2.1.



<Fig. 2.1> The Basic Structure for Deterministic Dynamic Programming

[11] Taha, H. A., 1987, *Operation Research* (4th ed.), New York, Macmillan Publishing Co., p.352-355.

2.4 Solution of the Model

In order to determine the optimal port investment programme we need to identify a coherent system of both port and inland transport network development. For a correct optimisation it is always necessary for the objective function and the decision variables to fit well together. Consequently, the computations that represent the purpose of this study are the most important parts of this model. Computation of the full model is voluminous and time consuming. For example, if there is a model in which there are just three berths to be built between two ports over three years, then the number of logically possible investment alternatives is 56[12]. As the model is extended by adding either berths or ports or investment periods, then the alternatives which need to be considered increase in geometric progression. Each alternative requires a computational procedure to yield its total system cost. Worst of all, the complexity of this mathematical model may make it impossible to find a solution. Accordingly, heuristic procedures and dynamic (multistage) programming may be used to obtain a satisfactory solution to such system problem within a reasonable period of computing time. Heuristic procedures are also iterative in nature, but do not guarantee exact optimality. Instead, heuristics seek a solution to the problem based on rules of thumb that are conducive to obtaining what Taha calls a "good" solution. "The advantage of heuristics is that they normally involve less computation when compared with exact algorithms. Heuristics are generally employed for two different purposes:

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[12] This example can be regarded as a model with 6 distinct locations for berth development. Namely at each of the two ports in each of the three years. The problem is to locate the three required berths in the six possible slots. This generates three possible patterns of development: (i) all three berths are built at one port, which can be done in six different ways; (ii) berths are allocated in the pattern 2:1 i.e. two berths in one slot and one in another. This yields 30 different alternatives and (iii) the pattern is 1:1:1 and this yields 20 different alternatives. Thus in total there are 56 logically possible investment paths.

(1) They can be used within the context of an exact optimisation algorithm to speed up the process of reaching the optimum. The need for "beefing up" the optimisation algorithm becomes more evident with large-scale models.

(2) They are simply used to find a good solution to the problem[13]. The resulting solution is not guaranteed to be optimum, and, in fact, its quality relative to the true optimum may be difficult to measure"[14].

Container port developments have the following characteristics: they need considerable construction time and an enormous budget. Economies of scale in provision mean that a container port terminal normally consists of several discrete berths. We may take advantage of these features to form heuristic algorithms for this model. We divide the period concerned into a number of sub-periods and in each sub-period, the budget constraint, together with the "lumpiness" of investments in container facilities, means that we can place limits on the number of alternative investment programmes that need to be considered. Thus the number of feasible alternatives is reduced to a finite set which in general contains less than the number of logically possible alternatives. In this way we reduce the computational complexity of the problem and ensure the existence of a "best" investment programme.

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[13] The word 'good' may be used to emphasise that theoretically the solution with heuristic procedures is not guaranteed to reach an exact optimum. The precise meaning of good will, however, depend on the context i.e. on the nature of the problem. Taha offers the example of the travelling salesman problem in which the salesman is required to visit each of 5 cities just once and then return home. The problem is to minimise the distance travelled. Heuristics suggest that a good solution may be achieved by adopting the rule that the salesman should always proceed to the nearest unvisited city (Taha, H. A., 1987, *Operations Research* (4th ed.), New York, Macmillan Publishing Co., p.16).
In the present study heuristics are employed to eliminate irrelevant logical possibilities and hence to reduce computational complexity. In this case the solution to the reduced problem is exact.

[14] Taha, H. A., op. cit., 1987, p.15.

2.4.1 The Heuristic Solution Procedure

2.4.1.1 Optimisation Over Time

The overall decision problem can be divided into stages, with a policy decision required at each stage. A stage in dynamic programming is defined as the portion of the problem that possesses a set of mutually exclusive alternatives from which the best alternative is to be selected. Each stage may have a number of states associated with it. The concept of a state is particularly important in a dynamic programming model. It represents the link between stages so that when each stage is optimised separately, the resulting decision is automatically feasible for the entire problem. The berths required to meet traffic demand in the end of the period concerned is treated as the *state* for this model. A *state* is normally defined to reflect the status of the constraints that bind all the stages together. For instance, here the period is divided into 3 stages and we define the states for stages 1, 2 and 3 as follows:

x_1 = number of berths built at stage 1

x_2 = number of berths built at stages 1 and 2

x_3 = number of berths built at stages 1, 2 and 3

The effect of the decision at each stage is to transform the current state into a state associated with the next stage.

2.4.1.2 Solution by Dynamic Programming

The solution procedure is designed to find an optimal investment programme for the overall problem, i.e. a prescription of the optimal port investment at each stage for each possible state. The solution can be made by a table for each stage that determines the optimal decision (X_t^*) for each possible state. Thus, in addition to identifying three optimal solutions (optimal decisions) for the overall problem, the table also shows us how we should proceed if we get detoured to a state that is not optimal. Providing this kind of additional information beyond simply specifying an optimal sequence of decisions can be helpful in a variety of ways, especially in conducting sensitivity analysis.[15]

2.4.2 The Static Problem of the Model

To solve the static problem of allocating the total demand from regions to ports for a given state at each period of time, t, a model of "assignment of traffic from regions to ports" is constructed. Once an optimum investment programme for new container berths among ports is determined, the Container Traffic Allocation model is used to obtain the optimum inland container pattern. This static problem of the model can be regarded as a kind of transportation problem in linear programming. In fact, it is merely an extended version of the classic transportation problem. The objective of the transportation problem is to determine the pattern of commodity flows from a set of supply nodes to set of demand nodes, which minimises the total transport cost over the system subject to the constraints of supply capacities and demand requirements. In our model, a set of supply nodes is replaced by a set of regions, and a set of demands is replaced by a set of container ports. At this point, there is a bridge which integrates the two models. The current set of container port capacities is given by the outputs of the optimum container port capacity model. That is, the optimal investment priority in container port development provides the constraints of the static problem. The

[15] Hillier, F. S. and G. J. Lieberman, 1990, *Introduction to Operations Research*(5th ed.), New York, McGraw-Hill, p.398-400.

objective function in this model is similar to that of the classic transportation problem, although with some differences.

2.4.2.1 Solution Procedures of the Linear Programming Problem.

Constraints (2.9) - (2.12) ensure that the sum of container traffic flows from region i to port j by transport mode k add up to total demand. However, we also need to determine the intermediate variables, namely the allocation of total demand in each period to each region, E_t^i and also modal split[16] i.e. F_{tk}^i. No individual shipper's or carrier's behaviour is explicitly shown in this model. The allocation of a region's traffic by transport modes is based on the following procedure.

First, the regional container volume is estimated by the following functions:

$$\lambda_t^i = [(E_{t-1}^i / Y_{t-1})(M_t^i / \sum_{i=1}^{N} M_t^i) / (M_{t-1}^i / \sum_{i=1}^{N} M_{t-1}^i)] \qquad (2.26)$$

$$E_t^i = Y_t [\lambda_t^i / \sum_{i=1}^{N} \lambda_t^i] \qquad (2.27)$$

where

E_t^i = the estimate of container volume in i region at t

$i = 1, 2, \ldots N$

Y_{t-1} = the demand of container volume over all the region at t -1

M_{t-1}^i = the area (in square Km) of the industrial complex in i region at t -1

$\sum_{i=1}^{N} M_{t-1}^i$ = the area of all the industrial complex at t -1

λ_t^i = the un-normalised share of region i in total container volume at t

[16] The term "modal split" must be kept separated from the term "mode choice". The former is used to describe passive action of a captive container carrier whilst the latter emphasises the preference behavior of carrier.

$\sum_{i=1}^{N} \lambda_t^i$ = the sum of un-normalised shares of all the region at t (which may $\neq 1$)

Thus Eq (2.26) and Eq (2.27)[17] assert that a region's share of total container volume is proportional to the growth of its industry complex.

Next, in order to determine the modal split of the regional container volume we make the important assumption that the "Road" option is passive, while the two other modes have an active strategy to increase their shares. It is assumed that both Rail and Coastal Shipping are run by active profit-seeking operators in which capacity is installed to meet demand and that at any point in time supply is constrained by capacity. By contrast, Road is more flexible - in particular, that Road can be used to meet unanticipated demands which can not be satisfied by Rail or Coastal Shipping

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[17] Without the normalisation applied by Eq (2.27), the sum of the shares, as calculated in Eq (2.26), may not add up to 1. This may be seen as follows.

If we define λ_{t-1}^i as E_{t-1}^i / Y_{t-1}, then we can write (2.26) as

$$\lambda_t^i = \lambda_{t-1}^i * \frac{M_t^i}{M_{t-1}^i} * \frac{M_t}{M_{t-1}} \qquad (2.26)'$$

where M_t is $\sum M_t^i$ and M_{t-1} is $\sum M_{t-1}^i$

This may be rewritten as

$$\lambda_t^i = \lambda_{t-1}^i \frac{(1+g^i)}{(1+g)} \qquad (2.26)''$$

where g^i is the rate of growth of M^i, that is $M_t^i = M_{t-1}^i(1+g^i)$ and g is the rate of growth of M i.e. $M_t = M_{t-1}(1+g)$.

Summing over i, we have

$$\sum \lambda_t^i = \frac{(1+\sum \lambda_{t-1}^i g^i)}{1+g}$$

This sums to 1 provided

$$\sum \lambda_{t-1}^i g^i = g$$

But g is defined by

$$M_{t-1}(1+g) = \sum M_{t-1}^i (1+g^i)$$

Hence $g = \sum \gamma_{t-1}^i g^i$

where $\gamma_{t-1}^i = \dfrac{M_{t-1}^i}{M_t}$

We can not in general assume that $\gamma_{t-1}^i = \lambda_{t-1}^i$, hence the normalisation is required.

because of inadequate capacity. Accordingly, it is assumed that "Rail" and "Coastal Shipping" traffic is allocated up to their respective capacities and the difference is accommodated by "Road". This is shown as follows:

$$F^{i}_{t,Road} = E^{1}_{t} - (F^{i}_{t,Rail} + F^{i}_{t,CoastalShipping}) \qquad (2.28)$$

It is further assumed that the annual growth rates of the handling capacities of "Rail" and "Coastal Shipping" can take two levels - high and low. Accordingly, there are four possible modal split scenarios to consider.

In order to have an optimal solution of any kind, a transportation problem must possess feasible solutions. The following property indicates when this will occur:

Feasible solution property: A necessary and sufficient condition for a transportation problem to have any feasible solutions is that aggregate supply equals aggregate demand. In the context of the present model this is equivalent to

$$\sum_{i=1}^{N}\sum_{k=1}^{M} F^{i}_{tk} = \sum_{j=1}^{P} K^{j}_{t} \qquad (2.29)$$

where K^{j}_{t} is the design capacity of port *j*.

The condition, that the total supply must equal the total demand, merely requires that the system be in balance. If the problem has physical significance and this condition is not met, a fictitious source or destination can be introduced to take up the slack in order to convert the inequalities into equalities and satisfy the feasibility condition. In this study, a *dummy port* has been created for the case of excess demand, while a *dummy region* has been created for the case of excess supply.

Clearly, actual port throughput may exceed design capacity and in order to fill the gap, a dummy port for the extra traffic volume can be introduced as H^{m}_{t} which is defined as:

$$H_t^m = \sum_{i=1}^{N}\sum_{k=1}^{M} F_{tk}^i - \sum_{j=1}^{P} K_t^j \qquad (2.31)$$

Thus, the capacity of the dummy port is defined as equivalent to the difference between total theoretical design capacity and total throughput of all ports by noting that from Eq (2.11)

$$\sum_{i=1}^{N}\sum_{k=1}^{M} F_{tk}^i = \sum_{i=1}^{N}\sum_{j=1}^{P}\sum_{k=1}^{M} Q_{tk}^{ij}$$

and hence from Eq (2.12)

$$\sum_{j=1}^{P} D_t^j = \sum_{i=1}^{N}\sum_{j=1}^{P}\sum_{k=1}^{M} Q_{tk}^{ij}$$

We may write

$$H_t^m = \sum_{j=1}^{P} D_t^j - \sum_{j=1}^{P} K_t^j \qquad (2.32)$$

Therefore, if H_t^m is positive, we have excess overall demand and here it is assumed that the excess demand is allocated among ports in proportion to their share of capacities. That is according to the following relationship:

$$D_t^j = K_t^j + (H_t^m \times (K_t^j / \sum_{j=1}^{p} K_t^j)) \qquad (2.33)$$

If H_t^m is negative, no allocation problem arises.

2.4.2.2 The Simplex Method

Since a transportation problem is just a special type of linear programming problem, it can be solved by applying the simplex method. However, significant computational shortcuts can be obtained by using the transportation simplex method.

This streamlined procedure uses what we call the transportation tableau. It is in a matrix form with its rows representing the regions and its columns the ports.

<Table 2.1> Cost and Requirement Table for Inland Container Transport

	Port A	Port B	Port C	F^i_k
Region X RD				
RL				
CS				
Region Y RD				
CS				
Region Z RD				
R L				
D^j_l				

Notes: RD = Road; RL = Rail; CS = Coastal Shipping.

Table 2.1 represents an example of the input data for the transportation problem. The matrix cells (i , j) are filled with unit transport costs. The column under F^i_k is based on container traffic projections, while the row D^j is based on the configurations of port investment projects.

Once the input data table is prepared, this model may be run in the transportation section of MS Keyware 5.0[18]. The algorithm for the problem adopted in the computer software is as follows.

Starting solution for the transportation model: The objective of the initialisation step is to obtain an initial basic feasible solution. Since all the functional constraints in the transportation problem are equality constraints, the simplex method would obtain this solution by introducing artificial variables and using them as the initial basic variables. The resulting basic solution is actually feasible only for a revised version of the problem, so a number of iterations are needed to drive these artificial variables to zero in order to reach a real basic feasible solution. The transportation simplex method bypasses all this by using a simpler procedure to directly construct a real basic feasible solution on a transportation simplex tableau.

There are several methods for the initialisation step. "The special structure of the transportation problem allows securing a non-artificial starting basic solution using one of three methods: 1) Northwest-corner method 2) Least-cost method 3) Vogel's approximation method. The difference among the three methods is the 'quality' of the starting basic solution they produce, in the sense that a better starting solution yields a smaller objective value. In general, the Vogel method yields the best starting basic solution, and the Northwest-corner method yields the worst. The trade-off is that the Northwest-corner method involves the least computations"[19]. Vogel's approximation method (VAM) was chosen for this project's initialisation step[20].

Vogel's approximation method operates as follows: for each row and column remaining under consideration, calculate its difference, which is defined as the arithmetic difference between the smallest and next-to-the-smallest unit cost still remaining in that row or column. In the row or column having the largest difference, select the variable having the smallest remaining unit cost. If only one row or only one column remains under consideration, then the procedure is completed by selecting every remaining variable.

Optimality test: The next step is to check whether this initial solution is optimal by applying an optimality test. There are two methods for this step, namely: the stepping

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[18] The software was developed by S. M. Lee, University of Nebraska-Lincoln. The software covers Linear programming, Transportation, Networks, PERT-CPM, Integer programming, Inventory, Queuing and Goal programming etc.

[19] Taha, H.A., 1998, *Operation Research* (6th ed.), New York, Macmillan Publishing Co. p.181.

stone method and the method of Multipliers (or the Modified Distribution Method). Although the stepping-stone method gives the impressions that the procedure is completely unrelated to the simplex method, the computations in the two methods are exactly equivalent[21]. Also, the computation of the method of Multipliers is more efficient than that of the stepping-stone method. Here the method of Multipliers is introduced for the optimality test. The procedure is as follows:

* Part 1. Select the non-basic variable having the largest negative value of cost improvement index.

* Part 2. Identify the chain reaction required to retain feasibility when the entering basic variable is increased. From among the donor cells, select the basic variable having the smallest value.

* Part 3. Determine the new basic feasible solution : Add the value of the leaving basic variable to the allocation for each recipient cell. Subtract this value from the allocation for each donor cell.

* Part 4 (Optimality Test). If all cost improvement indexes are not smaller than zero such that the variable is non-basic, then the current solution is optimal, so stop. Otherwise, go back to Part 1.[22]

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[20] MS Keyware 5.0 used in this study requires the choice of the three methods for the initialisation step.

[21] Taha, H.A., 1987, *Operation Research* (4th ed.), New York, Macmillan Publishing Co. p.184-185.

[22] Hillier, F.S., op.cit., 1990, p.64-71

Chapter 3

Forecasting the Growth of Container Traffic

3.1 Introduction

Long-term forecasts of the demand for public infrastructure facilities are essential as a guide for policy makers in the analysis of development opportunities and in the performance of an operation. Once the trend of a special field has been estimated, the institutions that it may concern can begin to estimate the future scale of its activity, size of facility, the facility extension required and so on. Container transport is an example of where the port authority needs forecasts of container activity to determine the future port capacity for container cargo. A carrier may also use long-term forecasts to plan its fleet and short-term forecasts to plan schedules. Finally, government agencies require forecasts for budgeting and managing the freight transport system as well as for evaluating and formulating transport policy in general.

The purpose of this chapter is to consider how to forecast the future amount of container traffic originating in Korea. In order to accomplish this, a number of different forecasting methods can be considered. There are no universally applicable forecasting techniques since the problems are different for each field. In general, the various forecasting methods can be divided into three broad categories: quantitative, qualitative or judgmental, and decision analysis which may be thought of as a combination of the first two methods.

Button (1993) pointed out that "It is generally considered that the demand for a commodity is influenced by its price, the prices of other goods and the level of income. While this simple framework holds for transport in general, in many cases it seems clear that price changes within certain limits have relatively little effect on the quantity of travel or transport services demanded. For example, the demand for cargo shipping is inelastic, in part because of the lack of close substitutes for container transporting services, in part because of the relatively small importance of freight rates in the final selling price of cargoes[23]"

There is relatively little data on past activity in the container traffic field due to its comparatively short history, namely 24-25 years, as compared with the forecast period (1997-2020). Therefore, it is unlikely that a single formal method can accomplish the task of generating a forecast. Accordingly, a combination of qualitative and quantitative analysis is proposed as a forecasting method in this study.

The procedure is outlined as follows. First, a relationship between total merchandise exports volume and export container cargo volume is proposed. There are some core factors that exert the greatest influence on this relationship. One possible procedure is to utilise the correlation of the growth in total merchandise export volume with growth in a more advanced country. If a regular time lag or trend in the data can be established, it is possible to forecast the future growth of the less developed country on the basis of what is known about the past and future growth of the more developed one. Scenario analysis is proposed as a comparison method. We consider a scenario to be a description of a possible future state of the factor's environment, also considering possible developments of relevant interdependent factors in the environment. J. de D. Ortuzar and L. G. Willumsen have indicated that "The preparation of realistic and consistent scenarios is not a simple task as it is very easy to fall into the trap of constructing futures which are not financially viable nor realistic in the context of the likely evolution of activities in the study area. Despite these difficulties, scenario writing is still more of an art than a technique and requires a good deal of engineering

[23] Button, K. J., 1993, *Transport Economics*(2nd ed.), Aldershot, Edward Elgar, p. 39-41.

expertise combined with sound political judgment.[24]" Once the most reasonable scenario has been chosen, the projected total merchandise export volume tonnage is transformed into export container cargo volume in TEU subject to the projected path of the relevant factors.

3.2 Growth of the Korean Economy

During the 1980s and early 1990s the countries of East Asia have experienced a remarkable expansion in trade. Despite Japan's domination of the region's trade, this extraordinary growth has been fuelled by the industrialisation of the newly developing economies of the region. Korea has been one of the fastest growing and most dynamic of the newly developing countries.

3.2.1 Growth of East Asian Economies

World gross domestic product grew at an average rate of 3.2 % per annum in 1981-90. Growth throughout this period was erratic with a stagnant world economy in the early 1980s due to the world recession and rapid growth during the mid-to-late 1980s. A similar picture has emerged for the early 1990s. However a number of East Asian countries were little affected by the early 1980s' recession and at a time when the major economies of Europe and North America were stagnating, these economies were experiencing a rapid expansion in their economies and as a consequence also an expansion of their international seaborne trade. Table 3.1 shows the growth of GDP by region.

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[24] Ortuzar, J. d. D. and L. G. Willumsen, 1994, *Modelling Transport*(2nd ed), Chichester, John Wiley & Sons Ltd.

<Table 3.1> World Growth Summary (percentage change per year in real GDP)

Region	1966-73	1974-80	1981-90	1991-93	1994	Forecasts 1995-96	Forecasts 1995-2004
World total	5.1	3.4	3.2	1.2	2.8	3.2	3.3
High-income countries	4.8	3.0	3.2	1.3	3.0	3.0	2.8
Developing countries	6.9	5.0	3.2	0.8	2.0	4.0	4.9
East Asia	7.9	6.8	7.6	8.7	9.3	8.1	7.7
South Asia	3.7	4.0	5.7	3.2	4.7	5.0	5.4
Sub-Saharan Africa	4.7	3.4	1.7	0.6	2.2	4.0	3.8
Latin America*	6.4	4.8	1.7	3.2	3.9	2.4	3.5
Europe & Central Asia	7.0	4.9	2.9	- 9.4	- 7.5	0.7	3.4
Middle East **	8.5	4.7	0.2	3.4	0.3	2.7	3.2

Notes: * including the Caribbean
** including North Africa
Source: OECD National Accounts Statistics; World Bank data and staff projections.

According to the World Bank, provided recently implemented policy reforms in developing countries stay on track, their output growth is expected to accelerate from 2.2 % in 1981-94 to 4.9 % over the coming decade. The developing countries' share in world output will rise from 21 % in 1994 to close to 25 % over the next ten years. Their exports are expected to grow 1 to 1.5 % points faster than those of industrial countries. The rising importance of developing countries in world trade and output helped dampen the effects of the recession in the early 1990s in industrial countries and are also likely to contribute to their output growth during recovery[25]. East Asian countries have been a major driving force in this process of growth.

3.2.2 The Korean Economy

3.2.2.1 Overview of Development

Korea has limited supplies of coal, iron and limestone, whilst other resources are either scarce or non-existent. Even resources for agricultural development are not plentiful. Climate, soil, rainfall and temperature are all unfavourable for agricultural production. In contrast to its poor endowment of natural resources, Korea is favoured

[25] *World Bank Report*, 1995, Global Economic Prospects and the Developing Countries, Washington, The World Bank.

with human resources. Because of its poor natural resources, Korea has to import most raw materials for its industries. The Korean economy has depended on the rest of the world making effective use of its comparatively abundant human resources in manufacturing. Exports have so far been Korea's engine of growth. The most remarkable aspect of Korea's development is its phenomenal growth of exports. Exports in Korea amounted to US $ 96 billion in 1994, double that of 1987 as shown in Table 3.2.

<Table 3.2> Korea: Composition of Merchandise Exports, 1971-95

YEAR	*EXPORTS	MANUFACTURED GOODS		NONMANUFACTURED GOODS(%)****
		LIGHT INDUSTRY(%)**	HEAVY INDUSTRY(%)***	
1971	1.1	62.4	26.3	11.3
1972	1.6	58.2	33.4	8.4
1973	3.2	58.1	34.4	7.4
1974	4.5	47.3	45.8	6.8
1975	5.1	51.4	38.2	10.2
1976	7.7	51.4	41.8	6.9
1977	10.1	46.1	44.1	9.9
1978	12.7	47.5	45.1	7.4
1979	15.1	44.3	48.3	7.4
1980	17.5	42.2	52.0	5.8
1981	21.3	41.4	52.9	5.6
1982	21.9	37.6	57.6	4.9
1983	24.5	34.4	61.3	4.4
1984	29.3	32.4	63.8	3.9
1985	30.3	31.6	64.9	3.5
1986	34.8	35.2	60.7	4.1
1987	47.4	35.1	61.0	3.9
1988	61.0	33.0	66.3	2.5
1989	62.4	33.3	63.6	3.1
1990	64.9	32.3	64.9	2.8
1991	71.7	29.8	67.6	2.7
1992	76.6	27.7	70.1	2.3
1993	82.2	25.1	72.9	1.9
1994	96.1	23.1	74.9	1.8
1995	125.5	19.2	79.2	1.5

Notes:* $ billion

** This consists of the Food, Beverage and Tobacco industry, the Textile industry, the Wood & Products industry and the Paper & Products industry.

*** This consists of the Chemicals industry, the Non Metal industry, the Basic Metal industry, the Metal Manufacturing industry and other Manufacturing industry.

**** This consists of the Agricultural and Mining and Quarrying industries.

Source: *International Trade Statistics* Yearbook, 1995, United Nations.

The process of industrialisation in Korea can be divided into 3 phases of development. In each phase, the industrial policies adopted by the Korean government had elements particular to different stages of industrial development and to different industrial environments.

Until it embarked on a policy of export promotion in the early 1960s Korea had been a country virtually sealed off from the rest of the world. The first Five-Year Economic Development Plan, a turning point for the country, was launched in 1962. The first phase from 1962 to 1972 was characterised by an export driven policy in which incentive schemes for outward looking policy were designed and the construction of basic industry was undertaken and largely completed.

The second phase lasted from 1973 to 1979 and was a period of heavy industrialisation. During this era the government tried to promote development of the heavy and petrochemical industries so as to obtain a higher level of industrial structure and thus enhance the international competitiveness of the Korean economy as a whole. Few other developing countries experienced such remarkable rates of growth during the 1960s and 1970s. The rates of growth of Korea and Taiwan during the 1960s and 1970s surpassed those of any advanced country at its commensurate period of development. In the third phase, from the 1980s to the present, government policy shifted its focus from maximising growth to the restructuring of industries. In line with the shift in policy direction, export promotion policy has shifted from maximising export growth to strengthening competitiveness through improvements of export structure. On the whole, the export promotion measures of the 1980s were more mature than those of previous decades. Exports still enjoyed a central position in economic policy, but they were no longer given sole priority.

3.2.2.2 Structural Change

Korea was a predominantly agricultural country in the 1950s; the agriculture and fishery share of GDP between 1953 and 1961 was about 40 %, as compared with 13 % for manufacturing. The share of agriculture and fisheries has rapidly shrunk since the early 1960s to about 9 % in the last 5 years. At the same time, the manufacturing sector increased from 13 % in the 1950s to 30 % in the last 5 years.

The structure of manufacturing has also undergone a tremendous change during this period. Although mainly labour-intensive light industries were established in the 1950s and in the early 1960s, the government shifted its support in favour of heavy and chemical industries towards the late 1960s and in the 1970s accelerated investment in electronics, machinery, steel and iron, shipbuilding, and chemical industries. As a result of this policy, the proportion of heavy and chemical industries in total manufacturing has increased to approximately 60 % in recent years.

On the other hand, resource-poor economies such as Korea and Taiwan can expand exports only through exporting manufactured goods. As shown in Table 3.2, more than 90 % of exports consist of manufactured goods. Moreover, exports of heavy-industry goods have become increasingly important whilst exports of light-industry products have shrunk as a share of total exports. Since 1982, the share of heavy-industry products has exceeded that of light-industry products. Since the industrial structure has undergone a transformation which moved it firmly into capital-intensive, high value-added and technology-intensive products at the expense of labour-intensive products, the share of advanced industries in total exports is expected to increase in the future.

3.3 Container Traffic Trends

3.3.1 Growth of Asian Pacific Rim Container Trades

Since the introduction of containers the growth of containerised trade has exceeded the rate of growth of world seaborne trade as a whole. In 1992, registered world container cargo showed an annual increase of 7.6 %, breaking the 100 million TEU barrier, rising from 93.6 million TEUs in 1991 to 100.7 million TEUs in 1992. Moreover, the average growth rate in the period, 1980-1993, has been 8.7 %, as compared with 1.4 % for world seaborne trade as a whole. Nevertheless, it must be remembered that a substantial proportion of total general cargo movements around the world remains uncontainerised. In 1980, more than 75% of world general cargo trade was estimated to have been shipped by conventional modes. By 1990 this proportion had fallen to about 50% and, although it is expected to continue declining through the 1990s to around 30% by 2000, it will still account for about 200m tonnes of cargo[26].

<Table 3.3 > World Seaborne Trade

	1980	1985	1990	1993	Av. Growth Rate 1980/93
Total trade (million tonnes)	3606	3293	3977	4299	1.4
Other cargo* (million tonnes)	1310	1360	1570	1710	
Container cargo(million TEU)	37.2	55.9	85.6	109.6	8.7

Notes: * Other Cargo = Total trade - (Crude oil + Oil products + Iron ore + Coal + Grain)
Source: *World Economy Survey*, 1994, United Nations.
Containerisation International Yearbook, various years, National Magazine.

Table 3.4 illustrates the growth in containerised traffic in each of the countries within the region between 1980 and 1992 and their changing positions within the world league of container port traffic. In 1980 the Asian Pacific Rim countries

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[26] *Drewry Report*, 1993, Pacific Rim Trade and Shipping- the powerhouse of world shipping in the 21st century, London, Drewry Shipping Consultants Ltd.

accounted for 29% of reported global container port movements. Through the next five years, the region advanced to account for 32% of world container movements. As the pace of economic and industrial activity of the region increased through the second half of the decade, the ports of the region experienced a growth in container traffic which outstripped that of any other region in the world.

<Table3.4 > Asian Pacific Rim Countries Ranked in the World League of Container Port Traffic 1980-1992 (million TEUs)

	1980	1985	1990	1992
China	0.1	0.4	1.1	1.2
HongKong	1.5	2.3	5.1	8.0
Japan	3.3	5.5	7.9	8.9
Singapore	0.9	1.7	5.2	7.6
Korea	0.7	1.3	2.3	2.8
Taiwan	1.6	3.1	5.4	6.2
*Oceania	1.5	1.8	2.1	2.4
**The others	0.9	1.7	4.3	5.0
Total (A)	10.4	17.8	33.5	42.0
World Total (B)	36.5	55.8	84.2	100.7
Percentage (A/B)	29	32	40	41.7

Notes: * Australia, New Zealand

** Includes Indonesia, Malaysia, Philippines and Thailand

Source: *Containerisation International Yearbook*, various years, National Magazine.

