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Title

A SYSTEMS APPROACH TO CARIBBEAN TRANSPORT PLANNING

Degree Sought

This thesis is being submitted to the University of Aston in Birmingham in support of a Master of Science degree in inter-disciplinary research.

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Every ultimate fact is but
the first of a new series and
every general law a particular
fact of some more general law
presently to disclose itself.

Ralph Waldo Emerson

FOREWORD

In late 1967 E-A Space and Advanced Military Systems Limited (EASAMS), examined how best its experience, gained in the military and space fields, could be applied to the benefit of the civil market.

After a short period of in-house study, it was decided that the company's experience in operational research, system design and project management could have a direct application to the field of transport planning. It soon became clear that there was a world wide need for methods of making investment decisions based on the best available predictions of the changing transport and economic environment. It was therefore decided to embark on a programme of research to develop such methods. This report is the outcome, and illustrates the application of the systems approach to the planning and investment needed to improve the sea transport system (ships and ports) serving a group of developing islands in the Caribbean.

This research was pursued through the Interdisciplinary Higher Degree scheme of the University of Aston in Birmingham; the candidate being supervised both by the University and the sponsoring company. In this case, responsibility for the complete project was delegated to two main and two associate supervisors to whom the candidate would report. They were:-

Professor E. S. Kirby of the University of Aston

D. J. Cashmore of E-A Space and Advanced Military Systems Ltd.

G. R. Lindfield of the Computer Centre at the University

J. C. Watt of the Department of Industrial Administration at the University

This report has been written as a thesis and presents the author's account of his programme of research. The author has asked me to express his sincere gratitude to his university supervisors for their stimulus, assistance and criticism received during the course of the study, to his company for its support, and to the various individuals and organisations who have given invaluable co-operation.

September 1971 D. J. CASHMORE

SUMMARY

This study shows how a system's approach was used to produce a methodology which could be used to derive a time-phased transport investment programme for the countries within the Caribbean Free Trade Association (CARIFTA). These comprise ten islands and mainland Guyana which are largely served by a few ships under a Regional Shipping Council. To enable port and shipping improvements to be designed by the Council in collaboration with the port authorities, this methodology combines a linear programming transport model with a demand model (which is assumed to be used by the island's economic planners).

A transport model was developed to minimise the cost of inter-island transport operation by selecting a pattern of regional shipping routes to permit the movement of intra-regional trade. The transport model only uses existing categories of data provided by the demand model and the port and shipping authorities to select :

- the shipping routes to be followed
- the allocation of commodity flows to each selected route
- the number of ship-journeys required over each route.

The model also identifies the effect on the cost of transport operation resulting from a change in shipping or port facilities. In this methodology, this information is fed back to both port and shipping authorities.

Trial runs with the model showed that while a direct annual cost saving of only 5% could be achieved with current levels of trade, it does show how the pattern of shipping routes can be improved to avoid the need to invest in additional ships and port facilities. Thus, a considerable longer term saving could result

by using it as an investment planning model where time-phased transport investment plans would be derived over a number of time periods in conjunction with the economic planners in the region.

ACKNOWLEDGEMENT

The material in this report, while primarily reflecting work undertaken within EASAMS Ltd. by the author, while an external student of the University of Aston in Birmingham, would not have been possible without the cooperation and assistance provided by a number of organisations.

The author is particularly indebted to the following :-

M. A. Nicolson of Booker McConnell, who provided samples of a ship manifest, prepared a sample voyage account, and who checked many of the assumptions on which the transport model is based.

Dr. Cracknell of the Overseas Development Authority who directed me to a study of the economy of Dominica and M. D. Kingston of the British Development Division in the Caribbean, who provided much of the associated data.

The West India Committee, who identified and made available numerous documents on the Commonwealth Caribbean.

B. Martin, Transport Director of the Greater London Council and Professor P. O. Roberts of Harvard University who provided details of their transport planning work in Colombia.

Dr. Paauw , Director of the National Planning Association in Washington, who discussed the problems he had identified in undertaking a not dissimilar study in Indonesia.

Due to the difficulties of obtaining data on the Caribbean, it is possible that errors of fact, in addition to drafting errors, may be found. The author of course accepts full responsibility for these mistakes.

CONTENTS

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C ONTENTS (continued)

LIST OF TABLES

NUMBER

LIST OF TABLES (continued)

LIST OF FIGURES

NUMBER

LIST OF SYMBOLS (continued)

Notation	Meaning
${}_{mn}X_i$	The input from region "m" to region "n" of the i^{th} commodity
${}_{n}R_i$	The total commodity of type "i" imported to region "n" from all regions
${}_{m}X_i$	The output of commodity "i" in region "m"
${}_{mn}Q_i$	A constant, estimated from base year data
M_i	The total imports of type "i" commodities
E_i	The exports from the i^{th} sector
F	Non-competing imports
f_i	The non-competing imports coefficient into the i^{th} industry
$Y(f)$	The final demand for non-competing imports
m_{ii}	A combination technical-market share coefficient
M_{ii}	Competing imports of the i^{th} type to the i^{th} industry
$\hat{m}_i$	A market share coefficient
h_{ii}	The input coefficient of home produced sales of commodity "i" to the i^{th} industry
$Y(h)_i$	Home final demand for the output of the i^{th} sector
$Y(m)_i$	The final demand for competing imports of the i^{th} type
M_{ij}	The value of competing imports of the i^{th} type to the j^{th} sector
B_c	The value/weight ratio of the c^{th} commodity
D_{ic}	The proportion of imports to the i^{th} sector consisting of commodities of the c^{th} type
e	A transport elasticity
W	The weight of a commodity
V	The volume of a commodity

LIST OF SYMBOLS*

Notation	Meaning
CA	Annual capital cost of ship
MX	Manning costs - X men at £M per man
NJ_k	Number of journeys per annum per ship over route "k"
D_k	Sailing distance over route "k"
CS	Cost of fuel per mile at service speed
TP_k	The total time spent in port in completing route "k"
CF	Cost of fuel in port per day
CPB_k	Port charges and berth rental costs incurred in completing route "k"
SH	The number of ships within the region
CT	The total annual cost of transport system provision
V_k	The cost per ship-journey over route "k"
v_{ij}	The revenue derived from shipping 1 ton of cargo from port "i" to port "j" over route "k"
a_{ij}	The tonnage of cargo to be exported from the i^{th} port to the j^{th} port of the system
NS_k	The number of ship-journeys over route "k"
T_k	The total single journey time over route "k", (in days)
TM	Time margin allowed
u	Ship speed (in knots)
C_k	The capacity of the ship assumed to operate over route "k"
a_{ijk}	That tonnage of cargo moved from port "i" to port "j" over route "k"
v_{ijk}	The cost of moving one ton from port "i" to port "j" over route "k"

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* These symbols are listed in the order in which they appear in the text.

LIST OF SYMBOLS (continued)

Notation	Meaning
$NSMAX_k$	The maximum number of ship journeys that can be completed by one ship in one year over route "k"
$a_{ij}^{(A)}$	The volume of cargo to be exported from port "i" to port "j" using facilities type (A)
$P_i^{(A)}$	The cargo handling capacity of origin port "i" in tons for ship of type (A) over the time period considered by the model
R_i	The set of routes serving the i^{th} port
μ_{Ak}	A factor, to indicate the possibility of ship type A docking at those ports served by route "k"
$S_i^{(A)}$	The ship-docking capacity at origin "i" over the time described by the model, in number of ships of type (A)
Z	The objective function
x_i	The i^{th} unknown
b_i	The i^{th} constraint
β_{ik}	The inverse coefficient of the i^{th} row and the k^{th} column
a	The vector of the amounts of cargo to be exported between each of the ports in the region
P	The vector of the port cargo handling capacities
S	The vector of ship docking capacities
π	The vector of simplex multipliers
ϵ_{ij}	The maximal error of estimate at the $(100 - 2\alpha)\%$ confidence level
n	The number of ports in a group of ports
N	The total number of ports in the region
H	The number of home ports
h	The number of home ports selected for inclusion in the group of ports
Q_i	The investment and operating cost of the i^{th} facility over the period considered

LIST OF SYMBOLS (continued)

Notation	Meaning
Y_i	The i^{th} facility, expressed as a (0, 1) integer
Y_{sh}	The ship, expressed as a (0, 1) integer
a_{ijm}	The tonnage of cargo to be exported from the i^{th} port to the j^{th} port of the system over mode "m"
a_{ijkm}	The tonnage of cargo to be exported from the i^{th} port to the j^{th} port of the system over route "k" of mode "m"
TR_{ijk}	The volume of traffic transferred from route "k" to another mode over the arc (i, j)
θ	The number of years
α_{ij}	The annual rate of increase of the "a_{ij}" flow of cargo
t_o	The base year (year zero)
a_{ijmt}	The tonnage of cargo to be exported from the i^{th} port to the j^{th} port of the system over mode "m" in year "t"
X_i	The total output of the i^{th} industry
X_{ij}	The demand by sector "j" for part of the output of the i^{th} sector
Y_i	The final demand for the output of the i^{th} sector
I	The unit or identity matrix
${}_pX_i$	The total output of the commodity produced by industry "i" in region "p"
${}_{pq}Y_i$	The final demand for industry "i" in region "q" met from region "p"
${}_{pq}a_{ij}$	The proportion of the output of sector "i" in region "p" consumed per unit of output of sector "j" in region "q"
${}_{pq}X_{ij}$	The delivery from industry "i" in region "p" to industry "j" in region "q"
${}_{pq}A_{ij}$	The elements of the inverse of the matrix of coefficients in the left hand side of the system
${}_qX_{ij}$	The input to the j^{th} industry in region "q" from the i^{th} industry in all regions
${}_qX_j$	The output of the j^{th} industry in region "q"

LIST OF SYMBOLS (continued)

Notation	Meaning
${}_{pq}t_i$	The proportion of inputs to all industries in region "q" received from region "p"
${}_{pq}X_i$	The inputs to all industries in region "q" from industry "i" in region "p"
${}_{q}R_i$	The total inputs from all regions of the i^{th} type of commodities to region "q"
X_n	The total output of the national industries
Y_n	The final demand for national commodities
${}_{p}X_n$	The production of X_n in region "p"
${}_{p}C_n$	That amount of X_n produced in region "p" per unit of X_n
Y_i^r	The final demand for the output of sector "i" by region "r"
K_i^r	The maximum amount of sector "i" which can be produced in region "r" per unit of time
L^r	The maximum amount of labour which the final demand sector (region "r") is able to supply
a_{ij}^p	That amount of sector "i" that is required to produce a unit of "j" in region "p"
${}_{i}v_j^{pq}$	The amount of sector "i" required to transport a unit of sector "j" from region "p" to region "q"
S_i^{pq}	The shipment of sector "i" between region "p" and region "q"
x_i^p	The output of sector "i" in region "p" which consists of the direct and indirect requirements necessary to satisfy the given regional final demands
x_i^r	The output of sector "i" in region "r"
m_i^r	The imports to region "r" of the i^{th} type
e_i^r	The exports of region "r" of the i^{th} type
n_i^r	The intermediate demand for the output of sector "i" in region "r"
w	The pounds per base year dollar's worth of each good

1 INTRODUCTION

1.1 THE AIMS OF THE STUDY

The stated aim of EASAMS in sponsoring this study was to determine how the tools of systems engineering could be adapted to the design and improvement of regional transport systems. Existing literature confirms the need for:

- A systems approach to transport planning

- Further research in this area

Fromm*, (1965) stated that:

> "while economists and policy-makers alike recognise the importance of transport as an instrument of economic progress, they lack the tools for making investment decisions that will serve economic development, without allocating too large or small a share of national income to the transport sector."

This is confirmed by Adler, (1967) who made the statement that:

> "the relationship between transport and development is an area where only very little research has so far been done."

These views suggest that a significant contribution could be made to knowledge if a systems approach to transport planning could be developed.

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* The references can be found in the bibliography.

1.2 THE SYSTEMS APPROACH

1.2.1 Introduction

The systems engineering method recognises each system as a whole, even though it may be composed of diverse, specialised structures and sub-functions. It further recognises that any system has a number of objectives and that the balance between the separate objectives may differ widely from system to system. The method seeks to optimise the overall system functions according to selected weighted objectives and to achieve maximum compatibility of its parts. The results are, of course, only as good as the validity of the data used, and of value only to the extent that the objectives are correctly defined. Wherever and however it is used, the systems approach follows the same sequence of activities. These define or structure the problem and draw the boundaries of the systems to be studied. The separate objectives of these systems are also identified from which an overall economic criterion is formed to measure the efficiency with which alternative systems fulfil their objectives. Next, all relevant data on the system and its environment are assembled and the field is searched for all feasible options for solving the problems. The next stage is to construct a model of the system and its environment so that an optimum system can be designed and then submitted for approval. This sequence of activities was used in this study.

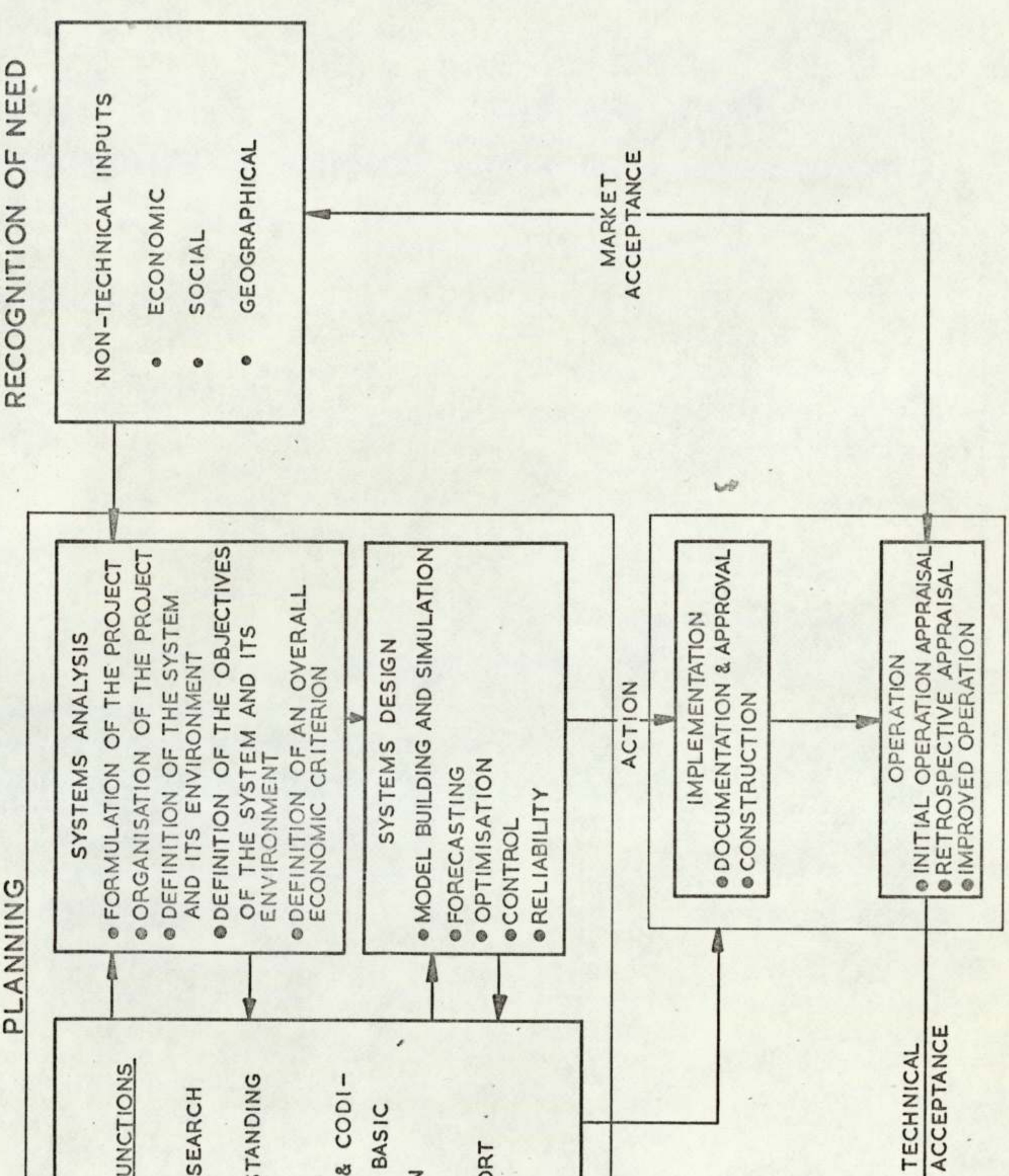
1.2.2 Outline Approach to the Study

1.2.3.1 Introduction

The breakdown of the four major stages used in typical systems engineering studies is given in figure 1.1 and demonstrates that the systems approach is an orderly and well disciplined procedure. Only the first part of the procedure was adopted for this transportation study, the implementation and operation phases being irrelevant to satisfying the aims of the study.

1.2.3.2 Systems Analysis

The first activity in this phase is to clarify the problem through "needs research". redefining it where necessary, so that the scope of the problem can be defined in sufficient detail for a project team to be organised. Once the terms of reference have been written and people assigned to a project team, the way in which the problem is to be tackled can be mapped out. Finally, "a decision network should be constructed, targets set, and duties allocated", (Jenkins,1969).



MAJOR PHASES OF A SYSTEMS STUDY.

Fig. 1.1

The problem can then be defined by "isolating, possibly quantifying, and relating that set of factors which will define the system and its environment. Since the problem is an outward expression of an unsatisfied need, the job is to find out what the need really is by gathering and analysing data to describe the operational situation, customer requirements, economic considerations, policy, possible system inputs and outputs" (Hall, 1960), and the environment within which the system has to function. This means identifying and then defining both the system that is to be studied and the wider system of which the system forms part.

Identifying and "selecting objectives is the logical end of problem definition. The objectives chosen guide the search for alternatives, imply the types of analysis required of the alternatives, and provide the criteria for selecting the optimum system" (Hall, 1960). "The final and most extensive stage in systems analysis is the gathering of data and information which will form the basis of any future modelling of the system" (Jenkins, 1969).

1.2.3.3. Systems Design

"The general objective of systems synthesis is to compile an extensive (ideally an exhaustive) list of hypothetical systems, each worked out in enough detail to be evaluated relative to the system objectives" (Hall, 1960).

To do this, a model of the system needs to be built, which describes the behaviour of the system in quantifiable terms and "can be used to predict performance over a relevant range of operating conditions and real life environments. Once a model of the overall system has been built, the model has to be converted from a passive device (a set of graphs or equations) into an active device to simulate the behaviour of the system when subjected to realistic inputs (or disturbances) which the operational system will have to meet in practice" (Jenkins, 1969). Clearly, accurate forecasts of the environment within which the system has to operate are essential for the efficient design of any system.

Having developed a model which can predict performance, a system can be chosen from a number of alternatives such that the most favourable value of the economic criterion can be realised. In order to obtain the most profitable conditions in practice, the necessary systems of control must be determined as well as the reliability of the system when subjected to realistic disturbances, which will cause the behaviour of the system to fluctuate from its steady-state performance.

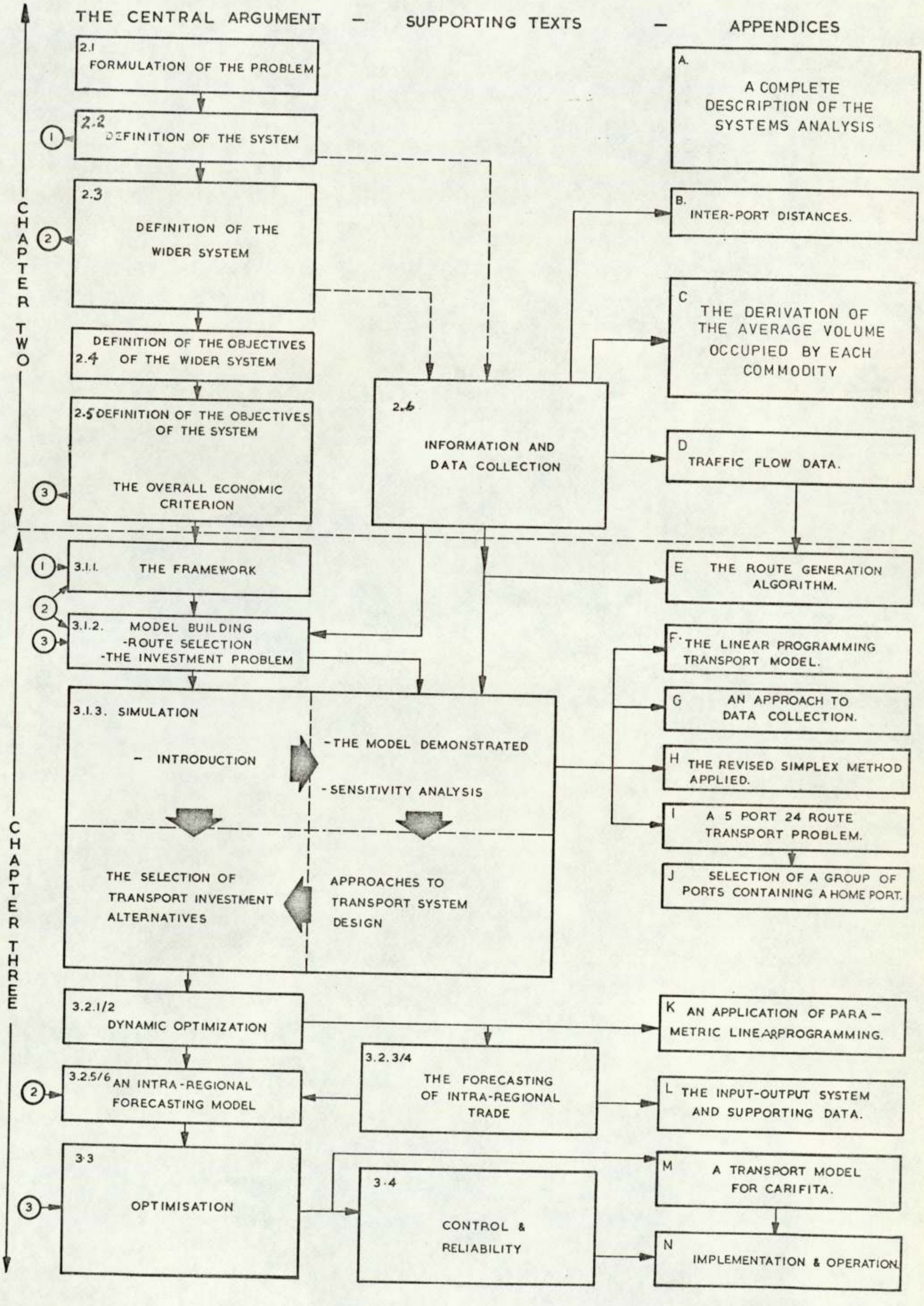
1.3 A SUMMARY OF THE STRUCTURE OF THIS REPORT

This thesis is divided into four chapters:

- Chapter 1 introduces the study and method of approach
- Chapter 2 is largely descriptive, in that the problem is gradually formulated, defined and structured, and the boundaries of the systems to be studied are drawn
- Chapter 3 is concerned with the solution of the defined problems and in it, the reader will learn how:
    - The region's transport problems were identified in terms of a number of inter-related sub-problems
    - The solutions to these sub-problems in terms of a number of improvement options were incorporated in the design method
    - The system and its relation to the islands' economies was determined
    - Improvements to the existing transport system reduced the cost of inter-island transport operation
    - Transport facility improvements affect the level of economic activity within the region
    - A design methodology, based on the limited data available, can be applied within the existing political, economic, and decision making structure of the region
    - The transport planning function was integrated with the planning of economic development within the region

- Chapter 4 identifies the contributions made by the study in developing:
  - the practical application of the techniques of systems engineering to the design of improvements to the transport system serving a group of developing countries relying largely on sea transport
  - a design methodology which incorporates decentralised decision making, where an "optimal" transport system is evolved through the collaboration of the separate transport authorities without affecting their autonomy.