3.3.2 Container Traffic in Korea

During Korea's economic development, there has been a substantial increase in trading activity between Korea and the rest of the world. Since 1970, container transport has gained in importance in Korea's trading system and in a comparatively short period, there has been very rapid growth in container traffic. Table 3.5 indicates developments from 1980 to 1994 of total exports volume, containerisable cargo traffic in tonnes, and container traffic originating in Korea[27].

[27] Containerisable cargo means cargo that is theoretically available as potential container cargo. Traffic containerised indicates cargo that is actually containerised in a particular year. Therefore, the containerisation ratio by commodity can be calculated by multiplying the proportion of containerisable commodity by the proportion containerised. For example, if 70 % of a commodity category (say steel products) is containerisable and only 60 % of the containerisable cargo is assumed to be actually containerised in a particular year, then 42 % of the total commodity category will be containerised.

<Table 3.5> Korean Container Cargo Development 1975-1994

YEAR	A	B	C	B/A	C/B
1975	9985	6364	2514	63.74	39.52
1980	22682	16220	7660	71.51	47.23
1985	31899	23391	14686	73.33	62.78
1986	41766	31668	20087	75.82	63.43
1987	51226	39657	24520	77.42	61.83
1988	54300	44948	28070	82.78	62.45
1989	50915	40513	27557	79.57	68.02
1990	49550	39628	27199	79.97	68.64
1991	52426	38474	26323	73.39	68.42
1992	60852	46664	27595	74.24	59.14
1993	71245	51579	29281	72.40	56.77
1994	76094	55353	33198	72.74	59.98

Notes: A: Total Exports Volume Tonnage (thousand tonnes)
B: Containerisable cargo (thousand tonnes)
C: Traffic Containerised in R/T (thousand tonnes)
Source: Korea Maritime Institute

Two different standards may be used to measure the container freight capacity: TEU (Twenty foot equivalent units) and R/T (Tonnage). The figures in Table 3.5 are expressed in tonnage in order to illustrate more precisely the growth of the cargo itself rather than the number of container movements. However, since the purpose of this chapter is to make projections of the future amount of container traffic originating in Korea, container cargo by weight needs be reconciled with volume measured in TEUs.

The following three items provide important steps in estimating the prospects for container traffic in TEUs: the proportion of containerisable cargo traffic to total export freight i.e. B/A in Table 3.5, the proportion of traffic containerised to the containerisable cargo traffic (containerisation ratio i.e. C/B in Table 3.5) and an estimate of R/T per TEU of container traffic. The main reason for adopting these relationships is because the total export freight includes some commodities whose containerisation is impossible. The share of containerisable cargo is deeply associated with the industrial structure of the export sector as well as with certain external factors such as the development of infrastructure, the competitiveness of the country and the positiveness to containerisation of the interested parties.

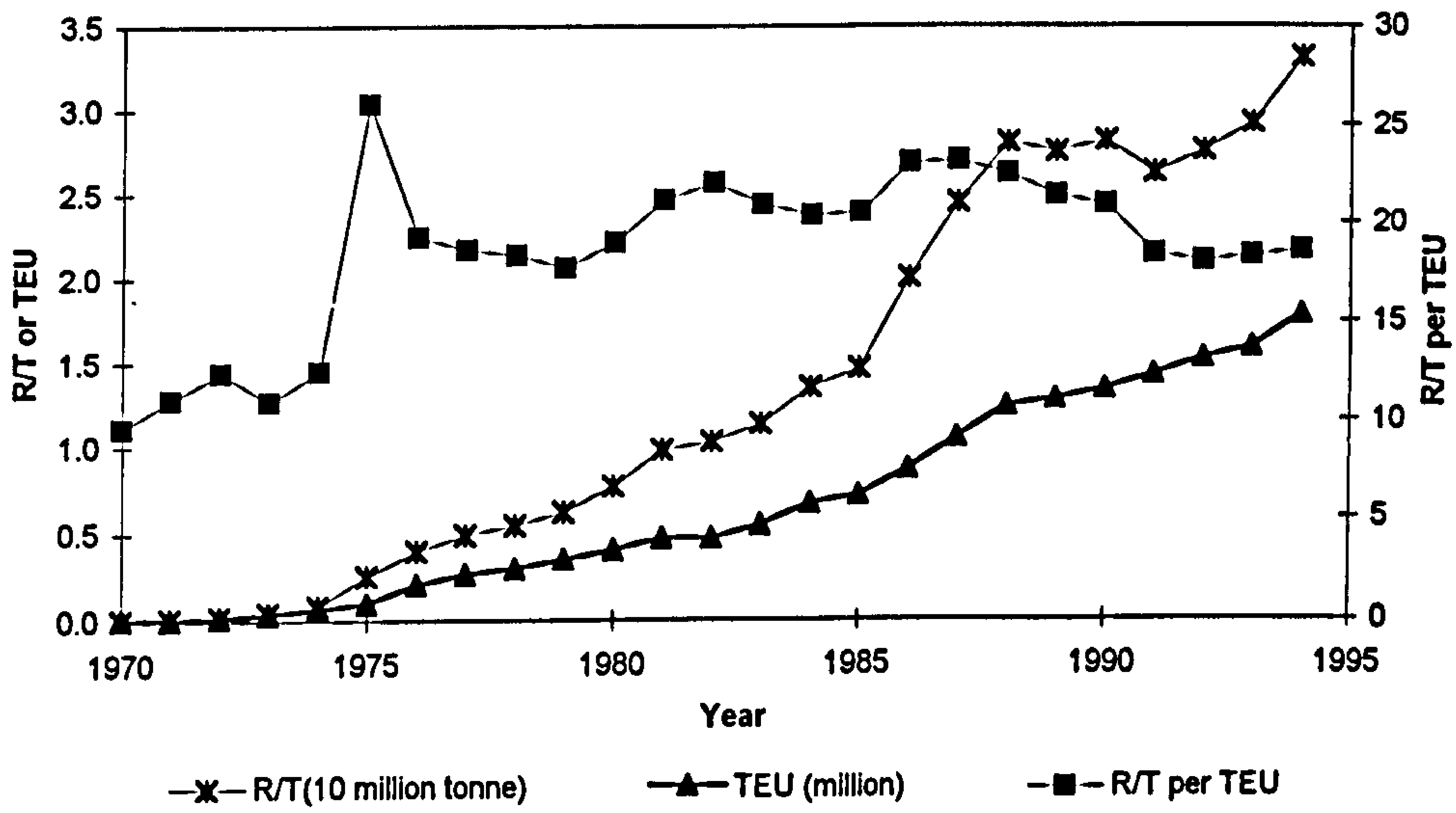
The development of the technology of cargo handling and packing as well as of container manufacture industry have contributed to the remarkable growth of container traffic which has overturned the earlier view in which container cargo was regarded as confined to high-valued freight. Containerisation has expanded to the categories which were traditionally considered as belonging to the general cargo sector. As a result, almost all cargo is potentially containerisable[28]. We should also consider the trend of special items of goods such as grain, oil, fertiliser, cements and minerals that are yet to be containerised. There was some rapid growth associated with increasing container cargo penetration to total general cargo in the 1970s. The proportion (B/A) in Table 3.5 shows that the year 1988 proved to be the peak year for this sector with the proportion reaching 82.8 %. The Seoul Olympics in 1988 promoted the country's image over the world and boosted the economy with a special procurement boom. The share of textiles to total value dropped from 32.8 % in 1986 to 30.6 % in 1988, whilst the share of metal manufacturing soared from 40.9 % in 1986 to 47.4 % in 1988. Until then, footwear and textiles industries had been the country's leading export sector since the industrialisation. 1988 was a turning point in the country's economic structure. With a buffer period in 1989-1990, the share of containerisable cargo has maintained a stable level, at 72.4-73.4 % since 1991.

The degree of containerisation tends to follow the pace of economic growth of a country as well as its transport infrastructure development. The proportion of

[28] The majority of container cargoes consist of the following goods: meat and meat preparations, chemical products, plastic and rubber products, leather products, clothing, fabricated textile products, non-ferrous metal products, iron and steel, general industrial machinery and equipment, transport equipment, electrical equipment and apparatus, paper and wood products and so on.

containerised to containerisable cargo is obtained by dividing the amount of container traffic served (R/T) into all possible freight traffic (R/T) that can be packed into containers to export. This proportion (C/B) in Table 3.5 reached a peak at 68.64 % in 1990. The trend of the proportion (C/B) has failed to follow that of the proportion (B/A). In reality, containerisation has lagged behind expectations. The main reason for the gap is that industries such as chemicals, cars and shipbuilding whose products have proved impossible to containerise have been remained significant exporters. Nevertheless, it is predicted that the growing trend towards containerisation will continue for some years and then weaken at some time in the future and eventually converge to a certain level.[29]

Finally, we need to consider R/T per TEU of container traffic which directly affects the calculation of container volume in TEU.



<Fig. 3.1> R/T per TEU of Container Traffic in Korea

[29] Lee, J. and Nine persons, 1996, *Investment Plan for New Port Development in Korea*, Seoul, Korea Maritime Institute.

Fig. 3.1 shows the trend of R/T per TEU for outbound containers loaded in Korea since 1970. The ratios of R/T per TEU increased at a rapid rate in the late 1970s and 1980s but in the early 1990s it has fallen back to a steady level of around 18. This trend has been influenced by changes in Korea's economic structure.

As mentioned above, since the 1980s, Korea has tried to shift its focus from maximising growth to restructuring industries. The country has made efforts to strengthen competitiveness through the improvement of its export structure. Therefore, industrial structure has undergone a transformation from labour-intensive products to more capital-intensive, high value-added and technology-intensive products. This is reflected in the lower R/T per TEU shown in Fig. 3.1.

3.4 Forecasting Container Traffic

There is obviously uncertainty over how many containers will be demanded in the 1997-2011 period. The future rate of growth of container traffic depends on both the general development of the economy and on developments in the structure of export-industries. For this reason, it is desirable to develop alternative scenarios for the longer-term development of total exports volume. Three alternative cases - a "High" case, a "Low" case and a "Base" case - were developed, each of which are based on different assumptions. The main determinant of future growth in exports volume will be the strength or weakness of the export economy. As mentioned in the previous section, there are three main areas of uncertainty in forecasting container traffic in volume: the proportion of containerisable cargo traffic to total export freight volume, the ratio of containerisation to containerisable cargo and the expected volume R/T per TEU of container traffic. Estimates of these ratios provide the basis for projecting future container traffic demand.

3.4.1 Total Export Volume

In order to project future export volume, it is proposed to use the correlation of the growth in aggregate merchandise exports volume in Korea with the growth in a more advanced country. For this, Japanese experience provides the Korean case with a possible model. During the last three decades, Korea has managed to transform from a traditional agricultural economy to an industrial one. The great transformation that Korea has achieved was comparable to what the advanced countries managed to achieve over the course of a hundred years. That is, Korea has condensed a century's worth of growth into three decades. Prior to the Korean experience, Japan also condensed the usually long and slow process of economic maturity into only several decades. Even though there are differences between the two cases, several interesting phenomena stand out. First, it was the East Asian countries with similar factor endowments that have managed to achieve condensed growth. Second, both countries have become heavily dependent on exports to provide a substantial amount of income and employment. Third, they have achieved the condensed growth during the post-World War II period. Finally, the economic growth of Korea during the last three decades and that of Japan during the 1955-73 period can be regarded more or less comparable.

The Quantum index data provided by the Department of International Economic and Social Affairs Statistical Office for the UN is suggestive. The Quantum index shows developments in the volume of aggregate merchandise imports or exports. Table 3.6 gives the exports Quantum index for Korea and Japan.

<Table 3.6> Korea, Japan : Export Quantum Index

	1950	1955	1960	1965	1970	1975	1980	1985	1990
Japan	3	7	14	31	62	100	155		
					42	64	100	142	162
Korea					12	49	100	181	304

Source: *International Trade Statistics Yearbook*; various years, United Nations

First, we may examine the Japan export volume to check for a pattern or a phase. We see Japanese exports have doubled at regular intervals. The pattern which begins in 1955 and ends in 1989 is shown in Table 3.7.

< Table 3.7> Japan : Phases of Export Growth 1955-1989

Japan	1955	(5)	1960	(5)	1965	(5)	1970	(6)	1976	(13)	1989
Quantum	7		14		31		62		122		239

Notes: The figures in brackets are years of a period
Source : *International Trade Statistics Yearbook*, various years, United Nations

Thus, the historical data of the past 4 decades for Japan shows a doubling of aggregate merchandise exports volume in 1960, 1965, 1970, 1976 and 1989. Except for the phase ending in 1989, the first 4 periods show rapid growth, with a period of 5-6 years. After 1976, the pace of export growth slackened and it took Japan a further 13 years to double its export volume.

Next, the data for Korea can be examined to identify phases for which values have doubled since 1970. On a 1985-1992 basis, Korea has experienced a doubling of aggregate merchandise exports volume in 1979, 1985 and 1992. Doubling has occurred at fixed periods, spanning 5-7 years.

<Table 3.8> Korea : Phases of Export Growth 1974-1992

Korea	1974	(5)	1979	(6)	1985	(7)	1992
Quantum	40		90		181		364

Notes: The figures in brackets are years of a period
Source: *International Trade Statistics Yearbook*; various years, United Nations.

The existence of these phases in terms of the index is evident from Table 3.5. In terms of total export tonnage, the volume leaped from 31,899 thousand tonnes in 1985 to 62,852 thousand tonnes in 1992, a net increase of about 100 % over the 7 year period.

If the phases of both countries are compared and the Japanese example is followed, the point is whether Korea will enter another rapid growth phase or a slack phase in the period starting in 1992. Japan experienced five intervals - four consecutive rapid growth periods and at last a comparatively slow growth phase with a period of 13 years - between 1955 and 1989, in the doubling of aggregate merchandise export volume. When the Korean case which has experienced three consecutive rapid growth periods with periods of 5-7 years between 1974 and 1992 is considered, three scenarios are developed for total exports volume tonnage - a "High" and a "Low" case, together with a "Moderate" case. If two consecutive rapid growth phases follow after 1992, then a "High" case is supposed. If a comparatively slow growth phase follows at 1992, a "Low" case is supposed. If a rapid growth phase and then a slow growth phase follow after 1992, a "Moderate" case is supposed. The Moderate scenario indicates the most reasonable forecast in the export volume growth for Korea. In other words, under the Moderate case, the forecasts are restrained from being either too optimistic or too pessimistic.

3.4.1.1 High Growth in Total Exports Volume - Case A

The scenario developed for "Case A" sets out to show what would be the outcome if recent growth trends in the export Quantum index continued at the same growth rate of the previous periods after 1992.

<Table 3.9> Korea's Future and Japan's Trend in the Export Quantum Index under Case A

Japan	1955	(5)	1960	(5)	1965	(5)	1970	(6)	1976	(13)	1989
Korea	1974	(5)	1979	(6)	1985	(7)	1992	(8)	2000	(8)	2008

Notes: The figures in brackets are the length of a phase in years.

That is, Korea's total export volume in 1992 is projected to double by 2000 and then the export volume in 2000 will double again by 2008. These phases are assumed to last for 8 years. Thereafter, a slack phase is projected, with export growth at a comparatively slow growth rate, with a doubling period after 16 years. Table 3.9 shows the phases. The continuing high growth rates are intended to reflect the successful implementation of the export-led growth policies, assuming that the favourable domestic and international economic environments continue. The results of case A - the high growth forecast - are summarised in Table 3.10.

<Table 3.10> Forecast Total Export Tonnage - Case A

YEAR	Total exports volume(million Tonnes)
1985	31.9
1992	60.9
2000	120.0
2008	240.0
2024	480.0

3.4.1.2 Low Growth in Total Export Volume - Case B

The alternative scenario, Case B, presents a more restrained scenario. It is forecast that growth trends in the Quantum index are not likely to be as high as that of the previous periods, and that post-1992 represents a slack phase. Therefore, the low case scenario projects total exports volume tonnage in 1992 doubling, at the earliest, by 2006. Under case B, the phases for two countries are shown in Table 3.11.

<Table 3.11> Korea's Future and Japan's Trend in Quantum Index under Case B

Japan	1955	(5)	1960	(5)	1965	(5)	1970	(6)	1976	(13)	1989
Korea	1974	(5)	1979	(6)	1985	(7)	1992	(14)	2006	(14)	2020

Notes: The figures in brackets are the length of a period in years.

Case B reflects the development of unfavourable domestic and external economic environments. Most of the country's exports will be concentrated in a handful of highly cyclical industries - electronics, cars, ships, petrochemicals and steel - facing increased competition from China and South-East Asia. The country will make efforts to diversify into more value-added products. Case B foresees that the industrial strategy will leave Korea with excess production capacity in many key sectors and a lack of cutting-edge technology. Factors sustaining high growth in the past, such as low wages and a cheap currency are assumed to disappear. Trade barriers protecting industry are falling and state financial aid to companies are assumed to be phased out. Therefore, the economy is not expected to experience such rapid growth in the future as it did in past decades. The results of Case B are summarised in Table 3.12.

<Table 3.12> Forecast Total Export Tonnage - Case B

YEAR	Total exports volume (million Tonnes)
1985	31.9
1992	60.9
2006	120.0
2011	170.0
2020	240.0

3.4.1.3 Moderate Growth in Total Export Volume - Case C, the Base Case

The Base Case developed as case C represents a moderate scenario located between two extremes. The projections under case C are based on following assumptions.

First, we need to take into account the prospects of Korea's economy during the Seventh Five-Year Plan (1992-1997). The seventh five-year plan set as its principal goal "pursuing an advanced economy and society." For this, the following three major strategies were adopted: strengthening competitiveness of industry, enhancing equity and balanced development, and pursuing internationalisation and liberalisation.

With the implementation of the Seventh Five-Year Plan, the economy is expected to shift from a high-cost and low-efficiency economic structure to a capital-intensive and higher value-added economic one. This may then lead to another rapid growth phase which began in 1992 similar to that experienced in the three previous periods but that this will be followed by a saturation period, with a comparatively slow export growth rate. This phase is expected to cover a period of 16 years. On this scenario Korea follows the Japanese pattern with four consecutive rapid growth phases followed by a comparatively slow growth rate and lagging behind Japan by between 19 and 25 years.

<Table 3.13> Korea's Future and Japan's Trend in Quantum Index under Case C

Japan	1955	(5)	1960	(5)	1965	(5)	1970	(6)	1976	(13)	1989
Korea	1974	(5)	1979	(6)	1985	(7)	1992	(8)	2000	(16)	2016

Notes: The figures in brackets are the length of a period in years.

In terms of total export volume, the 1992 tonnage will double by 2000. Thereafter, the volume in 2000 will double by 2016 again. The projection of total export volume under the Base Case is summarised in Table 3.14.

<Table 3.14> Forecast Total Export Tonnage - Case C

YEAR	Total exports volume (million Tonnes)
1985	31.9
1992	60.9
2000	120.0
2010	185.0
2016	240.0

3.4.2 Conversion of Export Volume to Container Demand

3.4.2.1 The Proportion of Containerisable Cargo to Total Export Volume

After 1988, the economy was affected by the end of the special procurement economic boom due to the Olympics. In addition, the principal export commodities have shifted to semiconductors, ships, cars, and crude steel products at the expense of footwear, textiles and agricultural products. These facts help to account for the volatility of both export volume and of container cargo traffic, in particular, between 1989-1992. Thus past data does not appears to provide a clear trend for the containerisable ratio. We adopt the assumption that for the remainder of the 1990s, we can expect the same level of the containerisable ratio as experienced in the previous 10 years at about 75 % and thereafter the proportion will increase to around 80 % by 2005. A study[30] executed by the KMI has predicted that the growth of the Korean containerisable ratio would have an upper limit of 80 %[31]. On these assumptions, the future of containerisable cargo traffic will be as indicated in Table 3.15.

<Table 3.15> Projected Containerisable Cargo Volume

YEAR	Total Export Volume*	Containerisable Ratio	Possible Container Cargo*
1994	76.1	72.74 %	55.4
2000	120.0	75.00 %	90.0
2005	148.0	80.00 %	119.1
2011	193.0	80.00 %	154.2

Notes: * million tonnes

3.4.2.2 Forecasting the Proportion of Containerisation

It is apparent from Table 3.5 that the proportion of containerisable cargo actually containerised is also not characterised by a well defined trend curve. The reason is the existence of a rapid decline since 1992. The decline can be explained by some negative factors affecting container traffic in recent years. e.g. chronic traffic congestion on the main roads and motorways and the inadequacy of container port facilities. Pusan port, handling 95 % of national container cargo volume, was deficient by more than 2 million TEU container capacity in 1995. This can be seen by comparing its actual throughput of 4.68 million TEU with its notional capacity of 2.22 million TEU. Table 3.16 shows the severity of container vessel delay at Pusan in the last five years.

[30] In a Study on the Investment Plan for New Port Development in Korea (1996) a forecast of total import and export volume was made using regression methods. The study also tried to forecast the container traffic demand by using the containerisable ratio and the containerisation ratio.

[31] The Japanese containerisable ratios of outbound cargo in terms of throughputs of its top 8 ports have stayed at around 80 % in recent years. Japanese experience suggests that the containerisable ratio shows a steady increase, which then slows down and then approaches an asymptote. This suggests a logistic curve. This is precisely what was used in the KMI study with an upper limit of 80 %.

These factors have a very negative influence on the demand for container traffic and hence, despite the steady growth of total export volume, the growth of container traffic has been sluggish.

<Table 3.16> Average Ship Turn-round Time of Container Vessels in Pusan Port 1991-1995

Year	Number of calls (A)	Number of Demurrage Vessels (B)*	(B/A)	Average Ship Turn-round Time per vessel
1991	3940	942	23.9	20.4
1992	3815	219	5.7	16
1993	3721	191	5.1	15.8
1994	4520	340	7.5	17.5
1995	6934	822	11.9	19.1

Notes: * A demurrage vessel is classified by a ship turn-round time in excess of 12 hours.
Source: *Congestion and Waiting of Vessels in Korea Ports*, 1996, Seoul, The Ministry of Maritime Affairs and Fisheries.

Moreover, the recent decline in containerisation gives rise to the possibility that in the future there may be a period of large increases in the containerisation ratio which eventually will slacken as the proportion begins to approach saturation. It is obvious that there is a upper limit to the degree of containerisation but it cannot be predicted precisely. Here we assume the proportion will approach an asymptote at 70 %, which is thought to represent the upper limit to the proportion of containerisation. This assumption is also supported by the KMI study mentioned above. The proportion is expected to increase to 65 % by 2000, after which the proportion will begin to approach the saturation level, at 70 % which is reached by 2011. The future trends for the proportion of containerisation are summarised in Table 3.17.

<Table 3.17> Projected Containerisation

YEAR	Possible Container Cargo	Containerisation Ratio	Container Cargo traffic*
1994	55.4	59.98 %	33.2
2000	90.0	65.00 %	58.5
2005	119.1	67.50 %	80.4
2011	154.2	70.00 %	107.9

Notes: * million tonnes

3.4.2.3 Forecast of R/T per TEU of Container Traffic

So far we have proceeded with projection in units of weight i. e. tonnage. As a final step, we need to consider R/T per TEU in order to have projections in TEUs. The historical trends in R/T per TEU have been positive mainly due to improvements in the technology of cargo packaging. However, there is a physical limit on the increase because a container is a confined box of standard size. Moreover, according to Gilman "theoretically a 20' container can carry 20 tonnes, a 40' box, 30 tonnes. Whilst the averages carried are much less than the maximum and 40' containers are limited to about 18 tonnes by road vehicle regulations in many countries, they are being used mainly for volume cargo[32]."

The trends in R/T per TEU for outbound containers loaded in Korea in the last two decades were shown in Fig. 3.1. The future trend in R/T per TEU is likely to be influenced by tightening of road regulations for heavy vehicles and shifting of the country's leading export sector into more high value-added and technology-intensive products. Moreover, data for Japan during the 1977-1992 period indicate small fluctuations between 18.06 and 19.96 R/T per TEU but seem to indicate a slightly increasing trend as shown in Table 3.18.

<Table 3.18> R/T per TEU in Japan :1977-1992

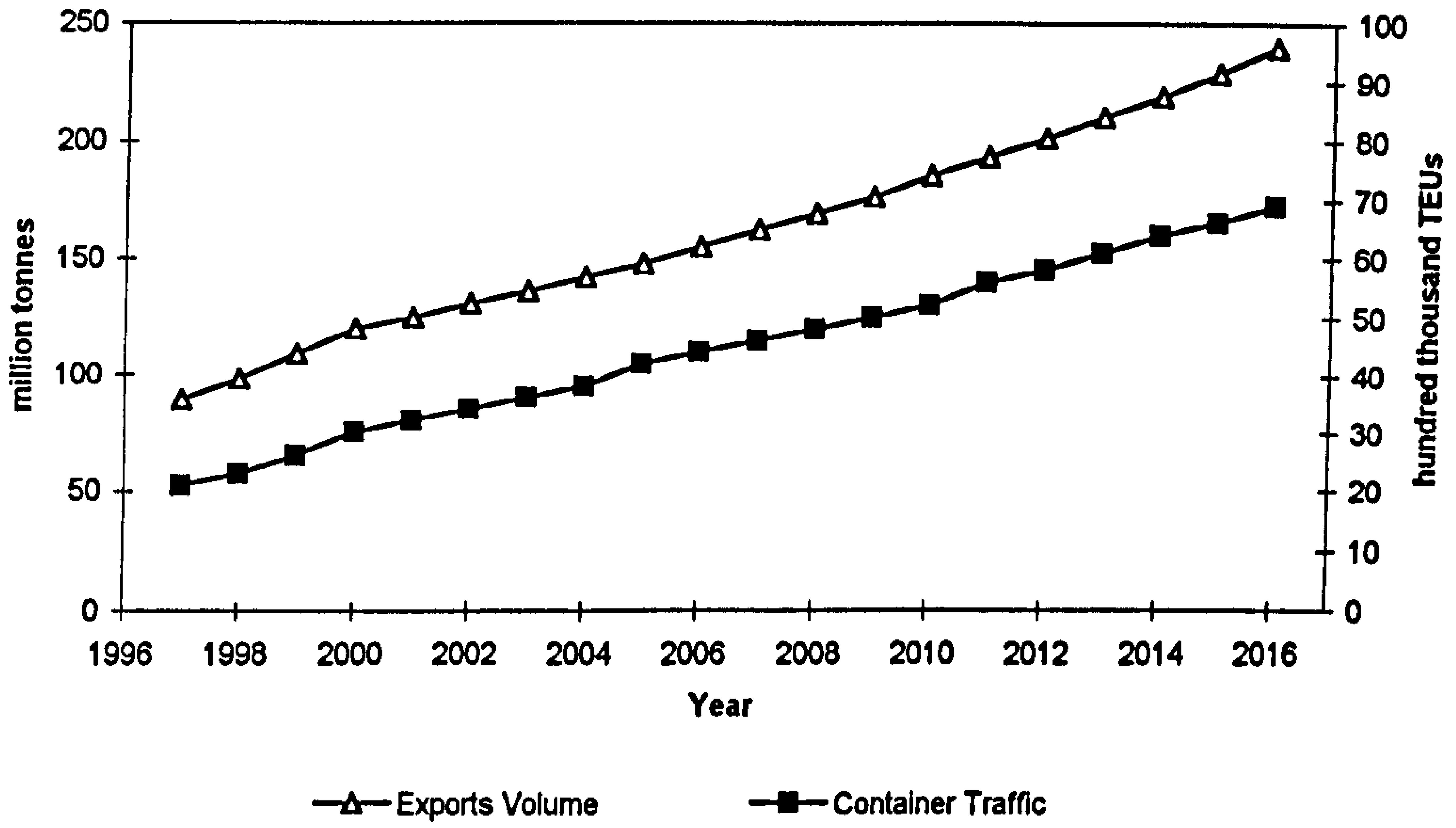
Year	R/T*	TEU**		Year	R/T	TEU	
1977	24	13	18.81	1985	50	26	19.58
1978	25	13	18.36	1986	50	26	19.17
1979	24	13	18.06	1987	51	26	19.27
1980	29	16	18.47	1988	54	28	19.19
1981	32	17	18.50	1989	58	30	19.32
1982	33	18	19.03	1990	66	33	19.81
1983	38	20	18.81	1991	70	36	19.24
1984	46	23	19.96	1992	74	38	19.62

Notes: * million tonnes
** hundred thousand TEUs
Source: *Containerisation International Yearbook*, various years, National Magazine.

[32] Gilman, S., 1983, *The Competitive Dynamics of Container Shipping*, Liverpool, Marine Transport Centre, University of Liverpool, U.K.

As with growth of total exports volume, we assume Japan provides a model for Korea and hence the trends in the 1977-92 period for Japan can indicate what might be expected in Korea for the period up to 2000.

The share of heavy-industry products as compared with light-industry products in Korean exports has increased through time as shown in Table 3.2. But this is likely to cease in the future as a consequence of the industrial structural transformation towards more advanced and technology intensive industries mentioned in section 3.2.2.2. Therefore, it is forecast that the trend of R/T per TEU experienced in early 1990s will continue throughout the remainder of the 1990s and will approach an asymptote at 19.30 tonnes. The projections of container traffic in TEUs are reported in Fig. 3.2.



<Fig. 3.2> Projected Container Traffic

The projections used here may be compared with some recent forecasts by the Office of Maritime and Port Authority (1991) and by the KMI (1996). Table 3.19 provides a comparison of these forecasts with the projections made in this study.

<Table 3.19> Comparison of Projected Container Traffic

Year	Export Freight Volume*		Container Traffic in TEU**		
	This study	Projection A	This study	Projection A	Projection B
2001	125	117	32	30	25-30
2006	155	150	44	41	39-44
2011	193	183	56	51	51-60

Notes: A: a working plan of the 4th Phase development in Pusan port (1991) by Office of Maritime and Port Authority
B: a study on the Investment Plan for New Port Development in Korea (1996) by KMI
* million tonnes
** hundred thousand TEUs

It can be seen that the projections in this study are near the upper limit of the other forecasts in the early 2000s but later are located in the middle of the range predicted by the KMI. All the projections and forecasts were undertaken before the onset of the Asian Crisis and the consequent growth slowdown. It is possible therefore that the slower growth scenario is a better indicator of medium term developments in the demand for container cargo rather than what is here taken as the base case.