The flow chart of figure 1.2 illustrates the structure of the report in terms of the major sections of each chapter and identifies the relationship between them. It also illustrates the relationship between the thesis and the appendices (bound separately) which contain supporting material.



THE STRUCTURE OF THE REPORT

Fig.1·2.

2 SYSTEMS ANALYSIS

2.1 FORMULATION OF THE PROBLEM

When EASAMS' aims were considered in relation to those of their potential clients[1] the objectives of the study were reformulated. With the agreement of the supervisory team, the author decided that a methodology for deriving a time-phased transport investment programme for the shipping system serving CARIFTA should be developed.

CARIFTA was formed to encourage the progressive development of the economies of the area by promoting the expansion and diversification of trade. A survey of the literature showed that these objectives would not be satisfied unless improvements to intra-regional shipping were made. The infrequency and unreliability of both scheduled and unscheduled transport services was regarded as a limiting factor, particularly to those industries seeking to establish a regular trade between the islands in perishable items. These difficulties are illustrated by three fundamental problems :

- The region's peculiar geography; a string of islands which, because of their small size, generate little transport revenue compared with the long and costly waiting times in harbour.
- Inadequate berthing facilities, creating congestion in ports which, for example, have sent up port charges per ton of cargo from $15 to $25 E.C. during 1970 and which, in turn, may increase freight rates.
- Seasonally fluctuating demand.

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1. Appendix A, Sections 1.1 and 1.2.

To develop a methodology to solve some of these problems, this study was divided into three distinct phases :

- The boundaries of the transport system to be studied, its environment, and their separate objectives were defined. An over-all economic criterion was then formulated from these objectives.
- An operational model of the transport system was developed together with a trade flow forecasting model, so that the behaviour of the real system and its environment could be reproduced to an acceptable degree of accuracy.
- The transport model was combined with a forecasting model to show that transport planning could be combined with the economic planning of the region within the existing political, economic and decision making structure of the region.

2.2 DEFINITION OF THE SYSTEM

Inter-island transport is carried out by a regionally subsidised shipping service, consisting of two ships, the "Federal Maple" and the "Federal Palm", as well as the two cargo vessels of Booker Shipping, and a number of schooners. The "Federal Maple" and the "Federal Palm" sail regularly on fortnightly runs along the chain of islands from Trinidad to Jamaica. The "Booker Trojan" completes a 17-day journey from Guyana calling at Trinidad, Barbados, St. Lucia, St. Vincent and Grenada, while the "Talisman" visits Trinidad, Barbados, Dominica, Monserrat, St. Kitts, Antigua, Martinique, Cayenne and Paramaribo before returning to Guyana. The large number of schooner owners operate unscheduled services between the Leeward and Windward group of islands.

To define this system in precise terms it was broken down into its important sub-systems and the interactions between the latter identified. Data[2] on flows of cargo, passengers, money, resources and information between the sub-systems (the ships and the ports) enabled a flow block diagram of the transport system to be derived. This is given in Figure 2. 1 where the interaction between one of the ships in the fleet any one of the ports it serves is given. Each box in this diagram is a transfer function and shows, for example, that ship costs are a function of the annual capital cost of the ship and manning costs. The circles identify decisions that have to be made and the categories of information that affect them. From this diagram the inputs to and outputs from the transport system and the decision circles were listed and are summarised as follows :

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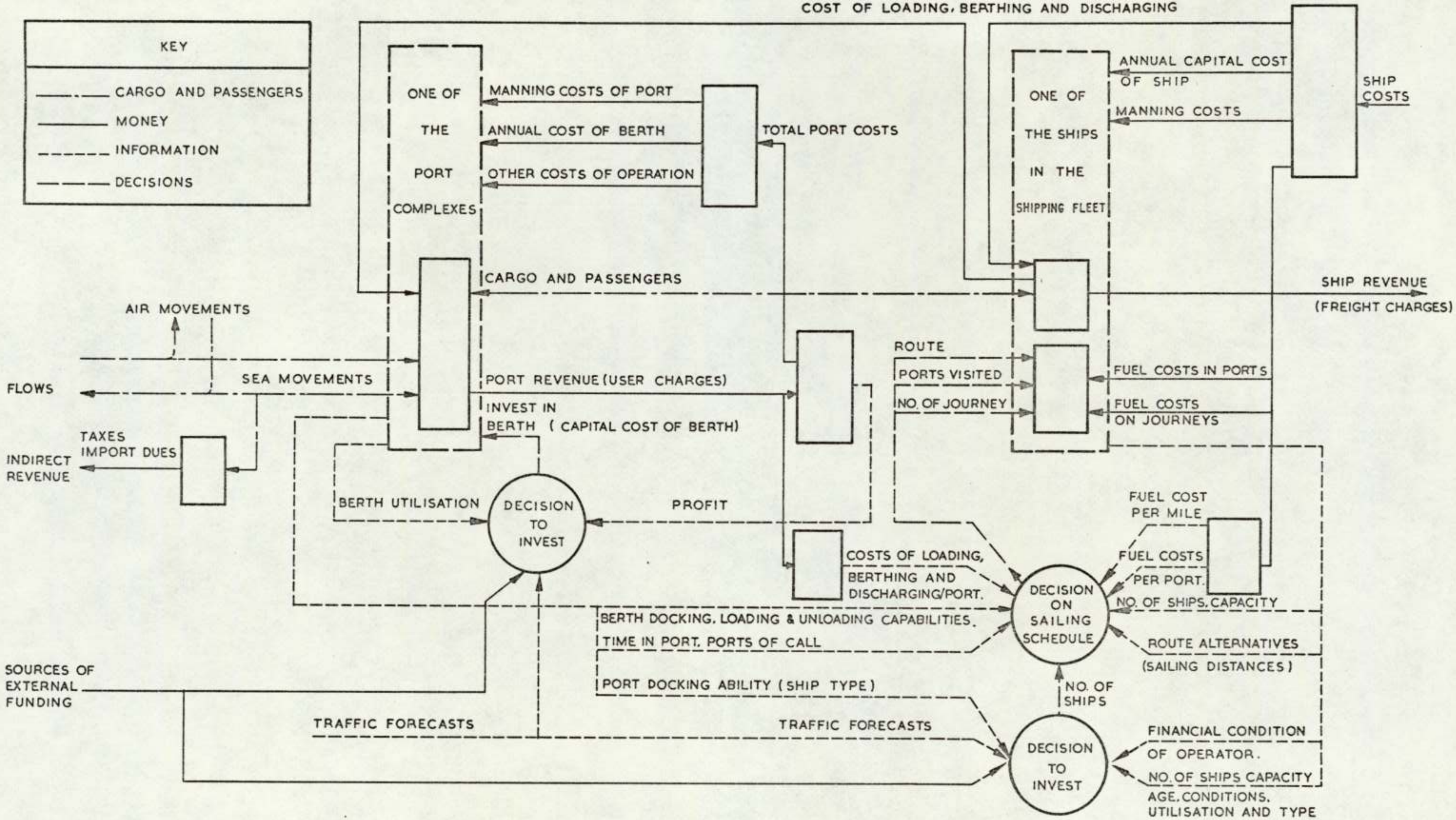
2. See Appendix A, Section 3.



THE TRANSPORT SYSTEM-FLOW BLOCK DIAGRAM (SHIPPING)

Fig. 2·1

- General and perishable commodities	Traffic flows	Factors
- Tourists and local travellers	Traffic flows	Factors
- Routes	System characteristics	Factors
- Ports of call	System characteristics	Factors
- Facilities (e.g. refrigeration, containers, LASH and roll-on/roll-off	System characteristics	Factors
- Frequency of service	System characteristics	Factors
- Freight and passenger revenue	Revenue and Expenditure	Factors
- Investment	Revenue and Expenditure	Factors
- Operating costs of system	Revenue and Expenditure	Factors

These factors identified those parts of the environment that affect, and are affected by the transport system. The categories of traffic flow suggested the need to study the needs of the users of the transport system, intra-regional commodity transactions and tourism, and their relationship to the economy of each territory, because each economy is a generator of traffic. The system's characteristics suggested the need to study the organisational structure of the region, while the elements of revenue and expenditure identified the need to study the effect of transport investment on each island's economy. These suggested areas of study provided a start in identifying those parts of the environment that affect, and are affected by, changes in the transport system.

2.3 DEFINITION OF THE WIDER SYSTEM

2.3.1 The Needs of the Users of the Transport System

A number of references discussed the inadequacies of the existing transport system and served to identify the more important needs of the users. These may be summarised as the need for :

- Additional cargo space, particularly for the carriage of perishable commodities
- Suitable facilities for the movement of chilled and frozen food products
- Improved receiving and surface transportation
- Frequent scheduled shipping services to satisfy the demand for movement.

To obtain a clearer picture of the transport needs of the region an interaction matrix was constructed from Figure 2. 1. Factors identified as relevant to the improvement of the transport system were listed so that the nature of each of the pairwise interactions affecting system improvement could be questioned.[3]

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3. For a full description of this approach see Gregory, S. A. The Design Method, Butterworths', 1960.
See also Hall, A. D. A Methodology for Systems Engineering. D. Van Nostrand Company Inc. , Priceton, New Jersey, 1960.

The matrix concerned is illustrated in Figure 2.2. This matrix was used to derive simple statementsof performance for each interaction.

2.3.2 Intra-Regional Commodity Transactions and Tourism

Inter-island flows of cargo were found to consist of :

- Imports from other territories within CARIFTA.
- Imports from the rest of the world, but transhipped at a CARIFTA port.
- Exports to other territories within CARIFTA.
- Exports to the rest of the world, but transhipped at a CARIFTA port.

A study of the relationship between an island's intra-regional transactions and its economy identified the fact that income from exports and tourism have a major effect on an island's demand for imports when they comprise a significant proportion of its industrial revenue.[4] In the Caribbean export income is comparatively stable - in terms of both price and volume from year to year - and tourism has become a major source of foreign exchange earnings for some of these developing countries. Thus, predictions of exports have to be supplemented by studies of the growth of earnings from tourism, if each island's import needs are to be estimated. In a pilot study, the impact of tourist expenditure on the economy of Antigua showed that, of every tourist dollar, only about half passed directly into the income of Antigua residents, while 40 per cent went to pay for imports.

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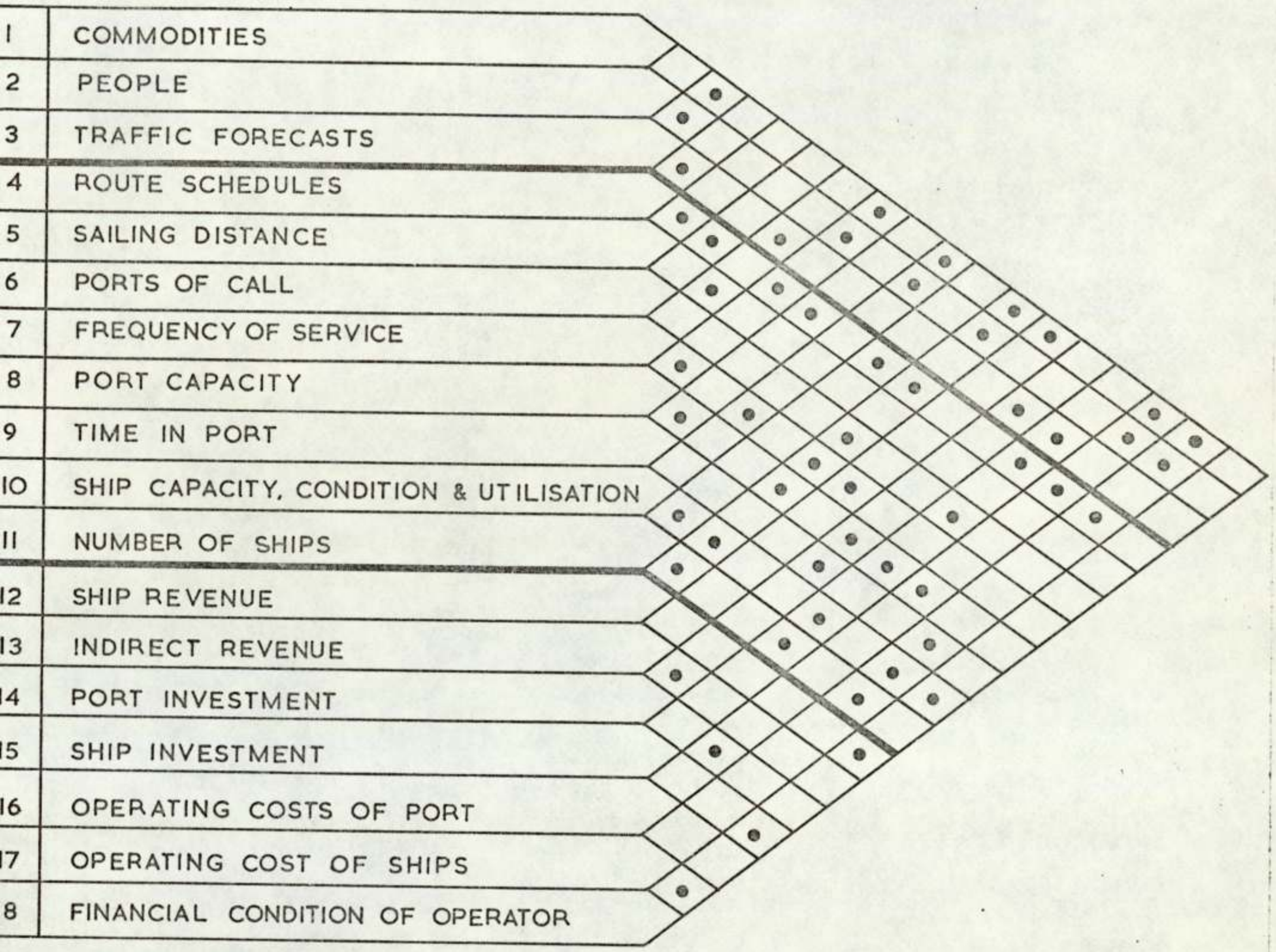
4. See Appendix A, Section 4.2.



INTERACTION MATRIX. FIGURE 2.2

2.3.3 The Organisation Structure

A commonwealth Caribbean Regional Secretariat (popularly known as the CARIFTA Secretariat), was established by the governments of the region to be at their service to assist them to pursue their agreed policies of regional integration and co-operation. Specifically, the main functions of the Secretariat are :

- To service the conference of the heads of governments of the CARIFTA territories and any Committees appointed to it.
- To service the Council of Ministers established to negotiate and administer the Caribbean Free Trade Agreement.
- To initiate, arrange and undertake investigations into questions of economic co-operation relating to the region as a whole.

In a detailed report to the Secretariat, the Institute of Social and Economic Research of the University of the West Indies suggested that a Transport and Allied Services Commission should be formed among the member territories to support a Regional Commission for Economic Integration, which would operate within the Secretariat. In developing the transport planning methodology described in this paper, it was assumed that this structure would become operative.

At present, the Secretariat functions in two broad divisions. Division I reviews development and reports on customs matters; deals with technical questions relating to day-to-day operation and functioning of the CARIFTA Agreement; facilitates the exchange of commercial information among Member Territories to enable traders and manufacturers to take full advantage of the opportunities created by the Agreement; and arranges and undertakes investigations into questions of economic co-operation relating to the region as a whole.

Division II concerns itself with the implementation of decisions of other aspects of the regional programme, namely: transport and communications, the Commonwealth Technical Assistance Programme, co-ordination of efforts in external representation, and the regional development of tourism. At a meeting in London,[5] it was stated that the Regional Shipping Council would be included within the CARIFTA Secretariat with responsibility for intra-regional shipping. The development of port facilities would continue to remain a perogative of each island's government, which would make requests for external aid without recourse to the CARIFTA Secretariat.[6]

2.3.4 Investment in Transport

An analysis of the effects of investment in additional ports or shipping facilities showed that the production requirements of the transport industry would be altered. That is, the purchases by the transport sector, from other sectors of the economy will be affected. Within an input-output model, these changes correspond

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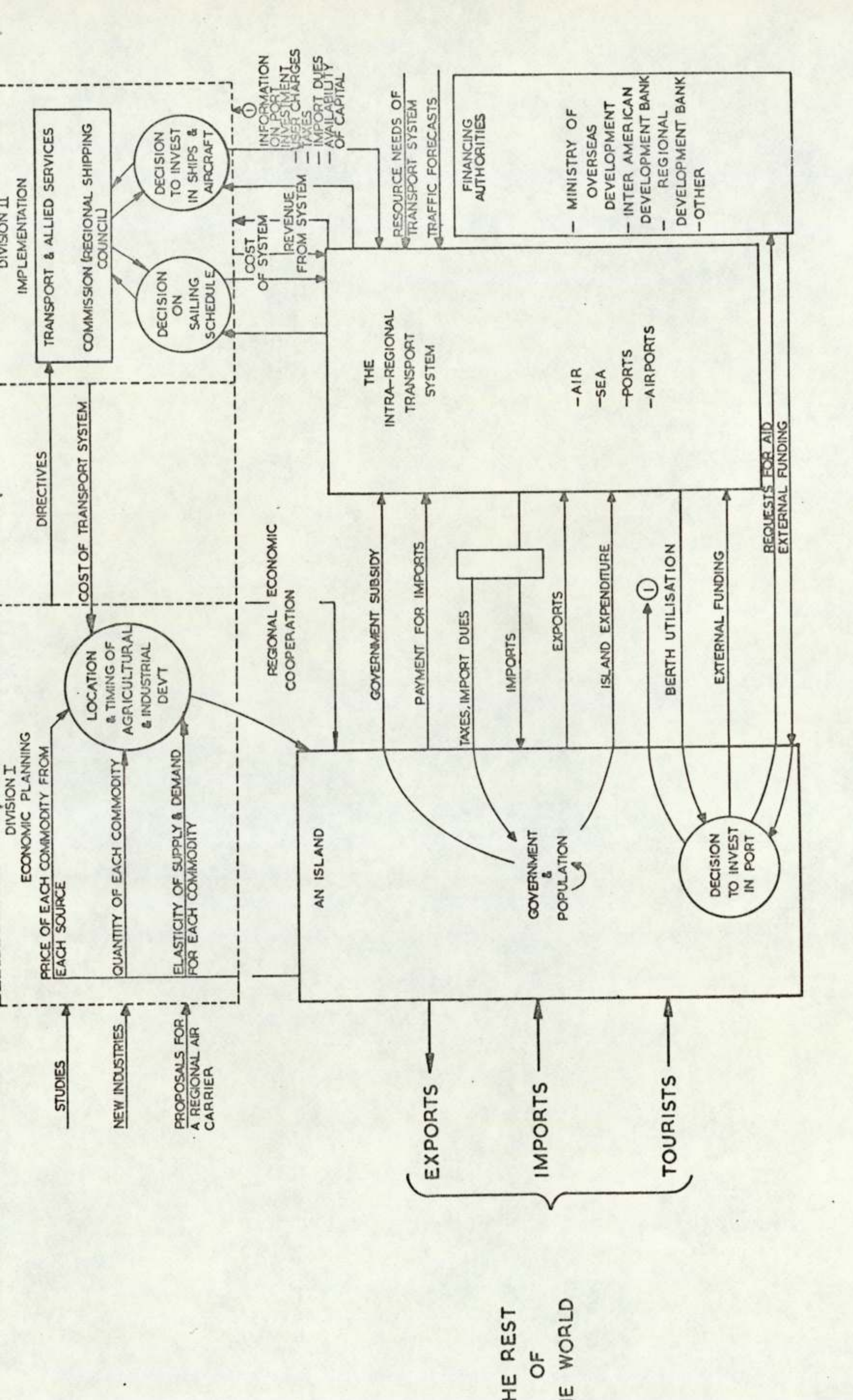
5. Lightbourne, R.C., West India Committee, London 26th Sept., 1969.
6. Humphreys, P., Overseas Development Authority, 13th July, 1970.

to changes in the technological coefficients of the processing sector (the transport columns). Similarly, network improvements resulting in cost savings to the carrier (operating the shipping service) will tend to alter the production needs of the transport sector of the island from which the shipping service obtains its requirements. Another effect of a network improvement is to modify the amount of transport purchased by shippers. This would result in an additional payment pattern to the transport sector by each industry, resulting in changes to the transport row of the input-output table.

The completion of this activity enabled those parts of the environment that affect, and are affected by, changes in the transport system to be identified. The completion of these activities enabled the environment, or wider system, to be defined in terms of a flow block diagram (Figure 2. 3). In this diagram, it can be seen that each island exports both to other islands and the rest of the world. In so doing, a demand for imports is generated from export revenue and tourist expenditure. The extent to which this demand is satisfied by the other territories within CARIFTA depends upon the characteristics of inter-island transportation and the availability of suitable commodities for export. This diagram also shows that the CARIFTA Secretariat, in conjunction with the governments of the various territories, determine both the location and timing of industrial and agricultural investment within the region. Such activities could have significant implications on the transport system concerned. For example, the expansion of beef production within CARIFTA will reduce, and perhaps completely eliminate, imports to the region from Australia and New Zealand. Thus, transport planning must be conducted in conjunction with the economic planning of the region if the objectives of CARIFTA are not be to limited by an inadequate transport system.



THE SYSTEM & WIDER SYSTEM.

Fig. 2.3

It can also be seen that control over the transport system is divided between the ports and the CARIFTA Secretariat (the Regional Shipping Council). The Regional Shipping Council can only implement improvements to the subsidised shipping service within the limits imposed by existing port facilities, and the availability of resources for development (controlled by the financing authorities). Changes in the characteristics of the service can also be made by modifying the routes served, the frequency of service, and the freight charges. Improvements to the service, such as the provision of refrigeration, could also modify the characteristics of the shipping service.

Each port within the system is free to modify port and berthing charges and to make facility improvements at any time it wishes. Each port has, however, to request funds from the island government, which in turn, can make requests for aid to such authorities as the Inter-American Development Bank and the British Overseas Development Authority.

2.4 DEFINITION OF THE OBJECTIVES OF THE WIDER SYSTEM

As the transport system is a sub-system of the intra-regional economic system, it would be wrong to dissociate the objectives of the system being studied from those of the system of which it forms part. In fact, it is the objectives of the wider system which might be the crucial ones, since they determine the environment in which the transport system has to function. The CARIFTA Agreement was used to obtain the broad objectives of the member territories which are broadly :

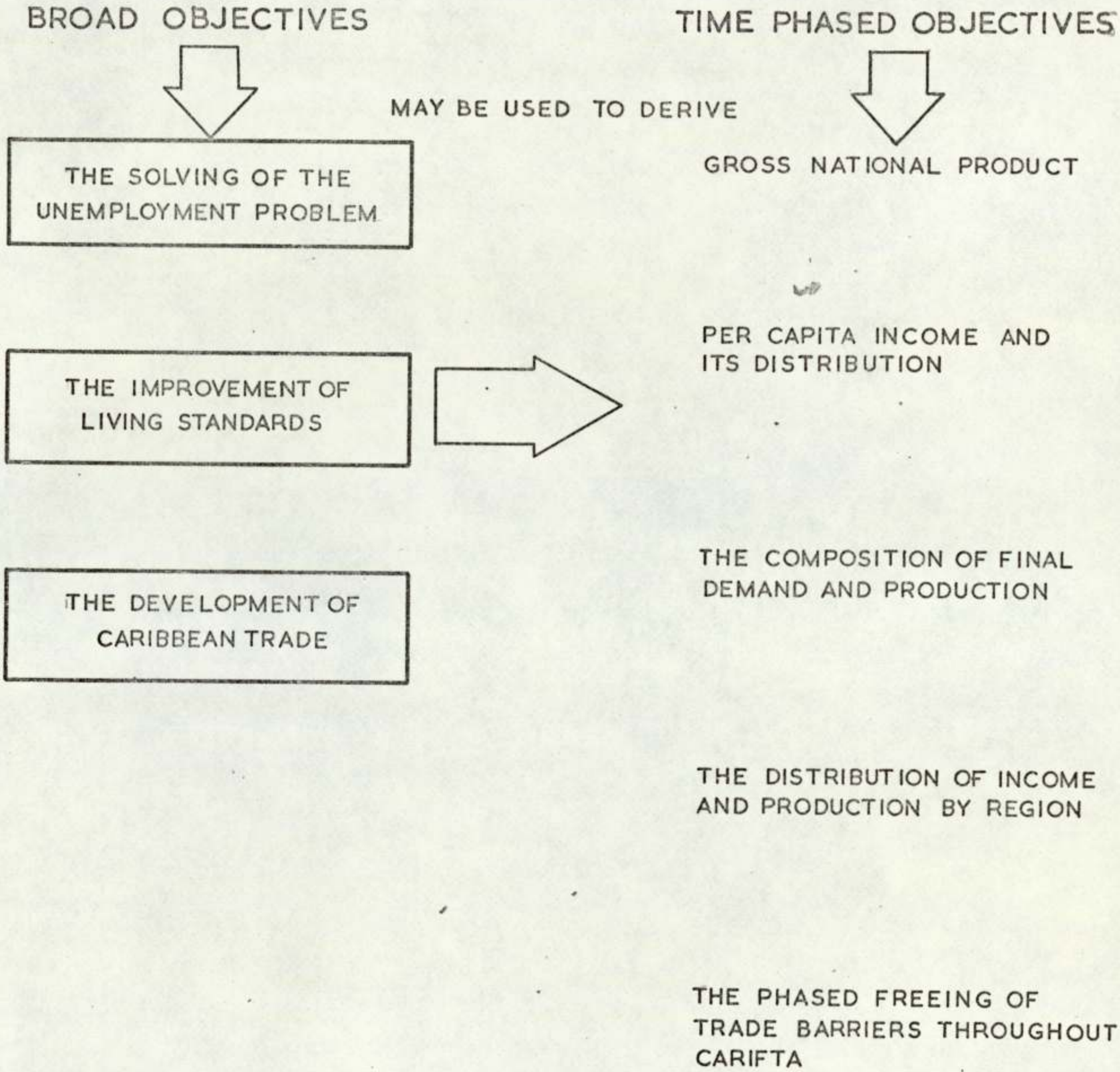
- To promote the expansion and diversification of trade in the area of the Association with a view to solving the unemployment problem.

- To ensure that trade between Member Territories takes place in conditions of fair competition.

- To encourage the progressive development of the economies of the area, to improve living standards.

- To foster the harmonious development of Caribbean trade by the removal of tariff barriers.

In general, these goals would encompass " a time spectrum for achieving such objectives as Gross National Product, per capita income and its distribution, the composition of final demand and production, and the distribution of income and production by region". (Fromm, 1965). The formulation of the objectives of the wider system is illustrated in Figure 2.4.



THE OBJECTIVES OF THE WIDER SYSTEM

Fig.2·4

To achieve these objectives, a number of proposals have been made which include :

- the development of tourism as a leading growth sector
- market research and development of new marketing channels within the area and outside
- industrial and agricultural development, i. e. specialised planning and promotional efforts to encourage industrial location in the region.

All these activities, it is assumed, will be programmed by a Regional Commission for Economic Integration (as proposed in a study conducted by the University of the West Indies) within which the proposed Transport and Allied Services commission would operate. Their long-term dynamic development plan would result in a broad programme of resource allocation, utilisation and production among islands over the forecasting period and would yield a near-optimal set of goods and services to meet the final demand.

The corresponding short-term plan would identify the number of industry sectors and corresponding final demand categories giving greater regional detail. The regional planners would programme these short-term plans to determine industrial capacities and outputs by island, to enable the transport planner to estimate the potential traffic volumes. The sub-systems of the wider system (the island economies) will define minimum and desired levels of growth within which the overall objectives of CARIFTA must be pursued.[7] This is because the degree of autonomy enjoyed by each island, and its political environment can significantly bias investment decisions.

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7. This is because systems in the same level in a heirarchy of systems are normally in conflict. Thus, defining the objectives of the wider system is essential so that the objectives of the competing systems can be formulated in such a way that they contribute effectively to the objectives of the wider system instead of pulling in different directions. (Jenkins, 1969).

2.5 DEFINITION OF THE OBJECTIVES OF THE SYSTEM

The objectives of the system are dictated by the objectives of the wider system, for if intra-regional trade is essential to the economic growth of the region, a transport system must be available to complete the required trade movements.

Those factors, linking the transport system to the wider system were used in an interaction matrix to derive simple statements of performance for each interaction. Some of these requirements were confirmed in discussions with some of the shipping authorities connected with the region, and from surveys of the relevant literature. From an analysis of the statments of performance, the discussions, and the survey, a value/ constraint system was devised for the transport system which was stated in the following terms :

Profit-cost :	To carry traffic at the lowest cost to the economy within the limitations of capital and other resources available to the transport sector.
Market :	To satisfy the demand for transport.
Quality :	To attain a minimum standard of service in respect to the surface transportation and delivery of commodities.
Characteristics :	To provide suitable facilities for the movement of chilled and frozen food products while maintaining existing facilities for the movement of general cargo.

Compatibility	:	Improvements or additions to the existing transport system must be compatible with the existing system.
Flexibility	:	To provide a transport system which can easily be adjusted to carry cargo, the commodity composition of which will change rapidly over the next few years.
Permanence	:	To avoid technical obsolescence.
Simplicity	:	System improvements should be compatible with the technical competence of the labour available.
Time	:	To provide a sufficiently frequent scheduled service for all commodities, particularly perishables, between sources of supply and destination. Target dates for the introduction of specific categories of transport improvement could then be defined if users requirements could be forecasted.

In this way, the objectives of the transport system were dictated by the requirements of the wider system. These factors form an overall economic criterion[8] (see Figure 2.5) where the choice between projects is made on the basis of the present discounted value of the benefits less costs in each year of the project's existence.

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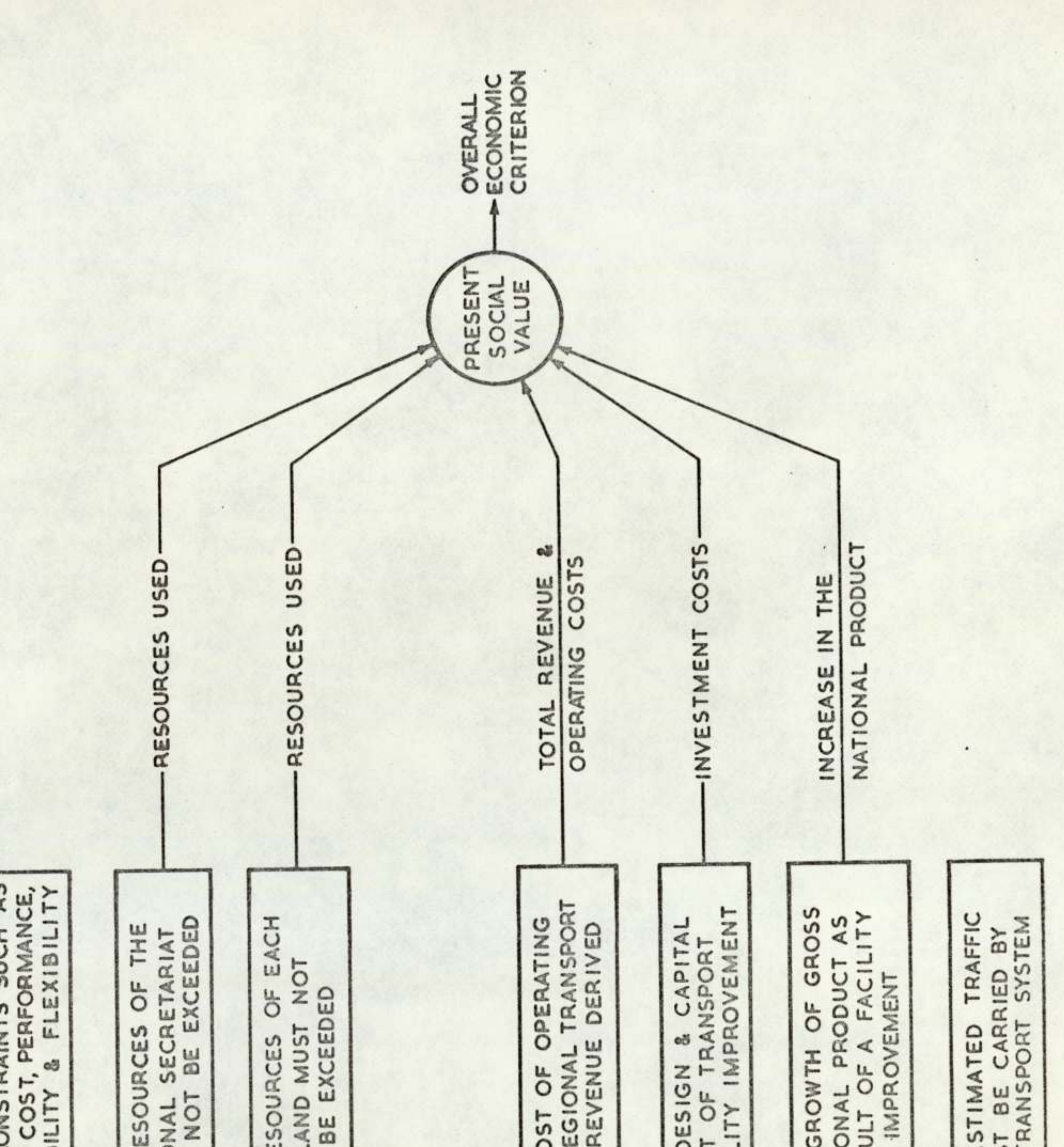
8. See Appendix A, Sections 5 to 7 where the formulation of the overall economic criterion is discussed in detail.



FACTORS DETERMINING THE OVERALL ECONOMIC CRITERION

Fig. 2.5

2.6 INFORMATION AND DATA COLLECTION

The earlier sections in Chapter 2 have indicated the need for information about the existing transport system if regional planning for future needs is to be possible. The data needs identified in the flow block diagram of the transport system can be classified under the following headings :

- The volume and composition of commodity flows.
- Physical facilities and their utilisation.
- The cost of transport and related charges.
- Population movements.

2.6.1 The Volume and Composition of Commodity Flows

An analysis of the data sources available in the Caribbean showed that inter-island commodity flows could be obtained from the Annual Trade Reports of the islands concerned. The proportion of intra-regional traffic carried by the shipping service could be obtained by sampling the ships manifests and/or the master documents used by forwarding agents.

The Annual Trade Reports were used to construct a table to give the value ($ BWI) and the volume (cubic feet) of imports and exports within the Caribbean according to certain commodity categories. The approach used is described in Appendix B where the different systems of recording trade statistics are also discussed.

All general cargo including oil - for which special shipping and terminal facilities are available - is carried almost entirely by sea.

2.6.2 Physical Facilities and their Utilisation

The flow block diagram of the transport system (figure 2. 1) identifies those elements of data that would be obtained or derived in any client sponsored study.

Recent unpublished studies by EASAMS suggest that the whole complex of port operations can be related to three main quantifiable factors :

- On-loading capacity
- Off-loading capacity, and
- Ship docking capacity.

Descriptions of the current situation showed that the ports within the region can be divided into two groups. The first group contains those ports with deep water harbours while the second group use lighters which discharge or collect their cargo from the jetty and move it to and from ships anchored several hundred yards from the shore.

Inter-island shipping is largely carried out by a fleet of privately owned schooners, which form the backbone of the Windward and Leeward islands' trade, and a shipping service consisting of two ships, the "Federal Maple" and the "Federal Palm", which now ply between Trinidad in the south and Jamaica in the north, calling at the islands in the chain. Both these ships are identical having gross tonnages of about 3200, speeds of 14 knots, accommodation for 50 cabin and 200 deck passengers (accommodated under cover and in dormitories), and 2000 cubic tons of total hold capacity, which with deductions made for the refrigeration area and broken storage could accommodate about 1500 cubic tons of dry cargo.[9]

2.6.3 The Cost of Transport and Related Charges

Those elements of data identified in the flow block diagram of the transport system (Figure 2. 1) are given in section 8 of Appendix A.

2.6.4 Population Movements

Estimates of the population novements within the Caribbean and the mode of transport used were derived from the 1960 population census and figures of birth, deaths and net migration, supplied by the Statistics Departments of the various

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9. Appendix A, section 3.

territories (Trinidad and Tobago Statistical Digest, 1966). Data given in Appendix A, section 8 shows that the volume of passenger traffic is heavily in favour of air travel in Barbados, St. Kitts, St. Lucia and Antigua. This is a reflection of the relatively better facilities for air travel in these territories and the greater availability and consequent importance of transport facilities by motor and sailing vessels in some of the other territories, especially in Grenada and St. Vincent in their traffic with Trinidad, and to a lesser extent with Barbados. However, competition between sea and air transport is very limited as ships' passengers generally belong to a lower income group than that of the flying public (who are largely tourists).

3 SYSTEM DESIGN

3.1 MODEL BUILDING

3.1.1 The Framework

3.1.1.1 Introduction

To compute the costs associated with different ways of running a transport system, it is necessary to predict the performance of the system over a wide range of operating conditions. To do this, a quantitative description of the behaviour of the system needs to be built. In the systems approach, the ultimate objective is to optimise the performance of the system as defined by the overall economic criterion. Thus, it is important to model those areas to which the overall economic criterion is sensitive.

Now in the system, the ultimate objective is to optimise the performance of the system as defined by the overall economic criterion. An examination of Figure 2.5 showed that the criterion was only sensitive to two areas of activity which therefore had to be modelled, before system improvements could be designed. These activities were :-

- The transport system
- The island's economies.

All other criteria act as constraints on the system design process and can be directly related to the overall economic criterion.

3.1.1.2 System Improvement Options

The range of improvement options and the analyses required before an optimal combination of improvements could be selected were identified from :

- the requirements to be met by the transport system (these were derived from the interaction matrix - figure 2.2)
- the objectives of the transport system
- a survey of the relevant literature[1]

The result of this exercise is given in figure 3.1. The survey 'also showed that there is some interaction between modes of transport. The Tripartite Survey, (1966) stated "a number of sporadic commercial shipments have already been made by air over the years in a wide variety of products - mangoes, melons, frozen chicken, tomatoes and cray fish". As further interaction between transport modes may occur in future, the methodology being developed in this study should cater for it.

From figure 3.1 it can be seen that improvement options are inter-related. This was confirmed by R.C. Lightbourne[2], Minister of Trade and Industry in Jamaica, who stated that "while consultants' reports abound, they all refer to the cost of expanding existing port facilities to the level of trade forecasted by each authority. In this they are inadequate, because they take no account of the development of the region as a whole. To assess the requirements of each port in isolation, without taking into account other competing port developments, could lead to over investment in the region" - This factor is of particular importance to financing authorities and confirms the need for a model of the transport system so that its performance can be predicted over a wide range of operational conditions.

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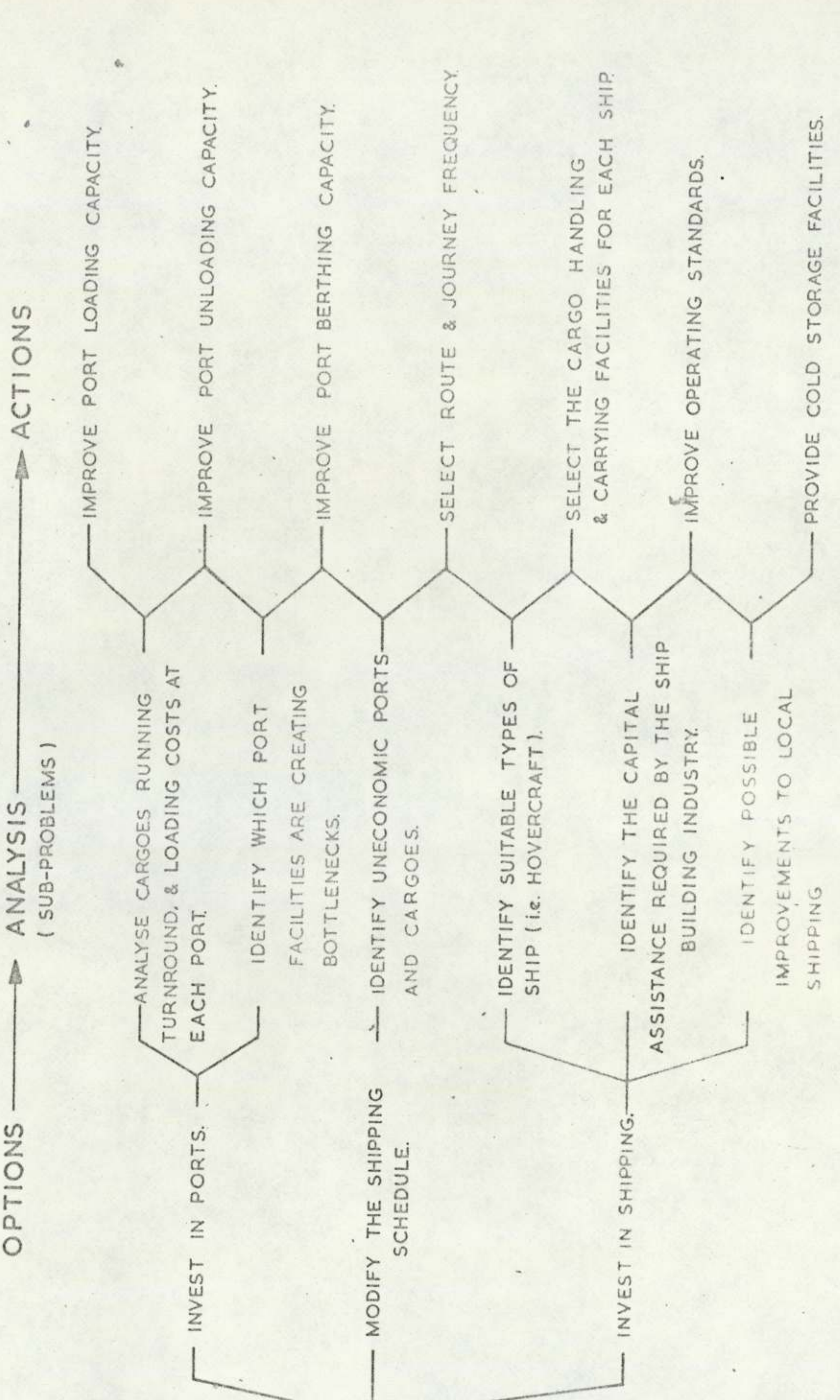
1. See (O'Loughlin, 1968) and the (Tripartite Survey, 1966).
2. At a meeting of the West India Committee in London, on the 26th September, 1969.