3.5 Distribution of Regional Container Traffic

Given the overall projection of container cargo in TEUs, it is necessary to estimate the split by regional origin. It is assumed that the regional split is independent of expectations about port development. There are various factors affecting the growth of container cargo by regions, but the principal determinant is assumed to be the size of a region's industrial complex. Using the known development plans for region industrial complexes, the future of growth regional container volume is estimated. The National Physical Planning Bureau has a programme for land development of all the industrial complexes. The blueprint for industrial complexes by region is indicated in the plan. Table 3.20 shows the share of each industrial complex to total national industrial complex size measured by area.

<Table 3.20 > Regional Industrial Complex Size

	1994	1996	2001	2005
Sudo	29898* (17.3)**	34126 (16.1)	42379 (14.4)	42379 (14.1)
Kangwon	1034 (0.6)	1608 (0.8)	3276 (1.1)	6032 (2.0)
Chungbuk	5014 (2.9)	6263 (3.0)	11287 (3.9)	12288 (4.1)
Chungnam	3999 (2.3)	8167 (3.9)	26475 (9.1)	29165 (9.7)
Kyongbuk	36265 (21.0)	37944 (17.9)	46074 (15.8)	46074 (15.3)
Kyongnam	63103 (36.5)	74945 (35.4)	77593 (26.5)	77593 (25.8)
Pusan	3287 (1.9)	3613 (1.7)	9718 (3.3)	11171 (3.7)
Chonbuk	7631 (4.4)	16094 (7.6)	23692 (8.1)	24479 (8.1)
Chonnam	22566 (13.1)	29031 (13.7)	52037 (17.8)	52037 (17.3)
Total	172797 (100)	211791 (100)	292531 (100)	301218 (100)

Notes:* The figure in thousand m^2.
** The figures in brackets are the regional percentages in distribution of industrial complex size.

The figures for regional shares in the industrial complex size are different from that of the regional container volume to the national export volume. However, each regional industrial complex has its principal industry and in Korea, the government national land development programme indicates the original development intention. Consequently, a given region's industrial complex may be characterised by heavy industries, while another industrial complex may be characterised by light industries. Their contribution to the amount exported and to the containerised system will generally differ. Thus almost all the goods produced from light industries such as electric goods, electronics, textiles and footwear become container cargoes, whilst the products from heavy and chemical industries are unlikely to be containerised.

It is here assumed that the primary characteristics of an industrial complex are maintained as the complex grows. That is, the extension of an industrial complex is considered to be the extension of its principal industry.

On this basis we estimate the regional container volume as specified in Eq (2.26) and this yields the regional shares shown in Table 3.21.

<Table 3.21> Projected Regional Distribution of Export Container Cargo

	1994	1996	2001	2005
Sudo	47.4	43.7	32.5	30.8
Kangwon	0.2	0.3	0.3	0.6
Chungbuk	2.4	2.4	2.6	2.7
Chungnam	7.0	11.6	22.6	23.5
Kyongbuk	8.3	7.0	5.1	4.8
Kyongnam	13.1	12.5	7.8	7.4
Pusan	12.3	10.9	17.6	19.2
Chonbuk	3.1	5.2	4.6	4.5
Chonnam	6.2	6.4	6.9	6.5
Total	100	100	100	100

Notes: All figures in share of total(in TEUs)

The source of container cargo has become clearly concentrated in the Sudo and Kyongsang province - Kyongbuk, Kyongnam and Pusan, which together accounted for 80.1 % of export container cargo by 1994. Sudo has been the predominant source of export cargo, accounting for nearly half of the total export volume in 1994. This high dependence is projected to fall to 30 % by 2005. Except for Pusan the country's dependence on Kyongsang province for export container cargo is assumed to decrease. However, the share of Chungnam is expected to rise to 23.5 % of the total by 2005, compared to 7.0 % in 1994. To relieve the problems arising from the concentration of economic activity in the Sudo region, a massive industrial complex is under construction in Chungnam region, especially Asan Bay to accommodate the industries which are likely to be forced out of Sudo region. This initiative is clearly reflected in the expected growth of Chungnam region.

3.6 Effect of the 1997 Financial Turbulence in Korea

The crisis has precipitated a sudden restructuring of the Korean economy through measures demanded by the International Monetary Fund (IMF) in exchange for a bail-out, resulting in severe difficulties for Koreans at large.

Despite the current crisis, the Korean economy's macroeconomic indicators continue to demonstrate underlying soundness, reflecting the nation's potential to cope with its current difficulties. Korea has maintained a stable increase in industrial production while keeping inflation within manageable limits. GNP growth is expected to be positive in 1998 at between 2-3 % and inflation is expected to remain relatively modest at less than 6 %. Exports, which have been the core of Korea's rapid economic growth, have also increased. Most economists have noted that due to steep currency devaluation, a rapid growth of exports, particularly to North America and Europe, represents the key to the recovery. According to the Bank of Korea, the country's export unit price index, which indicates the general price level of exports, was at the 61-63 level in December 1997 (when the exchange rate was around 1820 won against the US dollar) and even lower in January 1998. This represents a decline of nearly 40 % from 1995 - the base year - when the average exchange rate against dollar was about 748 won. The Korean Institute of Finance has estimate that at 1300 won per dollar rate, export growth in 1998 (as compared with 1997) is expected to be 19 % for steel; 9.5 % for semi-conductors; 7.5 % for computers; 5 % for household electronics; 4.9 % for cars; but only just over 2 % for shipbuilding; still less at just over 0.4 % for textiles. Thus, with export growth at 4-9 % and decreasing of import growth remaining, the current transactions account surplus in 1998 will be in the range 25 billion US dollar to 43 billion US dollar.

Most importantly, the new government regards the crisis as an opportunity to restructure the economy, which previous governments had attempted at but failed to realise. The government, acknowledging the structural weakness of the national economy as pointed out by the IMF, has embarked upon comprehensive and immediate policies designed to correct the problem and stabilise markets and foreign exchange rates. The Ministry of Finance and Economy has forecast[33] that Korea will have little opportunity to enjoy the high growth and low unemployment rate experienced before the 1997 financial crisis even if the country succeeds in restructuring the economy, especially, in the financial and *chaebol* sectors. However, as in the 1970s', the government will continue to encourage exports. Consequently, the expected pattern is similar to the moderate growth scenario in total export volume chosen above. Thus our projection with the moderate growth in total export volume is consistent with government forecasts.

[33] Ministry of Finance and Economy paper issued on 3rd of May, 1998.

Chapter 4

Implementation of the Inland Container Transport Model

4.1 Introduction

This chapter together with the next attempts to apply the models that have been developed in Chapter 2 to the inland container transportation development problem in Korea. The purpose is to provide an example of the model application to real inland container transport systems and to test the validity of the model formulation. It is hoped that the results obtained may be useful in evaluating the existing container transport system, in assisting effective investment planning for transport infrastructure development, and in generating alternative investment plans at several different demand levels. Total system costs have been chosen as the objective function to be minimised. The elements of the objective function are all expressed in the same monetary units. Furthermore, all the costs are discounted to present value. We begin with an overview the inland container transportation system in Korea which is then used as a basis for estimating the specification of the objective function.

4.2 The Port/Inland Container Transportation System in Korea

Despite both quantitative and qualitative enlargement of Korea's transportation facilities associated with its export oriented economic development Korea has suffered from a number of freight transportation problems ranging from an overloaded road transport system to inadequate port development and in particular, it has experienced a deficiency in container handling capacity.

These have been neatly summed up by Merchant (Financial Times: 15th Nov. [1996]) which reported that "As South Korea's economy grew 13 % annually in the mid-1980s, transport was neglected. Less than 2 % of GDP was spent on transport-low by OECD standards. Shortage of capital has been central to the problem. Distribution costs account for 14.3 % of turnover in South Korea, compared with 8.8 % in Japan and 7.7 % in the U.S. The country's appallingly congested roads - costing industry $ 11bn in 1994 in wasted time and vehicle service charges - are in for more jams as the number of cars rises from 8 million in 1995 to 23 million in 2001. Ports are only able to handle 68 % of cargo deliveries, costing the industry $ 800 million a year in delays and lost earnings".

The problems can be further illustrated by comparing the development of throughput and theoretical or design capacity at Korean ports. The throughput of container cargo in Korea increased from 2.71 million TEU in 1991 to 4.80 million TEU in 1995 but the theoretical annual handling capacity remained at 2.42 million TEU. Developments over the last five years are detailed in Table 4.1 which shows that the ratio of theoretical capacity to throughput has fallen from 89.4 % in 1991 to 50.4 % in 1995.

<Table 4.1> Throughput and Theoretical Container Capacity in Korea 1991-1995

	Throughput*(A)	Handling Capacity*(B)	B/A (%)
1991	2.71(0.14**)	2.42	89.37
1992	2.88(0.16)	2.42	84.13
1993	3.20(0.26)	2.42	75.53
1994	4.03(0.59)	2.42	59.98
1995	4.80(0.86)	2.42	50.40

Notes: * million TEU

**The figure in brackets indicates container traffic for transhipment which is included in the throughput.

Source: Office of Maritime & Port Authority

The direct and indirect economic losses per annum arising from delays and waiting at ports have been estimated as 620 billion Won in 1995. During the period 1990-1995 the accumulated losses were 2.6 trillion Won, a figure which exceeds the amount spent on total port investment over the same period[34].

This area has clearly been revealed as one of the main weaknesses of Korea's industrial structure and its severity has adversely influenced national competitiveness. Table 4.2 illustrates that the annual expenditure required to perform logistics operations in Korea has been increasing over the last decade. The main source for this increase has been transport cost which accounted for 8.1 % of GDP in 1988 but has increased to 10.2 % of GDP in 1994.

<Table 4.2> The Share of Logistics Costs in GDP in Korea

	Inventory Carrying Cost	Transport Cost	Administrative Cost	Total Cost
1986	4.5	9.0	1.1	14.7
1987	4.5	9.0	1.1	14.6
1988	4.5	8.1	1.1	13.7
1989	4.6	8.3	1.0	14.0
1990	4.7	8.4	1.1	14.3
1991	4.9	8.7	1.1	14.8
1992	4.6	9.8	1.2	15.4
1993	4.2	10.0	1.2	15.4
1994	4.3	10.2	1.2	15.7

Notes: All figures in percentage
Source: Kwon, O. and J. Park and S. Lee, 1995, *Determinants and Trends of Korea's Freight Distribution Costs*, Seoul, The Korea Transport Institute.

4.2.1 The "Links" of the Inland Container Transportation System

4.2.1.1 "Road"

The biggest advantage of Road transport as the inland link of a container system is its high accessibility. That is, the time necessary for waiting, transferring and

[34] Jun, I., 1996, *The Estimate of Congestion Costs in Korean Ports and Airports*, Congestion Cost Conference, Seoul, Samsung Economic Research Institute, May.

trans-shipping is quite small compared to other modes. In addition, the existing road network provides good general access. As a consequense of these advantanges road transport has been responsible for most Korean inland transportation of export-import goods. Since 1991, the share of the Road in container movements has been 85 %. However, in recent years it appears that the limits of road capacity have been reached.

Thus, the main motorways which carry the container traffic have experienced extreme congestion in recent years. This has resulted in a decrease of travelling speed on the main motorway as shown in Table 4.3.

<Table 4.3> Status of Congestion on the Kyongbu Motorway in Korea

Year	Total Traffic*	Total Motorway Length**	Average Speed***
1991	4.2	1597	62.8
1992	5.2	1600	58.2
1993	6.3	1602	47.3
1994	7.4	1650	45.2

Notes: * million vehicles
** Km
***Km/h
Source: Ministry of Transportation, Land Transport Bureau.

The overburdened transport system has resulted in higher distribution costs and has affected competitiveness. A shortage of capital and a myopic standpoint for infrastructure development have contributed to the problem. A key problem concerns the unbalanced distribution of socio-economic activities over space. Due to the heavy concentration of economic and industrial activities within Seoul and Pusan, the main transport networks have spanned the axis between Seoul and Pusan. Despite persistent efforts by the government the level of concentration of economic activities in this axis has to date appeared to be unchangeable. This concentration is reflected by the fact that the volume of container cargo whose Origins/Destination (O/Ds) were the Seoul region accounted for 47 % of container cargo in 1994, the Pusan region for 12 %, and that of the Kyongnam region for 13 %.

4.2.1.2 "Rail"

In Korea, Rail makes a significant contribution to the long distance transportation of bulk freight such as cement and coal. Comparing the freight transportation shares of Rail and Road by unit distance between Seoul and Pusan, Road is dominant over the shorter distances i.e. between Seoul and Taeku, but the share of Rail becomes higher for distances in excess of 300 km. A similar pattern applies in Japan where Rail is used much more for medium and long distance transportation. In particular, the share of Road transportation in Japan is almost zero when the distance exceeds 400 km, while the share of Coastal Shipping increases rapidly for distances in excess of 1000 km[35]. In Korea the share of Rail accounts for 13.1 % of total container traffic. Rail transport in Korea has state-run authority which controls the whole rail transportation system. The state-run authority currently controls everything from software to hardware although there are plans for privatisation. When privatised, a more aggressive strategy is expected to be employed. The following problems have retarded Rail transport in Korea:

a) The rail authority has ignored investment to improve its services and the development of a marketing strategy. For instance, containers have been transported by the general flat bed car instead of using designed flat bed cars suitable for the container box. This has resulted in inefficient fleet formation. Moreover, the frequency

[35] Rhee, J., 1992, *Direction for Constructing Eurasia Transportation Network*, Seoul, The Korea Transport Institute.

of container transport service could be improved by extending schedules to night times when the tracks are free for freight transport.

b) The state-run authority has concentrated its effort on passenger services and to date has not had a freight marketing strategy. This is reflected in an average speed of railfleet on the main rail lines of no more than 70 km/hr. Compared with either the British Freightliner or the Japanese rail service (56-120 km/hr, 95-100 km/hr, respectively) the Korean system is not very competitive.

c) The tariff system is inflexible: the authority maintains a uniform tariff system instead of imposing tariffs designated to attract freight. For example, for cargo over a comparatively long distance, a more competitive rate could be offered.

d) Container transportation by Rail in Korea involves complicated procedures and many steps. One possibility for easing this problem is to introduce information technology such as EDI[36].

However, the Seoul-Pusan High Speed Rail System (HSR), adapted from the French TGV system, is under construction and there is an infrastructure development plan which is intended to boost Rail freight transportation. One of the project's effects will be that the existing rail system will be used to transport mainly freight, while the new HSR system will be responsible for carrying only passengers.

4.2.1.3 "Coastal Shipping"

Container transport by Coastal Shipping can occur only when transport services have been provided at all stages from the origins to ports. Thus, Coastal

[36] Acronym for Electronic Data Interchange. The electronic linking of firms typically between the order entry operation of one and the purchasing operation of another.

Shipping requires adequate inland links and efficient services co-ordinating different modes of transportation. Despite these disadvantages over Rail and Road, Coastal Shipping has considerable potential in future transportation development: it has low operating cost, congestion-free movement, the ability to transport in almost all weather conditions, day and night transit and favourable operating conditions from an environmental point of view.

Coastal Shipping services have been provided by two of the major shipping companies in Korea since 1990 and the last five years have witnessed a dramatic increase in transportation of container cargo by Coastal Shipping with Pusan's throughput of 27 thousand TEU in 1990 increasing to 60 thousand TEU in 1995. This mode is sometimes regarded as the best solution for relieving the current inland container transport problems on the ground that the fixed cost of Coastal Shipping is comparatively low as compared with Rail or Road.

In practice, there are difficulties in the interface between port and customs operations and the potential growth of Coastal Shipping may be retarded if not accompanied by improvements in customs performance. This difficulty may be attributed to a lack of co-ordination. The port and customs functions are the responsibilities of two different agencies linked to two different ministries. To date, containers transported by Coastal Shipping have been accepted at container terminals via conventional berths. If feeder ships for Coastal Shipping are allowed to call at deep-sea ports and container yards for Coastal Shipping are offered at a section of the container terminals, then this transport mode may be expected to show dramatic growth. A study executed by the KMI[37] suggested that Coastal Shipping is the most

[37] Lee, Y and S. Lee, 1994, *Coastal Shipping for Transporting Enormous Volume Cargo*, Seoul, KMI.

efficient way for transporting a large volume of cargo including container cargo originating in Sudo region.

4.2.2 Problems of the "Node"

4.2.2.1 Container Ports

In Korea, ports have played a catalytic role in the country's economic development because most major industrial complexes were developed in maritime industrial development areas. Over the past 15 years, the number of containers handled at the country's principal ports has soared more than five-fold, rising from 672 thousand TEU in 1980 to 4.8 million TEU in 1995. However, throughout the period of rapid economic growth, container cargo handling has been concentrated at a limited number of ports. The main container terminals of the country are located in Pusan and Inch'on. Pusan is at the forefront of all the country's export-import transport activities with its throughput currently at 95 % of national total container cargo volume. Inch'on's close proximity to the capital, Seoul, gives it some advantage. However, its geographical advantage is offset by its remoteness from major deep-sea container ship routes and its wide tidal range. These factors have hindered Inch'on's growth as a container port for liner services and thus most of Korea's container traffic is handled in Pusan. The other container ports such as Masan, and Ulsan together handled only 1 percent of national total throughput in 1995. Because containers are handled at general cargo berths in these ports, these ports continue to support the main container ports through feeder services.

Extreme dependence on one-port has been accompanied by various issues and problems. Since 1990, throughput at Pusan, the world's fifth largest container port in 1995, has increased more than 95 % and current traffic levels are well ahead of the port's design throughput as shown in Table 4.1. As container traffic has already surpassed the capacity of Pusan the country has failed to match demand with new container port development. The new development of Kwangyang, 160 km west of Pusan, is designed to relieve the current situation. Due to the heavy concentration of industrial activities within Seoul and Pusan, the links and nodes within the axis between them have been overburdened as discussed above. Thus, the Kwangyang development has been accepted as a reasonable alternative, developing another axis between Seoul and Honam which is comparatively underdeveloped. Four container berths are expected to come on line at Kwangyang in 1998. Another 8 purpose-made berths are under construction due to be completed by 2001 and a further 12 berths will be ready by 2011. The port is favoured by an ample sea depth, a natural sea-wall, adequate surrounding space and accessibility to the main transportation routes.

However, the Kwangyang port development is against the world trend in that mainline port calls have become centralised. Thus, another new deep-sea container port development plan proposed by Pusan city is to build a container port at the Gadukdo Island, approximately 25 Km south west of Pusan's existing container terminals. The purpose is to provide an extension to Pusan which has never managed to offer enough container facilities to match the growing rate of throughput. The Gadukdo development is a project which could play a decisive role for the development of the local economy as a Mega-Hub container port. It also is claimed that the proposed development follows world trends in that mainline port calls are being increasingly centralised and focused on as few centres as possible.

Those in favour of the Kwangyang development insist that the prime function of Korea's container port is to act as a gateway which is intended to serve the Korean economy. This is in contrast to the role of top container ports such as Hong Kong and Singapore which are characterised as transfer ports for neighbouring nations.

The present study aims at contributing to this debate by identifying the development plan which incurs the lowest system cost.

4.2.2.2 Issues Associated with Facilities for Inland Container Transportation

There are many other issues associated with the inland transportation of international containers apart from port development. Failure to develop adequate domestic roads, motorways, railroads and coastal shipping in time has adversely affected the development of the economy. Delay in expanding container handling facilities in the ports has induced a deformed inland network system. Pusan has been coping with traffic demand by utilising Off-Dock Container Yards (ODCYs) which have been developed and operated by the private sector at sites scattered throughout the urban areas of the city. This situation has generated more pollution, increased the incidence of traffic accidents by trailers and worsened road congestion within the city. A number of ongoing projects have been initiated to cope with these problems. Yangsan ICD (Inland Container Depot), near the outskirts of Pusan, will play the role of ODCYs in 1997 and the fourth phase development of the container terminal in Pusan will be completed in 1998. Despite these efforts problems are expected to remain in Pusan in the near future. The Yangsan ICD project is not a fundamental solution but a makeshift one, a spatial shifting of the point and no further development plans seem to be in the pipeline.

Other problems of the inland container transportation system are as follows:

a) Lack of co-ordination among different transport modes and related services tends to prevent full deployment of the existing transportation infrastructures. The inefficient

Road-to-Rail linking operation is one of the weakest in Korea's inter-modal system. In order to set the whole network up efficiently, the construction of a Road-to-Rail linking operation is necessary, as well as a Road-to-Coastal Shipping linking operation.

b) Transporting companies, both state owned and private, with a more recognisably corporate approach to business are now in the ascendancy. Providers of freight services have to undertake strategic planning, marketing, market research and R & D activities that will give companies a competitive edge over rivals that persevere with a proprietorial approach. They need incentives to encourage the use of Rail or Coastal Shipping e.g. like Round-trip Loaded Rate or Contract Based on Volume.

c) Documentation and operational information exchange have become serious bottlenecks in the overall efforts to increase the nation's logistics. Whereas the hardware technology has found a natural place in the physical cargo flows, the institutional and management technologies have not been able to follow pace.

4.3 Data Description

Information on the following activities are required to implement the model introduced in Chapter 2:

(The Inland Container Traffic Allocation model)

- transportation network for each transport mode
- proposed transport links
- estimation of transportation cost per TEU for each mode on each transport link including congestion costs where relevant.

(The Optimum Port Capacity model)

- construction costs of a certain size by sites.

• congestion costs of container cargo per TEU incurred in port.

The primary data, collected from a variety of data sources, has been modified and transformed where necessary as input data to our models. All costs have been calculated and estimated using the Korean currency, the Won and have been expressed at 1995 prices. For the sake of convenience, all costs as input data expressed in the same monetary units, US dollars, have been converted at the 1995 exchange rate of 747.7 Won to the US dollar. Furthermore, all the container volumes as inputs or outputs to the models are defined in terms of TEU.

The study divides the country into nine container-origin regions, which coincide with the administrative provinces: Sudo, Pusan, Kyongnam, Kyongbuk, Chonnam, Chonbuk, Chungnam, Chungbuk, Kangwon. To simplify presentation of the model, each region is coded: A0, B0, B1, B2, C1, C2, D1, D2, E0, respectively. The former indicates a certain province, i.e. B is the whole Kyongsang region consisting of three regions - Pusan, Kyongnam and Kyongbuk. The latter is the indication of North or South within a specific region i.e. 1 is South, 2 is North.

The object of the model is to consider deep-sea container traffic for export commodities. In particular, this means that Inch'on has been excluded from the study since it is not on the main container shipping routes that lead to hub ports such as Hong-Kong and Pusan. Inch'on is used mainly for the import of bulk freight rather than for container cargo. Inch'on handles around 5 % of the national total container traffic and for geographical and other technical reasons is expected to be confined to only a supporting role in the national container transport system as a feeder service port rather than a deep-sea port for international trade. Other minor container ports have also been excluded. Thus, the three ports-Pusan, Kwangyang, Gadukdo are taken as the set of national container ports which are assumed to handle container cargo from the nine regions.

4.3.1 Inland Transportation Costs

4.3.1.1 Line Haul Costs by Transport Modes

This section will estimate line-haul costs[38] by mode involved in moving from each region to either one of the existing ports or to the port being planned. Line-haul costs can be estimated on the basis of costs or on freight rates. A cost-based analysis is regarded as preferable in the context of the model because it provides an indication of costs without the profit margin. In particular, it is consistent with the purpose of identifying the mode and port with the lowest economic costs from a national standpoint. Generally, cost-based analysis of O/D by transport mode is a rather difficult task for lack of published data. However, a study[39] executed by one of major transport companies in Korea appears to meet the needs of this model. Costs have been estimated on the basis of accounting data provided by the company. The study subdivided O/Ds of container cargo into 131 points. Almost all the routes and modes relevant to our model were contained in the study which identified the mode which provided the least cost movement between each point and the transport bases of the company. The company has actually operated all the transport modes for container

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[38] Transportation-Logistics Dictionary (1989) define line-haul costs as "those fixed and variable costs of performing the intercity segment of the total transportation operation. It may be contrasted to the terminal costs, or it is sometimes contrasted to the local pickup and delivery costs".
[39] HanJin, 1996. *A Study on Analysis of Transport Costs by Modes*, The Planning and Management Department, Seoul. The company, one of the leading transport companies in the world, analysed the inland transportation costs from 240 collection points over the country to a number of main ports. This was completed in 1996 and is an internal report not available to the public. The report has been used here because it is the only available source of tractable and comprehensive cost-based data.

cargo and its operations cover the whole country which adds to the reliability of the data.

The primary data drawn from the HanJin study has been converted into a consistent and model-relevant format. To do this we need to assume that all the points within each province have the same average transport cost per TEU. Transport costs as a function of distance by transport mode have been based on estimates of the linear relationship between transport costs and distances in the primary data. The 131 points were allocated to the nine regions, depending on the administrative province, and then for each region the distance was calculated by the arithmetical average transport distance of all the points included in the region to Pusan. Thus, a relationship between cost and distance between the nine regions and Pusan was obtained. This yields a relationship between cost and distance which may be used to calculate inland transport costs between the regions and the two new ports.

Transport costs by Road from each region to the existing port were estimated on the basis of primary cost data between the 131 points and Pusan, as follows:

Road: The following specification was adopted[40]

$$ROCO = 13045 + 1217\ DIST \qquad (4.1)$$

where ROCO = Average road transport cost per 40 Foot container
DIST = Distance (km) from point to port.

Transport costs of Rail from each region to the existing port were based on a survey with the primary data consisting of 29 points and Pusan.

Rail: The following specification was adopted[41]

$$RACO = 176644 + 447\ DIST \qquad (4.2)$$

where RACO = Average rail transport cost per 40 Foot container

[40] The details are referred to Appendix 4.3.1.1.
[41] The details are referred to Appendix 4.3.1.1.

Lastly, the transport cost of Coastal Shipping was based on primary cost data from 14 points within Sudo region and Pusan. In this case it was inappropriate to use regression techniques and the cost estimates of Coastal Shipping between Sudo region and the two new ports were based on the average cost of Coastal Shipping between Sudo and Pusan adjusted for the difference in distance to Kwangyang and Gadukdo.

The transport costs per 40 Foot container between each region and Pusan by transport mode had to be transformed to transport costs per TEU which were derived by the regression functions and the average distances. These are shown in Table 4.4.

<Table 4.4> Transport Costs per TEU between Regions and Pusan

Region	Average Distance (Km)	Transport Mode*	Transport Costs**
A0	454.2	RD	506.9
		RL	340.1
	703.0	CS	375.3
B0	9.5	RD	22.0
B1	102.2	RD	123.1
B2	213.8	RD	244.8
C1	279.1	RD	316.0
		RL	270.0
C2	322.4	RD	363.2
		RL	287.4
D1	375.4	RD	421.0
		RL	308.6
D2	365.1	RD	409.7
		RL	304.5
E0	455.2	RD	508.0

Notes: * RD= Road; RL= Rail; CS= Coastal Shipping.
** US $

In order to estimate transportation costs to the new planned ports the average distances between each region and the new ports were estimated by the arithmetical average distance based on the distance of mileposts between each point and the two ports. Given estimated distances, inland transport costs between the new ports and the regions were calculated using the regression equations above. The transport costs associated with Coastal Shipping between the new ports and Sudo region were estimated by multiplying the transport costs of Coastal Shipping to Pusan by the proportion of average distance[42] between Sudo region and the new ports to the distance between Sudo region and Pusan. Table 4.5 shows the region-port inland transport cost matrix between the regions and the new ports.

<Table 4.5> Transport Costs per TEU between Regions and New Ports

	Transport Mode*	Destination	
		Kwangyang**	Gadukdo**
A0	RD	458.7	518.6
	RL	322.4	344.5
	CS	289.9	362.0
B0	RD	240.6	38.9
B1	RD	207.3	131.6
B2	RD	273.3	257.0
C1	RD	120.7	284.2
	RL	198.3	258.4
C2	RD	235.2	344.2
	RL	240.4	280.4
D1	RD	306.0	431.4
	RL	266.4	312.4
D2	RD	327.8	420.5
	RL	274.4	308.4
E0	RD	480.5	518.6

Notes: * RD= Road; RL= Rail; CS= Coastal Shipping.
** US $

4.3.1.2 Congestion Costs

If a route in the inland transport system does not have sufficient capacity to handle increased traffic volume without congestion, then it affects the freight transportation between an origin and a destination resulting in delays and defaults of delivery. It is necessary to estimate congestion costs on such routes[43].

[42] The average distances consisted of inland transport distance between points within Sudo region and Inch'on and sea navigation distance between Inch'on and ports.

[43] Button (1982) has pointed that the speed-flow relationship is useful in explaining the physical effects of congestion, but it does not give any indication of the economic costs. Generalised costs (see Footnote 10) provide the vital link between physical traffic flows and cost. Nash (1981) and Else (1981) suggest that the better approach is to distinguish off-peak traffic and peak traffic on the relationship between the cost of using a road and the flow of traffic. In this thesis, this point is not considered because this study is based on information about observed congestion (revealed preference data) as reported in the KMI study, rather than an analysis of the response to an hypothesis (stated preference).

The congestion factors that are taken into account in the analysis for an export container tractor trailer are time delays and higher vehicle operating costs, due to reduced speeds and idling caused by congestion. The congestion costs of a container tractor trailer on a congested route consists of two parts:

(a) the monetary value of container tractor trailer time lost as long as the vehicle is idle,

(b) the monetary value of container delivery delay.

The decision to neglect factors such as air and noise pollution costs, road network maintenance costs is based on the belief that they are relatively small and on the knowledge that they are very difficult to quantify.

For this task, no general congestion cost function is available. However, the Korea Maritime Institute (1990) carried out an empirical study based on the relationship between the congestion costs and speed. The congestion costs used in this model have been based on the empirical measurements of the KMI study where the appropriate congestion costs approximated in this section have been added to the line haul costs estimated above. It is assumed that the present congestion situation is not better than that of the year 1990.