IMPROVEMENT OPTIONS-SEA MODE OF TRANSPORT.

Fig3.1(

3.1.1.3 The formulation of a model

The data availability survey described in section 2.6 showed that the only relevant data available would be :-

- The base year commodity flows between the ports of the region, defined in terms of their volume, value and commodity classification
- The published routes of the shipping services and their related freight rates.

- The characteristics, handling and docking capacity of each port

- The present domestic shipping fleet, its capacity, age and condition

- The financial situation and the instruments available for the implementation of transport improvements.

The views of individual shipping and port authorities within the region on the need for improvement would also be available.

The last factor is of doubtful value, being project oriented. It neglects the effect of possible developments outside the planning horizon and environment of the port concerned.

The other factors present a basis for building a model of the transport system, which, when built, could be used to confirm or deny views held by transport authorities while assisting the design process.

Before the model building activity can commence however, it is important to look once again at those factors which immediately affect the model building activity. These factors may be summarised under the headings of:-

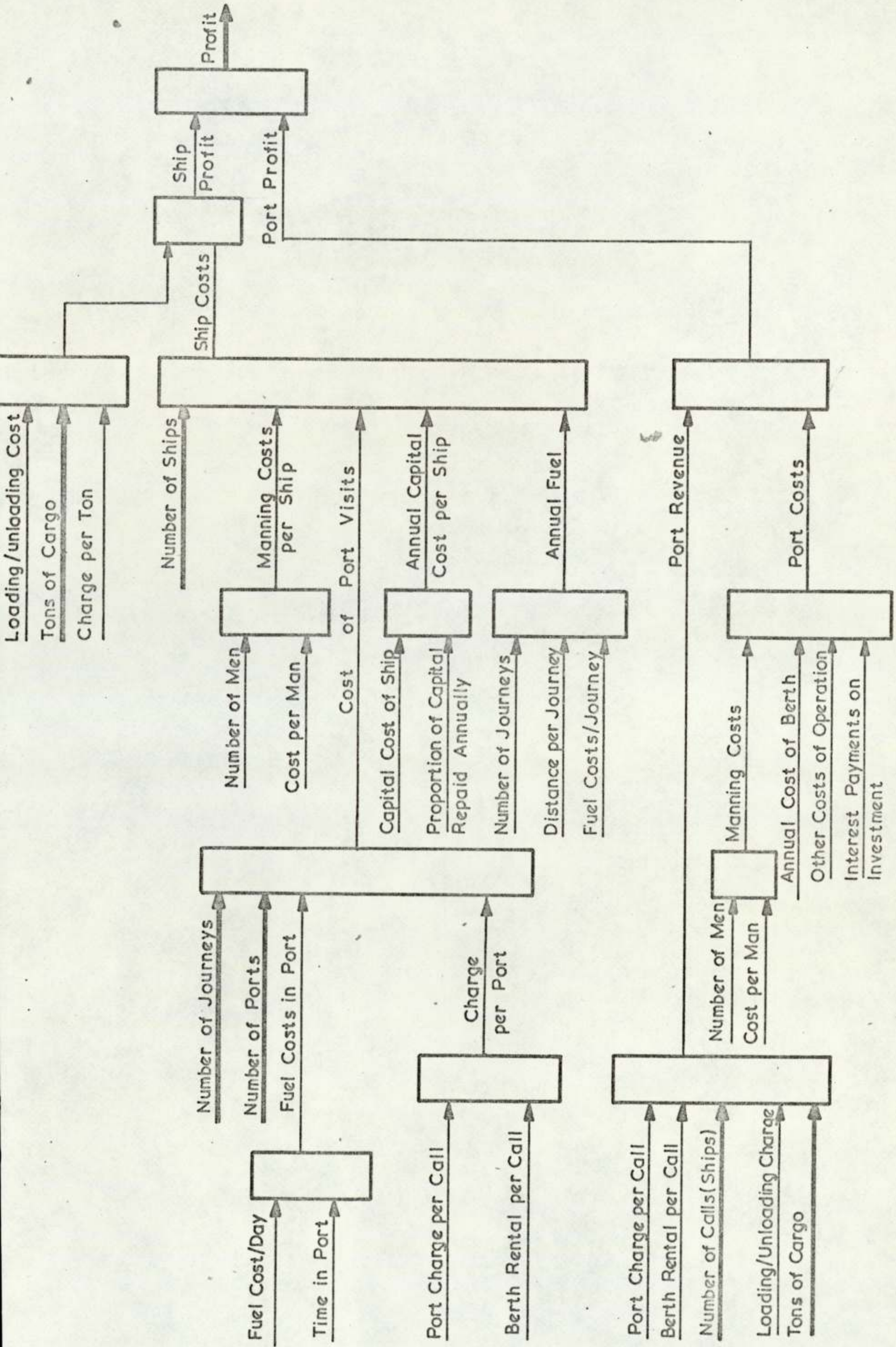
- The cost of the transport system

- Policy variables

- Policy constraints

3.11.4 The cost of the transport system

Those factors affecting the cost of transport system operation, and identified in the flow block diagram, are repeated here in the form of a dependency chart. Each "box" in this chart is a transfer function which



PORT AND SHIPPING COST DEPENDENCY CHART

Fig 3.2

must be derived so that the inter-relationships between variables can be quantified; intermediate relationships between the inputs and outputs of the system being submerged within the model. For example, the fuel cost in port is a function of the daily fuel cost and the time spent by the ship in the port.

3.1.1.5 Policy variables

If a model of the transport system is to be used as a design tool by the Transport and Allied Services Commission it must be able to use the instruments of transport policy available to it. Section 2.3.4 identified these as freight charges[3], frequency of service and route selection.

As the autonomy of each island has to be respected (see section 2.3.3) it is clear that each island must be able to participate in the design of improvements to the transport system while having ultimate control over port operation and investment. In this case, policy variables available to each island are port charges, taxes and import dues, and facility improvements, which are governed by the availability of capital.

3.1.1.6 Policy constraints

These constraints must all be included in the final formulation of the transport model if improvements to the transport system are to satisfy the minimum requirements of the participating authorities.

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3. Assuming that these can be agreed with the shipping conference and Regional Transport Commission.

These constraints, taken from section 2.6 of Appendix A are as follows :

- All estimated traffic must be carried by the transport system[4]
- The combined annual budgets of both the Carifta Secretariat and island governments must not be exceeded
- The autonomy of each island must be respected, in any transport system design activity
- All other constraints as given in Section 2.6 of Appendix A.

3.1.1.7 Conclusion

These considerations provide a framework for the initiation of the model building activity. However, as the jurisdiction of the Transport and Allied Services Commission only extends to the shipping fleet, improvements will have to be made within the constraints imposed by each island over its own port (and airport) facilities. The need to develop a cost model of port operation therefore becomes irrelevant, for port improvement schemes are only within the jurisdiction of the island governments.

The cost of port improvement and port profitability are however of vital interest to funding authorities, particularly where the cost of shipping could be reduced by port improvement. If the need for improvements in particular ports could be identified from the shipping model, the cost of port improvement could then be determined by the port authorities concerned and the benefits resulting from the same could be calculated.

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4. Mr. M. A. Nicolson of Booker Bros. (Liverpool) Ltd. informed me that this criterion is built into some conference systems.

3.1.2 MODEL BUILDING

3.1.2.1 The Parameters

Data immediately relevant to the model building process is that which relates to:

- The cost of operating the shipping system
- The cost of improving port facilities
- The revenue derived from the shipping system

3.1.2.1.1 The cost of Operating the Shipping System

A cost model of shipping operations, developed within EASAMS, was used in this study. Although not tested within the Caribbean it identified the pertinent factors affecting the cost of shipping operation, and was therefore relevant to the satisfaction of the aims of the study.

The cost model of ship operation over route "k" is as follows:

$$CT_k = \left[CA + MX + NJ_k \left\{ D_k . \; CS + TP_k . \; CF + CPB_k \right\} \right]^5 SH$$

	Notation	Meaning	Typical Values
where	CA	= Annual capital cost of ship	0.165 Capital cost of ship
	MX	= Manning costs - X men at £M/man-year	£150.000
	NJ	= No. of journeys per annum per ship over route "k".	Variable
	D_k	= Sailing distance over route "k".	Fixed for each "k"

5. Assumptions used to derive this equation are stated on page 4 of the EASAMS report to Autostrada S.p.A., June 1968.

CS	=	Cost of fuel per mile at service speed	£1.5/mile
TP_k	=	The total time spent in port in completing, route "k"	0.5 day per port
CF	=	Cost of fuel in port per day	£100/day
CPB_k	=	Port charge & berth rental costs incurred in completing route "k"	Fixed for each route "k"
SH	=	Number of ships within the region	Fixed

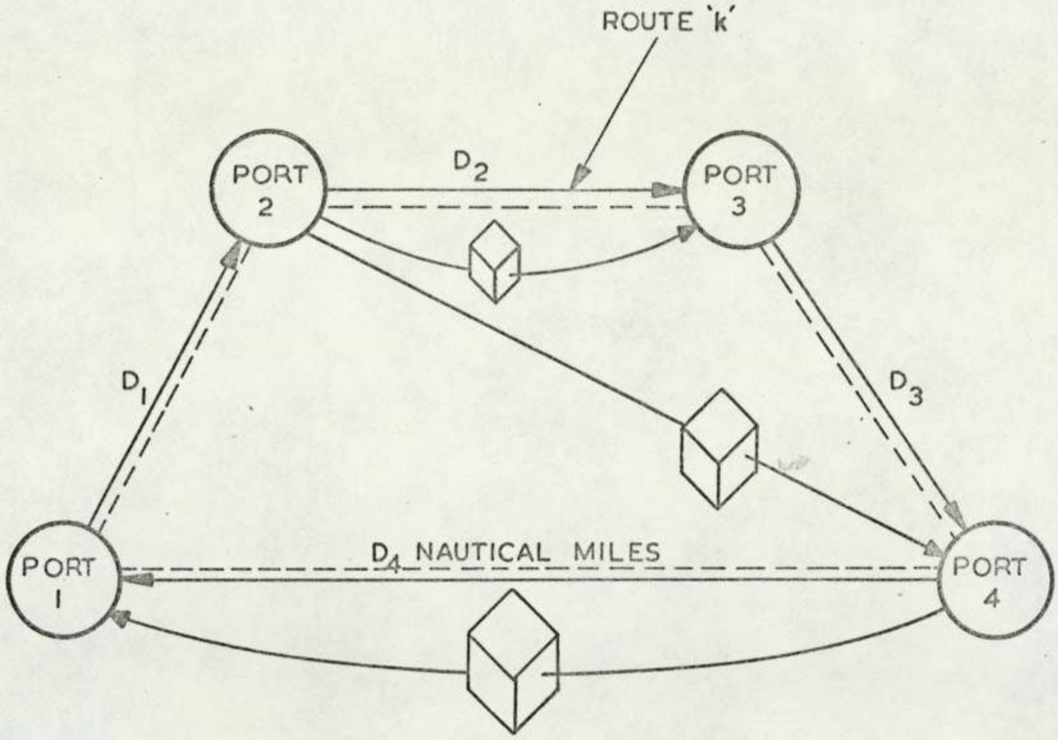
Thus, the total cost of ship operation is given by :-

$$CT = \sum_{\text{All } k} CT_k$$

where a shipping route "k" is the path followed by a ship and is defined by the ports it visits. Figure 3.3 illustrates this concept.

It is assumed that once the ship has returned to the port from which it originally sailed it has completed a journey "k" of D_k miles. In so doing, the ship will have spent TP_k days in stopping at the several ports visited. It will also have incurred port and berth rental costs in each port, the total port costs in completing route "k" being equal to CPB_k.

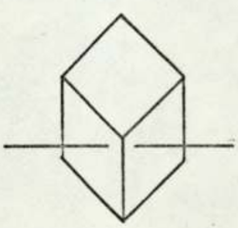
Thus, for each route "k", the equation for CT_k can be divided into its fixed and variable components as follows :-



PORT CHARGES = $CPB_1 + CPB_2 + CPB_3 + CPB_4 = CPB_k$

COST OF FUEL IN PORTS = $CF(TP_1 + TP_2 + TP_3 + TP_4) = TP_k\, CF$

COST OF TRAVELLING = $CS(D_1 + D_2 + D_3 + D_4) = D_k\, CS$



VARIOUS TRADE FLOWS.

---------- CARGO SHIPMENTS IN THE TRADE ROUTE.

THE ROUTE TAKEN BY A SHIP

Fig. 3·3

$CT_k = (CA + MX + NJ_k . V_k) SH = F.SH + NS_k . V_k$ where

$F = (CA + MX)$ = The fixed component of cost incurred by one ship

$NS_k = NJ_k . SH$ = The number of ship-journeys over route "k"

$V_k = (D_k . CS + TP_k . CF + CPB_k)$ = The cost per ship-journey over route "k"

Figure 3.3 shows that, for any defined route "k", the parameter V_k is a constant because inter-port distances, the average times spent by the ship in the ports visited, and the sum of the port charges are constant.

Thus, a linear relation results where the cost of ship-operation is proportional to the number of journeys completed over each defined route "k".

3.1.2.1.2 The cost of Improving port facilities:

Little information is available on the cost of improving particular transport facilities in the region. The lack of information is confirmed by HMSO,(1963) which, in discussing the harbour at Basseterre, St. Kitts states "a deep water harbour with berthing for 2 ships has long been considered a need, and the main justification for it is that it would ultimately reduce the cost of sugar loading and of importation." H.M.S.O. (1963) further states that no documentation is available on this harbour and steps should therefore be taken to obtain a summary assessment of the position by a qualified engineer. The only existing estimate of the cost is one of 6 million dollars based on the findings of a Canadian team who visited the territories in 1959. A further 2 million dollars will probably be required for engineering survey and design", (HMSO, 1963).

Other information is also scanty - while cost estimates for a particular improvement are given, the corresponding technical details, such as increase in the docking capacity of the port, are not provided.

The fact that such details are omitted is not particularly relevant. The main point is that such factors should be included in the model so that, should a client sponsored study be undertaken, then the relevant information could be acquired and used in the system design process.

3.1.2.1.3 The Revenue derived from the Shipping System

The traffic carried between each of the ports in the network determines the revenue derived by intra-regional shipping. That is:-

$$\text{Revenue} = \sum_{\text{All } i,j \text{ for } i \neq j} v_{ij} \cdot a_{ij}$$

where v_{ij} = the revenue derived from shipping 1 ton of cargo from port "i" to port "j"

a_{ij} = the tonnage of cargo[6] to be exported from the i^{th} port to the j^{th} port of the system

6. Measurement-tons. One measurement ton equals 40 cubic feet.

3.1.2.2 Assumptions

A number of important assumptions were introduced in order to simplify the model and concern, the region, existing shipping, shipping routes and freight rates.

3.1.2.2.1 The Region

For the purposes of this study those islands known to be members of the Caribbean Free Trade Association at the time of writing were considered. These were Jamaica, St. Kitts, Antigua, Montserrat, Dominica, St. Lucia, Barbados, St. Vincent, Grenada, Trinidad and Guyana.

3.1.2.2.2 Existing Shipping

It is assumed that all regionally owned vessels will operate within the CARIFTA region. These vessels are assumed to comprise two ships, the Federal Maple and the Federal Palm, and a number of schooners, but only the "Federal" ships come under the jurisdiction of the Transport Commission.

The schooners serve the Windward & Leeward islands and Barbados, but do not operate over the longer journeys between the Leeward and Windward group of islands and Jamaica and Guyana.

Foreign ships may reduce the capacity required from intra-regional shipping over any one link before departing from the CARIFTA region (which is the boundary of the system being considered).

Shipping Routes

Those ships operating under the jurisdiction of the Transport Commission are assumed to provide a liner service.[7]

Each shipping route is defined so as to permit a vessel operating over a route to make a round trip, that is, to return eventually to the port from which it originally sailed.

Intra-regional Freight Rates

It is assumed that an abrupt change in pricing is undesirable and unlikely because the Conference System maintains a charge structure, adhered to by the principal shipping lines operating in the Caribbean.

3.1.2.3 Model Formulation

The objective is to design a model which can be used to minimize the cost of transport system operation and provision over a given time period. To design an optimal combination of improvements, those sub-problems identified in the design tree of figure 3.1 must be solved.

The first of these sub-problems is to select an efficient set of shipping routes for each of the years included within the envisaged planning period. The second is to indicate appropriate investment strategies to meet future requirements. The immediate problems to be solved can be stated as follows:-

---

7. A liner service is one where the ships follow a regular schedule over a specified route.

- What pattern of shipping routes would have permitted the trade flows in 1965 to be carried out at minimum cost?

- What investment projects should be selected to reduce the cost of operating the transport system, while satisfying the economic and social objectives of each island within the region?

- When should such projects be implemented?

3.1.2.3.1 Route Selection

A solution to the problem of selecting an optimal routing pattern for the shipping available within the region will firstly be considered. Now the profit realised by the shipping system, can be represented as:-

$$\text{Profit} = \sum_{\text{All } i,j} v_{ij} \cdot a_{ij} - CT \quad \text{for } i \neq j \qquad \text{where}$$

v_{ij} [8] = The price per ton paid by the shipper for goods moved between the 'i' and 'j' nodes in the transport network. This figure is constant for each year, irrespective of the volume of cargo moved. This price incorporates the cost of loading and unloading cargo plus the amount required to realise a profit.

a_{ij} = The tonnage moved between the 'i' and 'j' nodes in the transport network. This will vary from year to year.

CT = The total cost of providing the shipping service over the selected year.

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8. In some cases, the shipping line quotes the landing, storage and delivery charge as a surcharge on the port in an attempt to persuade the port concerned to reduce its charges.

THE COSTS OF A CARGO LINER

TABLE 3.1

	£ per day	£000 p.a.	Variables *
Commissions	-	27	
Cargo-handling	-	136	CPB_k (Cargo-handling; Port dues, pilotage, tug hire, customs fees, etc.)
Port dues, pilotage, tug hire, customs fees, etc.	-	50	
Fuel	-	28	$(D_k CS + TP_k CF)$
Crew wages	150	55	$(CA + MX)$ (Crew wages to Administration)
Crew provisions	21	8	
Stores, including lubricating oil	30	11	
Repairs	125	46	
Insurance	55	20	
Sundries	11	4	
Administration	55	20	
TOTAL	£ 447	£ 405	

* See the list of symbols, page xiii.

Source : Goss, R.O., Journal of Transport Economics and Policy, January 1967

Clearly, the cost of transport system operation (given by CT) must be minimized while satisfying the demand for transport.

The cost of loading and unloading in a port can be affected by the route of the vessels. This is because ships of different types may be used on different routes, and cargo handling costs are affected by both the type of ship and the total tonnage handled in a port. The total tonnage is, in turn, influenced by the ports visited by the ships. The significance of port and cargo handling costs is indicated in Table 3.1 due to Goss (1967), where the typical costs of a cargo liner are given.

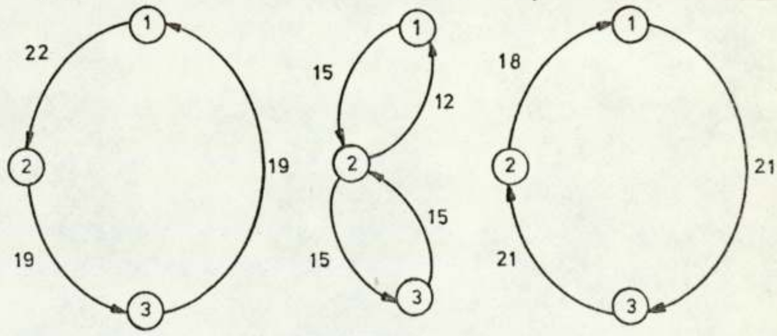
As cargo handling charges are related to the tonnage handled then only a marginal improvement in the cost of transport system operation may be possible. But a significant reduction in the cost of transport system provision might be possible because the shipping routes used by a vessel affect port capacity requirements. The interaction matrix of figure 2.2 suggests that in selecting a combination of least cost routes, the interaction between journey frequency, port, and ship capacity should be considered.

3.1.2.3.2 Journey Frequency, Port Capacity and Ship Capacity

Figure 3.4 was used to explore the above where a ship is offered the choice of one of several routes, in serving a three port region.

Exports	Imports		
	1	2	3
PORT 1	0	6	9
PORT 2	4	0	6
PORT 3	8	7	0

The trade flow matrix



Route 1 Route 2 Route 3

ALTERNATIVE SHIPPING ROUTES FIG. 3.4

The tons of cargo assumed to be moved between each port in every 12 day period is given in the trade flow matrix. For example, in the route 1 case, 22 tons of cargo are moved over arc (1,2). This figure comprises 6 tons (movement a_{12}), 9 tons (a_{13}) and 7 tons (a_{32}). If the ship operator only owns one ship with a cargo capacity of 5 measurement-tons then route 1 cannot be used because the flow of cargo over arc (1,2) equals 22 tons and exceeds the route capacity. Thus Fig. 3.4 illustrates the interaction between service frequency, port capacity, ship capacity and the selected route which is explained in Table 3.2.

Selected route	Number of journeys	Port occupancy (capacity)	Available route capacity
Route 1/3	4	1 ship every 3 days	4 x 5 tons
Route 2	3	1 ship every 4 days	3 x 5 tons

SERVICE FREQUENCY, PORT AND SHIP CAPACITY BY ROUTE

TABLE 3.2

In all cases, the ship is assumed to take one day in moving from one port to the next, while one night is assumed to be spent at each port of call. In the 3 port route, the journey time is, therefore, 3 days while it is 4 days in the limited capacity case.

These results show that choice of route and its direction, frequency of service, port capacity and ship capacity all interact with each other. If ship capacity is only 5 tons, route 2 must be chosen to satisfy the demand for transport but service frequency and port occupancy are lower. Route direction affects ship utilisation as shown in a comparison of the cargo carried on routes 1 and 3. Some links in a transport system may require a higher frequency of service than another link. Thus, to provide a sufficiently frequent service over those links requiring such a service involves the selection of a pattern of shipping routes which satisfy the demand for cargo space, the available ship capacity, the required frequency of service and existing port docking capacities. This knowledge was used to construct an algorithm[9] which could select a subset of routes serving up to 6 ports which wi satisfy transport demand, ship capacity, and service frequency criteria. The arguments used were as follows:-

To satisfy the demand for transport at minimum cost, every least cost route serving every combination of ports must be identified.

A least cost combination of routes serving all ports in a region can be selected. A least cost route is first selected from each combination of ports from the cost equation of ship operation.

The available movement capacity (C) will limit those routes selected because, for any given route "k", only $SH. C. NSMAX_k$ tons of capacity will ever be available, where C is the cargo capacity of the ship. The maximum number of journeys over any route "k" (equal to $NSMAX_k$) can be determined from the equation:-

---

9. See Appendix E.

$$NS_k\,(max) = \left(\frac{365}{T_k}\right) \text{ for route k.}$$ [10]

where:

T_k = Single journey time (total) over route "k" (in days)

$$= \left(TP_k + TM + \frac{D_k}{24\,u}\right)$$

TM = Time margin allowed

u = average port-to-port ship speed in knots. (Taken as 20 knots per hour)

Other variables are as previously defined.

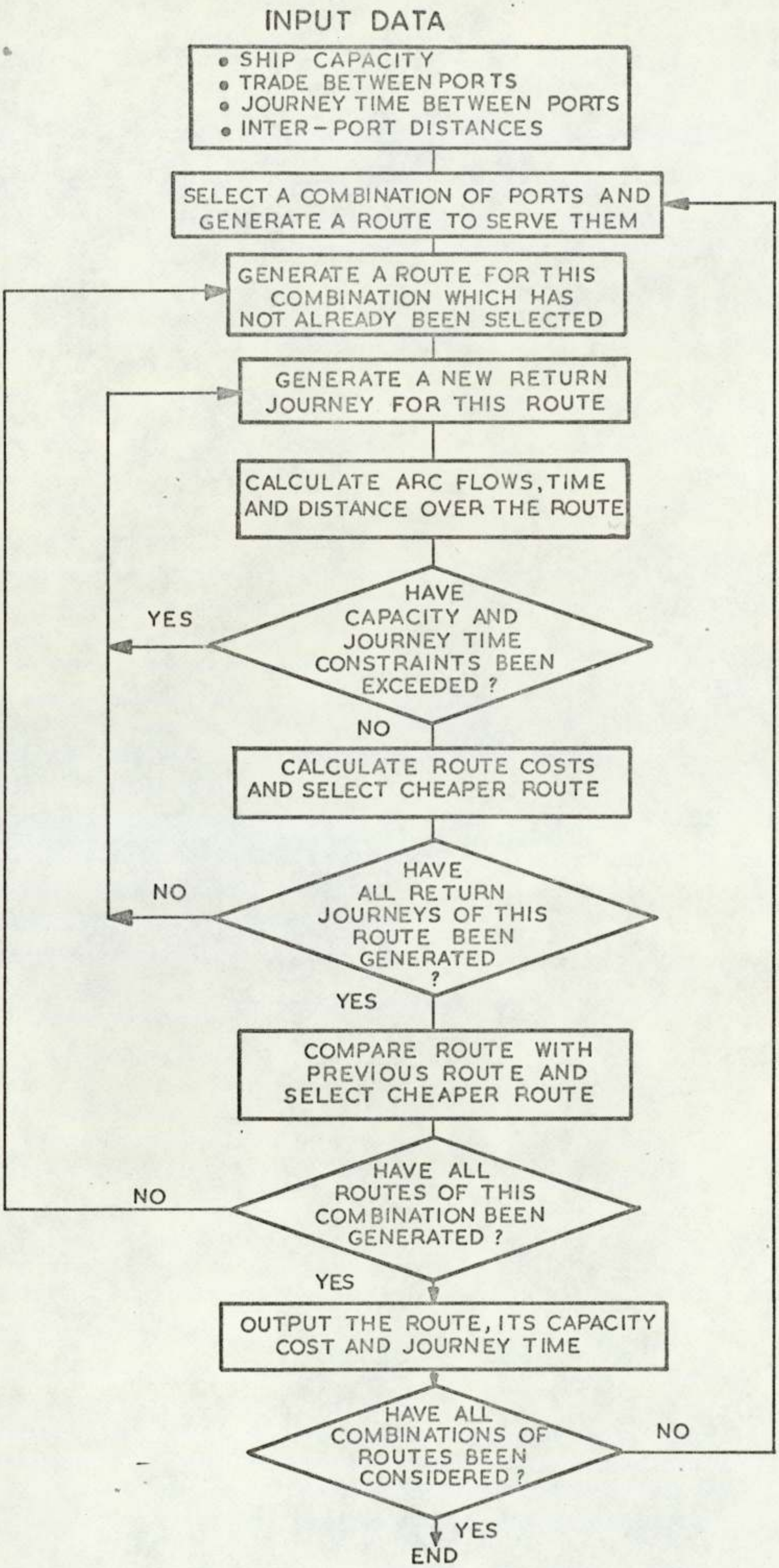
In an interview with the author, M. A. Nicolson of the Booker Line stated that voyage time, ship capacity and trade flow estimates were considered when shipping route schedules were being derived. He also stated that these factors were related because, if the demand for transport is to be satisfied with one or two 1000 ton coasters, voyage times must be limited. This means that demand for longer voyages can only be satisfied by limiting the number of ports to be visited. In certain cases the journey frequency was dictated by the nature of the cargo carried.

A service frequency criterion was accordingly incorporated into the algorithm such that the journey time over any route "k" must not exceed a given number of days.[11] A simplified flow diagram of the algorithm is given in figure 3.5.

---

10. The ships of Booker Bros. (Liverpool) Ltd. on the United Kingdom-Caribbean Service are operational throughout the year, but every 4 or 5 years they are out of service for an average of 5 days for overhauls to be undertaken.

11. The frequency of service between two ports is the number of journeys completed between them per year if the route schedules are liner services. (A regular non-seasonal service is assumed.)

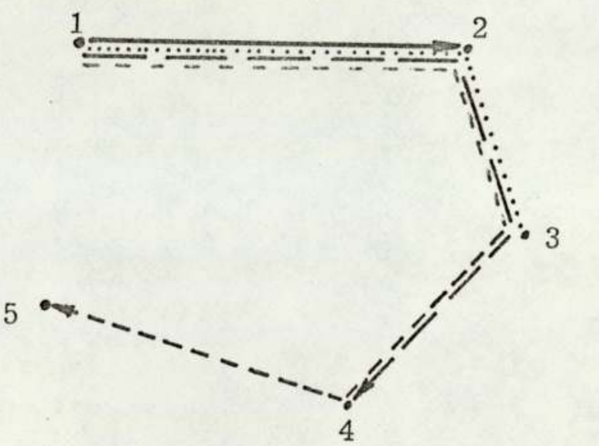


THE ROUTE GENERATION ALGORITHM

Fig. 3·5

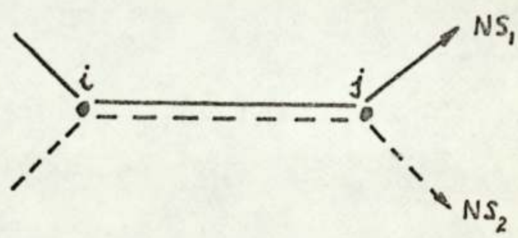
3.1.2.3.3 The demand for transport

If it is assumed that a least cost route[12] serving 5 ports has been selected by the algorithm; then the commodity movements over arc (i, j) in the network of five ports is the sum of the outbound cargo from port 'i', the inbound cargo to port 'j', plus the additional flows over the (i, j) link. This point is illustrated in Figure 3.6 for the outbound cargo from port 1.



CARGO OUTBOUND FROM PORT 1

FIG. 3.6



ARC CAPACITY

FIG. 3.7

$$\text{Over arc } (1,2)\text{, Cargo Flow} = \sum_{j=3}^{*N} a_{1j} + \sum_{i=1}^{N} a_{i2} + \sum_{i=4}^{N} \sum_{j=3}^{(i-1)} a_{ij}$$

*Port 2 is omitted from first summation, otherwise a_{i2} would be counted in both inbound and outbound equations.

12. These routes from which a subset of routes would be chosen need not be enumerated for:-

$^N C_n$ = the number of ways of selecting "n" ports from "N" ports

$(n - 1)!$ = the number of routes in each combination of 'n' ports. Hence the number of alternative routes in 'N' ports equals:- $\sum^{N} {}^N C_n (n-1)!$

Therefore, capacity provision over each directed arc (i,j) must be greater than the amount to be moved over that arc. That is:

$$\text{arc capacity } (1,2) = \sum_{j=3}^{N} a_{1j} + \sum_{i=1}^{N} a_{i2} + \sum_{i=4}^{N} \sum_{j=3}^{(i-1)} a_{ij}$$

Thus, this equation stipulates that the capacity provided over each arc must be equal to, or exceed, the use of capacity over that arc by shipments. The capacity over each directed arc (i,j) is the sum of the capacities of each route passing through arc i,j in the direction (i,j). This point is illustrated in figure 3.7 where over arc (i, j) the route capacities equal SH. C ($NS_1 + NS_2$).

Therefore, equations can be derived for each directed arc from the network of routes selected by the route generation algorithm.

Given these relationships, the selection of a combination of routes to minimise the cost of operating the transport system, may be formulated as a linear programming problem. The essential parameters of this initial formulation are as follows:-

V_k	=	The cost per journey completed over route "k" which is a constant for each defined route. [13]
NS_k	=	The number of ship-journeys over route "k" completed per year.
C_k	=	The capacity of the ship assumed to operate over route "k".
a_{ij}	=	The volume of cargo to be exported from port "i" to port "j" of the network. [14]

---

13. If two ships of different capacity are assumed to operate over the routes shown, two cost per journey figures will apply. Similarly, different ports may have different port and berth rental charges which will result in different values of V_k for different (k).

14. Each value of 'a_{ij}' is composed of many different commodities and is derived from the base year trade flow matrix. Thus, each derived value of 'a_{ij}' is, in fact, a vector, the matrix representing the flow of all commodities between all the ports in a region irrespective of the routes subsequently selected. This assumes that a change in NS_k has no effect

Using these definitions, the problem illustrated in figure 3.8 may be formulated as follows:-

Minimise $V_1 NS_1 + V_2 NS_2$

Subject to:-

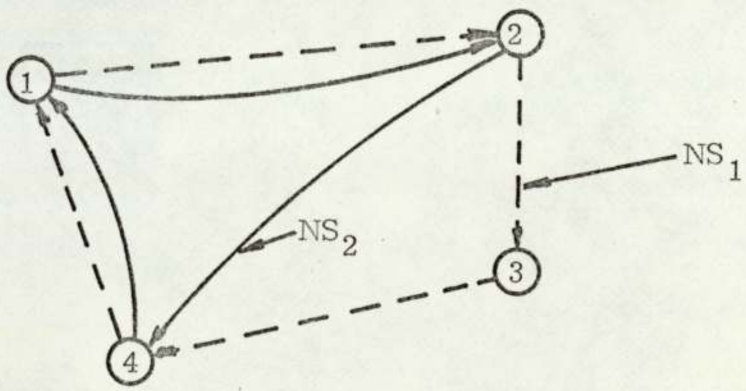
Arc 1,2 $C. NS_1 + C. NS_2 \geqslant (a_{12} + a_{13} + a_{14} + a_{42} + a_{43})$ [15]

Arc 2,3 $C. NS_1 \geqslant (a_{13} + a_{14} + a_{21} + a_{23} + a_{24} + a_{43})$

Arc 2,4 $C. NS_2 \geqslant (a_{14} + a_{21} + a_{24})$

Arc 3,4 $C. NS_1 \geqslant (a_{14} + a_{21} + a_{24} + a_{31} + a_{32} + a_{34})$

Arc 4,1 $C. NS_1 + C. NS_2 \geqslant (a_{21} + a_{31} + a_{32} + a_{41} + a_{42} + a_{43})$



A 2 route 4 port problem

FIGURE 3.8

The objective function, given by:-

$$(V_1 . NS_1 + V_2 . NS_2)$$

is the variable cost incurred in one year by a ship(s) operating over routes 1 and 2. The equation for arc 2,3 which is given by:-

$$C. NS_1 \geqslant (a_{13} + a_{14} + a_{21} + a_{23} + a_{24} + a_{43})$$

15. 'C' is a constant, for shipping companies generally utilise ships of the same tonnage. Mr. D. Pearce, Management Services, Ocean Steam Ship Company provided this view.

states that the capacity provided over arc 2, 3 must be greater than, or equal to, the volume of goods to be moved over the arc. Over this arc, C. NS_1 measurement-tons of capacity are available. The equation for arc 4, 1 is given by:-

$$C\ (NS_1 + NS_2) \geqslant (a_{21} + a_{31} + a_{32} + a_{41} + a_{42} + a_{43})$$

It can immediately be seen that the solution to this linear programming problem does not relate individual shipments to particular routes, and hence it does not exclude the possibility of transhipment from a ship operating over one route to a ship operating over a different route.

This point is illustrated in Figure 3.8 where, over arc (2, 3) for example, the trade flow a_{24} might move over route 1, route 2 or be divided between the two routes offered.

In this example, it can be seen that trade flows a_{14}, a_{21} and a_{24} are included in both arc equations 2, 3 and 2, 4 - a clear case of double counting. If both routes existed in a solution, the capacity requirements of route 2 over arc 2, 4 for example, would be overstated if part or all of the flows a_{24}, a_{21} and a_{14} were carried over the arcs (2, 3); (3, 4) by the ship operating over route 1.

It can also be seen that this formulation also allows particular flows to be transhipped between ships operating over different routes at zero cost. Clearly, each shipment must be assigned to each route in the model if this problem is to be overcome.

A re-examination of Figure 3.8shows that the shipper has two choices of route for shipping his goods to port 2 from port 1. Thus if

a_{121} = that amount of a_{12} moved over route 1

a_{122} = that amount of a_{12} moved over route 2

v_{121} = the cost of moving one ton between ports 1 and 2 over route 1

v_{122} = the cost of moving one ton between ports 1 and 2 over route 2

then the linear programme may be modified in the following way.

The objective function can now include the revenue derived from shipping the goods over the alternative routes. Thus, it now becomes:-

$$\sum_{\text{All } i,j,k} v_{ijk} \cdot a_{ijk} - \left((CA+MX)SH + \sum NS_k \cdot V_k \right)$$ - see Section 3. 2. 1

where the variables v_{ijk} and a_{ijk} are as defined above.

But section 3. 2. 1. stated that the revenue remains constant from year to year, if the cargo to be moved remains constant. This was because the freight rates quoted at present are not related to route utilisation. If this conference system allowed it, the freight rates quoted between ports could be related to the route and the service offered over the route.

The constraint equations now become:-

C. $NS_k \geq \sum a_{ijk}$ for each arc (i, j) served by route "k".

This equation states that the capacity of each route must be greater than, or equal to, the shipments assigned to that route, for each directed arc (i, j) where:

$\sum a_{ijk}$ = the amount of cargo to be moved over arc (i, j) over route k

3.1.2.3.3. The Investment Problem

What investment projects should be selected to reduce the cost of operating the transport system while satisfying the economic and social objectives of each island within the region? When should such projects be implemented?

These questions,asked as the beginning of section 3.1.2.3, cannot be answered by the existing formulation of the model for it assumes that all port facilities are adequate and that an unlimited supply of shipping is available. The effect of each of these factors on the cost of ship operation was examined.

At present, the linear programming model might select three routes to carry out the trade movements between four islands. If only two ships are available to the region, the solution will only be feasible if the two ships can complete the three journeys over the three routes within the time period specified.

:A feasible solution can be assumed in the following way.

In one year, only a maximum number of journeys can be completed by one ship over any one route k. That is

$$NSMAX_k = \frac{365}{T_k} \quad \text{where } T_k = \text{Journey time over route "k"}$$

therefore, if SH ships exist, then:

$$\sum_{\text{All } k} NS_k \frac{1}{NSMAX_k} \quad \text{SH ships}$$

because $\left(\frac{NS_1}{NSMAX_1}\right)$ = The proportion of the time spent by the ship on route 1.

These constraints, while ensuring that the available capacity is not exceeded, do not prevent a solution which includes all the routes. Where such solutions occur, the solution implies that the ship concerned will, having completed one loop, transfer to another loop or loops, before returning to the first.

Constraints on port capacity have not yet been included. To exclude them might mean that very large and highly efficient ships will dominate a solution involving undeveloped ports, if port limitations are not introduced.

The first constraint refers to cargo handling capacity at the onload (origin) and offload (destination) ports, while the second type concerns the docking capability and capacity at the onload and offload ports.

For the time period of interest (one year in this case)[16] it is possible to estimate the upper limit of cargo handling capacity at the point of interest, either the origin "i" or distination "j". This capacity may be a function of working operations. Consideration of this set of conditions requires upper limits to be placed on onloading and offloading operations with the resultant constraints:

The cargo outbound from port "i" $= \sum_{j=1}^{N} a_{ij}^{(A)} \leq P_i^{(A)}$ (Onloading at port of origin)

Cargo inbound to port "j" $= \sum_{i=1}^{N} a_{ij}^{(A)} \leq P_j^{(A)}$ (Offloading at destination port)

where $a_{ij}^{(A)}$ = the volume of cargo to be exported from port "i" to port "j" using facilities type (A)

$P_i^{(A)}$ = the cargo handling capacity of origin port "i" over the time described by the model, in tons for ship type (A)

16 This is not realistic due to the seasonal fluctuation of trade and could be reduced in an application of the model by redefining cargo flow in terms of months or quarters of a year.

$P_j^{(A)}$ = the cargo handling capacity of destination port "j" over the time described by the model, in tons for ship type "A"

(A) = the type of ship and the facilities used to load and unload it. Other variables are as previously described.

Again for the period of interest, it is possible to estimate the capabilities and capacities of the origin and destination ports to dock ships in terms of the number of ships, as well as their capabilities in terms of ship type. The applicable constraints are:-

$$\sum_{k \in R_i} \mu_{Ak} \cdot NS_k^{(A)} \leq S_i^{(A)}$$ [17] for all k passing through the i th port

and

$$\sum_{k \in R_j} \mu_{Ak} \; NS_k^{(A)} \leq S_j^{(A)}$$ [17] for all k passing through the j th port

where:-

$S_i^{(A)}$ = the ship-docking capacity at origin "i" over the time described by the model, in number of ships, of type A

$S_j^{(A)}$ = the ship-docking capacity at destination "j" over the time described by the model, in number of type A ships.

R_i = the set of routes serving the i^{th} port

μ_{Ak} = a factor, to indicate the possibility of ship type A docking at those ports served by route "k".

The values of the factors may be unity for permissible sets (A, k) and infinity for excluded sets (A, k). It is clear that in the particular expression given, the NS_k value will be forced to zero when μ_{Ak} equals infinity as S_i and S_j are finite. Thus, in the general case, the docking factors will force the variable $NS_k^{(A)}$ to be zero when the docking possibility does not exist.

3.1.2.3.4 Service Frequency

Certain commodities require special services when being shipped from point to point. This is particularly true in the Caribbean for perishable commodities, where services required must include either refrigeration or a high service frequency between points of origin and destination (Section 2.6). Consider the case where two routes serve two

17. Adapted from Whiton , J.C., Some constraints on linear programming models, Naval Research Logistics Quarterly, June 1967, pages 257-260.

of several ports. The frequency of service provided between these two ports must clearly exceed particular values for certain perishable commodities.

If, for example, the average time between successive port visits is not to exceed 15 days, then if ship journeys are equally spaced

$$\sum_{k} NS_k \geqslant \frac{365}{15}$$ for all "k" routes serving both "i" and "j" ports.

3.1.2.4 The Final Formulation of the Model

The formulation of the model may be summarised in terms of the objective function and the applicable constraints.

As the initial objective of the model is to maximise the profit from transport system operation while satisfying the demand for movement, the objective function can be written:-

$$\sum_{\text{All } i,j;\ \text{all } k} a_{ijk} \cdot v_{ijk} \quad - \quad \sum_{\text{All } k} NS_k \cdot V_k$$

where fixed costs are considered outside the model.

The conditions that must be satisfied by any solution of the model may be stated as follows:-

Firstly, the sum of the journeys between ports "i" and "j" of the network must not exceed a defined time interval. That is:-

$$\sum_{k \text{ all } (i,j)} NS_k \geqslant \frac{365}{T_{ij}}$$

Secondly, the shipping capacity of each route must be greater than, or equal to, the shipments assigned to that route, for each directed arc (i, j).