Vehicle Congestion Costs: Congestion is a significant feature on the Kyongbu Motorway and may result in considerable idle container tractor time. The first item that is taken into account is higher container tractor trailer operating costs due to reduced speeds and idling caused by congestion. It is assumed that the value lost is equal to the opportunity cost of its working time.

To calculate the costs, the operating costs at various speeds are needed as primary data. Empirical research[44] conducted by KMI offers an operating cost standard for a container tractor trailer with different speeds shown in Table 4.6. Operating costs for one vehicle-hour use of a container tractor-trailer were calculated according to traffic speeds. Operating costs are composed of a fixed component which is independent of the speed and a variable component that is related to vehicle speed. The costs include fuel and oil, repairs and maintenance. It appears odd that overhead costs should vary with speed. However, allocation of overheads is essentially arbitrary and here they have been allocated in proportion to operating costs which vary positively with speed. Hence overheads also vary positively with speed. Thus the overhead rate was determined on the basis of the previous years' cost figures. In the KMI study, overheads are assumed to account for about 21% of prime cost (where prime cost is defined as the sum of fixed costs and variable costs).

<Table 4.6> Container Tractor Trailer Operating Costs per Vehicle-hour at Various Traffic Speeds

Traffic Speed (Km/hr)	Fixed Costs	Variable Costs	Overhead Costs	Total
10	13.7	5.0	3.9	22.6
15	13.7	6.8	4.3	24.7
20	13.7	8.4	4.7	26.8
25	13.7	10.1	5.0	28.8
30	13.7	11.7	5.3	30.7
40	13.7	15.0	6.0	34.7
50	13.7	18.6	6.8	39.0
60	13.7	22.5	7.6	43.8
70	13.7	27.1	8.6	49.3
80	13.7	32.2	9.6	55.6
90	13.7	37.9	10.8	62.5

Notes: All figures in US $

The KMI study subdivided the Kyongbu Motorway into ten sections and then surveyed traffic speed and total time delay experienced in each section as shown in Table 4.7. This data may be used to provide a difference of congestion severity by

[44] Lee, Y., 1991, *An Estimation of Congestion Costs in Export-Import Goods Transport System*,

section and to classify container traffic by regions entering the motorway. Almost all the container cargoes from five regions have been carried on the Kyongbu Motorway, which is the only major motorway between Sudo region and Pusan passing through the four regions - Chungnam, Chungbuk, Kyongnam and Kyongbuk.

<Table 4.7> Operating Costs for Container Trailer by Sections

Section *	Average Speed (Km/hr)	Operating Cost per TEU**	Average Delay Time per TEU (hour)	Cost of Delay per TEU**
1	51.8	39.83	0.5	19.92
2	68.8	48.64	0.028	1.36
3	68.8	48.64	0.076	3.70
4	73.7	51.62	0.067	3.46
5	73.1	51.25	0.017	0.87
6	78.3	54.51	0.027	1.47
7	76.1	53.13	0.022	1.17
8	78.6	54.70	0.018	0.98
9	77.9	54.26	0.017	0.92
10	78.1	54.38	0.016	0.87

Notes: *The motorway between Seoul and Pusan is divided by Suwon, Osan, Cheonan, Hoiduk, Daejeon, Gumi, Daegu, Kyongju, Unyang.
** US $

The operating costs per vehicle-hour corresponding to the average traffic speed of each section were obtained by using the proportion of average traffic speed shown in column 2 of Table 4.7 to the standard traffic speed in Table 4.6. Consequently, congestion costs per vehicle are obtained multiplying the average delay time per TEU by the operating costs per TEU. Cost of delay per TEU by sections on the Motorway are given in the last column of Table 4.7.

Time Costs of Container Cargo: The costs associated with the delay of container cargo on congested routes are assumed to correspond to the cost of forgoing the opportunity to earn interest on the container cargo value. That is, time lost in the congested periods is valued at the interest rate times the value of the container cargo.

Seoul, Korea Maritime Institute.

In order to calculate this we first of all need a value for export container cargo. There are no exact statistics on the value of a typical container cargo. We make an estimate by the following procedure.

The value of exports by commodity in 1990 drawn from trade statistics classifies the export commodities into 21 industries[45].

We obtain the value of container cargo by employing containerisation ratios by commodity to the data shown in Table 4.8.

<Table 4.8> The Value of Export Container Cargo in 1990

HS Heading No*	Exports (A)**	Containerisation Ratio (B)	Exports of Container Cargo (C = A x B)**
3	2.6	0.75	1.9
4	791	0.85	673
6	1594	0.75	1196
7	2511	0.85	2134
8	3468	0.75	2601
9	156	0.85	133
10	522	0.85	444
11	12228	0.9	11005
12	4611	0.9	4150
13	561	0.9	505
14	532	0.9	478
15	5826	0.85	4952
16	19990	0.9	17991
17	6397	0.05	320
18	1141	0.9	1027
19	16	0.85	13
20	1859	0.85	1580
21	214	0.85	182

Notes: * No 3, animal or vegetable fats and oils products: No 4, prepared foodstuffs: No 6, chemical products: No 7, plastics: No 8, raw hides and skins, leather: No 9, wood articles: No 10, pulp: No 11, textiles: No 12, footwear: No 13, ceramic products: No 14, precious metals: No 15, base metals: No 16, machinery: No 17, transport equipment: No 18, precision instruments: No 19, arms and ammunition: No 20, miscellaneous manufactured articles: No 21, works of art

** $ millions

The value of container cargo exported was estimated at $ 49.4 billion in 1990. The total number of containers handled for export were 1.35 million TEU in 1990 as shown in Table 3.6. The average value of cargo per TEU can be obtained by dividing the value of export container cargo by the total number of export containers. The average value per TEU was estimated at $ 36,600 at 1990 prices.

The cost due to the delay of container cargo is defined as follows:

$$\begin{pmatrix} \text{The Congestion} \\ \text{Cost of} \\ \text{Container Cargo} \end{pmatrix} = \begin{pmatrix} \text{Average Value of} \\ \text{an Export} \\ \text{Container Cargo} \end{pmatrix} \times \begin{pmatrix} \text{Hourly} \\ \text{Interest} \\ \text{Rate} \end{pmatrix} \times \begin{pmatrix} \text{Delay} \\ \text{Time} \end{pmatrix}$$

Given the average value of export container cargo per TEU, the depreciation of the value is estimated by using the average delay time per TEU by section of the motorway and the year's interest rate. In particular, the interest rate is adopted as the hourly interest rate. The estimates of delay costs to a container cargo on the congested motorway by section are presented in Table 4.9. Clearly, compared with the costs of idle vehicle time these costs are negligible.

<Table 4.9> Delay Costs to a Container Cargo

Section	Average Delay Time per TEU (hour)	Time Cost per TEU*
1	0.5	0.209
2	0.028	0.012
3	0.076	0.032
4	0.067	0.028
5	0.017	0.007
6	0.027	0.011
7	0.022	0.009
8	0.018	0.007
9	0.017	0.07
10	0.016	0.07

Notes: * US $

Congestion Costs on Route by Region: Congestion costs due to delays on the Motorway are extracted from Table 4.7 and Table 4.9. Combining the two yields the congestion costs by sections on the Kyongbu Motorway which are shown in Table 4.10.

[45] Export goods are classified according to the "Harmonised Commodity Description and Coding System (HS) on "Statistical Yearbook of Foreign Trade" by Korea Customs Service. Goods with HS heading No1, 2 and 5 provided no containerised cargo and hence are excluded from Table 4.8.

<Table 4.10> Congestion Costs by Section

Section	Unit Congestion Cost of Vehicle	Unit Congestion Cost of Container Cargo	Total
1	19.92	0.21	20.1
2	1.36	0.01	1.37
3	3.70	0.03	3.73
4	3.46	0.03	3.49
5	0.87	0.01	0.88
6	1.47	0.01	1.48
7	1.17	0.01	1.18
8	0.98	0.01	0.99
9	0.92	0.01	0.93
10	0.87	0.01	0.88

Notes: All figures in US $ at 1990 prices

However, the Motorway examined in this study stretches over five regions: Sudo, Chungnam, Chungbuk, Kyongnam, Kyongbuk. Each region is associated with certain sections on the motorway. For example, the whole distance from section 1 to section 10 related to cargo from Sudo. Cargo from Chungnam involves section 4 to section 10 of the motorway. Thus, the congestion costs on cargo from Sudo correspond to the sum of the operating costs from Section 1 to Section 10; Chungnam, from Section 4 to Section 10; Chungbuk, from Section 6 to Section 10; Kyoungbuk, from Section 7 to Section 10; Kyoungnam, from Section 9 to Section 10. The congestion costs have to be re-valued at 1995 prices by using the transportation cost index of the Producer Price Index because all the earlier data was in 1990 prices.

At 1995 prices the additional cost of a container cargo from Sudo to Pusan port by Road per TEU amounts to $ 38.16; from Chungnam, $ 10.55; from Chungbuk, $ 5.85; from Kyoungbuk, $ 5.06; and from Kyoungnam, $ 1.94.

4.3.1.3 Total Inland Transport Costs

Combining line-haul and delay costs yields the following matrix of inland transport costs. Total inland transport costs are estimated in Table 4.11 which summarises the figures by port and mode.

<Table 4.11> Total Inland Transport Costs per TEU

Region	Transport Mode	Destination		
		Pusan	Kwangyang	Gadukdo
A0	RD	550.0	495.2	561.8
	RL	340.1	322.4	344.5
	CS	375.3	289.9	362.0
B0	RD	22.0	240.6	38.9
B1	RD	125.3	207.9	133.8
B2	RD	250.5	273.3	262.7
C1	RD	316.0	120.7	284.2
	RL	270.0	198.3	258.4
C2	RD	363.2	235.2	344.2
	RL	287.4	240.4	280.4
D1	RD	432.9	306.0	443.3
	RL	308.6	266.4	312.4
D2	RD	416.3	327.8	427.1
	RL	304.5	274.4	308.4
E0	RD	551.1	480.5	561.8

Notes: All figures in US $ at 1995 prices
* RD= "Road"; RL= "Rail"; CS= "Coastal Shipping"

4.3.2 Construction Costs

Construction costs at a port depend on a variety of factors such as the physical characteristics of the location, the design of the terminal, the inland connections and the costs of various inputs. There is no general formula which predicts how much it will cost to build a container berth anywhere. Detailed engineering design needs to be specified before costs are known precisely. It is noted that the costs of a new container terminal may depend significantly on the possible expansions which are already taken into account at the time of the original construction. i.e. sometimes very wide fundamental reclamation work is used to make later expansions possible at low cost. Moreover, there is a difference between the cost for construction in one go and construction in stages. The cost related to this can be very high especially when an expansion is not provided for in advance.

In order to estimate construction costs for a new container port we have used data from the Investment Proposal for "New Container Port Plan[46]" prepared by the KMI.

The study contains investment proposals for both Kwangyang and Gadukdo. The investment proposal for Kwangyang New Container Port assumes the construction of 20 berths, each rated to handle 240000 TEU per year. The individual berth length is assumed to be set at 350m. The total construction cost has been estimated to be $ 3.86 billion at 1995 prices. The construction cost per berth therefore accounts for $ 197 million .

On the other hand, the plan for Gadukdo port has 15 berths for 5000 TEU container ships and 9 berths for 2000 TEU ship. The berth lengths are 350m, 250m, respectively. The total construction cost has been estimated at $ 7.555 billion. Standardising at a berth of 350m, the number of berths planned is 21. The construction cost per berth therefore accounts for $ 353 million.

The main reason for the huge difference between their construction costs is the need for costly foundation engineering works at Gadukdo. About half of the cost $ 3.85 billion for the Gadukdo project is projected to be spent on foreshore reclamation work and on foundation consolidation work.

[46] Office of Maritime & Port Authority, 1996, A Study on the Investment Plan for New Port Development in Korea, Seoul.

Appendix 4.3.1.1 Regression Analysis of Estimated Inland Transport Costs

The raw data of the HanJin study provided a source of observations for the cost of transport by distance and by mode. It was decided to use regression analysis to estimate a relationship between cost and distance for both road transport and for rail transport but not for Coastal Shipping where there were insufficient observations. For Road there were 131 origin/destination points and a simple linear regression performed well (high R-square and a significant distance coefficient[47] – the constant term was not significantly different from zero reflecting the fact that fixed costs are likely to be of minor importance in road transport). Accordingly the linear form was adopted,

For rail transport there were 29 observations and the simple linear regression performed less well in terms of R-square but both the distance coefficient and the constant were found to be significant. In this case a significant positive constant term is to be expected because of a more important fixed cost element. Accordingly the following functional forms were investigated[48]:

Linear: $\text{RACO} = bo + b_1\text{DIST}$
Double-log: $\ln\text{RACO} = bo + b_1\ln\text{DIST}$
Semi-log: $\ln\text{RACO} = bo + b_1\text{DIST}$,
$\text{RACO} = bo + b_1 \ln\text{DIST}$

Of these the double-log form was marginally the best with an R-square equal to 72.3 % and significant the t-ratios. Despite the marginal superiority of the double-log specification the linear has nevertheless been adopted. This is for the following reason. The sample range for distance (the explanatory variable) was 198km-506km but at

[47] The software used in these regression analysis is MINITAB Release 11.2. The outputs of the regressions are shown on Regression Analysis (1) to Regression Analysis (4) below.
[48] The outputs of the regressions are shown on Regression Analysis (5) to Regression Analysis (8) below.

100km the Chonnam-Kwangyang rail service – one of the services for which cost needed to be estimated – lies outside this range and there are reasons to believe that the linear form better represents this region of the relationship. A comparison of linear and double-log cost estimates is shown in Table A.4.1. It can be seen that with the exception of Chonnam-Kwangyang (and possibly also Chonbuk- Kwangyang which is also a short-haul service) the two specifications give very similar cost estimates. For the short-haul routes the linear form is preferred as more realistic because it gives more weight to fixed (distance-independent costs).

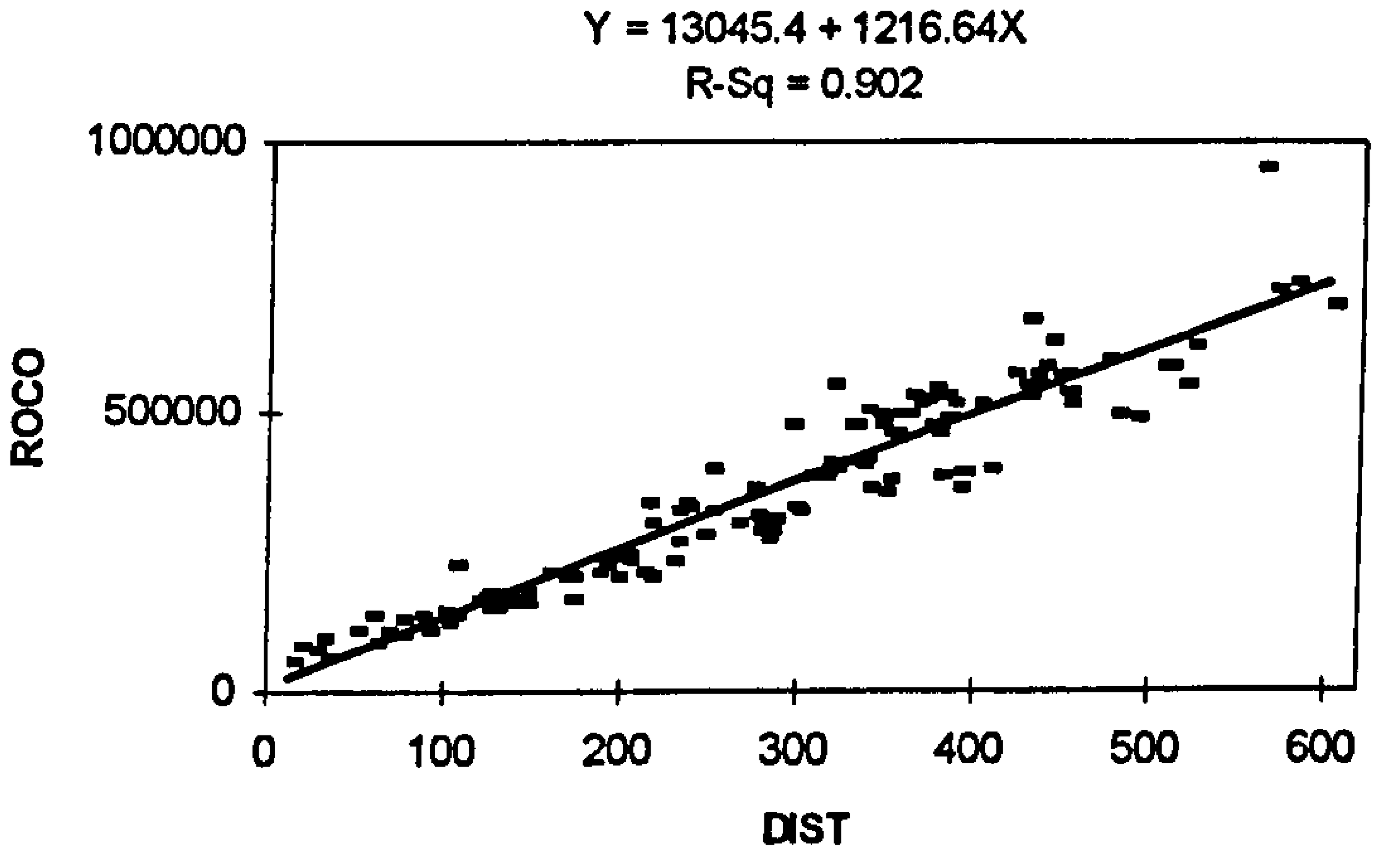
<Table A.4.1> Comparison of Estimated by Specification

Railway Service	Distance	The Linear Form	The Double-log Form
Sudo - Kwangyang	410	322.4	323.6
Chonnam - Kwangyang	100	198.3	162.8
Chonbuk - Kwangyang	205	240.4	230.9
Chungnam - Kwangyang	270	266.4	264.0
Chungbuk - Kwangyang	290	274.4	273.4
Sudo - Gadukdo	465	344.5	344.0
Chonnam - Gadukdo	250	258.4	254.3
Chonbuk - Gadukdo	305	280.4	280.2
Chungnam - Gadukdo	385	312.4	313.8
Chungbuk - Gadukdo	375	308.4	309.8

Regression Analysis (1)

```
The regression equation is
ROCO = 13045 + 1217 DIST

Predictor        Coef        StDev          T        P
Constant        13045        11134       1.17    0.243
DIST          1216.64        35.24      34.52    0.000

S = 56294        R-Sq = 90.2%      R-Sq(adj) = 90.2%

Analysis of Variance

Source        DF           SS           MS          F         P
Regression     1 3.77689E+12 3.77689E+12    1191.81     0.000
Error        129 4.08806E+11  3169038424
Total        130 4.18569E+12

Unusual Observations
Obs      DIST       ROCO         Fit   StDev Fit    Residual    St Resid
  4       408     393897      509433        6592     -115536      -2.07R
  8       600     702590      743027       12192      -40437      -0.74X
 15       317     552020      398719        5059      153301       2.73R
 16       561     949030      695578       10949      253452       4.59R
 22       489     487786      607980        8756     -120194      -2.16R
 63       428     673935      533766        7081      140169       2.51R
113       389     357817      486317        6167     -128500      -2.30R

R denotes an observation with a large standardized residual
X denotes an observation whose X value gives it large influence.
```

Regression Plot



Regression Analysis (2)

```
The regression equation is
LOGRO = 3.64 + 0.778 LOGDI

Predictor        Coef       StDev          T        P
Constant      3.64406     0.05515      66.07    0.000
LOGDI         0.77763     0.02307      33.70    0.000
```

S = 0.08419 R-Sq = 89.8% R-Sq(adj) = 89.7%

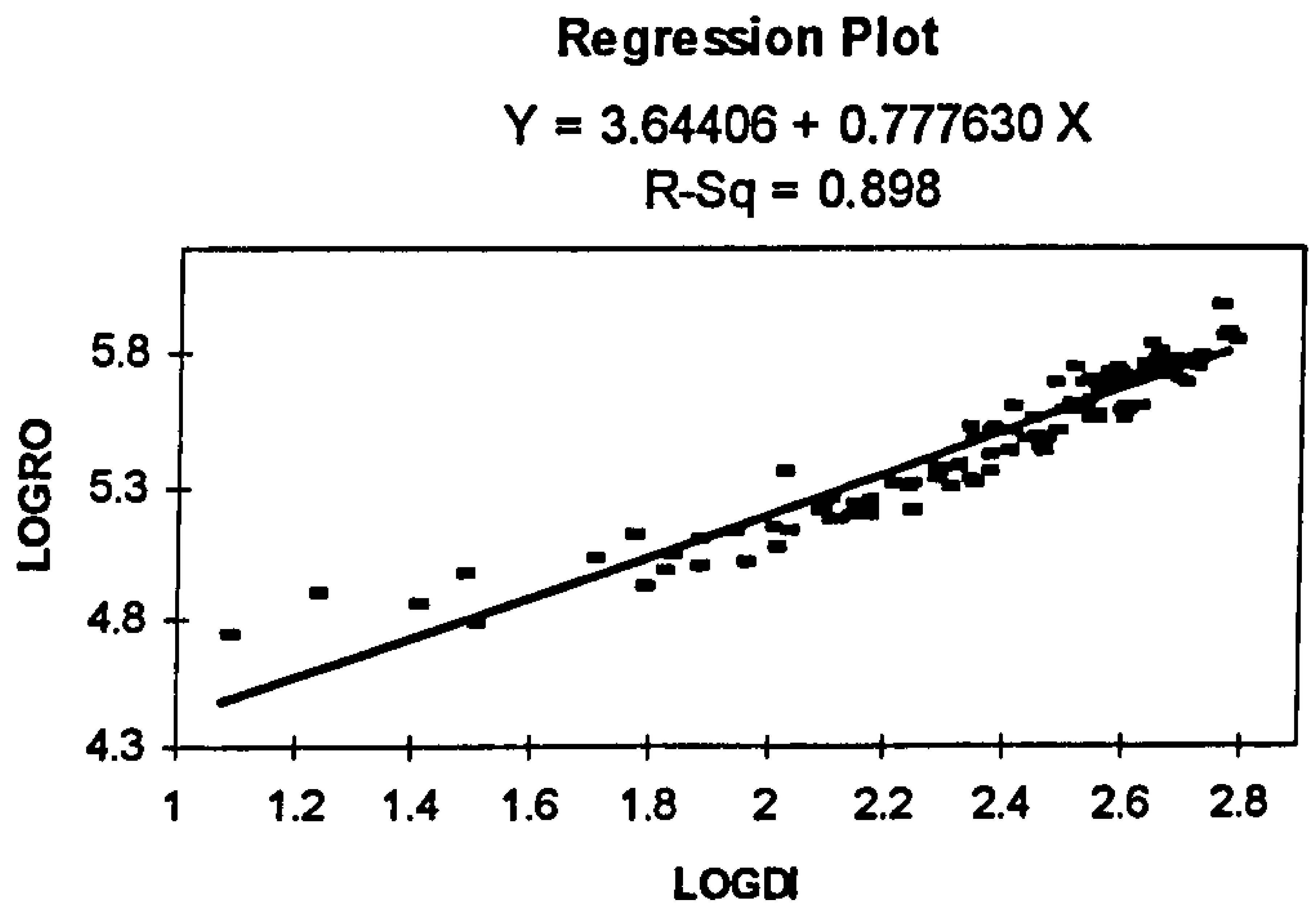
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	8.0517	8.0517	1135.84	0.000
Error	129	0.9145	0.0071		
Total	130	8.9662			

Unusual Observations

Obs	LOGDI	LOGRO	Fit	StDev Fit	Residual	St Resid
16	2.75	5.97728	5.78174	0.01145	0.19554	2.34R
42	1.48	4.97178	4.79272	0.02185	0.17906	2.20RX
72	1.49	4.78672	4.80379	0.02154	-0.01707	-0.21X
76	1.23	4.89978	4.60090	0.02728	0.29888	3.75RX
77	1.08	4.74093	4.48327	0.03065	0.25766	3.29RX
78	1.40	4.86144	4.73115	0.02358	0.13030	1.61X

R denotes an observation with a large standardized residual
X denotes an observation whose X value gives it large influence.



Regression Analysis (3)

The regression equation is
ROCO = - 765419 + 474202 LOGDI

Predictor	Coef	StDev	T	P
Constant	-765419	62955	-12.16	0.000
LOGDI	474202	26339	18.00	0.000

S = 96109 R-Sq = 71.5% R-Sq(adj) = 71.3%

Analysis of Variance

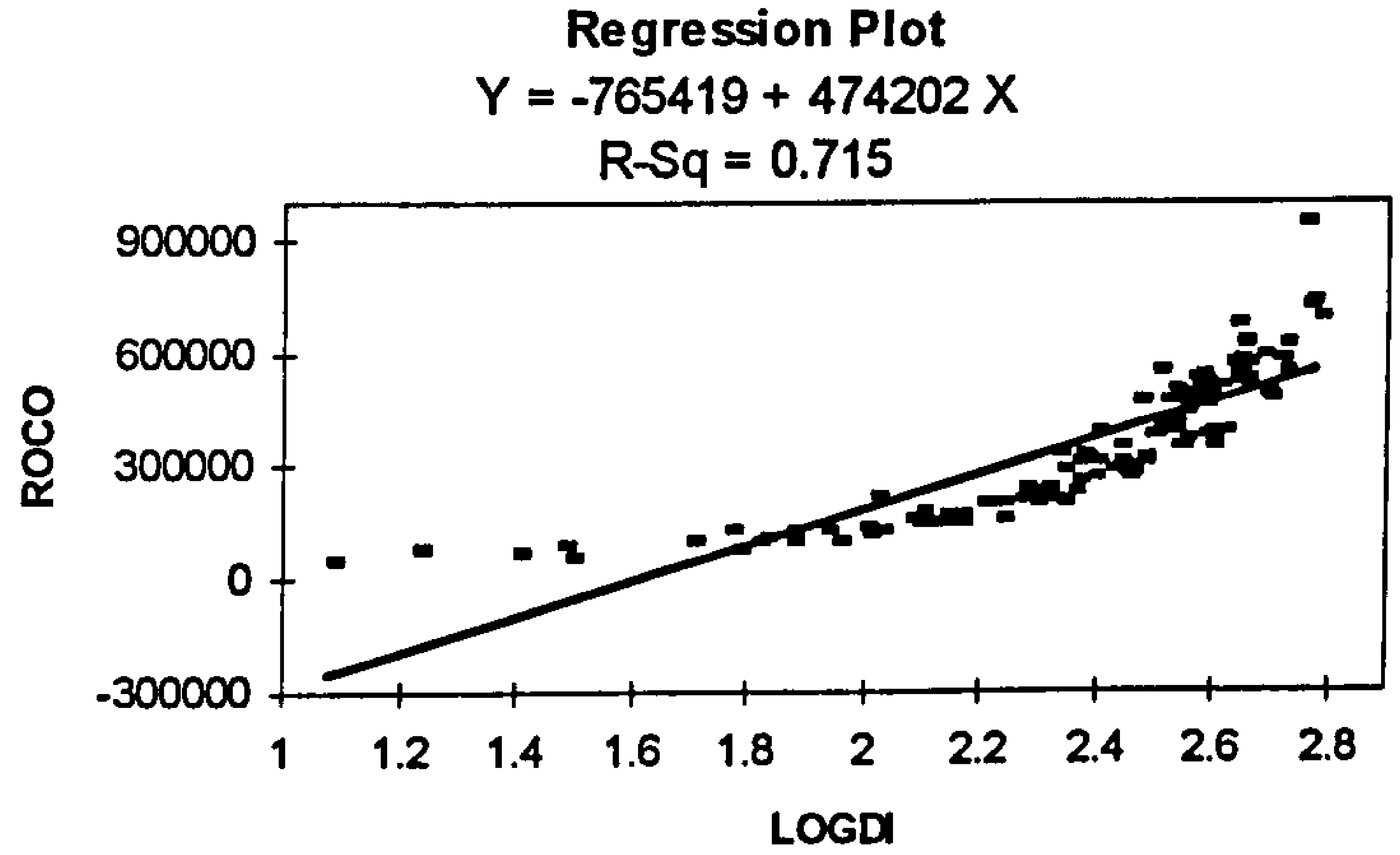
Source	DF	SS	MS	F	P
Regression	1	2.99412E+12	2.99412E+12	324.14	0.000
Error	129	1.19157E+12	9236991954		
Total	130	4.18569E+12			

Unusual Observations

Obs	LOGDI	ROCO	Fit	StDev Fit	Residual	St Resid
16	2.75	949030	538144	13067	410886	4.32R
42	1.48	93708	-64965	24943	158673	1.71X
63	2.63	673935	482417	10879	191518	2.01R

72	1.49	61196	-58212	24590	119408	1.29X
76	1.23	79392	-181938	31137	261330	2.87RX
77	1.08	55072	-253669	34991	308741	3.45RX
78	1.40	72685	-102513	26916	175198	1.90X
118	2.76	740794	545004	13361	195790	2.06R

R denotes an observation with a large standardized residual
X denotes an observation whose X value gives it large influence.



Regression Analysis (4)

The regression equation is
LOGRO = 4.98 + 0.00177 DIST

Predictor	Coef	StDev	T	P
Constant	4.98330	0.01684	295.90	0.000
DIST	0.00177409	0.00005330	33.28	0.000

S = 0.08515 R-Sq = 89.6% R-Sq(adj) = 89.5%

Analysis of Variance

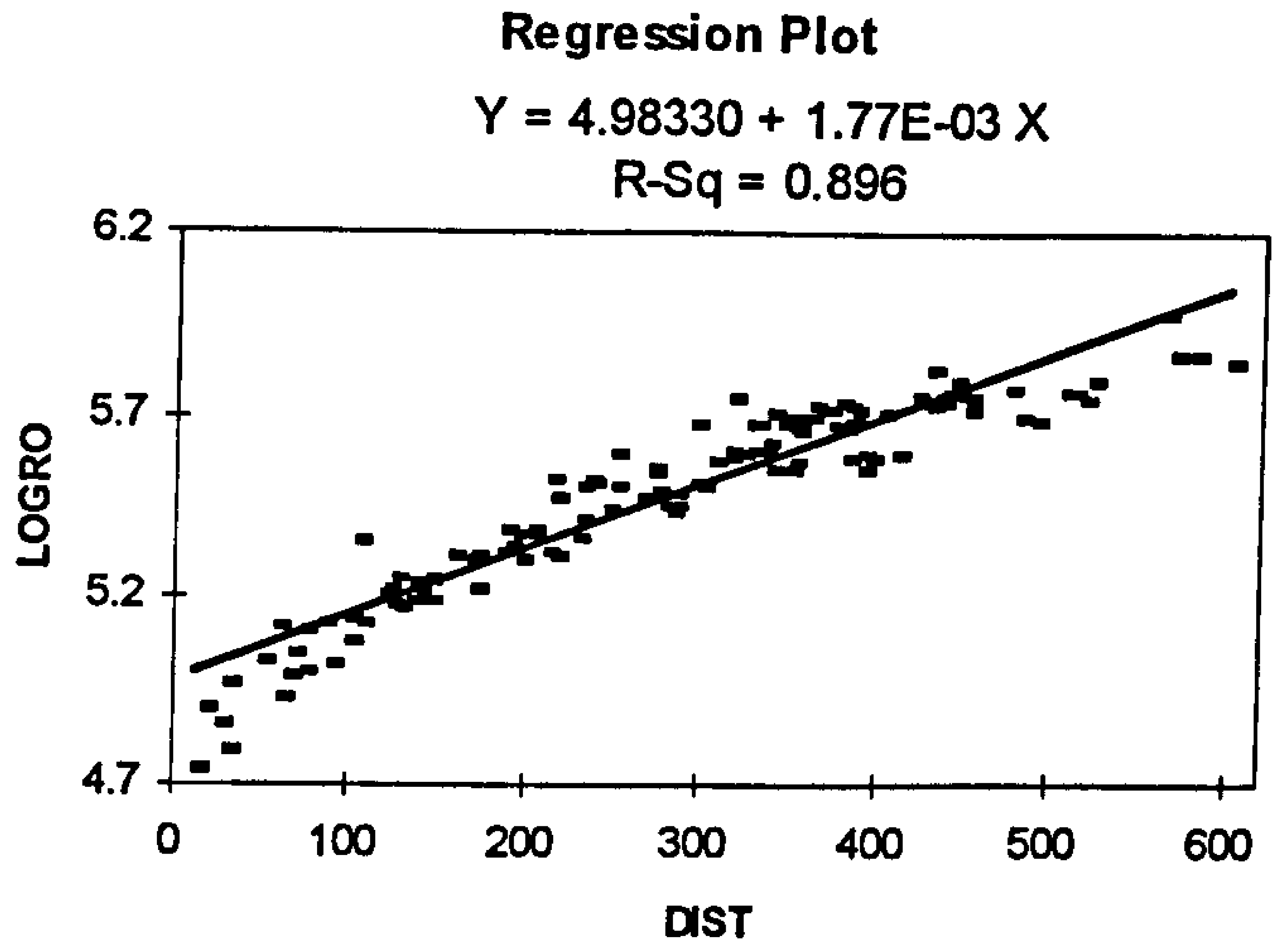
Source	DF	SS	MS	F	P
Regression	1	8.0309	8.0309	1107.71	0.000
Error	129	0.9353	0.0073		
Total	130	8.9662			

Unusual Observations

Obs	DIST	LOGRO	Fit	StDev Fit	Residual	St Resid
8	600	5.84670	6.04775	0.01844	-0.20105	-2.42RX
15	317	5.74196	5.54569	0.00765	0.19627	2.31R
72	31	4.78672	5.03829	0.01538	-0.25157	-3.00R
75	104	5.35641	5.16780	0.01212	0.18860	2.24R
77	12	4.74093	5.00459	0.01627	-0.26366	-3.15R
88	294	5.67724	5.50488	0.00746	0.17236	2.03R

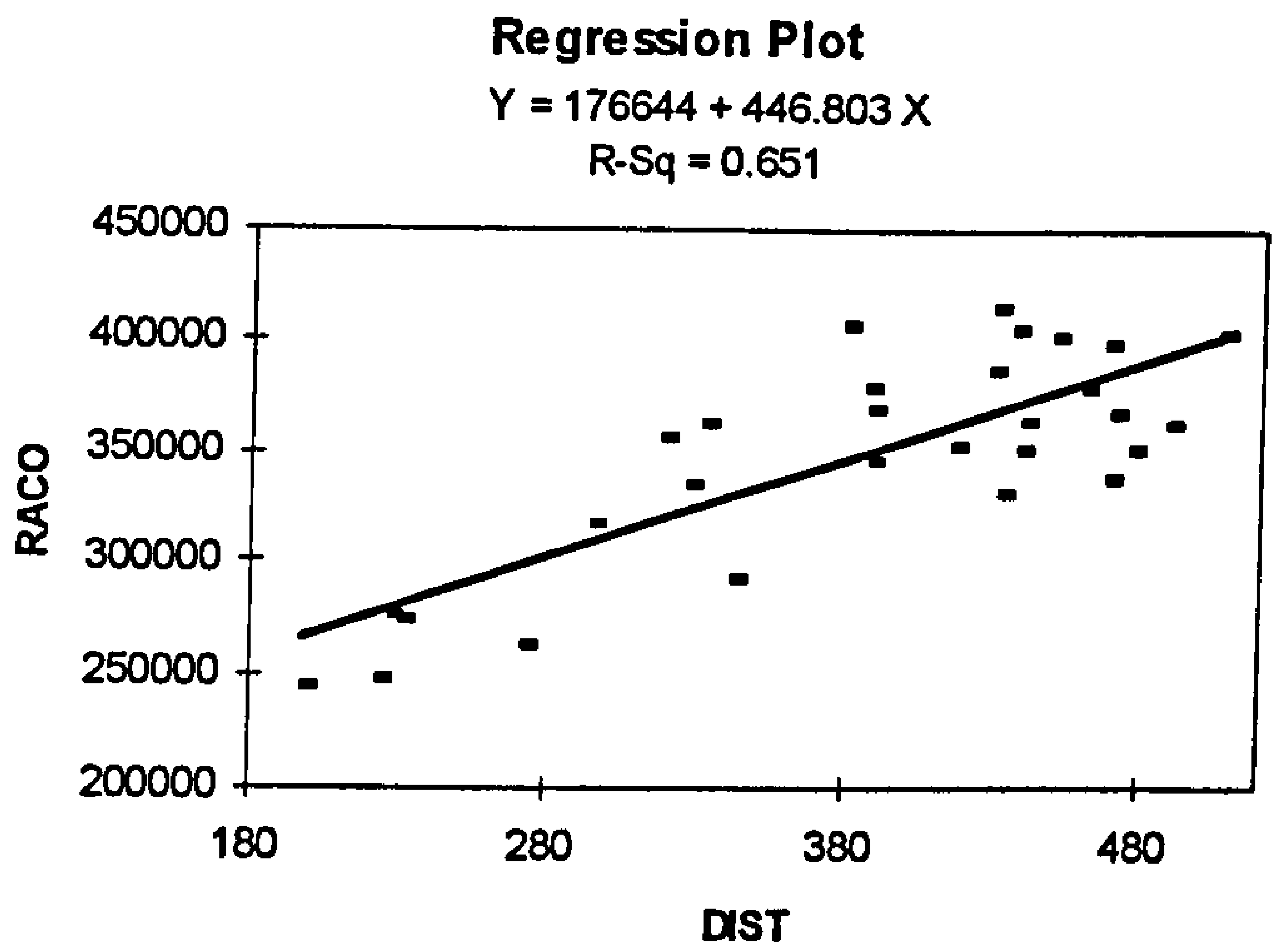
R denotes an observation with a large standardized residual
X denotes an observation whose X value gives it large influence.

Regression Plot



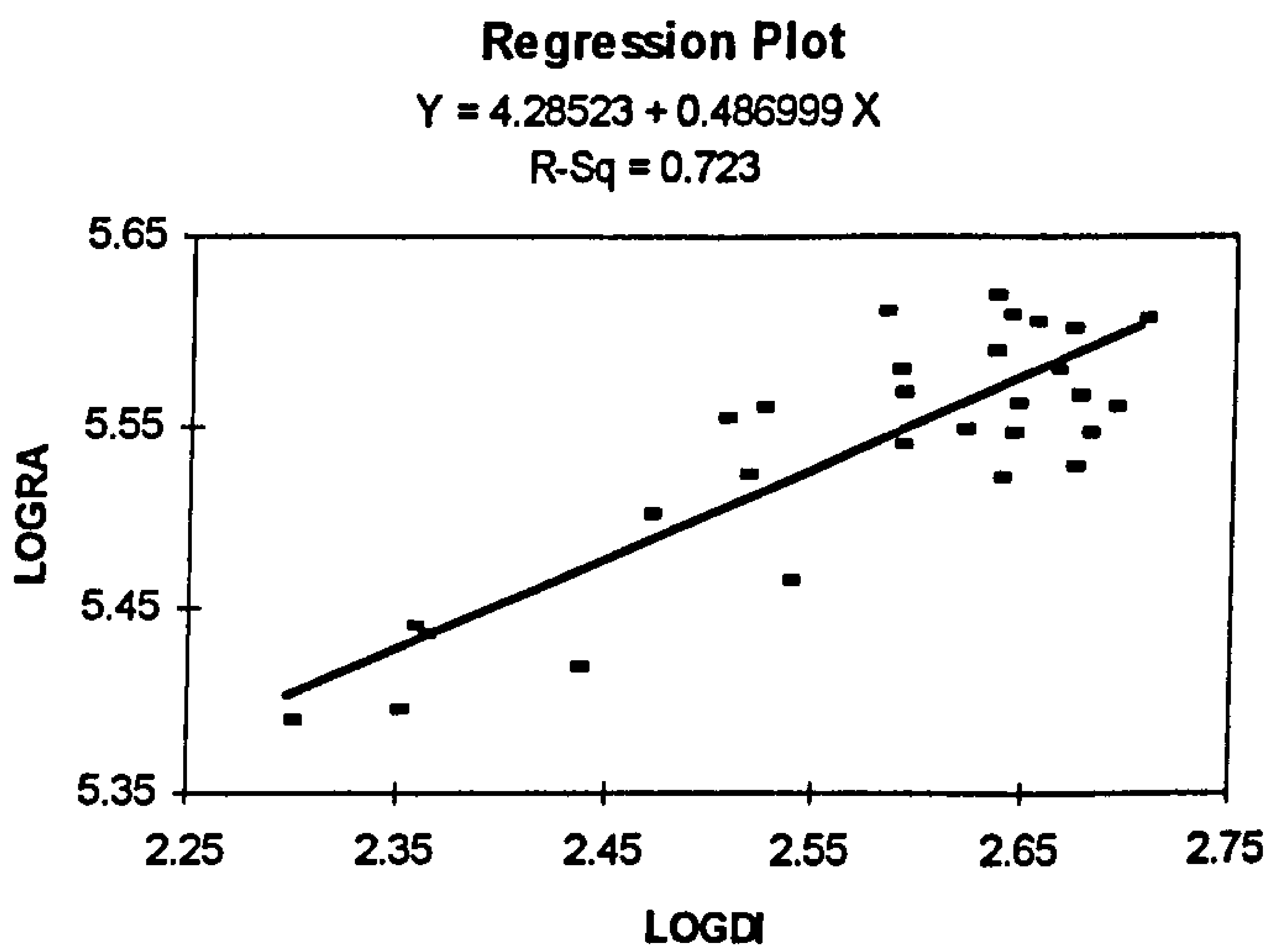
Regression Analysis (5)

```
The regression equation is
RACO = 176644 + 447 DIST

Predictor        Coef        StDev          T        P
Constant       176644        24730       7.14    0.000
DIST           446.80        62.94       7.10    0.000

S = 29714        R-Sq = 65.1%      R-Sq(adj) = 63.8%

Analysis of Variance

Source        DF           SS           MS          F        P
Regression     1  44490122512  44490122512      50.39    0.000
Error         27  23838564309    882909789
Total         28  68328686821

Unusual Observations
Obs        DIST        RACO         Fit  StDev Fit    Residual    St Resid
 21         379      407178      345983       5523       61195       2.10R

R denotes an observation with a large standardized residual
```



Regression Analysis (6)

```
The regression equation is
LOGRA = 4.29 + 0.487 LOGDI

Predictor        Coef        StDev          T        P
Constant       4.2852       0.1492      28.72    0.000
LOGDI         0.48700      0.05801       8.39    0.000

S = 0.03541     R-Sq = 72.3%     R-Sq(adj) = 71.3%

Analysis of Variance

Source        DF          SS          MS          F         P
Regression     1    0.088372    0.088372      70.47     0.000
Error         27    0.033860    0.001254
Total         28    0.122232

Unusual Observations
Obs     LOGDI      LOGRA        Fit   StDev Fit    Residual    St Resid
 26      2.30    5.38947    5.40370     0.01715    -0.01423      -0.46x

X denotes an observation whose X value gives it large influence.
```



Regression Analysis (7)

The regression equation is
RACO = - 567857 + 356318 LOGDI

Predictor	Coef	StDev	T	P
Constant	-567857	117575	-4.83	0.000
LOGDI	356318	45710	7.80	0.000

S = 27902   R-Sq = 69.2%   R-Sq(adj) = 68.1%

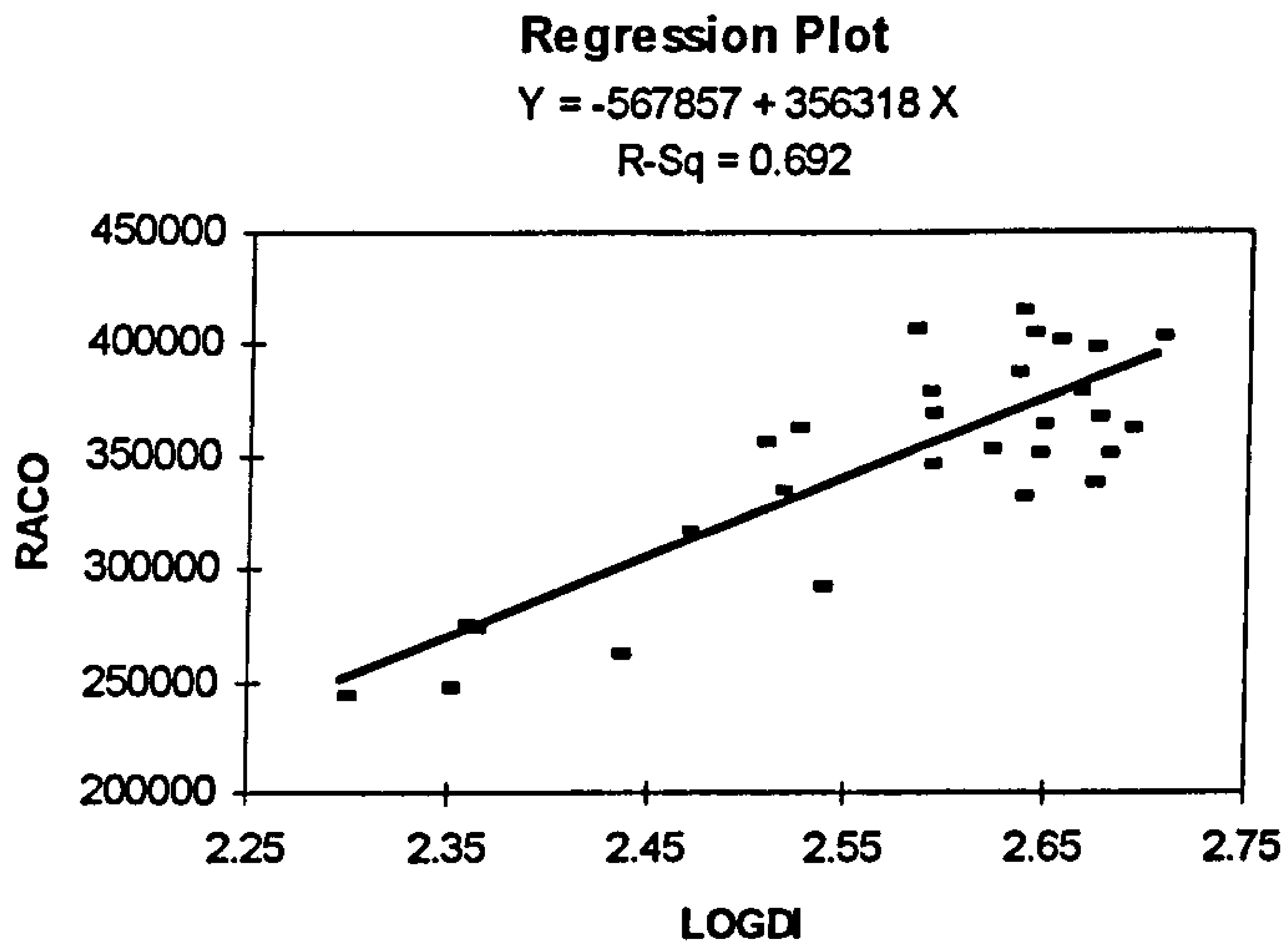
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	47308009828	47308009828	60.76	0.000
Error	27	21020676992	778543592		
Total	28	68328686821			

Unusual Observations

Obs	LOGDI	RACO	Fit	StDev Fit	Residual	St Resid
21	2.58	407178	350959	5197	56219	2.05R
26	2.30	245171	250487	13513	-5316	-0.22X

R denotes an observation with a large standardized residual
X denotes an observation whose X value gives it large influence.



Regression Analysis (8)

The regression equation is
LOGRA = 5.30 +0.000608 DIST

Predictor	Coef	StDev	T	P
Constant	5.30366	0.03193	166.08	0.000
DIST	0.00060837	0.00008128	7.49	0.000

S = 0.03837   R-Sq = 67.5%   R-Sq(adj) = 66.3%

Analysis of Variance

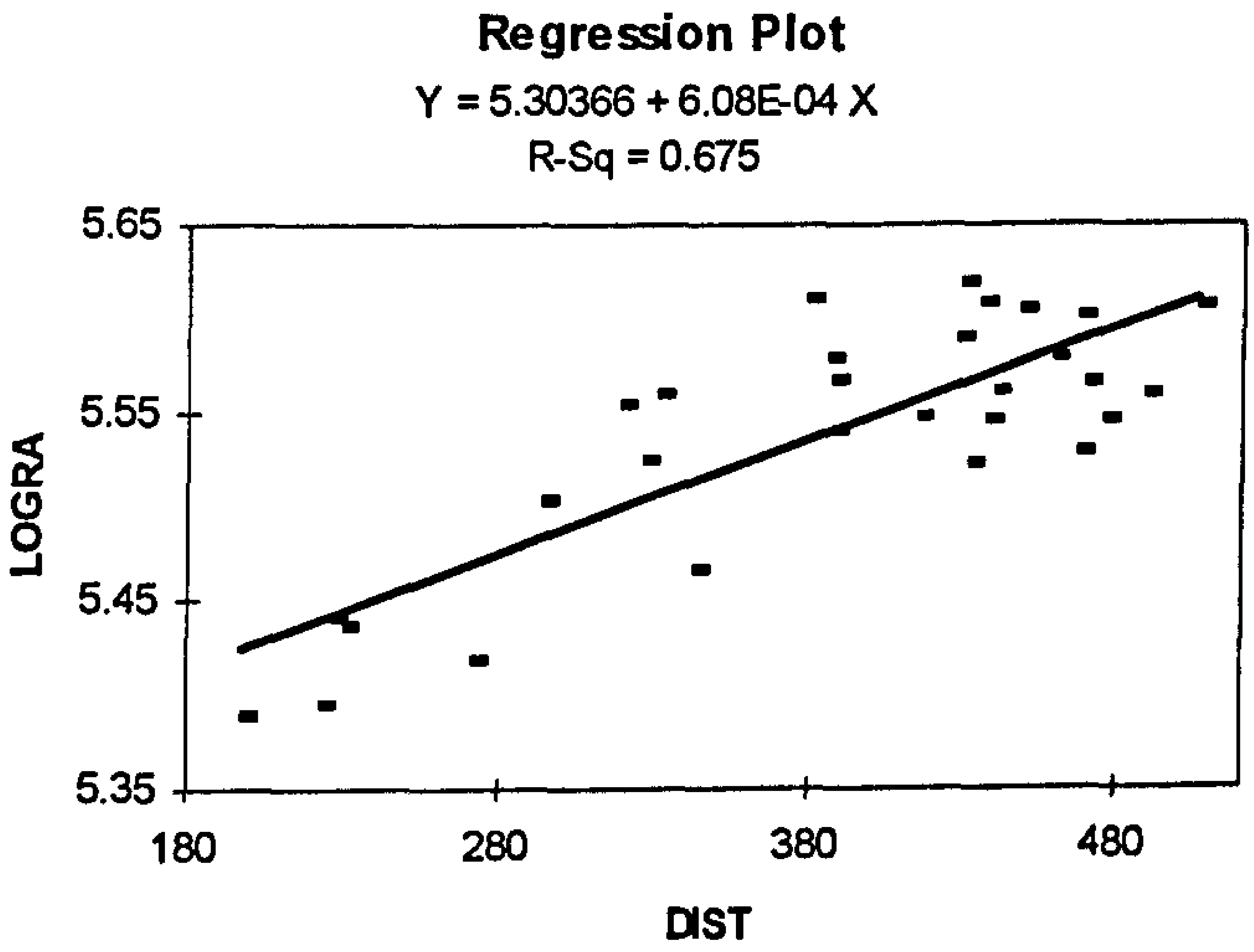
Source	DF	SS	MS	F	P
Regression	1	0.082483	0.082483	56.03	0.000

Error	27	0.039749	0.001472			
Total	28	0.122232				

Unusual Observations

Obs	DIST	LOGRA	Fit	StDev Fit	Residual	St Resid
21	379	5.60978	5.53423	0.00713	0.07556	2.00R

R denotes an observation with a large standardized residual



Appendix 4.3.3. The Model Incorporating Terminal Congestion Costs

Appendix 4.3.3.1 Introduction

As discussed earlier, the method of evaluation for this model compares alternative proposals on the basis of the costs of each project at a given interest rate. Implicitly, this method assumes that the benefits from all the alternatives are the same, since the benefits are not included. Total system costs composed of inland transport costs and construction costs have been chosen as the objective function to be minimised. Other costs may arise with transportation improvement projects and may appear in a number of different ways, such as economic, environmental, social effects, etc.

This appendix attempts to add one extra cost criterion, namely, terminal congestion cost to total system cost. The reason for examining separately terminal congestion cost is that a number of special assumptions are needed to incorporate it. For example, how much container traffic is allocated to each port given that there exists an overall excess demand? We have no direct information about this and it depends purely on assumptions. Even if the relationship between the delay time and excess demand at an existing port is known, we also need other assumptions on delay severity of the new planned ports' facilities.

Appendix 4.3.3.2 Unit Terminal Congestion Cost

If export containers are delayed at the terminal by the lack of port facilities and handling capacity, the effects can be significant. As with road congestion it is assumed that terminal congestion cost is compensated by the opportunity to earn hourly interest on the delayed container cargo. Given the value of container cargo per TEU, congestion cost per TEU at terminal as a function of the excess level of handling capacity, the extra container cargo demand that each port must handle over the port's theoretical design capacity, is obtained by fitting a linear regression.

We begin by estimating average value for export container cargo per TEU in 1995. The value of exports are calculated on the basis of the statistics published in 1995 "Exports by H.S. Heading No" by the Korea Customs Service. The primary data has been converted to values and is shown in Table A 4.2. Export container cargo was $ 97.8 billion in 1995.

<Table A 4.2> The Estimation of the Value for Export Container Cargo in 1995

H.S. Heading No*	Exports (A)**	Containerisation Ratio (B)	Exports of Container Cargo (C = A*B)**
3	22	0.80	18
4	1265	0.90	1138
6	4612	0.80	3689
7	6845	0.90	6160
8	2623	0.80	2098
9	144	0.90	130
10	1360	0.90	1224
11	17807	0.95	16917
12	1729	0.95	1643
13	542	0.95	515
14	2843	0.95	2701
15	10256	0.90	9230
16	50398	0.95	47878
17	16117	0.05	806
18	2113	0.95	2007
19	45	0.90	41
20	1718	0.90	1546
21	26	0.90	24

Notes: * This classification follows that of Table 4.5.
** $ millions

Since the volume of export container cargoes were 2.0 million TEU in 1995. The average value of an export container cargo per TEU was estimated at $ 48,287.

It is natural to suppose that delay time at terminal depends on the severity of shortage of a port's handling facilities. The severity is represented by excess demands for handling capacities in ports with differences between the traffic demand estimated in Chapter 3 and the original handling capacities of ports. To confirm this, we use data collected in Pusan port from1991 to 1995, shown in Table A.4. 3.

<Table A.4.3> The Status of Delay at Terminals in Pusan port

Terminal	Year	Traffic Throughput (thousand TEU)	Excess Demand (%)	Average Delay Time(hours)
Terminal A (900)*	1991	1293	43.67	7.5
	1992	1109	23.22	3.2
	1993	1124	24.89	3.5
	1994	1330	47.78	7
	1995	1539	71.00	9.9
Terminal B (960)*	1993	1006	4.79	2.5
	1994	1162	21.04	3.5
	1995	1262	31.46	4.1

Notes: * Annual theoretical handling capacity

The table shows that the average delay time is related to the level of excess demand for handling capacity in port. We can formulate a linearised delay time equation on the basis of the information on the level of excess demand for handling capacity in port. In other words, given data such as the traffic demand and theoretical handling capacities, the delay time can be estimated.

Therefore, the delay time functions are estimated by regression analysis based on the relationship between delay time per TEU and excess demand for handling capacity in port. The estimated regression used in this study is as follows:

The regression equation[49] is

$$QT = 0.943 + 0.126\ EC \tag{4.3}$$

where QT = the delay time per TEU

EC (%) = the excess level of handling capacity.

Using the average value of an export container estimated earlier the terminal congestion cost per TEU is as follows:

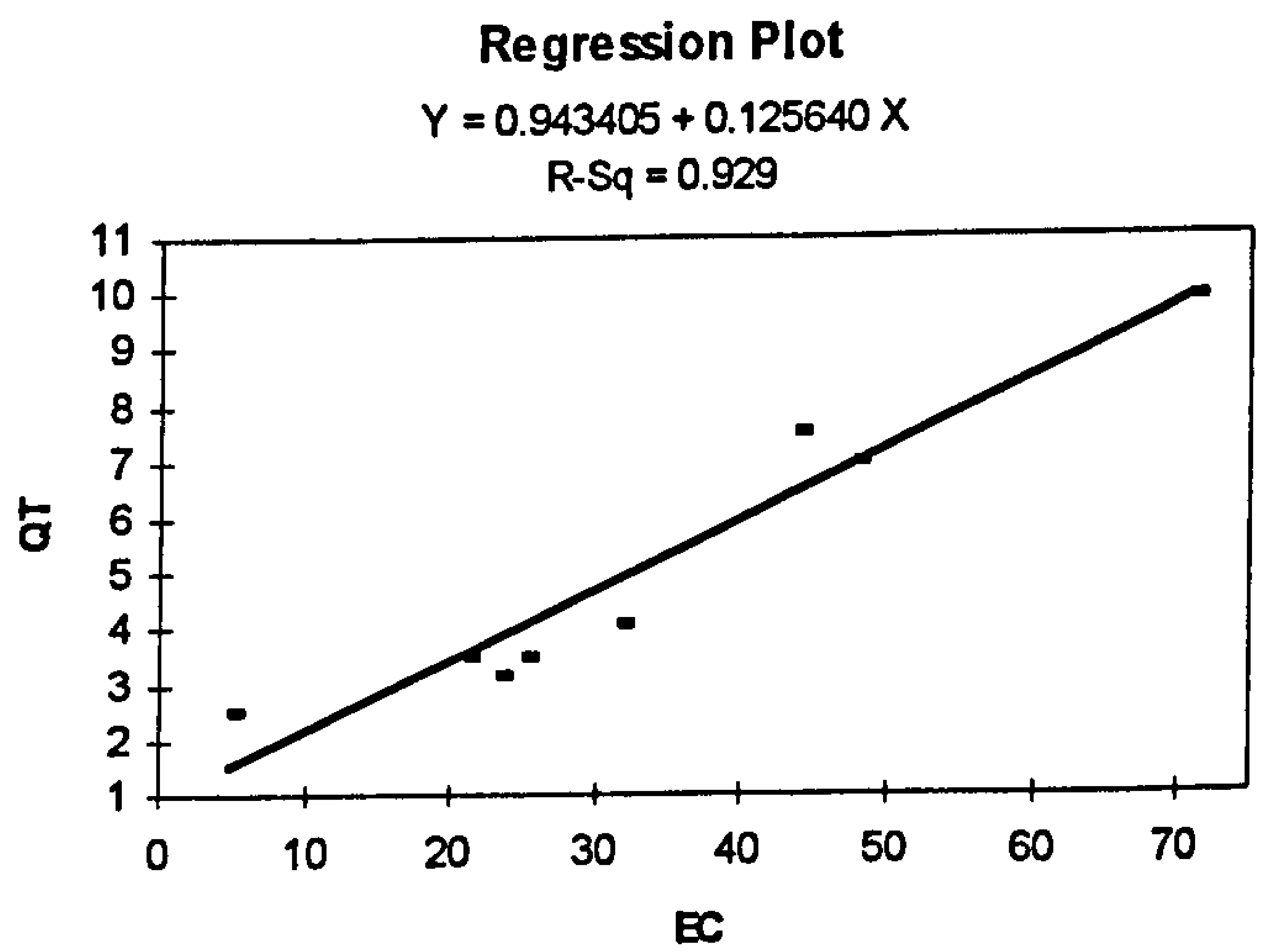
[49] In this case, the four functional forms like the Road and Rail transport costs estimation were investigated. Of these the semi-log form ($\ln QT = 0.327 + 0.0101\ EC$) was slightly better than the linear form comparing an R-square equal to 93.3 % with 92.9 %. However, considering the fact that there were the insufficient observations (8 observations), the difference is of no concern. Thus, the linear form was adopted. The details and results [Regression Analysis (9) ~ Regression Analysis (12)] of the regression are shown below.

$$\begin{pmatrix} \text{Terminal} \\ \text{Congestion} \\ \text{Cost} \end{pmatrix} = \begin{pmatrix} \text{Average Value of} \\ \text{an Export} \\ \text{Container Cargo} \end{pmatrix} \times \begin{pmatrix} \text{Hourly} \\ \text{Interest} \\ \text{Rate} \end{pmatrix} \times \begin{pmatrix} \text{Delay} \\ \text{Time} \end{pmatrix}$$

Thus, given the excess level of handling capacity based on results obtained in Chapter 3 and the average value of an export container cargo, the terminal congestion costs at terminal can be estimated for the period in question.