That is:-

$$\sum C_k^{(A)} . NS_k^{(A)} \geq \sum a_{ij\ k} \quad \text{for each route k serving arc (i,j)}$$

Thirdly, the sum of the cargoes allocated to each route of the network at port "i" when exporting to port "j" must equal the amount to be exported. That is:-

$$\sum_{i,j,k} a_{ijk} = a_{ij}$$

(All (i, j) for i $\neq$ j)

Fourthly, a solution will only be feasible if a solution results where the number of ships required are equal to, or less than, the number available. That is:-

$$\sum_k NS_k^{(A)} / NSMAX_k^{(A)} \leq SH^{(A)}$$

Fifthly, for cargo outbound from port "i" and inbound to port "j" the following constraints apply, where the cargo to be exported or imported on ship type A through the related facilities type A must be less than, or equal to, the maximum handling capacity of these facilities.

$$\sum_{\text{All } j,} a_{ij}^{(A)} \leq P_i^{(A)} \quad \text{and} \quad \sum_{\text{All } i,} a_{ij}^{(A)} \leq P_j^{(A)}$$

The value of these constraints will be determined by the time period represented by the model. Such constraints may be a function of working rules, crane capacity or any complex set of operations.

Sixthly, the docking-capacity of each port in terms of the numbers of ships handled over the time period envisaged, can be described by the constraints:-

$$\sum_{k \in R_1} \mu_{Ak} \cdot NS_k^{A} \leqslant S_1^{(A)} \qquad \text{(origin limit, port 1)}$$

$$\sum_{k \in R_2} \mu_{Ak} \cdot NS_k^{(A)} \leqslant S_2^{(A)} \qquad \text{(destination limit, port 2)}$$

This formulation of the transport model is described in detail in Appendix F.

For a given level of traffic, this model should simulate the operation of the system for it now incorporates all those factors, identified during data collection, which were considered relevant to the operation of the transport system.

3. 1. 3 Simulation

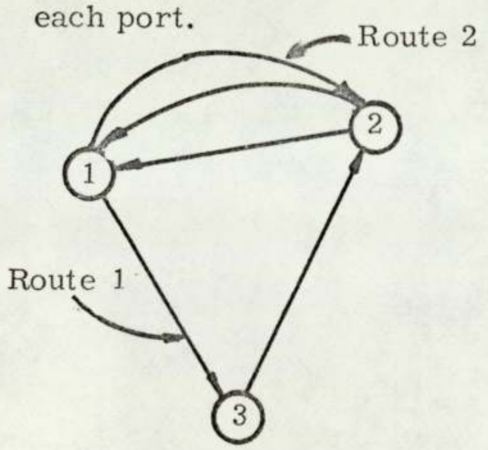
3. 1. 3. 1 Introduction

"A simulation is a working model of the system which should be able to reproduce the actual behaviour of the real system to an accepted degree of accuracy. If the simulation is accurate, data generated from the simulation should agree closely with data from the operational system. In other words, from the point of view of systems design, one can treat the simulation as if it were the actual system and make changes to the parameters to see how to optimise the system." (Jenkins, 1969).

Before a working model of the system is set up, a demonstration of the model is given in the following pages, so that its application can be more clearly understood.

3. 1. 3. 2 The Model Demonstrated

A two route, three port problem was selected where the route structure and direction are given in Figure 3. 9, together with the trade flow matrix which illustrates the annual movement of commodities between each port.



A 2 ROUTE 3 PORT PROBLEM

FIGURE 3. 9

IMPORTS / EXPORTS	1	2	3
PORT 1	0	10	4
PORT 2	9	0	2
PORT 3	7	1	0

TRADE FLOW MATRIX (measurement-tons)
SHIP CAPACITY = 1 Measurement ton

In this model only three constraints are considered.

Thus, the model can now be written as:-

$$\text{MINIMIZE:} \quad 3.NS_1 + 2.NS_2 + \sum_{\text{all } i,\, j,\, k} v_{ijk}.\, a_{ijk}$$ [18]

18. The objective function originally formulated was as follows:

$$\text{Maximize Profits} = \text{Revenue} - \text{Cost of Operation}$$
$$= \text{A constant} - \sum_{\text{All "k"}} V_k.\, NS_k$$

This is equivalent to minimising $+ \sum_{\text{All "k"}} V_k \cdot NS_k$

Subject to:-

							ARC
		$1.NS_2$	-	(a_{122})		≥ 0	1,2
$1.NS_1$			-	$(a_{121} + a_{131} + a_{231})$		≥ 0	1,3
$1.NS_1$			-	$(a_{211} + a_{231} + a_{311})$		≥ 0	2,1
		$1.NS_2$	-	(a_{212})		≥ 0	2,1
$1.NS_1$			-	$(a_{311} + a_{321} + a_{121})$		≥ 0	3,2

$NS_1 + NS_2 \leq S_2$ (the ship docking capacity of port 2)

$$a_{121} + a_{122} = a_{12} = 10$$
$$a_{131} = a_{13} = 4$$
$$a_{211} + a_{212} = a_{21} = 9$$
$$a_{231} = a_{23} = 2$$
$$a_{311} = a_{31} = 7$$
$$a_{321} = a_{32} = 1$$

The three constraints are as follows:-

- the shipping capacity of each route over each arc must be greater than, or equal to, the shipment assigned to that route.
- the docking capacity of port 2 in terms of the numbers of ships that it can handle in the time period envisaged is assumed to be limited to some number.
- the sum of the cargoes allocated to each route of the network at port "i" when exporting to port "j", must equal the amount to be exported.

This formulation can be re-written in detached coefficient form as illustrated in Table 3.3.

By adding non-negative slack variables to the equations containing inequalities, and by adding non-negative artifical variables to the remaining equations containing equalities, the system of equations illustrated in Table 3.4 is obtained.

TABLE 3.3

MIN:	$3.NS_1$ +	$2.NS_2$ +	a_{121} +	a_{122} +	a_{131} +	a_{211} +	a_{212} +	a_{231} +	a_{311} +	a_{321}	=	Z
		-1		+1							⩽	0
	-1		+1		+1			+1			⩽	0
	-1					+1		+1	+1		⩽	0
		-1					+1				⩽	0
	-1		+1						+1	+1	⩽	0
	+1	+1									⩽	S_2
			+1	+1							=	10
					+1						=	4
						+1	+1				=	9
								+1			=	2
									+1		=	7
										+1	=	1

The problem in detached coefficient form

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}		b
1		-1		1							1													0
2	-1		1		1			1				1												0
3	-1					1		1	1				1											0
4		-1					1							1										0
5	-1		1						1	1					1									0
6	1	1														1							=	S_2
7			1	1													1							10
8					1													1						4
9						1	1												1					9
10								1												1				2
11									1												1			7
12										1												1		1
Z =	3	2	1	1	1	1	1	1	1	1														
	NS_1	NS_2	a_{121}	a_{122}	a_{131}	a_{211}	a_{212}	a_{231}	a_{311}	a_{321}	SLACK VARIABLES						ARTIFICIAL VARIABLES							

The complete system of equations

The artificial variables are introduced because they provide an initial basic feasible solution. That is:-

$$x_{17} \text{ ----- } x_{22} = b_i \quad \text{for } i = 1, 2 \text{ ----- } m$$

$$x_1 \text{ ----- } x_{16} = 0$$

The two phase method simplex method for solving this problem was applied. Here, the infeasibility form of the objective function, defined by

$W = x_{17} + x_{18} + \text{-----} x_{22}$ is minimised, followed by

the minimisation of the resulting modified objective function

The minimization of the infeasibility form of the objective function is called Phase I, while the minimization of the actual objective function is called Phase II.

The solution of this problem is given in Appendix H, using the revised simplex method which is also described. The actual solution of this problem is given in Table 3.5.

From this table it can be seen that the cost of transport operation is made up as follows:-

$$Z = 3.NS_1 + 2.NS_2 + a_{122} + a_{131} + a_{212} + a_{231} + a_{311} + a_{321} + a_{121}$$

$$78 = 27 + 18 + 9 + 4 + 9 + 2 + 7 + 1 + 1$$

This demonstration of the model shows that, while minimizing the cost of transport operation, the model will determine simultaneously:-

VARIABLE	BASIS	VALUE	1	2	3	4	5	6	7	8	9	10	11	12	π_i	b_i
SLACK 1	x_{11}	0	1		−1	−1	1		−1		1	1		−1	0	0
a_{121}	x_3	1			−1		1					1		−1	0	0
a_{231}	x_8	2										1			3	0
a_{212}	x_7	9									1				2	0
a_{321}	x_{10}	1												1	0	0
SLACK 16	x_{16}	5_2-18			1	1		1			−1	−1	−1		0	a_2
a_{122}	x_4	9			1		−1		1			−1		1	−1	a_{12}
a_{131}	x_5	4								1					−1	a_{13}
NS_2	x_2	9				−1					1				−3	a_{14}
a_{311}	x_9	7											1		−4	a_{23}
SLACK 2	x_{12}	2		1			−1			−1		−1	1	1	−4	a_{31}
NS_1	x_1	9			−1							1	1		−1	a_{32}

THE SOLUTION

Table 3.5

- the shipping routes to be followed given an initial number of defined routes
- the allocation of commodity flows to each selected route
- the frequency of service required over each route to satisfy the demand for transport.

The demonstration does not, however, illustrate how the system will react to changes in the input data. This must be possible if the system is to be improved. Such an activity can be performed by conducting a sensitivity analysis of the final solution.

3.1.3.3 Sensitivity Analysis

Changes in the objective function resulting from changes in the values of the "b_i" can be determined from the equation:

$$\Delta Z = - \sum_{i=1}^{m} \Pi_i . \Delta b_i$$ where

ΔZ = the change in the cost of operating the transport system

Δb_i = the change in constraint parameters

Such parameters could include port docking capacity, trade flow, or service frequency constraints.

Now changes in the "b_i" directly affect the value of the "x_i" through the relationship

$$\Delta x_i = \sum_{k=1}^{m} B_{ik} . \Delta b_k \qquad \text{for } i = 1, 2 \text{ ----- } m$$

where Δx_i = the change in the values of the NS_k or a_{ijk} where

NS_k = the number of journeys per year completed over route "k"

a_{ijk} = the amount of cargo to be exported annually from port "i" to port "j" over route "k".

The above relationships are only satisfied, however, if the original basis remains feasible, the feasibility condition being given by:-

$$\sum_{k=1}^{m} B_{ik} \; (b_k + \Delta b_k) \geq 0 \quad \text{for } i = 1,2 \text{ -----} m$$

which can be written

$$x_i + \Delta x_i = x_i + \sum_{k=1}^{m} B_{ik} \cdot \Delta b_k \geq 0 \quad \text{for } i = 1,2, \text{ -----} m$$

where the x_i and Δb_k have already been defined and where the B_{ik} are obtained by inverting the original system of equations.

Thus, changes to the input data can be related to changes in the operation of the transport system.

3. 1. 3. 4 Sensitivity Analysis Applied

From the solution of the problem discussed in section 3. 1. 3. 2, and the theoretical summary of sensitivity analysis discussed in section 3. 1. 3. 3, it can be seen that changes in the cost of transport operation can be related to changes in the values of the commodity flows. That is:-

$$Z = 1. \; \Delta a_{12} + 1. \; \Delta a_{13} + 3. \; \Delta a_{21} + 4. \; \Delta a_{23} + 4. \; \Delta a_{31} + 1. \; \Delta a_{32}$$

as long as the following conditions are satisfied:-

$$a_{321} + \Delta a_{32} \geqslant 0$$
$$a_{311} + \Delta a_{31} \geqslant 0$$
$$a_{231} + \Delta a_{23} \geqslant 0$$
$$a_{212} + \Delta a_{21} \geqslant 0$$
$$NS_2 + \Delta a_{21} \geqslant 0$$
$$a_{131} + \Delta a_{13} \geqslant 0$$
$$a_{122} + \Delta a_{21} \geqslant 0$$
$$NS_1 + \Delta a_{23} + \Delta a_{31} \geqslant 0$$
$$a_{121} + \Delta a_{12} - \Delta a_{21} \geqslant 0$$
$$X_{12} - \Delta a_{13} - \Delta a_{12} + \Delta a_{31} + \Delta a_{21} \geqslant 0$$ *Refers to comment on page 117
$$X_{16} + \Delta S_2 - \Delta a_{21} - \Delta a_{23} - \Delta a_{31} \geqslant 0$$

INVERSE OF BASIS - TABLE 3.6

Thus, the solution of the problem will remain optimal if, for example,

$$(S_2 - 18) + \Delta S_2 - \Delta a_{21} - \Delta a_{23} - \Delta a_{31} \geqslant 0$$

If $S_2 = 18$ then:-

$$\Delta S_2 - \sum \Delta a_{ij} \geqslant 0 \text{ for } i = 2, 3 \text{ and } j = 1, 3 \text{ for } i \neq j$$

Hence, if Δa_{21}, Δa_{23} or Δa_{31} increased beyond the capacity of the port, (given by S_2), then the additional number of journeys through the port (equal to ΔNS_2) could not be undertaken, due to the ports limited docking capacity. In other words, increases in traffic (a_{ij}) through a port can only occur if the capacity of the port to handle the traffic is increased in proportion.

These two examples illustrate the fact that changes in the costs of operating the transport system can be determined from changes in parameters affecting the system.

In a full scale model of a transport system, where all those factors given in Appendix F are assumed to be included, a sensitivity analysis of the solution to the model would result in an equation of the form:-

$$Z = \Pi_T 365/\Delta T_{ij} + \Pi_a \ \Delta a_{ij} + --- \ \Pi_{SH} \Delta SH \ + \ --- \ \Pi_P \ \Delta P_i + --- \Pi_i \Delta S_i$$

where T_{ij} = the maximum acceptable average waiting time between visits

a = the vector of the amounts of cargo to be exported between each of the ports in the region

SH = the number of ships available to the region

P = the vector of port cargo handling capacities

S = the vector of ship docking capacities

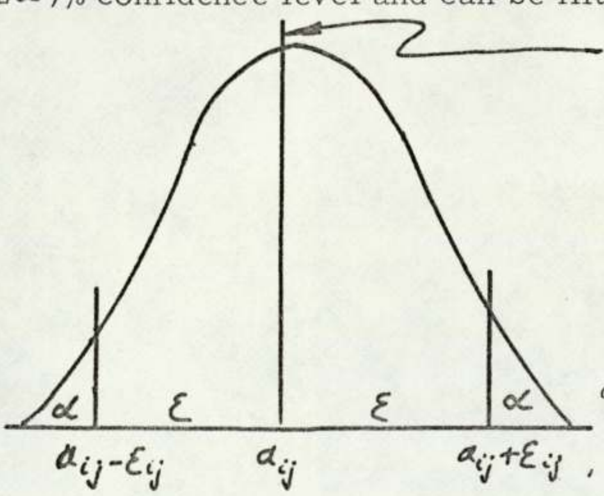
Π = the vector of simplex multipliers derived during the analysis

Now the inter-relationships between the trade flows, as defined by the problem postulated in section 3. 1. 3. 2 can be immediately identified from the inverse of the original basis, which is given in Table 3. 6. It can be seen that the optimality of the solution depends upon the values of Δa_{ij}, which are themselves inter-related. In practice, the accuracy of trade flow estimates can be determined.[19]

---

19. A suitable test for sampling data, to ensure, for example, a 90% confidence level in the statistical accuracy of the data is described in Appendix F (An approach to data collection).

In this case, $\mathcal{E}_{ij}$ stands for the maximal error of estimate at the $(100-2\alpha)$% confidence level and can be illustrated as shown below.

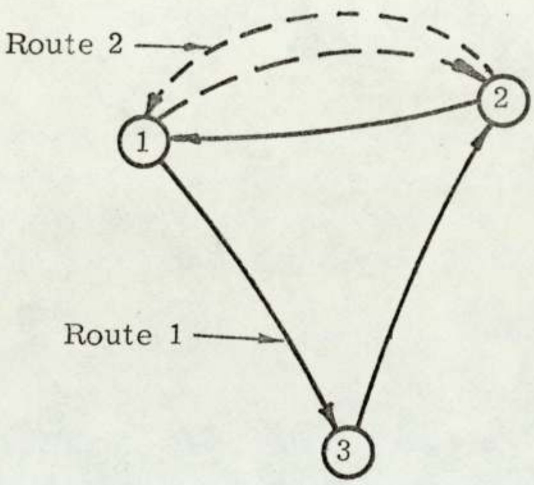


estimated value (V)

% of total area is in each tail.

The actual value will lie within the limits of $(a_{ij} \pm \mathcal{E}_{ij}$ with $(100-2\alpha)$% confidence.

Thus, if the transport system is to be feasible, it should be able to carry all the flows given by $(a_{ij} + \mathcal{E}_{ij})$. Clearly, the trade flow estimates input to the transport model should always be those given by $(a_{ij} + \mathcal{E}_{ij})$ to ensure a feasible solution. In this example, the effect on the solution of such errors in the input data [equal to a maximum of $-2\mathcal{E}$) where $\Delta a_{ij} = 2\mathcal{E}ij$ for all i, j $(i \neq j)$], can be understood from an examination of figure 3.10 and table 3.6.



$a_{12} = 10$

$a_{13} = 4$

$a_{21} = 9$

$a_{23} = 2$

$a_{31} = 7$

$a_{32} = 1$

OPTIMAL ROUTING PATTERN FIGURE 3.10

This will show that the system is always feasible for any error estimate in any a_{ij}, but that optimality is not always obtained. For example, if both a_{31} and a_{21} were in error by 10% then the asterisked expression in table 3.6 would be negative, and the solution would not be optimal.[20]

It can also be seen that if Δa_{21} equalled $-2\mathcal{E}_{21}$, the number of journeys to be completed by NS_2 would be reduced by $2\mathcal{E}_{21}$. Similarly, the model would be in error by $(\Delta a_{23} + \Delta a_{31})$ journeys over route 1 if a_{23} and a_{31} were both over-estimated by Δa_{23} and Δa_{31}.

20. It is assumed that all flow data input to the model is of the form $(a_{ij} + \mathcal{E}_{ij})$ for all i,j $(i \neq j)$. Hence $2(-0.7 - 0.9) = -3.2$ and $X_{12} - 3.2 = -1.2$. Δa_{13} and Δa_{12} are assumed to be zero.

This simple illustration shows that:-

- All flows input to the model should include the positive error term to ensure a feasible solution.
- Errors in estimating traffic may result in only near optimal solutions.
- Changes in trade flows can modify the number of journeys required over a route.
- Changes in one trade flow can interact with others in determining the optimality of a solution.[21]

The last point means that the effect on the solution of a change (or error) in two or more flows occurring simultaneously can only be explored by repeatedly re-running the model with different values of $b_j = a'_{ij}$ and noting the results. The results of a simple sensitivity analysis will indicate those variables which will modify the solution with a small change.[22] This means that the values of the b_j and/or the a_{ij} are large. Thus the non-sensitive variables can be ignored in subsequent investigation.

---

21. That this is so can be illustrated by using the optimality equations where, in the general case:-

$$x_i + \Delta x_i = x_i + \left[\beta_{i1} \Delta b_1 + \beta_{i2} \Delta b_2 + \cdots \beta_{im.} \Delta b_m \right] \geq 0$$

A simple sensitivity analysis gives the value of Δb_1 as $\frac{\Delta x_i}{\beta_{i1}}$ whereas it should really be given by the second term below if $\Delta b_2 - \cdots \Delta b_m > 0$.

That is $\frac{\Delta x_i}{\beta i1} \rightarrow \dfrac{x_i - \sum_{j=2}^{m} \beta_{ij} \Delta b_j}{\beta_{i1}}$ as the Δb_j increase

22. An examination of Table 3.6 and figure 3.10 shows that the β_{ij} associated with NS_i and port docking constraints equal 1/ship capacity while the β_{ij} associated with the a_{ij} equal unity.

When the operation of this transport model was considered in relation to the problems it had to solve (illustrated in figure 3.1), it was seen that it would:-

- identify which port facilities might require improvement
- re-allocate shipping to more efficient routes
- identify the need for investment in shipping.

In the latter case, the essential characteristics of new vessels, such as speed and carrying capacity, could be used to establish the input parameters to the route generation algorithm. The model could then be run with the inclusion of the projected vessel and the results compared to other runs with different vessels. This iterative process would enable the transport planner to decide on the desirability or otherwise of perhaps providing a hovercraft service or capital assistance to the existing boat building industry. The effect of providing such improvements as cold storage facilities cannot however, be determined, until the additional traffic generated by such an improvement has been estimated. A detailed evaluation of the model, as formulated in this section, was carried out,[23] and resulted in a number of changes. Firstly, mixed linear - Firstly, mixed integer programming may be required if the number of ships in the region is severely limited. The modification ensures that the number of routes selected do not exceed the number of ships available.

Secondly, the number of port groups in a region from which a subset of shipping routes can be selected is limited to:-

$$\sum_{n=1}^{N} {}^{H}C_{h} \left({}^{(N-H)}C_{(n-h)} \right)$$

group of ports where:-

---

23. See Appendix I , where a solution to a 5 port 24 route transport problem was derived using the formulation described in section 3. 1. 2. An evaluation of the results suggested a number of improvements.

h = the number of home ports selected for inclusion in the group of "n" ports.

n = the number of ports in a group of ports

N = the total number of ports in the region

H = the number of home ports.

This is because ships always operate from a home port, and must return to it on certain Sundays (a factor governed by those who man them). This additional constraint limits the journey times of each ship to 6 or 13 days or less.

3.1.3.5 Approaches to Transport System Design

To commence system design, two major activities would normally have to be undertaken.

Firstly, a list of reasonable development projects for the region would be prepared. This list would include as many projects as are at all plausible, either designated by the island administration, suggested by an assessment of the current situation, or by private investors. At this point an effort would be made to avoid any tendency towards undue haste in prejudging the desirability, urgency, or feasibility of these proposals, but projects not meeting the development requirements of the financing authority would be excluded.

Secondly, a number of possible alternative solutions should be generated for subsequent evaluation. "The preparation of alternative solutions requires, first of all, the selection of a limited number of solutions which will be studied in greater detail. For each of these, forecasts of income and expenditure have to be made, and a table drawn up, showing for each year of the anticipated life of the project, its income and expenditure" (O.E.C.D., 1968).