Regression Analysis (9)

```
The regression equation is
QT = 0.943 + 0.126 EC

Predictor        Coef        StDev          T        P
Constant       0.9434       0.5451       1.73    0.134
EC            0.12564      0.01417       8.87    0.000

S = 0.7598       R-Sq = 92.9%      R-Sq(adj) = 91.7%

Analysis of Variance

Source       DF         SS          MS         F         P
Regression    1     45.416      45.416     78.67     0.000
Error         6      3.464       0.577
Total         7     48.880
```



Regression Analysis (10)

The regression equation is
LOGQT = - 0.081 + 0.522 LOGEC

Predictor	Coef	StDev	T	P
Constant	-0.0806	0.1805	-0.45	0.671
LOGEC	0.5216	0.1231	4.24	0.005

S = 0.1146   R-Sq = 75.0%   R-Sq(adj) = 70.8%

Analysis of Variance

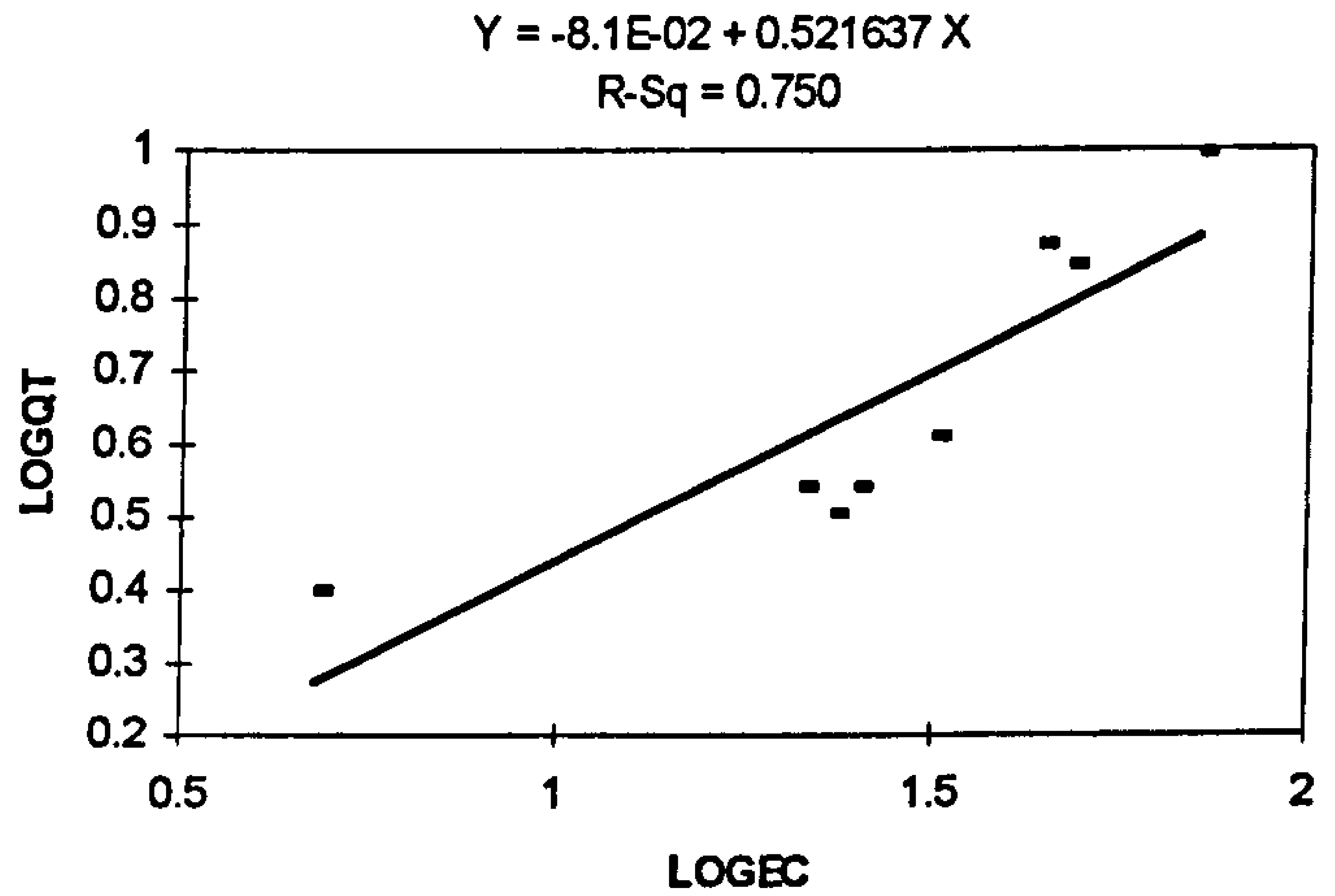
Source	DF	SS	MS	F	P
Regression	1	0.23593	0.23593	17.96	0.005
Error	6	0.07880	0.01313		
Total	7	0.31473			

Unusual Observations

Obs	LOGEC	LOGQT	Fit	StDev Fit	Residual	St Resid
6	0.68	0.3979	0.2743	0.1007	0.1236	2.26RX

R denotes an observation with a large standardized residual
X denotes an observation whose X value gives it large influence.

Regression Plot



Regression Analysis (11)

The regression equation is
QT = - 3.47 + 6.03 LOGEC

Predictor	Coef	StDev	T	P
Constant	-3.469	2.678	-1.30	0.243
LOGEC	6.031	1.826	3.30	0.016

S = 1.700   R-Sq = 64.5%   R-Sq(adj) = 58.6%

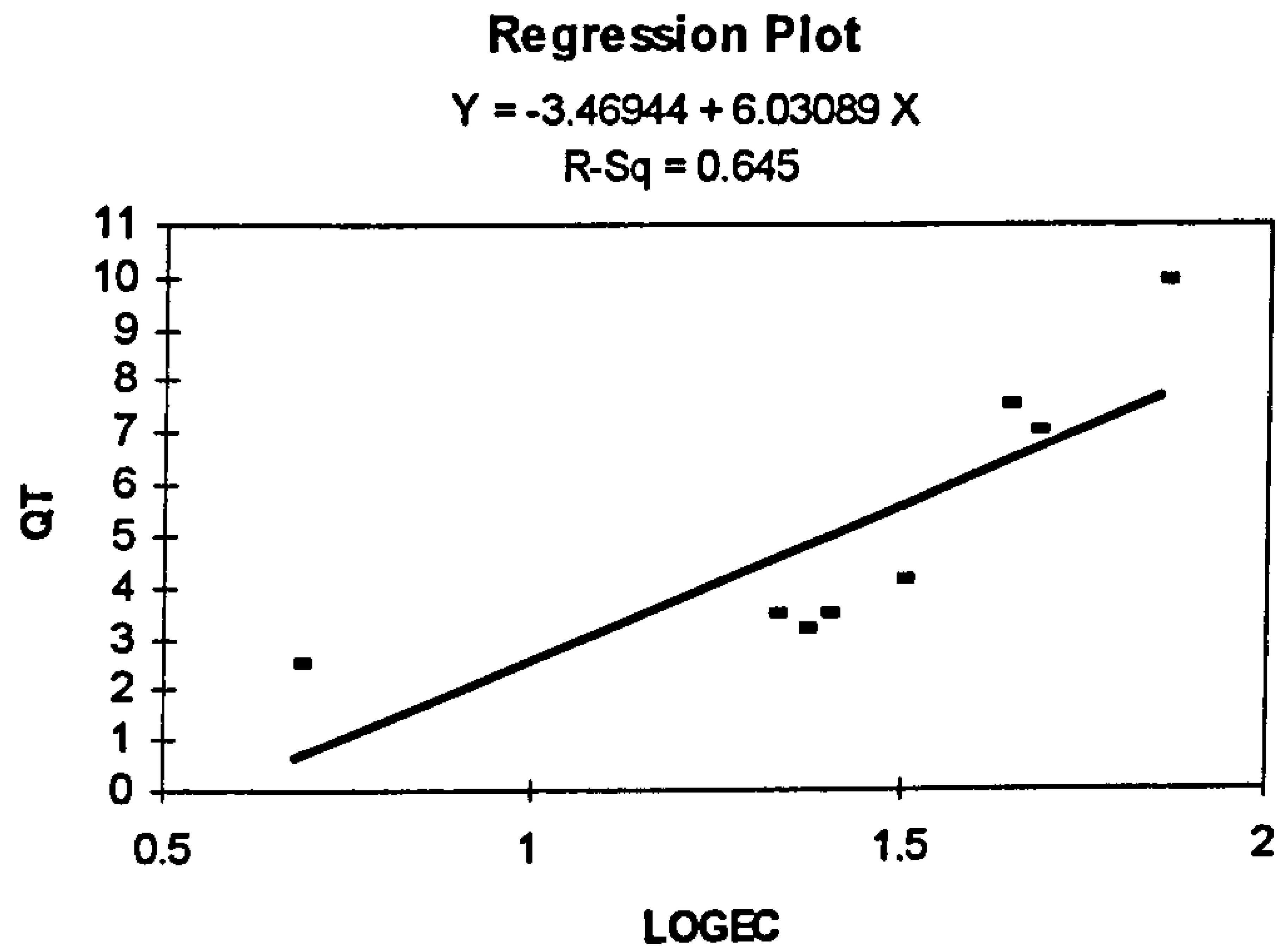
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	31.536	31.536	10.91	0.016
Error	6	17.344	2.891		
Total	7	48.880			

Unusual Observations

Obs	LOGEC	QT	Fit	StDev Fit	Residual	St Resid
6	0.68	2.500	0.634	1.494	1.866	2.30RX

R denotes an observation with a large standardized residual
X denotes an observation whose X value gives it large influence.



Regression Analysis (12)

The regression equation is
LOGQT = 0.327 + 0.0101 EC

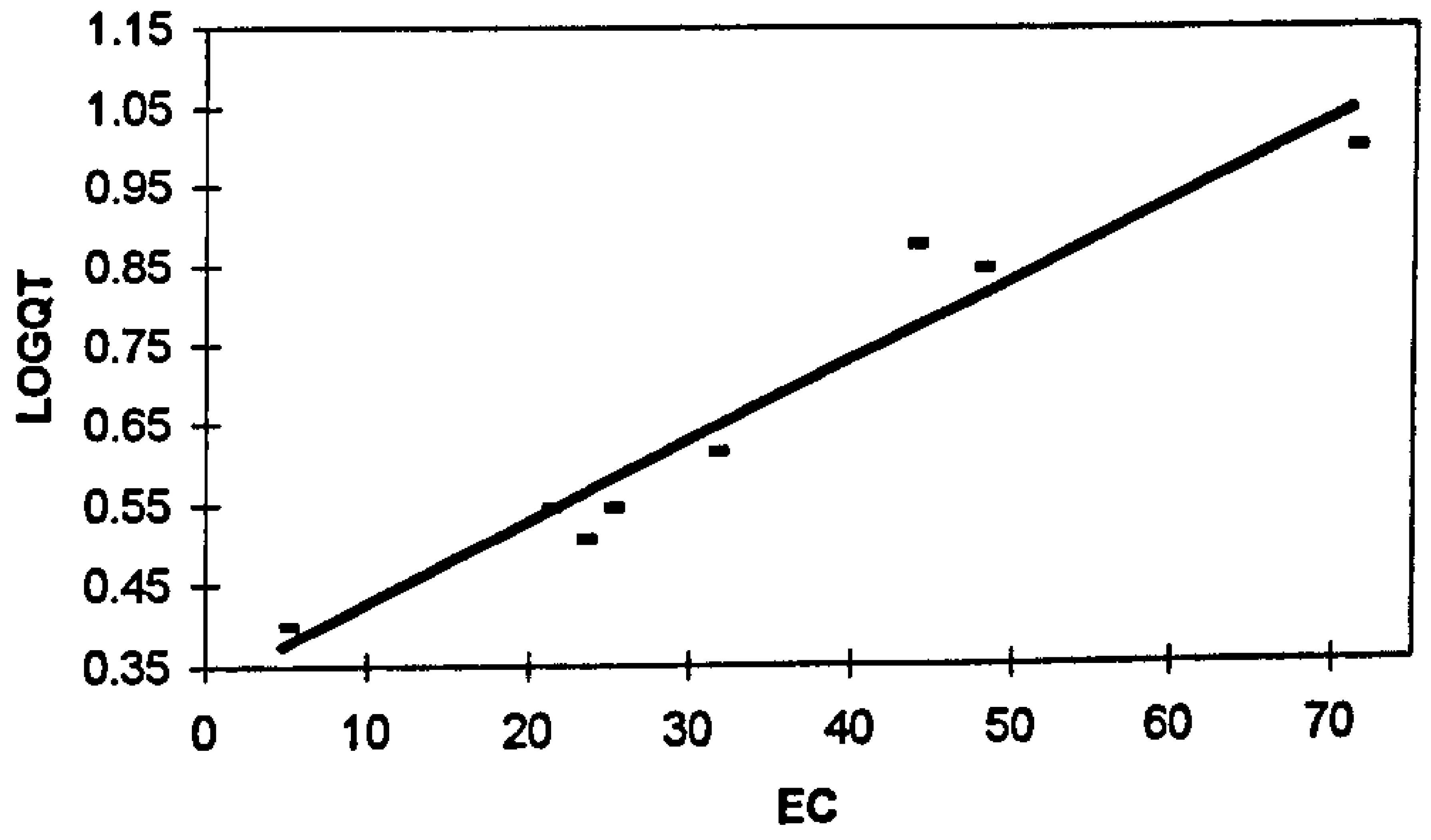
Predictor	Coef	StDev	T	P
Constant	0.32666	0.04241	7.70	0.000
EC	0.010105	0.001102	9.17	0.000

S = 0.05911   R-Sq = 93.3%   R-Sq(adj) = 92.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.29376	0.29376	84.07	0.000
Error	6	0.02097	0.00349		
Total	7	0.31473			

Regression Plot



Chapter 5

Computation of the Model and Interpretation of the results

5.1 Introduction

This chapter uses the data of the previous chapter to apply both the Optimising Port Capacity model and the Container Traffic Allocation model to developing a system cost minimising container port investment programme for Korea. In terms of the structure of the problem, the Optimum Container Traffic Allocation model relies on the outputs of the Optimum Port Capacity model as its capacity constraints. In addition, to identify a "best" programme sensitivity analysis concerning the effects of different parameter values is carried out. In particular, we consider alternative scenarios for the annual growth rates of different transport modes and also sensitivity with respect to the interest rate.

5.2 The Optimal Solution of the Master Problem

For correct optimisation it is necessary for the objective function and the decision variables to fit together well. The overall objective of the model is to minimise the total system cost of container port development projects for the period from 1997 to 2020, subject to a number of constraints including budget constraints. These system costs are composed of :

(a) inland transport costs, including congestion costs, and

(b) construction costs.

This objective function i.e. the sum of the above costs, is minimised subject to constraints, such as limitations on the capacities of transport modes and differences in the handling capabilities of the ports.

To overcome the computational complexity of this problem, a simplification has been used. This takes the form of dynamic (Multi-stage) programming with a limited number of proposals for port investment projects to be determined at certain intervals.

It is assumed that investment is undertaken at six-yearly intervals. This is supported by the knowledge that in Korea, the construction period for a typical container terminal is normally six years, although there can be some variation. Thus we assume four sub-periods called stages, which make up the whole period of this study. A limited number of alternative proposals are considered for each of the six year stages, starting at 2003, 2009 and 2015. First, the objective is to find the best overall project for stage 1 i.e. the one that yields least total system cost. We then proceed by successively finding the lowest total system costs of stage 2 and stage 3 for each of the possible initial states. It is assumed there is no investment in stage 4 because it is the last stage to this model. The total system costs according to alternatives at stage 3 are calculated at the last stage

The following notation is adopted. The state variable K_n is denoted as the input state prior to entering stage n. Thus, K_2 represents the configuration of port development at the beginning of stage 2. I_n is denoted as a decision variable at stage n. I_2 represents the proposal selected to move to stage 3. Consequently, K_3 is the output of stage 2. This will be the state we reach after considering the input K_2 and the decision I_2. This will also be the input for stage 3.

On the other hand, among all the proposals considered, some might not be feasible because of the restrictions or constraints placed on the problem. For example, there might be a budget limitation. Additionally, some of the proposals might be mutually exclusive. Other proposals might be contingent so that one proposal cannot be selected unless another proposal is also selected. Thus, depending on the restrictions present, the number of feasible alternatives can be considerably reduced. The following assumptions are adopted:

(1) Each berth is assumed to handle 240,000 TEU per year. In the last decade, ports in Korea have handled container cargo on average in the ratio of 53.94 % of export to 46.04 % of import. Due to the steady growth of import container cargo, the last 3 years show the share of export cargo decreasing to 52.5 % on average. The percentage of total TEU which is export cargo is assumed to be 52 %. Thus, a berth can handle 124,800 TEU of export container cargo per year.

(2) The total number of additional berths allocated over the whole period is 34. This is based on the assumption that demand at the end year of the third stage is satisfied. The substate at each stage is constrained by the investment budget.

(3) A container port terminal normally consists of 4 or 6 berths. This figure is determined by economies of scale in provision. Thus, the development of a new container port proceeds by construction of terminals; where one terminal has either 4 berths or 6 berths.

(4) Based on its development plan, the total number of berths to be built at Kwangyang is assumed to be no more than 20 and at Gadukdo, no more than 21.

Thus, there are a set of alternatives for terminal development at each stage. The addition of berths at any port would incur both port construction costs as well as the cost of the lowest cost traffic allocation and would imply a cost structure at the following stage. For each alternative the construction cost for all six years of the stage is calculated. Total inland transport cost is then calculated in the following stage on the basis of the number and pattern of berths provided. Also, queuing costs at port terminals are estimated at the following stage on the basis of the investment at the previous stage. At this stage, the economic worth of all the costs by investment alternatives is converted to present value. The method converts all the costs to a single sum equivalent at 1997 present value using a given real interest rate. A practical difficulty is to decide upon which interest rate to use in the calculations. While there is agreement among economists that costs or benefits accruing at different points in time can not simply be added up, there is not always full agreement as to what rate of interest should be used in any particular situations[50]. Different theoretical considerations point to the public sector discount rate, the money market rate, the corporate bond rate, the deposit rate, or the lending rate or to a weighted average of some subset of these. There are no clear guidelines on which rate should be used[51]. Here, a rate of 10 % was adopted as the standard rate. This is not inconsistent with an *ex post* real interest rate of 9.9 % based on the above five rates for the period 1992-1996.

Another factor to consider is how to treat the uncertainty associated with the unpredictability of future needs and costs. A standard procedure for dealing with the uncertainty of costs or returns is to incorporate a risk premium in the interest rate[52]. However, here, this procedure is not regarded as appropriate for the following reasons.

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[50] Lansing, J. B., 1966, *Transportation and Economic Policy*, London, Collier-Macmillan, p. 33.
[51] White et al (White. J. A., K. E. Case, D. B. Pratt and M. H. Agee, 1998, *Principles of Engineering Economic Analysis* (4th ed.)) note that an empirical study conducted by Haveman (1969) in 1966 suggested the appropriate weighted average to be 7.4 % at that time. However, White et al also argue that in the changed circumstances of the early 2000s 10-15 % might be a more appropriate rate (p.336).

(i) From a commercial point of view the project is a state-sponsored development with government finance and government guarantees so it is not obvious that a commercial risk premium is appropriate and (ii) from a social point of view all the potential developments risks have virtually identical profiles across investment alternatives - typically, uncertainty about demands in the far future. Accordingly, no explicit risk premium has been incorporated into the interest rate[53]. Instead, the alternative of conducting a sensitivity analysis using low, standard and high interest rates has been chosen. This tests the robustness of the optimal investment against the possibility of a mis-specified interest rate (whatever the reason for mis-specification). Robustness is also tested by considering alternatives time paths of demand. It found out that, with one exception, the choice of interest rate makes no difference to the optimal investment plan.

A set of combined alternatives which are arranged from the alternatives chosen in each stage can be created. Thus a set of coherent investment programmes for the whole period concerned can be defined. Obviously, there is a combination which generates the lowest present value of total system cost and this is the alternative recommended.

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[52] Brealey, R. and S. Myers, 1981, *Principles of Corporate Finance*, New York, McGraw-Hill, p.112-130.

[53] US Treasury Bills, arguably the safest global investments, have yielded 2.5 % over the last 50 years. So a central interest rate of 10 % may be said to contain an implicit risk premium.

5.2.1 Stage 1

We start with Stage 1 which consists of the period starting in 1997 and ending in 2002. With the assumptions mentioned above, we can form 26 logically possible investment alternatives, as depicted in Table 5.1.

< Table 5.1> Developing Investment Alternatives from Investment Proposals

Proposals		
Kwangyang	Gadukdo	Explanation
0	0	No action (proposals Kwangyang, Gadukdo not included)
4	0	Accept proposal Kwangyang (4 berths) only
6	0	Accept proposal Kwangyang (6 berths) only
8	0	Accept proposal Kwangyang (8 berths) only
10	0	Accept proposal Kwangyang (10 berths) only
12	0	Accept proposal Kwangyang (12 berths) only
0	4	Accept proposal Gadukdo (4 berths) only
0	6	Accept proposal Gadukdo (6 berths) only
0	8	Accept proposal Gadukdo (8 berths) only
0	10	Accept proposal Gadukdo (10 berths) only
0	12	Accept proposal Gadukdo (12berths) only
4	4	Accept both proposals (4 berths each)
6	6	Accept both proposals (6 berths each)
8	8	Accept both proposals (8 berths each)
4	6	Accept both proposals (4 berths and 6 berths)
4	8	Accept both proposals (4 berths and 8 berths)
4	10	Accept both proposals (4 berths and 10 berths)
4	12	Accept both proposals (4 berths and 12 berths)
6	4	Accept both proposals (4 berths and 6 berths)
6	8	Accept both proposals (6 berths and 8 berths)
6	10	Accept both proposals (6 berths and 10 berths)
8	4	Accept both proposals (4 berths and 8 berths)
8	6	Accept both proposals (6 berths and 8 berths)
10	4	Accept both proposals (4 berths and 10 berths)
10	6	Accept both proposals (6 berths and 10 berths)
12	4	Accept both proposals (4 berths and 12 berths)

Some of the logically possible alternatives might not be feasible, because of the constraints placed upon the problem. In particular, we assume a budget constraint. At this point, it is assumed that the investment at Stage 1 does not exceed \$ 2.5 billion. This limit is based on the expected budget for container port development contained in the draft budget of the Korea Economic Planning Board. In 1994 and 1995, the Korean government invested \$ 575 million, \$695 million, respectively, in Korean port developments and of this investment, the amount allocated to container port development did not exceed $ 201 million. Even on generous assumptions about the growth in budget, the limit of $ 2.5 billion over six years is unlikely to be exceeded.

Proposals which require more capital than the budget available are excluded. It is then assumed that given the budget as many berths as possible are selected. It is reasonable to accept this assumption considering the current situation of deficient capacity as described it in Section 4.2. Accordingly, at least 8 berths have to be constructed at Stage 1. Based on these restrictions only four of the 18 investment alternatives remain to be considered. Table 5.2 summarises the conditional decisions for Stage 1 and also shows estimated construction costs for each alternative.

<Table 5. 2> Investment Alternatives for Stage 1

Alternative	Combination (berth)			Construction Cost Required*
	Pusan	Kwangyang	Gadukdo	(Maximum = 2500)
1	0	4	4	2198
2	0	8	0	1575
3	0	10	0	1968
4	0	12	0	2362

Notes: * The figures in $ million

Alternative 1 in Stage 1 involves the development of new container terminals at both Kwangyang and Gadukdo with four berths each. The three other alternatives have new container ports only at Kwangyang in Stage 1. The Gadukdo project has comparatively high construction costs because its geographical features make engineering the foundations difficult and costly. Hence, Gadukdo only development is dominated by Kwangyang only development and any alternative with four berths at Kwangyang and more than four at Gadukdo exceeds the budget constraint. Thus the last three alternatives involve development at Kwangyang only with either two four-berths, or one four-berth and one six-berth, or two six-berths. All the alternatives satisfy the limits of the budget. Once the set of investment alternatives has been specified, the other cost categories can be calculated.

Next, the construction costs are converted to 1997 present value in the following way. First, the estimated construction costs presented in Table 5.2 are given on the basis of estimated construction cost per berth in Section 4.3.2 at 1995 prices. A sixth of the estimated construction cost is assumed to be equally assigned to each of 6 years of development. Each element is converted to 1997 present value and added up. The following table shows the 1997 present value of construction costs using $i = 10$ %.

<Table 5.3> Present Values of Construction Costs by Investment Alternatives at Stage 1

Year	Alternative			
	1	2	3	4
1997	3.66	2.62	3.28	3.94
1998	3.03	2.17	2.71	3.25
1999	2.75	1.97	2.47	2.96
2000	2.50	1.79	2.24	2.69
2001	2.27	1.63	2.04	2.45
2002	2.07	1.48	1.85	2.22
Total	15.96	11.43	14.29	17.15

Notes: All figures in $ hundred million.

5.2.1.1 Inland Transportation Costs

The inland transportation costs corresponding to each alternative at Stage 1, are estimated by the following procedure. Each proposal chosen implies a distribution of new container berths among ports. It is assumed that given a configuration of new port development, the lowest-cost traffic allocation is achieved by the transportation model of linear programming. The transportation model is called the Container Traffic Allocation model in this thesis. That is, each alternative provides the Traffic Allocation model with a new configuration of port development as the constraint set of the transportation problem. Under each configuration of port development, there is a lowest-cost inland container allocation. Total traffic volume by regions and unit transportation costs by modes are given in Chapter 3 and Chapter 4.3.1, respectively. Once the constraints and unit transport costs are known, this problem can be solved using a mathematical programming solution software package, M.S. Keyware with transportation option. Consequently, each alternative generates a least-cost total inland transport traffic allocation.

The matrix of input data for the container traffic allocation model running in the software under proposal 1 at Stage 1 is shown in Table 5.4. The entries at the right hand column of the matrix in Table 5.4 represent the container traffic originating by regions and by modes, and the entries in the bottom row represent the container traffic by container ports. The entries in each cell represent the costs per TEU of transporting over the corresponding route. The year of the matrix is for the first year after the completion of alternative 1 at Stage 1.

<Table 5.4> A Matrix of Input Data under Alternative 1 in Stage 1

Region	Transport mode	Destination			TEUs by regions and modes**
		Pusan*	Kwangyang*	Gadukdo*	
A0	RD	550.0	495.2	561.8	846.5
	RL	340.1	322.4	344.5	358.9
	CS	375.3	289.9	362.0	71.8
B0	RD	22.0	240.6	38.9	691.8
B1	RD	125.3	207.9	133.8	304.7
B2	RD	250.5	273.3	262.7	200.2
C1	RD	316.0	120.7	284.2	258.3
	RL	270.0	198.3	258.4	11.5
C2	RD	363.2	235.2	344.2	153.1
	RL	287.4	240.4	280.4	28.7
D1	RD	432.9	306.0	443.3	859.6
	RL	308.6	266.4	312.4	25.8
D2	RD	416.3	327.8	427.1	87.7
	RL	304.5	274.4	308.4	14.4
E0	RD	551.1	480.5	561.8	13.4
TEUs by ports**		499.2	2090.4	1747.2	

Notes: RD = Road; RL = Rail; CS = Coastal Shipping
* The figures in US $
** The figures in thousand TEU

The total container traffic expected in 2003 was estimated in Chapter 3.4 and the regional split was estimated in Chapter 3.5. Additionally, the modal split of each region's container traffic is estimated following the assumptions in Chapter 2.4.2.1. The share of each transport mode for each region's container traffic is based on the current capacities of Rail and Coastal Shipping with Road taking the remainder. Thus, over time the modal split of each region's container traffic would depend on the annual growth rates of "Rail" and "Coastal Shipping". It has not been possible to forecast these growth rates. Accordingly, the discussion will, instead, concentrate on answering a number of "what if" questions concerning the effects of different growth rates on the results of the model. That is, the model is run at scenarios representing high and low levels of the growth rates by "Rail" and "Coastal Shipping". Thus, there are four scenarios which depend on the annual growth rates of the capacity of "Rail" and "Coastal Shipping";

(1) "Rail" : 3% and "Coastal Shipping" : 6%

(2) "Rail" : 3% and "Coastal Shipping" : 9%

(3) "Rail" : 6% and "Coastal Shipping" : 6%

(4) "Rail" : 6% and "Coastal Shipping" : 9%.

The handling capacities of "Rail" and "Coastal Shipping" are assumed to be fully utilised and the difference between a specific region's container traffic and the capacities of the two modes is treated as the capacity of "Road". Beginning with Scenario 1, the process is then repeated with the remaining scenarios. At the end of this chapter, the total system costs corresponding to the four scenarios are compared in order to consider how the best investment programme might be influenced by Rail and Coastal Shipping developments.

For the input data of Table 5.4, the minimised total inland transport cost has been calculated as $ 969,644,363 per annum automatically by M.S. Keyware software package used in this study.

We can make the same calculations for the other five years of each investment proposed. The present value of total transport costs for each alternative at Stage 1 under scenario 1 are shown in Table 5.5.

<Table 5.5> Present Values of Transport Costs by Investment Alternatives at Stage 1

Year	Alternative			
	1	2	3	4
2003	4.98	4.87	4.84	4.82
2004	4.77	4.65	4.63	4.60
2005	4.83	4.71	4.69	4.66
2006	4.62	4.50	4.48	4.46
2007	4.41	4.30	4.28	4.26
2008	4.22	4.11	4.09	4.07
Total	27.82	27.14	27.00	26.87

Notes: All figures in $ hundred million

The present value converts all the costs to a single sum 1997 present value using i = 10 %. E.g. total inland transport cost calculated for the input data of Table 5.4 was converted to the present value at 1997 of 497,580,877 as follows:

$969{,}644{,}363 * (1.1)^{-7} = 497{,}580{,}877.$

5.2.1.2 Comparing the Alternatives at the First Stage

First, a set of alternatives were chosen which satisfy Stage 1's budget constraint of $ 2.5 billion. Among them, the four alternatives with the most possible berths were selected. The present value of system costs associated with each alternative have been calculated in Table 5.6.

We can now compare investment alternatives on the basis of economic considerations. However, these calculations are not for the whole period but for Stage 1 only and hence no decision is made based on this stage only.

<Table 5.6 > Present Value of System Costs by Investment Alternatives at Stage 1

Cost	Alternative			
	1	2	3	4
TC	278.3	271.4	270.0	268.7
SC	159.6	114.3	142.9	171.5
Total	437.8	385.7	412.9	440.2

Notes: TC= Total Inland Transport Costs; SC= Construction Costs
* All figures in $ ten million

5.2.2 Stage 2

5.2.2.1 The Costs

This calculation seeks a conditional, optimal solution for Stage 2 as a function of the state K_2. However, the problem is now different from that of Stage 1 in that the state K_2 now includes the additional berths to be allocated in Stage 1 and Stage 2. Such a definition guarantees that a decision made for Stage 2 is automatically feasible for Stage 1. We have to select the alternative in Stage 2 given K_2 which yields the lowest total system cost for Stage 1 and Stage 2 together.

We consider seven alternatives for Stage 2. They are limited by the budget available at Stage 2 and by the other assumptions discussed above. It is assumed that the investment at Stage 2 does not exceed $ 3.5 billion. Consequently, the number of alternatives available at Stage 2 are reduced considerably. Certain alternatives at Stage 2 are also unavailable because they are inconsistent with Stage 1 or with other primary assumptions. For example, it is not feasible for the 6th alternative at Stage 2 to be associated with both 3rd and 4th alternatives at Stage 1 because the total berths in Kwangyang exceeds 20. The non-feasible solutions are indicated by N.A. at Table 5.7. All the feasible combinations for Stage 2 are shown in the table.

<Table 5.7> Investment Alternatives for Stage 2

Alternative (I_2)	Configuration of New Terminals at Stage 2	Configuration of New Terminals at Stage 1 (K_2)				Construction Cost
		1	2	3	4	
		(0,4,4)	(0,8,0)	(0,10,0)	(0,12,0)	($ billion)
1	(0,4,8)					3.4
2	(0,6,6)					3.3
3	(0,8,4)					3.0
4	(0,10,4)				N.A.	3.4
5	(0,10,0)				N.A.	2.0
6	(0,12,0)			N.A.	N.A.	2.4
7	(0,0,10)					3.5

Notes: The figures in brackets are additional berths at Pusan, Kwangyang, Gadukdo, at each stage.

The present value of system costs according to alternatives at Stage 2 are shown in Table 5.8 and we see that total system cost of a given alternative at Stage 2 varies with the input to Stage 2. The present values are as of 1997 using i = 10 %.

<Table 5.8> Present Value of System Costs by Alternatives at Stage 2

Alternative I_2	The Input to Stage 2, K_2			
	1	2	3	4
1	3.69	3.65	3.76	3.63
2	3.54	3.50	3.51	3.48
3	3.39	3.35	3.33	3.33
4	3.54	3.50	3.49	-
5	2.94	2.90	2.90	-
6	3.09	3.06	-	-
7	3.71	3.65	3.64	3.62

Notes: All figures in $ billion

5.2.2.2 Present Value of Total System Costs

A table is again used to help identify the optimal decision. Since the input to Stage 2, K_2, is unknown, we have to consider all possible states at Stage 1. Also, all possible proposed I_2 have to be considered. The entries under the heading $V_2(K_2, I_2) + X_1(K_1)$ represent the total system costs over both stages, given the inputs K_2 and the decision I_2. The total system costs are transformed to 1997 present values using i = 10 %. It is still premature to choose an overall optimum at this stage.

<Table 5.9> Present Value of Total System Costs by Alternatives to Stage 2

Alternative I_2	$V_2(K_2, I_2) + X_1(K_1)$ The Input to Stage 2, K_2			
	1	2	3	4
1	8.07	7.50	7.89	8.03
2	7.92	7.35	7.64	7.88
3	7.77	7.21	7.46	7.74
4	7.92	7.36	7.62	-
5	7.32	6.76	7.03	-
6	7.47	6.92	-	-
7	8.09	7.51	7.76	8.03

Notes: All figures in $ billion

5.2.3 Stage 3 Optimisation

5.2.3.1 Total System Costs

The procedure carried out here is much the same as for Stage 2. At Stage 3, the alternatives are formed depending on the restrictions or constraints placed on the problem. There is one further consideration at Stage 3. It is reasonable that total additional berths allocated over the whole period in question meet, more or less, the demand at the end of the period. Hence, 34 is the required number of additional berths. Consequently, the final state of the system at Stage 3 will reach one of four configurations :

(1) Kwangyang: 14 berths and Gadukdo: 20 berths,

(2) Kwangyang: 16 berths and Gadukdo: 18 berths,

(3) Kwangyang: 18 berths and Gadukdo: 16 berths,

or, (4) Kwangyang: 20 berths and Gadukdo: 14 berths.

Therefore, the alternatives at Stage 3 have to bridge the input to Stage 3, K_3 and one of these configurations. There are 17 alternatives at Stage 3 which satisfy the budget available at this stage, which is assumed to be $ 4.5 billion. The calculation of costs associated with alternatives at Stage 3 is carried out in the same way as for the previous stage.

The system costs corresponding to alternatives at Stage 2 are shown in Table 5.10. The total system cost of a given alternative at Stage 3 varies with the input to Stage 3. Also, the total system costs are transformed into 1997 present values using $i = 10\%$.

<Table 5.10> Present Value of System Costs by Alternatives at Stage 3

The output of Stage 1, K_2	The output of Stage 2, K_3	The decision state of Stage3, I_3	The Total Costs*
(0,4,4,)	(0,8,12)	(0,10,4)	2.43
		(0,8,6)	2.51
		(0,6,8)	2.59
	(0,10,10)	(0,10,4)	2.41
		(0,8,6)	2.50
		(0,6,8)	2.58
		(0,4.10)	2.67
	(0,12,8)	(0,8,6)	2.48
		(0,6,8)	2.57
	(0,14,8)	(0,6,6)	2.39
		(0,4,8)	2.48
	(0,14,4)	(0,6,10)	2.72
		(0,4,12)	2.80
	(0,16,4)	(0,4,10)	2.63
	(0,4,14)	(0,16,0)	2.36
		(0,12,4)	2.53
		(0,10,6)	2.61
(0,8,0)	(0,12,8)	(0,8,6)	2.48
		(0,6,8)	2.57
		(0,4,10)	2.65
	(0,14,6)	(0,6,8)	2.56
		(0,4,10)	2.64
	(0,16,4)	(0,4,10)	2.63
		(0,0,14)	2.80
	(0,18,4)	(0,0,12)	2.62
	(0,18,0)	(0,0,16)	2.95
	(0,20,0)	(0,0,14)	2.77
	(0,8,10)	(0,10,6)	2.59
		(0,12,4)	2.50
(0,10,0)	(0,14,8)	(0,6,6)	2.39
		(0,4,8)	2.48
		(0,0,12)	2.65
	(0,16,6)	(0,4,8)	2.63
		(0,0,12)	2.46
	(0,18,4)	(0,0,12)	2.62
	(0,20,4)	(0,0,10)	2.45
	(0,20,0)	(0,0,14)	2.77
	(0,10,10)	(0,10,4)	2.41
		(0,8,6)	2.50
		(0,6,8)	2.58
		(0,4,10)	2.67
(0,12,0)	(0,16,8)	(0,4,6)	2.30
		(0,0,10)	2.47
	(0,18,6)	(0,0,10)	2.46
	(0,20,4)	(0,0,10)	2.45
	(0,12,10)	(0,8,4)	2.49
		(0,6,6)	2.40
		(0,4.8)	2.32

Notes: The figures in brackets are additional berths at Pusan, Kwangyang, Gadukdo, at each stage.
* All figures in $ billion

5.2.3.2 Comparison of Total System Costs

The calculation of all the costs at Stage 3 made use of the same procedures as in the previous stages. Table 5.11 shows the calculation of final network costs. When examined carefully, we find that the computations are recursive. This characteristic is an important part of the dynamic programming procedure. Computations at Stage 3 are based on computations at Stage 2. In other words, the computations at a current stage utilise Table 5.11 as in the immediately preceding stage. The table provides the lowest total system costs of all stages previously considered. In using the table, the specific decisions taken in the preceding stages are of no concern

The solution of this problem is now complete. We have now determined the optimal decisions of the development of container ports for the whole period. In order to identify the overall optimal solution, we must identify the lowest total system cost from Table 5.11.

It is easy to see that the top five projects for new container port development are as follows:

<Table 5. 12> Top Five Optimal Alternatives under i = 10 %.

Alternative			Present Value
Stage 1	Stage 2	Stage 3	of Total System Cost*
(0,8,0)	(0,12,0)	(0,0,14)	9.69
(0,8,0)	(0,10,0)	(0,0,16)	9.71
(0,10,0)	(0,10,0)	(0,0,14)	9.80
(0,8,0)	(0,8,4)	(0,4,10)	9.83
(0,8,0)	(0,6,6)	(0,6,8)	9.91

Notes: The figures in brackets are additional berths at Pusan, Kwangyang, Gadukdo, at each stage.
* All figures in $ billion

<Table 5.11> Present Value of Total System Costs by Alternatives up to Stage 3

The output of Stage 1, K_2	The decision state of Stage 2, I_2	The decision state of Stage3, I_3	Total System Costs*
(0,4,4,)	(0,4,8)	(0,10,4)	10.49
		(0,8,6)	10.58
		(0,6,8)	10.66
	(0,6,6)	(0,10,4)	10.33
		(0,8,6)	10.42
		(0,6,8)	10.50
		(0,4.10)	10.58
	(0,8,4)	(0,8,6)	10.25
		(0,6,8)	10.34
	(0,10,4)	(0,6,6)	10.31
		(0,4,8)	10.40
	(0,10,0)	(0,6,10)	10.04
		(0,4,12)	10.12
	(0,12,0)	(0,4,10)	10.10
	(0,0,10)	(0,16,0)	10.44
		(0,12,4)	10.61
		(0,10,6)	10.70
(0,8,0)	(0,4,8)	(0,8,6)	9.99
		(0,6,8)	10.07
		(0,4,10)	10.16
	(0,6,6)	(0,6,8)	9.91
		(0,4,10)	9.99
	(0,8,4)	(0,4,10)	9.83
		(0,0,14)	10.00
	(0,10,4)	(0,0,12)	9.98
	(0,10,0)	(0,0,16)	9.71
	(0,12,0)	(0,0,14)	9.69
	(0,0,10)	(0,10,6)	10.09
		(0,12,4)	10.01
(0,10,0)	(0,4,8)	(0,6,6)	10.56
		(0,4,8)	10.24
		(0,0,12)	10.41
	(0,6,6)	(0,4,8)	10.08
		(0,0,12)	10.25
	(0,8,4)	(0,0,12)	10.09
	(0,10,4)	(0,0,10)	10.07
	(0,10,0)	(0,0,14)	9.80
	(0,0,10)	(0,10,4)	10.18
		(0,8,6)	10.26
		(0,6,8)	10.35
		(0,4,10)	10.43
(0,12,0)	(0,4,8)	(0,4,6)	10.33
		(0,0,10)	10.50
	(0,6,6)	(0,0,10)	10.34
	(0,8,4)	(0,0,10)	10.18
	(0,0,10)	(0,8,4)	10.35
		(0,6,6)	10.43
		(0,4,8)	10.52

Notes: The figures in brackets are additional berths at Pusan, Kwangyang, Gadukdo, at each stage.
* All figures in $ billion

The best decision at each stage is through the development of 8 berths in Kwangyang at Stage 1, 12 berths in Kwangyang at Stage 2 and 14 berths in Gadukdo at Stage 3. In terms of annual capacity at ports, Pusan port has an annual capacity of 2.09 million TEU for export from 1998 to the end of the period concerned. Kwangyang port will start the service with an annual capacity of 499,200 TEU for export in 1998, which increases to 2.25 million TEU in 2003 and capacity is extended to 3.74 million TEU in 2009 which is maintained until 2020. Gadukdo first has an annual capacity of 1.75 million TEU in 2015. Thus, the results show that Kwangyang is given priority for the new container port development in all cases. In particular, the two top alternatives indicate that Gadukdo development should follow only after Kwangyang is completely developed. The present value of total system cost of the best decision accounts for $ 9.69 billion. The amount is 1997 present value using $i = 10$ %. This is the result under Scenario 1 of the inland transport capacity scenarios in which it is supposed that the annual growth rates of the capacity "Rail" and "Coastal Shipping" are 3 % and 6 %, respectively.

5.3 Post-Optimality Analysis

5.3.1 Sensitivity Analysis with Changes in Modal Capacity

Having found an optimal solution for the model under Scenario 1, we solve for the model again under the alternative scenarios for the annual growth rates of "Rail" and "Coastal Shipping". With each scenario, the modal split of each region's traffic is varied. This predicts changes in total inland transport costs as generated by the traffic allocation problem. Table 5. 13. shows present values of total system costs up to Stage 3 based on the other three scenarios associated with different annual growth rates by Rail and Coastal Shipping.

No matter which scenario, the top five decisions at each stage are the same as in scenario1. However, it is natural that the total system cost is sensitive to changes in scenario with regard to the modal split. In particular, Scenario 4 is the best one having the lowest total system cost. This is due to Scenario 4 having the lowest inland transport costs compared to other scenarios. It means that the modal split affects only the traffic allocation problem without having any influence on the calculation of the construction cost. This suggests that "Rail" and "Coastal Shipping" should be encouraged to take over the overburdened traffic of "Road" in order to ease the inland container transport problem.

<Table 5.13> Present Value of Total System Costs by Alternatives to Stage 3 on the different Scenarios

Alternative			Scenario*		
Stage 1,	Stage 2	Stage 3	2	3	4
(0,4,4,)	(0,4,8)	(0,10,4)	10.46	10.34	10.31
		(0,8,6)	10.54	10.43	10.39
		(0,6,8)	10.63	10.51	10.48
	(0,6,6)	(0,10,4)	10.30	10.18	10.15
		(0,8,6)	10.38	10.27	10.23
		(0,6,8)	10.47	10.35	10.32
		(0,4.10)	10.55	10.44	10.40
	(0,8,4)	(0,8,6)	10.22	10.10	10.07
		(0,6,8)	10.30	10.19	10.15
	(0,10,4)	(0,6,6)	10.28	10.16	10.13
		(0,4,8)	10.36	10.25	10.21
	(0,10,0)	(0,6,10)	10.00	9.89	9.85
		(0,4,12)	10.09	9.97	9.94
	(0,12,0)	(0,4,10)	10.06	9.95	9.92
	(0,0,10)	(0,16,0)	10.40	10.29	10.26
		(0,12,4)	10.58	10.46	10.43
		(0,10,6)	10.66	10.55	10.51
(0,8,0)	(0,4,8)	(0,8,6)	9.95	9.84	9.80
		(0,6,8)	10.04	9.92	9.89
		(0,4,10)	10.12	10.01	9.97
	(0,6,6)	(0,6,8)	9.88	9.76	9.73
		(0,4,10)	9.96	9.85	9.81
	(0,8,4)	(0,4,10)	9.80	9.69	9.65
		(0,0,14)	9.97	9.86	9.82
	(0,10,4)	(0,0,12)	9.95	9.84	9.80
	(0,10,0)	(0,0,16)	9.68	9.57	9.54
	(0,12,0)	(0,0,14)	9.66	9.55	9.52
	(0,0,10)	(0,10,6)	10.06	9.94	9.91
		(0,12,4)	9.97	9.86	9.82
(0,10,0)	(0,4,8)	(0,6,6)	10.12	10.01	9.97
		(0,4,8)	10.21	10.09	10.06
		(0,0,12)	10.38	10.26	10.23
	(0,6,6)	(0,4,8)	10.05	9.93	9.90
		(0,0,12)	10.22	10.10	10.07
	(0,8,4)	(0,0,12)	10.06	9.95	9.91
	(0,10,4)	(0,0,10)	10.04	9.93	9.89
	(0,10,0)	(0,0,14)	9.77	9.66	9.63
	(0,0,10)	(0,10,4)	10.14	10.03	9.91
		(0,8,6)	10.23	10.11	10.08
		(0,6,8)	10.31	10.20	10.16
		(0,4,10)	10.40	10.28	10.25
(0,12,0)	(0,4,8)	(0,4,6)	10.30	10.18	10.15
		(0,0,10)	10.47	10.35	10.32
	(0,6,6)	(0,0,10)	10.31	10.19	10.16
	(0,8,4)	(0,0,10)	10.15	10.04	10.01
	(0,0,10)	(0,8,4)	10.31	10.31	10.20
		(0,6,6)	10.40	10.40	10.28
		(0,4,8)	10.48	10.48	10.37

Notes: The figures in brackets are additional berths at Pusan, Kwangyang, Gadukdo, at each stage.
* All figures in $ billion

<Table 5.14> Present Value of Total System Costs by Alternatives to Stage 3 on the different Interest Rates

Alternative			Interest Rate*	
Stage 1,	Stage 2	Stage 3	$i = 7\%$	$i = 13\%$
(0,4,4,)	(0,4,8)	(0,10,4)	14.52	7.57
		(0,8,6)	14.66	7.63
		(0,6,8)	14.79	7.68
	(0,6,6)	(0,10,4)	14.30	7.45
		(0,8,6)	14.43	7.51
		(0,6,8)	14.57	7.56
		(0,4.10)	14.70	7.62
	(0,8,4)	(0,8,6)	14.21	7.38
		(0,6,8)	14.34	7.44
	(0,10,4)	(0,6,6)	14.27	7.44
		(0,4,8)	14.40	7.50
	(0,10,0)	(0,6,10)	13.98	7.19
		(0,4,12)	14.11	7.25
	(0,12,0)	(0,4,10)	14.04	7.25
	(0,0,10)	(0,16,0)	14.45	7.53
		(0,12,4)	14.71	7.65
		(0,10,6)	14.85	7.70
(0,8,0)	(0,4,8)	(0,8,6)	13.96	7.12
		(0,6,8)	14.09	7.17
		(0,4,10)	14.23	7.23
	(0,6,6)	(0,6,8)	13.87	7.05
		(0,4,10)	14.00	7.11
	(0,8,4)	(0,4,10)	13.79	6.99
		(0,0,14)	14.05	7.09
	(0,10,4)	(0,0,12)	13.98	7.10
	(0,10,0)	(0,0,16)	13.71	6.86
	(0,12,0)	(0,0,14)	13.65	6.87
	(0,0,10)	(0,10,6)	14.13	7.18
		(0,12,4)	14.00	7.12
(0,10,0)	(0,4,8)	(0,6,6)	14.10	7.30
		(0,4,8)	14.23	7.36
		(0,0,12)	14.50	7.47
	(0,6,6)	(0,4,8)	14.01	7.23
		(0,0,12)	14.28	7.35
	(0,8,4)	(0,0,12)	14.07	7.23
	(0,10,4)	(0,0,10)	14.00	7.24
	(0,10,0)	(0,0,14)	13.73	6.99
	(0,0,10)	(0,10,4)	14.13	7.31
		(0,8,6)	14.27	7.36
		(0,6,8)	14.40	7.42
		(0,4,10)	14.53	7.47
(0,12,0)	(0,4,8)	(0,4,6)	14.24	7.49
		(0,0,10)	14.51	7.60
	(0,6,6)	(0,0,10)	14.29	7.48
	(0,8,4)	(0,0,10)	14.09	7.36
	(0,0,10)	(0,8,4)	14.28	7.49
		(0,6,6)	14.41	7.55
		(0,4,8)	14.54	7.60

Notes: The figures in brackets are additional berths at Pusan, Kwangyang, Gadukdo, at each stage.
*All figures in $ billion

5.3.2 Sensitivity Analysis with Changes in Interest Rate.

In the initial calculation i = 10 % was used as a standard discount rate. We now consider the influence of different interest rates. Given different interest rates, it is expected that there may be changes in selection of the preferred solution. Lower and higher interest rates such as 7 % and 13 %, respectively, are used to compare the differences. Present values of total system costs up to Stage 3 based on i = 7 % and i = 13 % under Scenario 4 is shown in Table 5.14.

For the sake of convenience, only results under Scenario 4 are shown in the summary of the top five alternatives by interest rates presented in Table 5.15.

<Table 5. 15> Top Five Optimal Alternative by Interest Rates

Ranking	i = 7 % Stage 1	i = 7 % Stage 2	i = 7 % Stage 3	i = 10 % Stage 1	i = 10 % Stage 2	i = 10 % Stage 3	i = 13 % Stage 1	i = 13 % Stage 2	i = 13 % Stage 3
1	(0,8,0)	(0,12,0)	(0,0,14)	(0,8,0)	(0,12,0)	(0,0,14)	(0,8,0)	(0,10,0)	(0,0,16)
2	(0,8,0)	(0,10,0)	(0,0,16)	(0,8,0)	(0,10,0)	(0,0,16)	(0,8,0)	(0,12,0)	(0,0,14)
3	(0,10,0)	(0,10,0)	(0,0,14)	(0,8,0)	(0,8,4)	(0,4,10)	(0,8,0)	(0,8,4)	(0,4,10)
4	(0,8,0)	(0,8,4)	(0,4,10)	(0,10,0)	(0,10,0)	(0,0,14)	(0,10,0)	(0,10,0)	(0,0,14)
5	(0,8,0)	(0,6,6)	(0,6,8)	(0,8,0)	(0,6,6)	(0,6,8)	(0,8,0)	(0,6,6)	(0,6,8)

Notes: The figures in brackets are additional berths at Pusan, Kwangyang, Gadukdo, at each stage.

In the case of i = 13 %, the best project is altered as compared with i = 10 %. The best alternative [Stage 1: (0,8,0) ; Stage 2: (0,12,0) ; Stage 3: (0,0,14)] has the lead in present values of almost all the costs over the alternative [Stage 1: (0,8,0) ; Stage 2: (0,10,0) ; Stage 3: (0,0,16)] . However, the construction costs of the latter is less than that of the former only in the case of i = 13 %, accounting for \$ 2.546 billion over \$ 2.564 billion. This reverses the ranking between them. It means that when the interest rate is significantly high, the relatively costly invesement should be made later, as this will reduce the overall present value.

On the other hand, in the case of $i = 7$ %, there is no change in the ranking from the case of $i = 10$ %. It is noted that Kwangyang maintains the priority in container port development over Gadukdo in all cases.

5.4 Results of the Traffic Allocation Sub-Problem

The Container Traffic Allocation model is a short run model since it achieves the least cost traffic allocation for a given distribution of container berths among ports. However, construction of additional berths in any of the ports will, in general, change the lowest cost traffic allocation. Given the optimum distribution of new container berths among ports over the whole period, the Container Traffic Allocation model is used to obtain the optimum inland container traffic allocation year by year. That is, the optimum container traffic allocation model employs the outputs of the optimum port development model as inputs. The optimum distribution of new container berths among ports has already been characterised in the previous chapter. Thus, the optimum container traffic allocations are determined by the investment plan.

The transportation cost for each unit between regions and ports has been discussed in Chapter 4. This allocation model is formulated as linear programming and solved using linear programming solution software with a transportation option. It also needs a matrix of input data for this model as in Table 5.3. All the optimal container traffic allocations presented below are based on the optimum port development project that 8 berths in Kwangyang at Stage1, 12 berths in Kwangyang at Stage2 and 14 berths in Gadukdo at Stage 3. The optimum port development project is selected under Scenario 4 and with $i = 10$ % for present value.

5.4.1 The Container Traffic Allocation at Stage 2

On the basis of the optimum port development project identified in the previous section, the optimal container traffic allocation can be calculated. The optimal container traffic allocation solution is summarised in a matrix similar to the input matrix in Table 5.16. If new container port development, in accordance with the best alternative shown in Table 5.12, is implemented at stage 1, the optimal container traffic allocations for Stage 2 as shown in Table 5.16 will result.

<Table 5.16> The Optimal Container Traffic Allocation for the Year 2003

Region	Mode*	Container Ports				
		Pusan		Kwangyang		Share
Sudo	RD	12.8	(30)	27.9	(70)	(100)
	RL	20.1	(100)	0	(0)	(100)
	CS	0	(0)	4.3	(100)	(100)
Pusan	RD	36.6	(100)	0	(0)	(100)
Kyongnam	RD	16.1	(100)	0	(0)	(100)
Kyongbuk	RD	10.6	(100)	0	(0)	(100)
Chonnam	RD	0	(0)	12.7	(100)	(100)
	RL	0	(0)	0.6	(100)	(100)
Chonbuk	RD	0	(0)	7.4	(100)	(100)
	RL	1.6	(0)	0	(0)	(100)
Chungnam	RD	0	(0)	42.2	(100)	(100)
	RL	1.4	(100)	0	(0)	(100)
Chungbuk	RD	0	(0)	4.3	(100)	(100)
	RL	0.8	(100)	0	(0)	(100)
Kangwon	RD	0	(0)	0.6	(100)	(100)
Share		100		100		

Notes: * RD= Road; RL= Rail; CS = Coastal Shipping.
The figure in brackets indicates the share of each port in the container volume originating from each region by each mode.

The first figure in each cell in Table 5.16 indicates the share of the container volume by the relevant mode in the total handling volume of the pertinent port. The second figure (in brackets) indicates the share of each port in the container volume originating from each region by each mode, i.e. the share of Pusan in cargo transported by Road and originating in Sudo is 30.0 %.

This table characterises the optimum inland container flow in 2003, the first year with additional container berths. The most significant feature is that Kwangyang takes over a considerable quantity of the container cargo originating in the Sudo region. In particular, around 70 % of the container volume by "Road" from Sudo will be headed for Kwangyang port. On the other hand, all container cargo carried by "Rail" will remain headed for Pusan port and the cargo from Sudo by "Coastal Shipping" head for Kwangyang port. Pusan remains the exclusive port for transporting container cargo from the eastern region of the country, which includes Pusan, Kyongnam and Kyongbuk.

All the container cargo from Chonnam both by "Road" and "Rail" and Chonbuk by "Road" will head for Kwangyang port. Chungnam's and Chungbuk's container cargo by "Road" will be collected at the new container port, Kwangyang. Container cargo from Kangwon will head for Kwangyang port.

Pusan port will keep a comparative advantage in "Rail" taking full charge of shipping all Rail cargo from Chonbuk, Chungnam and Chungbuk.

The pattern of the inland container flow shown in Table 5.16 continues to the year 2008, maintaining all the shares in the table with only small differences.

5.4.2 The Container Traffic Allocation at Stage 3

The optimal container traffic allocation in 2009, the first year after the development project at Stage 2, is summarised in Table 5. 17. The most significant feature of the distribution of container cargo to ports at Stage 3 is a clear reallocation of container cargo towards Kwangyang. In particular, the destination of container cargo from Sudo is changed mainly from Pusan port to Kwangyang port. All container cargo from Sudo by "Road" and "Coastal Shipping" are recommended to use the route to Kwangyang port. While by "Rail", the route to Pusan port remains dominant over that to Kwangyang. Most of the container cargo from Sudo in terms of absolute quantity will be concentrated at Kwangyang port.

<Table 5.17> The Optimal Container Traffic Allocation of the Year 2009

Region	Mode*	Container Ports				Share
		Pusan		Kwangyang		
Sudo	RD	0	(0)	29.2	(100)	(100)
	RL	16.2	(63.9)	5.5	(36.1)	(100)
	CS	0	(0)	4.1	(100)	(100)
Pusan	RD	51.2	(100)	0	(0)	(100)
Kyongnam	RD	19.7	(100)	0	(0)	(100)
Kyongbuk	RD	12.9	(100)	0	(0)	(100)
Chonnam	RD	0	(0)	9.9	(100)	(100)
	RL	0	(0)	0.5	(100)	(100)
Chonbuk	RD	0	(0)	6.0	(100)	(100)
	RL	0	(0)	1.2	(100)	(100)
Chungnam	RD	0	(0)	36.5	(100)	(100)
	RL	0	(0)	1.1	(100)	(100)
Chungbuk	RD	0	(0)	3.7	(100)	(100)
	RL	0	(0)	0.6	(100)	(100)
Kangwon	RD	0	(0)	0.9	(100)	(100)
Share		100		100		

Notes: * RD= Road; RL= Rail; CS= Coastal Shipping.
The figure in brackets indicates the share of each port in the container volume originating from each region by each mode.

The remaining features will be the same as those at the previous stage. All of the container cargo from Chonnam, Chonbuk, Chungnam, Chungbuk and even Kangwon are attracted to Kwangyang port to take advantage of its geographical proximity to these regions. Pusan port obtains cargo from the eastern region of the country including Pusan, Kyongnam and Kyongbuk. These features of the optimum inland container flow continue until the year 2014 in spite of small differences of the shares as compared with Table 5.17.

5.4.3 The Container Traffic Allocation at Stage 4

According to the optimum port development project given, Gadukdo port, about 25 Km west of Pusan, is employed in the container transport system as a new container port from the year 2015. New features to the distribution of container cargo to ports will appear as shown in Table 5.18.