In this study, it is assumed that a list of candidate projects has been prepared by the authorities concerned. The development of a methodology for the selection of a time-staged transport investment programme is regarded as the problem to be solved.

Section 3.1.3.3 showed that a limited number of transport facility improvements can be identified with the use of the linear programming transport model. This is because the cost of transport system operation can be directly related to the parameters governing the system, through the optimal simplex multipliers, or "shadow prices", as they are sometimes called. "In the early stages of this analysis the "shadow prices" will reveal the substitution ratios between investment projects. This approach has the value that the effect on the system as a whole resulting from investment in any part of the system can be determined"(Fromm, 1965). Some of the proposed development projects will be rejected by the model as irrelevant to the improvement of the transport system while the relevant ones will be identified through the simplex multipliers derived from a solution of the model.

For example, the expression (π_i . ΔS_i) will indicate the potential reduction in the cost of operating the transport system resulting from an increase in the ship-docking capacity of the i^{th} port.

Now the values of ΔS_i can, in turn, be related to the amount of manpower, equipment and capital that would be required to obtain it. Thus, the saving in the cost of operating the system is offset by the investment required to improve it.

Practical considerations limit the values of ΔS_i to integer values. For example, investment in a wharf or a new ship is an all or nothing investment. For this reason, a number of solutions to the model may be derived by using the "shadow prices" to determine the desirability or otherwise of investment in particular facilities. "In short, the role of prices is to serve as appropriate substitution ratios among inputs, intermediate outputs, and end items in the whole sequence of choices - designing alternative systems redesigning the alternatives, and comparing the alternatives in the narrower menu of proposals that is finally presented to higher authorities" (McKean, 1966).

To illustrate the role of the simplex multiplier, the 5 port problem considered in appendix H was formulated as a linear programming problem using the trade flow data given therein. The port docking and shipping constraints selected were as given in Table 3.7.

CONSTRAINT	NOTATION	CAPACITY[24]
Port 1	S_1	24
Port 2	S_2	209
Port 3	S_3	48
Port 4	S_4	230
Port 5	S_5	20
Number of Ships	SH	4

PORT DOCKING & SHIPPING CONSTRAINTS
TABLE 3.7

A sensitivity analysis of the solution derived by the model when using the above data, resulted in the equation:

$$\Delta Z^{25} = -4298.7\Delta S_2 - 2752.5\,\Delta S_3 + \sum_{i=1}^{5} \sum_{j=1}^{5} \pi_{ij}\,\Delta a_{ij} + \text{other terms}$$

If trade flow is static, the only terms relevant to transport investment are those containing ΔS_2 and ΔS_3. This result shows that the cost of transport operation could be reduced if the ship docking capacities at either, or both ports are increased.

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24. The values were chosen arbitrarily

25. Solution reference 2C. (For author's reference only).

Four investment options exist; that of no investment, where the higher cost of transport operation over a specified period is less than any contemplated investment, that of investment in S_2, investment in S_3, or that of investing in both S_2 and S_3. These options are considered using the 5 port problem described in appendix I.

The two port investment projects ΔS_2 and ΔS_3, were regarded as having identical characteristics (port docking capacities) equal to +2. The direct and immediately measurable effect of their inclusion or otherwise was determined by running the linear programming transport model for each option. The results of this analysis are given in table 3.8. By increasing the capacity of a port, certain ships are then able to make additional visits to it, while making less visits over the previously used, but more costly shipping routes.

OPTION	REF. No. [27]	REGIONAL GAIN ΔZ £	PORT THROUGHPUT				
			1	2	3	4	5
No change	2C	0	23.54	209 [26]	48 [26]	221.16	19.16
ΔS_2	2B	7041	22.63	211 [26]	48 [26]	221.22	17.16
ΔS_3	2D	5955	22.48	209 [26]	49.09	221.57	17.80
$\Delta S_2+\Delta S_3$	2E	7138	22.48	211 [26]	48.30	221.52	17.16

THE DIRECT EFFECTS OF PORT IMPROVEMENT

Table 3.8

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26 Constraint value

27 For author's use only

Under static conditions of trade, two effects can be immediately identified from the results. These are:

- The reduction in the cost of operating the transport system obtained from each investment strategy
- The effect on one port resulting from investment in another[28]

The first of these effects may be regarded as a complementary or additive benefit in that all islands will gain. The second may be regarded as a substitutive or displacement effect. The second effect will result in further indirect effects which must be determined quantitatively before any one investment strategy can be regarded as better than any other.

From Table 3.8 it can be seen that the complementary benefits[29] resulting from investment in the system, differ between projects where one project may be substituted for another in any specified sequence of developments. It can also be seen that any of the projects added subsequently in the sequence has an incremental value less than the preceding elements in the sequence.

Two alternative sequences of project construction can be considered, to determine the effect of a current investment on future investment strategy. These are considered in Figure 3.11.

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28. Investment in one port may result in a lower volume of ship traffic through another port, caused by changes to some of the shipping routes.

29. Such gains may result where those islands forming the region co-operate in the design of their transport system. Such benefits could be distributed among the island in terms of reduced subsidy charges and increased economic activity.

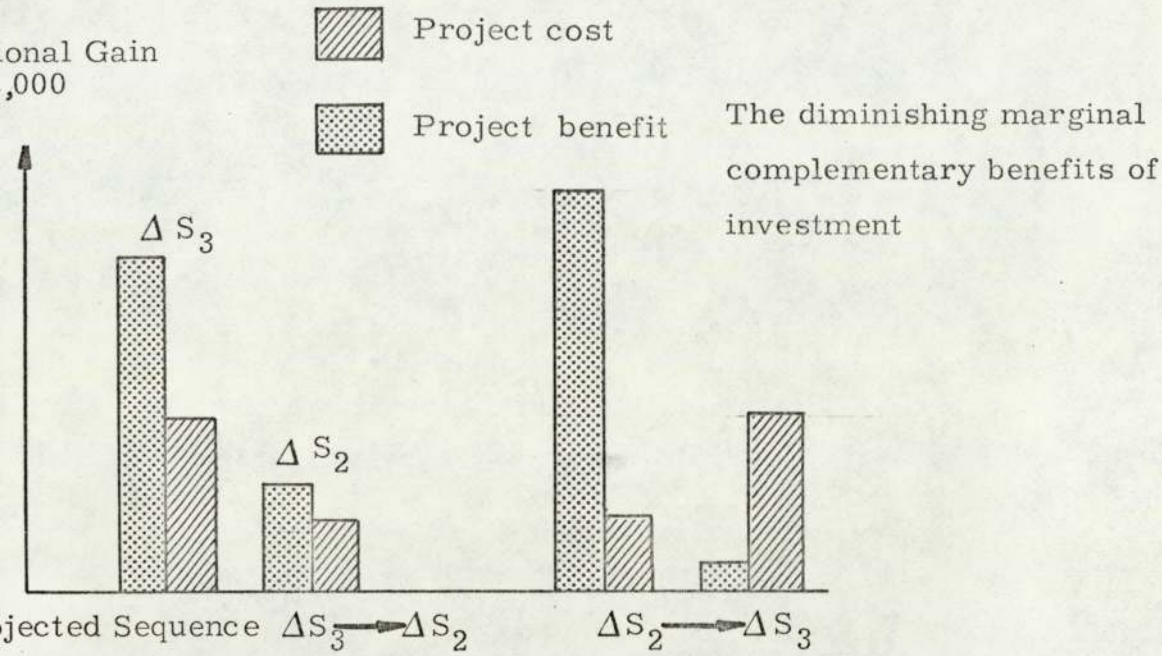

Figure 3.11

If the costs of each project are as illustrated in figure 3.11 the marginal benefit associated with project investment $\Delta S_2 = +2$ in the sequence $\Delta S_3 \rightarrow \Delta S_2$ exceeds its cost, while the benefits associated with each project ordered in the least cost sequence reveals that the incremental cost of the second investment exceeds the benefit it can realise, thus reducing the net return to the investment in the transport system as a whole.

Considered separately, both projects (ΔS_2 and ΔS_3) have favourable cost-benefit ratios, but together they reduce the net direct return to the investment in transportation.

Accordingly, if the ojective of a regional cooperative venture is to maximise the net gain for mutual sharing, it is important to introduce projects in their most economical sequence for two reasons:

Firstly, if this is not done, it is possible to include projects whose benefits exceed their cost on a first-added basis, only because they pre-empt some part of the benefits of subsequent investment in the system. Such an approach would result in a larger gross benefit, the last increment of which, however, has a value which is less than the cost involved in obtaining it. The net gain consequently will be reduced.

Secondly, although a test could be performed on the last project of any sequence to evaluate the comparative costs and benefits and so screen out any project which would appear to be unwarranted only because it pre-empts a part of the benefits of some other projected investment, there will be no assurance that the economic projects will not be added in an uneconomic sequence[30]. In this event, higher costs will be incurred earlier in time than necessary.

Thus, the use of sensitivity analysis ensures that all those ports which could contribute to a gross regional benefit are identified, and that the net gain of alternative construction sequences can then be determined in a succession of computer runs with the model. Such an approach overcomes the objection referred to above, and identifies the effect of a current investment strategy on future investment strategy. "While a funding authority can use the above approach to identify a project construction sequence which satisfies the cash and resource flow limitations, and can evaluate these investment proposals (prepared by island or regional authorities) in terms of the gross direct benefit, the indirect effects of such investment are ignored" (Krutilla, 1967).

An alternative method of selecting a number of transport facility improvements from a larger number, exogenously specified or identified from a sensitivity analysis, is suggested if the objective is simply to minimise the cost of transport operation and investment. A procedure due to Burns, (1969) is as follows:

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30. The need for additional investment over time is assumed, for trade flows do change over time, although static flows have only been considered in the preceding chapters.

Specify all those facilities, identified as important (from the shadow prices) with their attendant capacities, capital costs, maintenance costs and operating costs. The linear programming formulation is as follows:

The capacity of a facility cannot be exceeded. Any one project must be completely built or not built at all, hence the integer nature of the programme. In addition to the constraint changes, the objective function is altered from the simple minimisation of transport costs to include the capital and maintenance costs of alternative improvements considered. In this manner, the solution with the linear programming system has a figure for total charges or costs and a separate figure for the capital and maintenance costs associated with the network. To apply this approach to the transport model developed by the author, the required changes are as follows:

The objective function must now be written:

$$\text{Maximise} \sum_{\text{All ijk}} \overline{\sum a_{ijk} \cdot v_{ijk}} - \left[SH.F + \overline{\sum_{\text{All k}} NS_k . V_k} + \overline{\sum_{i} Q_i . Y_i} \right]$$

where

Q_i = the investment and operating cost of facility "i" over the period considered (e. g. ΔP_i is one such facility whose total cost may be equal to Q_i).

Y_i = the i^{th} facility, expressed as a (0, 1) integer.

V_k = the cost incurred by a ship in completing a journey over route "k".

NS_k = the number of ship-journeys completed over route "k" over the period considered

v_{ijk} = the revenue derived from shipping 1 ton of cargo from port "i" to port "j" over route "k".

a_{ijk} = the amount of cargo to be exported annually from port "i" to port "j" over route "k".

The only conditions, or material balance equations, that have to be altered are those concerned with the facility improvements to be considered.

Firstly, a solution will only be feasible if a solution results where the number of ships required are equal to, or less than, the number available. That is:

$$- \Delta SH \, . \, Y_{sh} + \sum_{\text{All } k} NS_k / NSMAX_k \leq SH$$

where

ΔSH = the additional ship that could be allocated to the intra-regional transport system

Y_{sh} = the ship, expressed as a (0, 1) integer

Secondly, for cargo outbound from port "i" and inbound to port "j", the following constraints apply, where the cargo to be moved on ship type (A) through related facilities type (A) must be less than, or equal to, the maximum handling capacity of these facilities. That is:

$$- \Delta P_i . Y_i + \sum_{\text{All } i,j}^{(A)} a_{ij} \leq P_i^{(A)} \quad \text{for all "i" ports}$$

$$- \Delta P_j . Y_j + \sum_{\text{All } i,j}^{(A)} a_{ij} \leq P_j^{(A)} \quad \text{for all "j" ports}$$

where

$\Delta P_i^{(A)}$ = the postulated improvement in the cargo handling capacity of port "i"

Y_i = the facility improvement expressed as a (0, 1) integer

Thirdly, the docking capacity of each port in terms of the number of ships handled over the time period envisaged, can be described by the equation:

$$- \Delta S_1^{(A)} . Y_1' + \sum_{k \in R_i}^{N} \mu_{kA} . NS_k^{(A)} \leq S_i^{(A)} \quad \text{(for origin, port 1)}$$

where the variables are as previously described.

Due to the limited number of projects that need to be considered at any one time, this formulation need not be used, for the former model may be run after the sensitivity analysis to enable the comparison of alternative investment strategies. For example, each facility improvement (Y_i) could be input to the model in turn and the results compared. The approach described above also has the disadvantage that it selects one investment programme, using one criterion, that of minimising both the cost of transport provision and operation. It ignores the design criteria identified in Section 2.

Section 2.7 stated that one has to estimate what kind of changes in the economy a particular project will lead to; then one must consider what these changes are worth to the country by, implicitly, comparing them with other changes that might have happened instead. Thus the objective of the wider system precludes the use of an objective function which minimizes both investment plus operating costs, for such a model would not generate solutions with higher investment costs. Yet such a solution could result in a larger benefit to the region, as determined from the overall economic criterion. If the transport system is to be improved by exercising a model of the system, the only known factors which would be available, would be the cost of the improvement The benefits, or outputs, would have to be determined subsequently, because the effect of a new transport network on each island within the region could not be immediately determinable. Now, a solution to the model using existing data on the system will identify, through sensitivity analysis, those ports which, if improved, could reduce the cost of transport system operation.

Clearly, several transport system improvements could be postulated, if several ports are identified through sensitivity analysis. Each investment option could result in a solution with different network characteristics, which could affect each island economy within the region. Thus, a solution of the transport model for every investment option would be necessary so that the P. S. V. of each could be calculated and an optimal solution found. Thus, while the choice of an investing authority in choosing between alternative projects will be made on the basis of the present social value of each project, the only criteria that can be used to identify a subset of investment strategies for further evaluation when using the transport model is that each strategy:

- Must minimize the cost of transport operation.[31]
- Must not exceed the funds available to the region. region.

While the first criterion is satisfied by the approach formulated, the second can be applied outside the model, for only those projects which can be implemented with the funds available can be considered.

3.1.3.6 The Selection of Transport Investment Alternatives

Section 2. 3. 3 showed that the Transport and Allied Services Commission is limited to the improvement of shipping services, within the limits imposed by existing port facilities and the availability of resources for development. If the transport model is to be used to design improvements to the regional transport system it should make use of the existing political, economic and decision making structure within the region. The autonomy of each authority responsible for transport investment decisions must also be respected.

A re-examination of Figure A. 16 of Section 4. 7 of App. A solved the problem in the following way. Each island is considered to forward its views to the Commission on its own transport investment proposals, including any planned changes in user charges and/or availability of capital for port improvement. Facility improvements

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31. If a service between two nodes was provided, where previously none existed, which increased the cost of transport operation, the resultant gain to the operator and related islands could justify the additional expenditure. Thus, this criterion is only of value when trade between two nodes already exists. The decision to initiate a service between two or more nodes in a network can only be taken after potential traffic studies have been made.

would be specified in terms of the ports docking capacity.

Given these proposals and the intra-regional traffic movements, the linear programming model could then be used to derive a solution.

A sensitivity analysis of this solution would result in an expression of the form: -

$$\Delta Z = - \sum_i (\pi_i \Delta S_i + \text{other terms})$$

where the cost of ΔS_i would have been determined by the island responsible for the i^{th} port.

If the improvement in port "i" (equal to ΔS_i) is implemented, it would reduce the cost of transport operation by ΔZ, where

ΔZ = the change in the cost of operating the transport system resulting from a change in S_i.[32]

S_i = the ship docking capacity at port "i".

π_i = the simplex multiplier related to S_i.

If the basic solution is non-degenerate,[33] then the simplex multipliers will remain constant as long as the basis remains the same. Hence a solution can be found which can induce the separate islands to submit summarised proposals, which can be combined to result in a cheaper, and still cheaper cost of transport operation

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32. This statement assumes that the conditions for optimality have not been violated.

33. If degeneracy occurs it will be possible to go through a number of iterations of the simplex method without decreasing the value of the objective function.

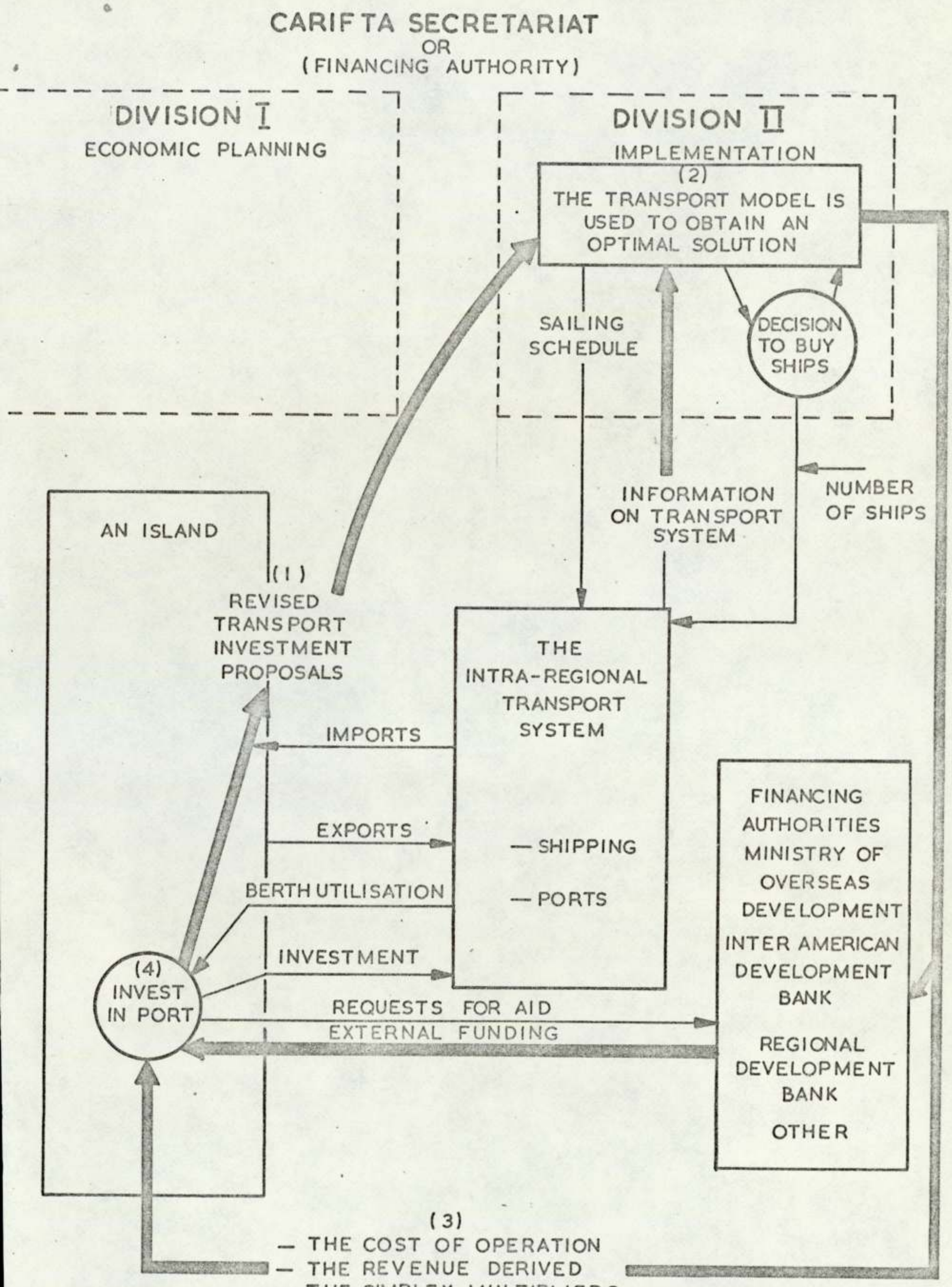
while allowing islands and the Commission to decide on the type of investment and its timing.

This planning process is illustrated in Figure 3.12 where the flow of information has been overlaid on the relevant part of Figure A. 16 of Appendix A.

The iterative planning process could proceed as follows: -

- Each island authority, intending to invest in sub-systems of the regional transport system, submits its investment proposals to the Transport Commission.
- The Commission uses the linear programming model to derive an improved solution which satisfies the constraints of each "autonomous" island or port authority.
- New prices, the π_i, are issued to each authority which may induce them to revise their initial proposals, to further reduce the cost of transport provision.
- Each island decides whether or not to invest further in their port. Presumably it will only do so if the gross benefits of doing so exceed the cost of the facility improvement. Benefits include the reduction in the transport subsidy paid to the Commission, the additional port revenue and the effect of the improvement on the island's economy. Alternatively, modifications may be made by each island to their original proposals, and the design sequence repeated.

The fact that this approach could be integrated into the more detailed port planning process is suggested from a study of two



THE DESIGN CYCLE

Fig.3·12

ports which are considered to be typical of those in developing countries (United Nations, 1969). The study suggested that information which was essential to port planning included:

- The interaction between port expansion and ship traffic and cargo flow
- Ship traffic and cargo flow forecasts
- Port service pricing

Successive runs of the combined route generation algorithm and the transport model would illustrate the interaction between port expansion, ship traffic and port service pricing.

Now the selection of a transport investment programme through the iterative process presented here is only of value when a Transport Commission is available to co-ordinate the transport planning activities of those islands forming the region, and where the complete autonomy of each island is recognised.[34] The method is not of value when each of several islands within the region is competing for limited investment funds for its own transport projects from such funding authorities as the Ministry of Overseas Development and the

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34. The danger that a sub-optimum will result exists with this method in that the wrong project sequence may often occur unless appropriate incentives can be devised such that a global optimum will be obtained.