<Table 5.18> The Optimal Container Traffic Allocation of the Year 2015

Region	Mode*	Container Ports						
		Pusan		Kwangyang		Gadukdo		Share
Sudo	RD	12.9	(20)	15.8	(41)	26.4	(39)	(100)
	RL	0	(0)	0	(0)	37.4	(100)	(100)
	CS	0	(0)	6.9	(100)	0	(0)	(100)
Pusan	RD	69.6	(100)	0	(0)	0	(0)	(100)
Kyongnam	RD	0	(0)	0	(0)	27.9	(100)	(100)
Kyongbuk	RD	17.5	(100)	0	(0)	0	(0)	(100)
Chonnam	RD	0	(0)	13.4	(100)	0	(0)	(100)
	RL	0	(0)	0	(0)	1.2	(100)	(100)
Chonbuk	RD	0	(0)	8.1	(100)	0	(0)	(100)
	RL	0	(0)	0	(0)	3.0	(100)	(100)
Chungnam	RD	0	(0)	49.5	(100)	0	(0)	(100)
	RL	0	(0)	0	(0)	2.7	(100)	(100)
Chungbuk	RD	0	(0)	5.0	(100)	0	(0)	(100)
	RL	0	(0)	0	(0)	1.5	(100)	(100)
Kangwon	RD	0	(0)	1.3	(100)	0	(0)	(100)
Share		100		100		100		

Notes: * RD= Road; RL= Rail; CS= Coastal Shipping.
The figure in brackets indicates the share of each port in the container volume originating from each region by each mode.

We begin by examining the allocation of container cargo from Sudo. "Road" cargo from Sudo appears to be allocated over the three ports. The majority of the container cargo from Sudo by "Road" will be concentrated at Kwangyang port and Gadukdo port with the share of 41 % and 39 %, respectively. A small portion of the container cargo from Sudo by "Road" will be diverted to Gadukdo port and Pusan. The share of Gadukdo decreases from 39.0 % in 2015 to 35.5 % in 2020, while the share of Pusan increases from 20.0 % to 22.5 % over the same period. All container cargo from Sudo by "Rail" and "Coastal Shipping" will be handled outbound via Gadukdo port and Kwangyang port, respectively.

All the cargo from Pusan and Kyongbuk will be headed for Pusan port as previously. Gadukdo port takes exclusive charge of handling all the container cargo from Kyongnam which is the immediate hinterland of Gadukdo.

Container cargo from Chonnam and Chonbuk by "Road" will be handled outbound via Kwangyang port. Kwangyang port also attracts all the container cargo from Chungnam, Chungbuk and Kangwon by "Road". All of the container cargo from Chonnam, Chonbuk, Chungnam, Chungbuk and Kangwon by "Rail" will be collected at Gadukdo port.

Pusan port is expected to remain the main port for the eastern regions of the country including Pusan and Kyongbuk. Kwangyang port will emerge as the main port for Sudo and the western regions of the country including Chonnam and Chonbuk. Gadukdo port will be given priority for handling the cargo by "Rail" from all regions.

These are the dominant features of the optimum inland container flow up to the year 2020 despite small differences as compared with the shares shown in Table 5.18.

Appendix 5.3 Computation of the Model Incorporating Terminal Congestion Cost

Appendix 5.3.1 Introduction

As assumed in Chapter 2.4.2.1, if total export container traffic demand is greater than total theoretical design capacity, all the terminals have to manage the over-loaded traffic in proportion to their handling capacities. It is recognised that additional costs will be created at new ports in this situation. If the total demand is less than total capacity, the solution is found using a dummy region. The allowance to be assigned to the dummy region is ignored by this model. Thus, benefits due to the sufficient port facilities are excluded in our model. We have already defined the additional cost as terminal congestion cost in Appendix 4.3.3. The objective of this Appendix is to present the results of the implementation and computation for the model adding terminal congestion cost to the total system costs measurement criteria.

Appendix 5.3.2 Stage 1

The functional relationship between the level of over-burdened handling capacity and the unit congestion cost at terminal has been discussed in Appendix 4.3.3. The functional relationship of congestion is based on the Pusan experience. It is unreasonable to suppose that a relatively new port will experience the same congestion costs as an existing port. It is necessary to adopt the difference of the terminal congestion cost per TEU by ports. Thus, in the case of every alternative at stage 1, terminal congestion costs per TEU at Kwangyang and Gadukdo are assumed to be 30% that of Pusan, as estimated in Appendix 4.3.3, because of their relatively modern facilities and efficient control system. Thus, the terminal congestion costs every year are calculated by using the functional relationships in Appendix 4.3.3.2 and the preceding assumptions. All the terminal congestion costs at the port terminal are also converted into 1997 present values using $i = 10\ \%$ as shown in Table A.5.1. The blank columns in the table indicate cases where the total demand is less than the total handling capacity in ports which are ignored by this model, as assumed above.

<Table A.5.1> Present Values for Terminal Congestion Costs by Investment Alternatives at Stage 1

Year	Alternative			
	1	2	3	4
2003				
2004				
2005				
2006				
2007	1.18	1.28		
2008	1.91	2.06	2.18	
Total	3.09	3.35	2.18	0

Notes: * All figures in $ million

First, a set of alternatives are chosen which satisfy Stage 1's budget constraint of $ 2.5 billion. Among them, the four alternatives with the most possible berths are selected. The present value of all the costs associated with each alternative have been calculated in Table A.5.2.

<Table A.5.2 > Present Value of System Costs by Investment Alternatives at Stage 1

Cost	Alternative			
	1	2	3	4
TC	278.3	271.4	270.0	268.7
QC	0.31	0.33	0.22	0
SC	159.6	114.3	142.9	171.5
Total	438.1	386.1	413.1	440.2

Notes: * TC = Total Inland Transport Costs; QC = Terminal Congestion Costs;
SC = Construction Costs.
** All figures in $ ten million

We are now ready to begin comparing investment alternatives on the basis of economic considerations. However, these calculations are not for the whole period but for Stage 1 only and no decision has made yet based on this stage only.

Appendix 5.3.3 Stage 2

The procedure for computing system costs according to alternatives at Stage 2 is similar to that of Stage 1. There are, however, some differences in the assumptions. For example, the differences in severity of congestion in port must be considered. The terminal congestion cost function is estimated based on the Pusan experience in Chapter 4.3.2. In spite of new, more advanced ports, coping with huge amounts of container cargo without experience is difficult. It is considered that unit terminal congestion costs by new container ports are varied depending on the quantity of the additional container port capacity. Thus, unit terminal congestion costs by new ports are made in proportion to the Pusan case. The following table indicates the estimated proportions by new ports which correspond to alternatives at Stage 2.

< Table A.5.3> Unit Terminal Congestion Costs in Ports by Alternatives at Stage 2 as % of Pusan

Alternative	Unit Terminal Congestion Cost (Pusan = 100)	
I_2	Kwangyang	Gadukdo
1	30	40
2	30	30
3	40	30
4	40	30
5	40	0
6	50	0
7	0	40

Under these assumptions, the present value of system costs according to alternatives at Stage 2 are shown in Table A.5.4 and we see that the system cost of a given alternative at Stage 2 varies with the input into Stage 2. Again we report 1997 present value using i = 10 %.

<Table A.5.4> Present Value for System Costs by Alternatives at Stage 2

Alternative I_2	The Input to Stage 2, K_2			
	1	2	3	4
1	3.69	3.65	3.76	3.63
2	3.54	3.50	3.51	3.48
3	3.39	3.35	3.33	3.33
4	3.54	3.50	3.50	-
5	2.94	2.91	2.90	-
6	3.10	3.07	-	-
7	3.71	3.65	3.64	3.63

Notes: All figures in $ billion

A table is again used to help identify the optimal decision. Since the input to Stage 2, K_2, is unknown, we have to consider all possible states at Stage 1. In addition, all possible proposed I_2 have to be considered. The entries under the heading $V_2(K_2, I_2) + X_1(K_1)$ represent the total system costs over both stages, given the inputs K_2 and the decision I_2. The total system costs are transformed to 1997 present value using $i = 10\,\%$.

<Table A.5.5> Present Value of Total System Costs by Alternatives to Stage2

Alternative I_2	$V_2(K_2, I_2) + X_1(K_1)$ The Input to Stage 2, K_2			
	1	2	3	4
1	8.08	7.51	7.90	8.03
2	7.93	7.36	7.64	7.88
3	7.78	7.21	7.47	7.74
4	7.93	7.36	7.63	-
5	7.33	6.77	7.04	-
6	7.48	6.93	-	-
7	8.09	7.51	7.77	8.03

Notes: All figures in $ billion

Appendix 5.3.4. Stage 3

The calculation of costs associated with alternatives at Stage 3 is carried out in the same way as for the previous stage. However, some assumptions on the severity of congestion in ports are again changed. Thus, unit terminal congestion costs by new ports are calculated in proportion to the Pusan case summarised in Table A.5.6.

< Table A.5.6> Unit Terminal Congestion Costs in Ports by Alternatives at Stage 3 as % of Pusan

Alternative	Unit Terminal Congestion Cost (Pusan = 100)	
I_3	Kwangyang	Gadukdo
(0,4,6)	20	20
(0,4,8)	20	30
(0,4,10)	20	50
(0,4,12)	20	50
(0,6,6)	20	20
(0,6,8)	20	30
(0,6,10)	20	50
(0,8,4)	30	20
(0,8,6)	30	20
(0,10,4)	50	20
(0,10,6)	50	20
(0,12,4)	50	20
(0,16,0)	70	0
(0,0,10)	0	50
(0,0,12)	0	50
(0,0,14)	0	60
(0,0,16)	0	70

Notes: The figures in brackets are additional berths at Pusan, Kwangyang, Gadukdo, at each stage.

Under these assumptions, the system costs corresponding to alternatives at Stage 3 are shown in Table A.5.7. The system cost of a given alternative at Stage 3 varies with the input into Stage 3. As in the previous stage, system costs are transformed into 1997 present values using $i = 10$ %.

<Table A.5.7> Present Value of System Costs by Alternatives at Stage 3

The output of Stage 1, K_2	The output of Stage 2, K_3	The decision state of Stage3, I_3	The Total Costs*
(0,4,4,)	(0,8,12)	(0,10,4)	2.43
		(0,8,6)	2.51
		(0,6,8)	2.60
	(0,10,10)	(0,10,4)	2.41
		(0,8,6)	2.50
		(0,6,8)	2.58
		(0,4.10)	2.67
	(0,12,8)	(0,8,6)	2.48
		(0,6,8)	2.60
	(0,14,8)	(0,6,6)	2.39
		(0,4,8)	2.48
	(0,14,4)	(0,6,10)	2.72
		(0,4,12)	2.80
	(0,16,4)	(0,4,10)	2.63
	(0,4,14)	(0,16,0)	2.36
		(0,12,4)	2.53
		(0,10,6)	2.61
(0,8,0)	(0,12,8)	(0,8,6)	2.48
		(0,6,8)	2.57
		(0,4,10)	2.65
	(0,14,6)	(0,6,8)	2.56
		(0,4,10)	2.64
	(0,16,4)	(0,4,10)	2.63
		(0,0,14)	2.80
	(0,18,4)	(0,0,12)	2.62
	(0,18,0)	(0,0,16)	2.95
	(0,20,0)	(0,0,14)	2.77
	(0,8,10)	(0,10,6)	2.59
		(0,12,4)	2.50
(0,10,0)	(0,14,8)	(0,6,6)	2.39
		(0,4,8)	2.48
		(0,0,12)	2.65
	(0,16,6)	(0,4,8)	2.46
		(0,0,12)	2.63
	(0,18,4)	(0,0,12)	2.62
	(0,20,4)	(0,0,10)	2.45
	(0,20,0)	(0,0,14)	2.77
	(0,10,10)	(0,10,4)	2.41
		(0,8,6)	2.50
		(0,6,8)	2.58
		(0,4,10)	2.67
(0,12,0)	(0,16,8)	(0,4,6)	2.30
		(0,0,10)	2.47
	(0,18,6)	(0,0,10)	2.46
	(0,20,4)	(0,0,10)	2.45
	(0,12,10)	(0,8,4)	2.32
		(0,6,6)	2.41
		(0,4,8)	2.49

Notes: The figures in brackets are additional berths at Pusan, Kwangyang, Gadukdo, at each stage.
* All figures in $ billion

Appendix 5.3.5 Comparison of Total System Costs

The calculation of total system costs up to Stage 3 followed the same procedures as in the case of the model without a terminal congestion cost category. Table A.5.8 provides the total system costs of all stages previously considered under Scenario 1, 2, 3 and 4 using $i = 10$ %. Successively, the total system costs of all stages under Scenario 4 using $i = 7$ %, $i = 10$ % and $i = 13$ % are presented in Table A.5.9.

We have repeated the computation for the model under the four scenarios adopting the three interest rates to compare with the model without a terminal congestion cost category. The inclusion of terminal congestion costs does not change the ranking of the top five optimal alternatives. This is because the absolute values of terminal congestion costs are comparatively small compared with the absolute values of inland transport costs and construction costs. The differences of terminal congestion costs between alternatives are not significant enough to affect the ranking of total system costs. Thus, the results show that inland transport costs and construction costs are the most decisive factors of those we have considered

<Table A.5.8> Present Value of Total System Costs by Alternatives up to Stage 3 on the different Scenarios

The output of Stage 1, K_2	The decision state of Stage 2, I_2	The decision state of Stage3, I_3	Total System Costs* Scenario			
			1	2	3	4
(0,4,4,)	(0,4,8)	(0,10,4)	10.50	10.47	10.35	10.32
		(0,8,6)	10.59	10.55	10.43	10.40
		(0,6,8)	10.67	10.64	10.52	10.49
	(0,6,6)	(0,10,4)	10.34	10.30	10.19	10.15
		(0,8,6)	10.42	10.39	10.27	10.24
		(0,6,8)	10.51	10.47	10.36	10.32
		(0,4.10)	10.59	10.56	10.44	10.41
	(0,8,4)	(0,8,6)	10.26	10.23	10.11	10.07
		(0,6,8)	10.35	10.31	10.19	10.16
	(0,10,4)	(0,6,6)	10.32	10.28	10.17	10.13
		(0,4,8)	10.40	10.37	10.25	10.22
	(0,10,0)	(0,6,10)	10.05	10.01	9.90	9.86
		(0,4,12)	10.13	10.10	9.98	9.95
	(0,12,0)	(0,4,10)	10.11	10.07	9.96	9.92
	(0,0,10)	(0,16,0)	10.45	10.42	10.30	10.26
		(0,12,4)	10.62	10.59	10.47	10.43
		(0,10,6)	10.71	10.67	10.55	10.52
(0,8,0)	(0,4,8)	(0,8,6)	9.99	9.96	9.85	9.81
		(0,6,8)	10.08	10.05	9.93	9.90
		(0,4,10)	10.16	10.13	10.02	9.98
	(0,6,6)	(0,6,8)	9.92	9.88	9.77	9.73
		(0,4,10)	10.00	9.97	9.85	9.82
	(0,8,4)	(0,4,10)	9.84	9.81	9.69	9.66
		(0,0,14)	10.01	9.98	9.86	9.83
	(0,10,4)	(0,0,12)	9.99	9.95	9.84	9.81
	(0,10,0)	(0,0,16)	9.72	9.69	9.58	9.55
	(0,12,0)	(0,0,14)	9.70	9.67	9.56	9.53
	(0,0,10)	(0,10,6)	10.10	10.07	9.95	9.92
		(0,12,4)	10.02	9.98	9.87	9.83
(0,10,0)	(0,4,8)	(0,6,6)	10.16	10.13	10.01	9.98
		(0,4,8)	10.25	10.21	10.10	10.06
		(0,0,12)	10.42	10.38	10.27	10.23
	(0,6,6)	(0,4,8)	10.09	10.05	9.94	9.90
		(0,0,12)	10.26	10.22	10.11	10.07
	(0,8,4)	(0,0,12)	10.09	10.06	9.95	9.92
	(0,10,4)	(0,0,10)	10.07	10.04	9.93	9.90
	(0,10,0)	(0,0,14)	9.81	9.77	9.67	9.64
	(0,0,10)	(0,10,4)	10.18	10.15	10.03	9.99
		(0,8,6)	10.27	10.23	10.12	10.08
		(0,6,8)	10.35	10.32	10.20	10.17
		(0,4,10)	10.44	10.40	10.29	10.25
(0,12,0)	(0,4,8)	(0,4,6)	10.33	10.30	10.18	10.15
		(0,0,10)	10.50	10.47	10.35	10.32
	(0,6,6)	(0,0,10)	10.34	10.31	10.19	10.16
	(0,8,4)	(0,0,10)	10.18	10.15	10.04	10.01
	(0,0,10)	(0,8,4)	10.35	10.31	10.20	10.16
		(0,6,6)	10.43	10.40	10.28	10.25
		(0,4,8)	10.52	10.48	10.37	10.33

Notes: The figures in brackets are additional berths at Pusan, Kwangyang, Gadukdo, at each stage.

* All figures in $ billion

<Table A.5.9> Present Value of Total System Costs by Alternatives up to Stage 3 on the different Interest Rates

The output of Stage 1, K_2	The decision state of Stage 2, I_2	The decision state of Stage3, I_3	Total System Costs* $i = 7\%$	$i = 10\%$	$i = 13\%$
(0,4,4,)	(0,4,8)	(0,10,4)	14.53	10.32	7.58
		(0,8,6)	14.67	10.40	7.63
		(0,6,8)	14.80	10.49	7.69
	(0,6,6)	(0,10,4)	14.31	10.15	7.45
		(0,8,6)	14.44	10.24	7.51
		(0,6,8)	14.58	10.32	7.56
		(0,4.10)	14.71	10.41	7.62
	(0,8,4)	(0,8,6)	14.22	10.07	7.39
		(0,6,8)	14.35	10.16	7.44
	(0,10,4)	(0,6,6)	14.27	10.13	7.45
		(0,4,8)	14.41	10.22	7.50
	(0,10,0)	(0,6,10)	13.99	9.86	7.20
		(0,4,12)	14.13	9.95	7.25
	(0,12,0)	(0,4,10)	14.05	9.92	7.26
	(0,0,10)	(0,16,0)	14.46	10.26	7.54
		(0,12,4)	14.73	10.43	7.65
		(0,10,6)	14.86	10.52	7.71
(0,8,0)	(0,4,8)	(0,8,6)	13.97	9.81	7.12
		(0,6,8)	14.10	9.90	7.18
		(0,4,10)	14.24	9.98	7.23
	(0,6,6)	(0,6,8)	13.88	9.73	7.05
		(0,4,10)	14.01	9.82	7.11
	(0,8,4)	(0,4,10)	13.80	9.66	6.99
		(0,0,14)	14.06	9.83	7.10
	(0,10,4)	(0,0,12)	13.99	9.81	7.11
	(0,10,0)	(0,0,16)	13.73	9.55	6.87
	(0,12,0)	(0,0,14)	13.66	9.53	6.87
	(0,0,10)	(0,10,6)	14.14	9.92	7.18
		(0,12,4)	14.00	9.83	7.13
(0,10,0)	(0,4,8)	(0,6,6)	14.10	9.98	7.30
		(0,4,8)	14.24	10.06	7.36
		(0,0,12)	14.50	10.23	7.47
	(0,6,6)	(0,4,8)	14.29	10.07	7.35
		(0,0,12)	14.02	9.90	7.24
	(0,8,4)	(0,0,12)	14.07	9.92	7.23
	(0,10,4)	(0,0,10)	14.00	9.90	7.24
	(0,10,0)	(0,0,14)	13.74	9.64	7.00
	(0,0,10)	(0,10,4)	14.14	9.99	7.31
		(0,8,6)	14.27	10.08	7.37
		(0,6,8)	14.41	10.17	7.42
		(0,4,10)	14.54	10.25	7.48
(0,12,0)	(0,4,8)	(0,4,6)	14.25	10.15	7.49
		(0,0,10)	14.51	10.32	7.60
	(0,6,6)	(0,0,10)	14.30	10.16	7.48
	(0,8,4)	(0,0,10)	14.09	10.01	7.36
	(0,0,10)	(0,8,4)	14.28	10.16	7.50
		(0,6,6)	14.41	10.25	7.55
		(0,4,8)	14.54	10.33	7.60

Notes: The figures in brackets are additional berths at Pusan, Kwangyang, Gadukdo, at each stage.
* All figures in $ billion

Chapter 6

Concluding Remarks

6.1 Summary of the Study

Purpose and Methodology

In the thesis, the systems approach has been applied in order to identify a sensible and tractable infrastructure development plan for the inland container transport system in Korea. It begins with the discussion on how best to define the systems approach with the aim of developing practical solutions to the policy maker's decision problem. The problem of optimising container port investment involves consideration of a very large number of logically possible investment proposals with a correspondingly large computational burden. In order to circumvent this problem, a heuristic algorithm was adopted, making it impossible to guarantee that this model yields the exact optimal solution. The distinctiveness of the thesis lies in its demonstration of the usefulness and pragmatism of a solution algorithm to the container network problem by way of matching mathematically a framework for dynamic programming with a linear programming mechanism. Additionally, the dynamic characteristics of parameters have been taken into account in the mathematical model formulation.

The overall inland container transport system model consists of three sub-models: projection of future total export container demand, the Inland Container Traffic Allocation model and the Optimum Port Capacity model.

The whole period concerned was divided into a number of sub-periods. At each sub-period, a set of feasible alternatives which depend on various constraints e.g. the budget available to the programme, were formed. On the basis of a number of feasible investment alternatives and the demands obtained in the first sub-model, total system costs are calculated through the optimum port capacity model, and the inland container traffic allocation model. The equations of the latter are treated as a linear programming problem. Thus, the inland container traffic allocation model defines the optimal inland container transport flow for a given container port development which in turn is optimised by the optimum port capacity model.

The results and recommendations of each of the previous chapters will be briefly reviewed with some suggestions for future research.

Projecting Growth of Container Traffic in Korea

One of the most crucial factors in transportation systems planning is projecting future demand. In Chapter 3, this study attempts to make projections of the demand for container traffic for export originating in Korea over the period. Because of inadequate past data, decision analysis has been used as a forecasting method instead of more formal quantitative methods such as regression analysis. The approach involved the identification of those leading indicators which are thought to reflect the change of aggregate economic conditions which precede or lead to changes in container traffic trends. It was noted that in terms of the aggregate merchandise export volume, historical developments in Japan are similar to the present in Korea. Consequently, the future progress of the Korean indicators can be anticipated on the basis of comparison with Japanese developments. Thus, a set of scenarios on the gap between the two countries' respective progress were formed and a projection of future container traffic demand was chosen by adopting the likeliest scenario. This national demand for container traffic was disaggregated into regional container traffic by using the share of each region's container traffic within the total national container traffic where these shares at each period reflected expected regional economic growth.

This procedure suggests that the demand for container cargo for export in Korea can be expected to reach 3 million TEU in 2001, exceed 5 million TEU in 2009 and will account for 7.2 million TEU in 2016. The results of the regional distribution exercise show that the share of Sudo's export container cargo to total export volume will decrease from 47 % in 1994 to 30 % in 2005. The country's dependence on Kyongsang province - especially, the regions of Kyongbuk and Kyongnam will decrease, while the share of the provinces which make up the middle of the country - Chungbuk, Chungnam and Chonbuk regions, will increase. In short, the current concentration of Sudo and Kyongsang province will be relieved and the origins of container cargoes for export will then be comparatively more evenly distributed throughout the country.

Optimising Korean Port Development

Chapter 4 and Chapter 5 present the application of the model to the actual inland container transport system in Korea. Total system costs were chosen as the objective function to be minimised. These system costs are composed of inland transport costs and construction costs. Additionally, terminal congestion costs were considered and incorporated to the total system costs.

Much of Chapter 4 was devoted to estimating unit cost per TEU for each type of activity. The results of this were as follows:

(a) Using raw data from cost-based analyses of O/Ds by transport modes executed by a leading transport company, inland transportation costs by modes were estimated. In addition, estimates were made of congestion costs for the road transport mode on certain routes. This was based on another set of raw data which describes the severity of delay by different sections on the main motorway. Thus, total inland transport costs by transport modes show the following: For Sudo region's container cargo, Rail is competitive over other modes and Road is the most costly mode. The routes from Sudo region to Kwangyang port have the lowest cost regardless of which transport mode is employed. For container cargoes from Kyongsang province which consists of Pusan, Kyongbuk and Kyongnam, the port of Kwangyang does not seem to appeal irrespective of mode. For the other regions - Chungbuk, Chungnam, Chonbuk, Chonnam and Kangwon, Rail is more competitive than Road and any route between Kwangyang port and these regions is less costly than that between other ports and regions.

(b) Estimates of construction cost at different ports were based on data from the investment proposals contained in "New Container Port Plan" published by the KMI[54]. The investment proposals include details ranging from foundation engineering work costs to terminal construction costs. The construction cost data were converted into construction cost per berth. The results are that unit construction cost at Gadukdo port is higher than at Kwangyang port. This is largely

[54] Office of Maritime & Port Authority, 1996, A Study on the Investment Plan for New Port Development in Korea, Seoul.

because development at Gadukdo requires considerable foreshore reclamation work and foundation consolidation work.

Total system costs were calculated by using a framework which combined linear programming and dynamic programming on the basis of the feasible alternatives at each stage and were converted to 1997 present value at 1995 prices. The investment plan with the lowest total system costs was identified as the optimal container port investment scheme. For illustrative purposes, the top five optimal alternatives were identified. These show that Kwangyang port should be given priority over other ports for new container port development. That is, only after Kwangyang port has been developed completely, should Gadukdo development follow. Additionally, the model has been run under different assumptions for annual growth rates of Rail and Coastal Shipping and for different interest rates, but this resulted in no change in the top five optimal alternatives except at a higher interest rate i.e. 13 %. However, even here the change does not seem to be very significant since Kwangyang maintains its priority over Gadukdo in all circumstances.

Inland Container Flows

The optimum container traffic allocation model employs the outputs of the optimum port investment model as inputs in order to yield the optimum inland container traffic allocation year by year. The best overall container port development is the configuration that recommends building 8 berths in Kwangyang port from 1997 to 2002, and subsequently, 12 berths in Kwangyang port from 2003 to 2008 and then 14 berths in Gadukdo port from 2009 to 2014. On the basis of this configuration the predicted optimal inland container traffic flows over the period are as follows:

For the container cargoes from Sudo by Road, Kwangyang port will attract the majority of the container cargo from the beginning but with the entry of Gadukdo after 2014, part of the traffic will switch to Gadukdo. Container cargoes from Sudo by Rail and Coastal Shipping will head for Pusan, but as soon as Gadukdo port starts its service, Gadukdo will take over all container cargoes by Rail. Container cargoes from Pusan, Kyongnam and Kyongbuk, will flow exclusively through Pusan and Gadukdo. Container cargoes from other regions by Road will be handled at Kwangyang ports. Once developed, Gadukdo will become specialised in accommodating cargoes by Rail. The delay in developing Gadukdo until 2014 is explained by the fact that construction costs at Gadukdo are much the highest of the alternative ports. Thus, despite Gadukdo's comparative advantage in servicing rail-carried cargo, development there is not justified until cheaper construction alternatives are exhausted.

6.2 Some Thoughts for Further Studies

The aim of the thesis has been to develop a practical solution to a practical problem facing Korea. In order to arrive at a concrete solution a number of assumptions and "short-cuts" have been employed. Further study might be aimed at examining the consequences of relaxing some of the special assumptions employed here. An example is the treatment of inland modal split. Here, it was assumed that the mode of inland transport between origin and destination was determined by capacities except for the core of road which acted as a residual. The results were checked for sensitivity to different assumptions about the growth of Rail and Coastal Shipping capacity. A more satisfactory approach would be to model modal split explicitly as an optimising problem.

At a deeper level possible extensions to the thesis include;

(a) This study runs the inland container transport model with deterministic data despite the fact that there is much uncertainty regarding many of the factors relevant to decision making. A standard textbook approach to decision-making under uncertainty would specify a policy-maker objective function and maximise (or minimise) its expected value subject to relevant constraints. Here the objective function has been identified as system costs but the problem with using an expected value approach lies in the inability to accurately specify all possible future states of the world and their associated probabilities. Since this can not be done, the alternative adopted here is to use a deterministic approach supplemented by sensitivity analysis to test the robustness of the optimal solution with respect to the variability of certain key assumption about future developments.

(b) The objective function used here has been total system costs. The system costs consist of inland transport cost, construction cost and terminal congestion cost. The results show that the first two categories are the most decisive factors within this model. At the beginning of this study, benefit-cost analysis was considered but was not pursued because placing a monetary figure on certain social benefits was difficult.

Typically, the direct benefits of a port infrastructure investment accrue to users in the forms of faster handling, reduced transit times, improved access and so on. These physical benefits are translated into reduced transport costs and ultimately into lower prices for goods and services. Thus, ultimately the benefits accrue in the form of higher consumers surplus (or higher profits, if transport cost reductions are not passed on). To the extent that benefits accrue in the form of reduced transport costs the cost minimisation approach captures them anyway. There may be additional, indirect, benefits in the forms of generated traffic and a positive impact on the growth of the local and national economy. These effects are difficult to predict and measure and are left out in the cost minimisation approach. However, leaving these effects out may be justified in this case because each of the alternatives are likely to have similar levels of indirect effects. Thus, the approach followed here corresponds to what White (1998) calls the cost effectiveness approach which is a useful technique for deciding between projects or systems for the accomplishment of certain goals[55].

(c)There are many interested parties in container network development such as a variety of transport operators, local port authorities, local government, shippers, etc. Typically, they may have no common interests, and in fact they may have a conflict of interest. However, this conflict aspect has been ignored in this study. That is, the system has been viewed from the viewpoint of a social planner whose aim is to optimise the performance of the entire system rather than to optimise any individual component. If a country has the favoured path for container port development as Multi-port system instead of one Mega port system, then ultimately these ports might find themselves in a competitive situation. Therefore, further research might investigate the relationship of interested parties and form a mathematical model by using game theory which deals with the general features of competitive situations like this in a formal and abstract way.

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[55] White, J. A., K.E. Case, D.B. Pratt and M. H. Agee, 1998, *Principles of Engineering Economic Analysis* (4th ed), New York, John Wiley & Sons, p.337-346

(d) A follow up to this study might be to estimate what the actual performance of the system once it is in operation by means of a simulation model. This might be done by reducing the real system to a set of components linked together by a master flow diagram. After specifying these elements and logical linkages, the model could be tested. This study might be thought of as executing as the initial stage of such a simulation.

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