Inter American Development Bank. An additional factor, the timing of investment projects, has also to be considered. In such a case the islands' proposals would be forwarded to the funding authority, who would use the transport model to identify those ports which would reduce the cost of operating the transport system. Figure 3.13 illustrates this method, where a range of construction programmes can be postulated for each port selected. In this figure, each value of X refers to the estimated expenditure in the year concerned although only some of the possible combinations have been selected for illustration.

Postulated improvement	P.S.V.	YEAR 1	YEAR 2	YEAR 3	YEAR 4
ΔS_2	A	X_1	X_2	X_3	
$\Delta S_2'$	B		X_4	X_5	X_6
ΔS_3	C	X_7	X_8		
$\Delta S_3'$	D		X_9	X_{10}	
$\Delta S_2 + \Delta S_3$	E	$(X_1 + X_7)$	$(X_2 + X_8)$	X_3	
$\Delta S_2' + \Delta S_3'$	F		$(X_4 + X_9)$	$(X_5 + X_{10})$	X_6
Resource Flow Limit		X_{11}	X_{12}	X_{13}	X_{14}
Budget Limit			X_{15}		

INVESTMENT SELECTION

Figure 3.13

Those investment programmes satisfying budget and annual resource flow limitations would be selected for further evaluation. That is, each investment strategy would be input to the transport model so that an optimal route structure can be derived and its effect on the region determined.

Only then can the P. S. V. (the present social value) of each alternative be calculated, and an optimal investment strategy selected.

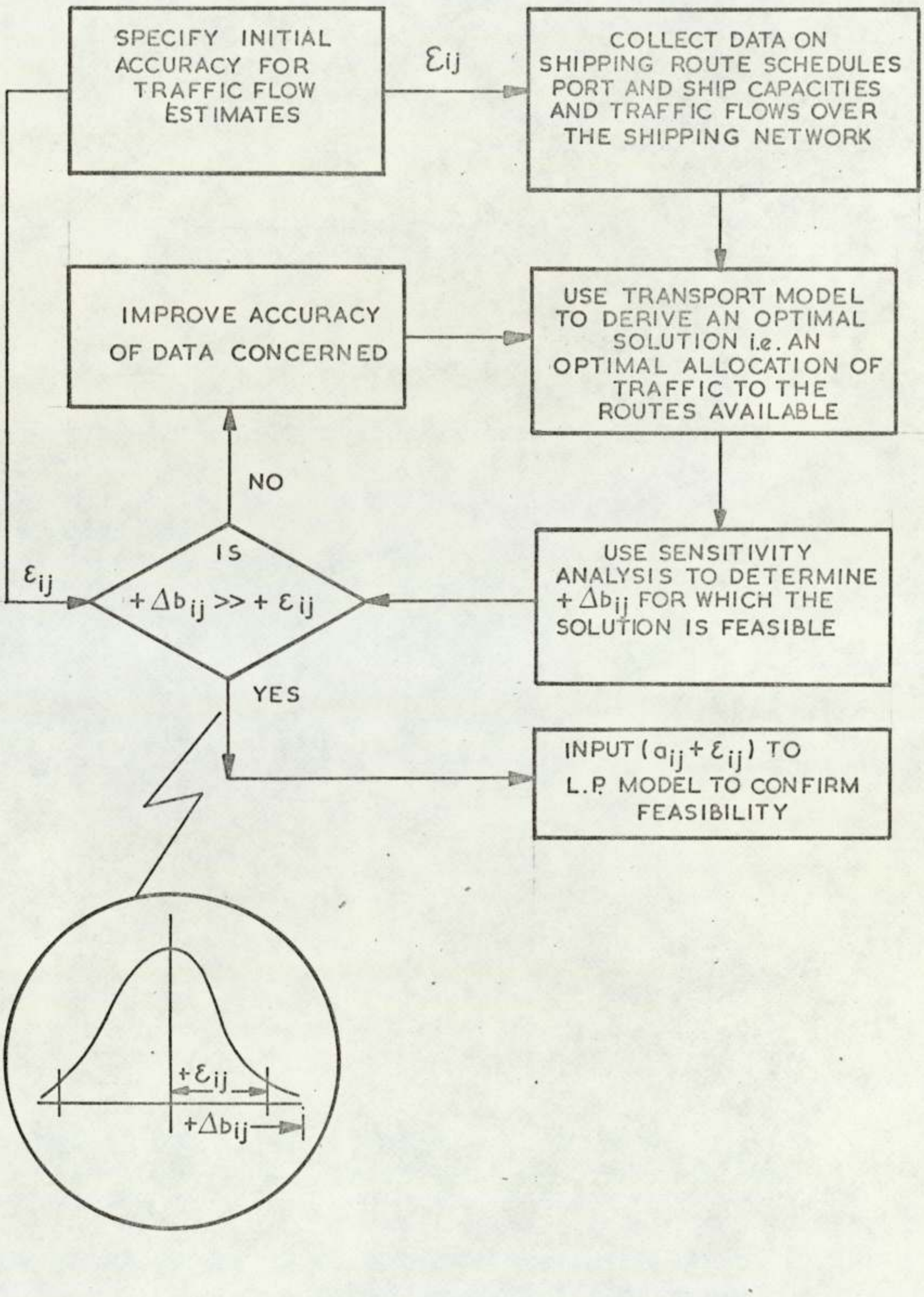
In summary, the first approach allows the islands to decide on the location and timing of investment in the transport system, while the second approach enables the funding authority to do the same as long as: -

- the solutions derived by the model are not too sensitive to errors in data
- the effect of the transport system on intra-regional trade can be determined
- forecasts of commodity flows can be made

3.1.3.7 Data Errors

The approach to transport investment planning, as formulated in the preceding chapters, has largely assumed that the input data to the model has been without error and that the trade flow was static. Neither of these assumptions can be accepted for trade flow statistics are never more than approximations to the truth and trade flows can change with time.

Now section 3.1.3.4 showed that commodity flows can be estimated to an accuracy of $(a_{ij} \pm \epsilon_{ij})$ and that solution feasibility can therefore be assured (in the static case) by deriving a solution for this case where all flows equal $(a_{ij} + \epsilon_{ij})$ for $i, j = 1, 2 \ldots\ldots N$. Sensitivity analysis can be used to assist data collection. The approach suggested is illustrated in Figure 3.14 and is used to determine



DATA COLLECTION ACTIVITIES

Fig.3·14

the degree of statistical accuracy required for each of the N(N - 1) trade flows, in aggregate, which have to be collected. Crude estimates may be used initially and those flows which are identified as critical to a solution of the model, can subsequently be improved in terms of their statistical accuracy.

Data on the existing shipping system is input to the transport model in terms of the shipping routes, ship and port capacities, the number of ship journeys per year being set at the number which occur in practice. As the system is known to be feasible, then if a feasible solution results when estimates of traffic handled are input to the model, the estimates must be reasonable approximations.

A sensitivity analysis of the problem given in Appendix H resulted in Table 3. 9. Those flows which might be regarded as relevant to transport planning have been given an asterisk. The sensitivity of the solution to changes in these flows should be investigated[35]. Now the trade flows used in the model were those based on the import statistics of Guyana. The composition of these goods, in terms of their value, volume and commodity composition is given in Table 3.10. If the import needs of Guyana and every other island can be forecasted in terms of the major commodity flows, then the required extent of data collection for transport investment planning could be considerably reduced. A closer examination of the trade flow from Jamaica to Guyana shows that cement consists

35. In practice route changes occur significantly less often than changes in the allocation of traffic between routes.

Trade Flow	Volume[36]	Acceptable Limits	Acceptable Variation[37]
a_{12}	4008	0 to 5969	-100% + 48%
a_{13}	5200	0 to 13710	-100% + 164%
a_{14}	3400	0 to 3642	-100% + 7%
a_{15}	865	0 to 10023	-100% + 1058%
a_{21}	3200	2639 to 3570	- 20% + 11.6%
a_{23}	29000	28169 to 29370	-2.86% + 1.26% *
a_{24}	45760	831 to 177204	- 98% + 287%
a_{25}	8600	7769 to 8970	-9.7% + 4.3% *
a_{31}	11	0 to 381	-100% + 3370%
a_{32}	5974	0 to 17400	-100% + 192%
a_{34}	10539	0 to 23026	-100% + 119%.
a_{35}	0	0 to 370	+ %
a_{41}	19655	18824 to 20025	-4.2% + 1.88% *
a_{42}	201360	69916 to 205088	- 65% + 2.36%
a_{43}	14000	13169 to 14370	- 6% + 2.64% *
a_{45}	3642	3400 to 4473	-6.6% + 23% *
a_{51}	7	0 to 377	-100% + 5300%
a_{52}	1201	830 to 9431	- 31% + 685%
a_{53}	1475	0 to 9985	-100% + 580%
a_{54}	31	0 to 8541	-100% + 27500%

CONSTRAINTS $SH = 4$, $S_1 = 40$, $S_2 = 240$, $S_3 = 70$, $S_4 = 240$, $S_5 = 40$

Journey Frequency $= 365/T_{ij}$ 22.

SENSITIVITY ANALYSIS TABLE 3.9

36. No particular importance should be attached to the values used. They were taken from Table 3.11of Section 3.2, where their derivation is described.

37. The method used to calculate the percentage variation was as follows: - 4008 (1 + Percentage Variation) = 0 or 5969.

TRADE FLOW - JAMAICA TO GUYANA

STATISTICS SOURCE		EXPORTS FROM JAMAICA	
COMMODITY		VALUE (£ J)	VOLUME cu. ft
01	Meat & Meat Preps	7	
02	Dairy Produce, eggs and honey	510	73
05	Fruits and Veg.	49112	4674
06	Sugar and Sugar Preps	2075	512
07	Coffee, Tea, Cocoa, etc.	27797	4340
08	Feeding stuff for animals	43	9
11	Beverages	200	15
12	Tobacco & Tobacco manu.	1067	125
41	Animal & Veg. oils	173	45
53	Dying, Tanning & colouring matl.	14504	4004
54	Medical & Pharm. products	7020	312
55	Essential oils & perfume	53205	7020
59	Starches, glues & other chem. mtls.	80	< 1
62-64	Rubber, wood & paper prods	7712	1743
65	Textile, yarn and fabric	25	1
66	Non-Metal mineral manu.	26065	162304
68	Base Metals	1172	60
69	Man. of metals	3004	258
71	Mach. other than elec.	931	12
72	Electrical mach.	312	9
73	Transport equip.	3550	910
81-89	Misc. Man. Prods.	13944	2130
	TOTAL VOLUME[1]		4714 (3156)[2]

1. measurement ton terms (40 cubic feet = 1 measurement ton)
2. Based on summary trade statistics from Guyana

Source: Annual Trade Report, Jamaica, 1965

TABLE 3.10

of over 80% (in volume terms) of the total flow. If the import needs of Guyana, in terms of such major commodities can be forecast for each year of the planning period, then the trade flow from Jamaica to Guyana could then be forecast if no alternative sources of supply existed. If alternative sources of supply did exist, then the views of both the shippers (in each source island) to the network and the views of the buyers in Guyana to each source of supply would need to be considered. In fact, only Barbados and Trinidad could be considered as alternative sources of supply within the region in this case. In practice, the statistics collected from the annual trade statistics of each island would have to be reconciled to the trade flows which pass through the ports of each island. Sample survey techniques[38] such as those employed for land based transport studies could be used.

3.1.3.8 System-Environment Interaction

As the share of traffic on one mode of transport can be affected by changes in the characteristics of other modes, it is clear that competing modes of transport must be considered when designing improvements to the shipping system.

Consider the two mode transport system illustrated in Figure 3.15.

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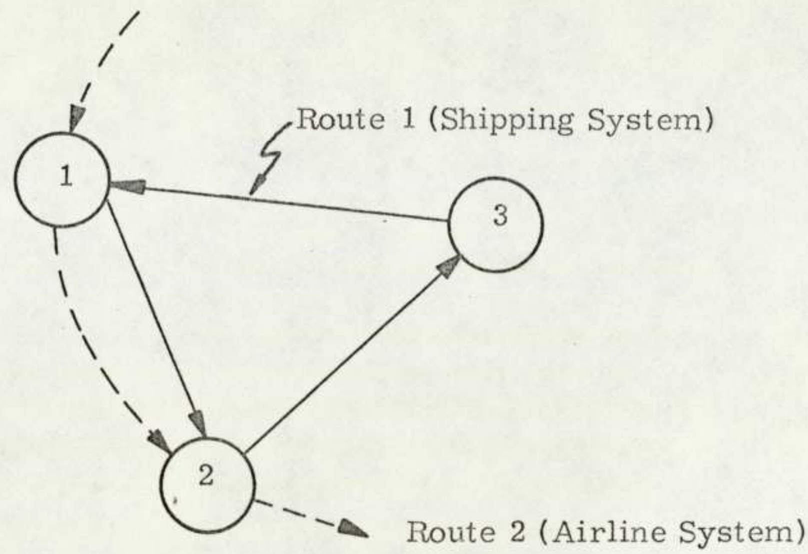
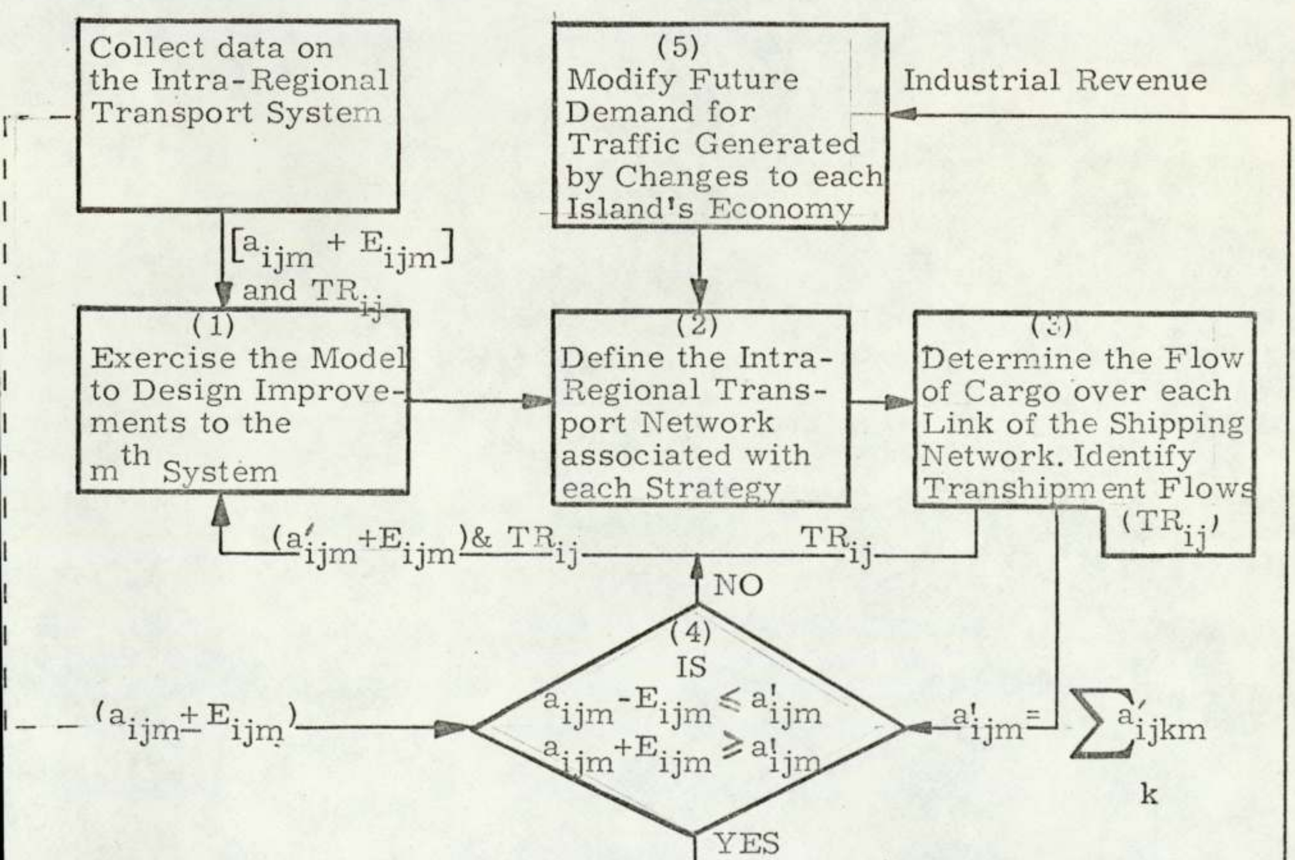
38. See Map 16, Page 143 where a 1% waybill sample was used to determine the citrus fruit shipments within the United States. "Methods of Regional Analysis", Isard, M.I.T. Press, 1960.



A TWO MODE TRANSPORT NETWORK

Figure 3.15

It can be seen that both modes of transport share the total flow of traffic over link (1, 2). It is also clear that changes to one mode of transport may modify the flow of traffic using it. If an improved network for one mode of the transport system was derived from the transport model the flow allocated to each mode must subsequently occur in practice, if solutions are to be valid. It is therefore necessary to determine the effect of each derived network on intra-regional traffic flows.



TRANSPORT SYSTEM DESIGN ACTIVITIES

Figure 3.16

Figure 3.16 outlines the approach which may be explained as follows: -

(1) Improvements to the transport system are designed from estimates of the original flows of traffic on each mode (a_{ijm}).

(2) An improved network of routes is derived for the shipping system from a solution of the model.

(3) The intra-regional traffic over the whole network is determined in terms of the flows a'_{ijm} over each mode of transport, where: -

$$a'_{ijm} = \sum_{ij,k} a_{ijkm} \qquad \text{for each mode "m".}$$

TR_{ijk} = the volume of traffic transferred from route "k" to another mode over the arc (i, j).

(4) For each mode, the new flows over each arc a'_{ijm} are compared with the range of a_{ijm} over which the solution is both optimal and feasible. That is, if $(a_{ijm} + \epsilon_{ijm}) \geq a'_{ijm}$ and $(a_{ijm} - \epsilon_{ijm}) \leq a'_{ijm}$ then the solution is both optimal and feasible. In other words, the flows which result from the introduction of the improved network should not affect the optimality of the solution for that mode.

(5) The effect of the total network on each island can be determined in terms of the exports of each island. This is because the total exports of the i^{th} island can be given by the equation: -

$$\sum_{j=1}^{N} \sum_{\text{All}k} a_{ijk} \quad \text{for the } i^{th} \text{ island}$$

Now the transport model allocates the flow of traffic a_{ijk} to particular routes "k" while the shipper allocates each commodity in turn to the routes available so that his costs are minimised. Thus, these ship owners would aim to maintain the allocation of traffic generated by the model in the theatre of operation.

In practice, the ship owners and shippers confer jointly[39] in allocating cargo to the routes offered. Now the shipper's objective is to minimise his costs. Thus, if the cost to the shipper of each route could be determined, then the transport model could be modified so that the cost of transport to both the shipper and the ship-operator was minimised. This point was not pursued due to lack of time.

Consideration of figure 3.17 shows that transhipment may occur between modes. In the case illustrated, transhipment from air to sea transport of cargo flow a_{23} could occur at port 1. The effect on the shipping transport model is as follows: -

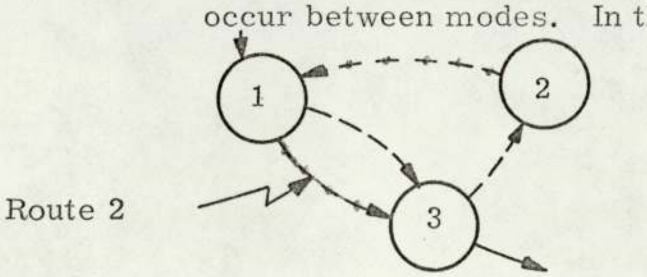


Figure 3. 17

ARC (2, 1) $\quad C.\ NS_1 \geq \sum_{i=2}^{3} \sum_{j=1}^{3} \sum_{k=1} a_{ijk} \quad i \neq j$

ARC (1, 3) $\quad C.\ NS_1 \geq \sum_{i=1}^{2} \sum_{j=2}^{3} \sum_{k=1} a_{ijk} - TR_{1(1,3)} \quad \text{for } i \neq j$

---

39. According to Furness Withy & Co., (British Agents for the West Indies Shipping Service).

where $TR_{1(1,3)}$ is the amount transferred from route 1 (shipping) to the airline over arc(1,3). Thus, the transhipped flows must be input to the transport model before iteration. These transhipment flows are shown in dotted form on Figure 3. 17 Thus, all modes of a transport system can be included in this a system approach to transport planning.

3. 2 FORECASTING

3. 2. 1 The Problem of Dynamic Optimization

Dynamic optimization, in this context, implies the need to maximize the present social value of the transport system over the time period considered by the transport planner. This entails the need to predict the demand for transport in time and space. Because of the complexities involved, four main approaches to transport planning are currently in use.[40]

The first approach concentrates on removing obvious bottlenecks in the transport system. This approach removes the necessity to predict the inter-island trade flows, the function of the planner being solely to provide an efficient solution as soon as possible.

The second approach, is really a project by project approach, where the potential benefits and costs of each project are considered in isolation. For various forecasts of trade, the benefit-cost ratio or internal rate of return of each project can then be considered.

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40. The text that follows is largely based on an article by R. E. Burns in the Journal of Transport Economics, Sept. 1969.

Neither of these two approaches considers the inter-relationships between transport projects or between transport investment and economic development. The third and fourth approaches consider both the system effects of the transport system created by a change to one or more of its elements, and the inter-relationship of the transport system to the wider system or environment in which it operates.

The third approach is to apply well developed techniques such as linear programming, to the current transport system, to determine the system effects of changes in its elements.

The fourth extends the above approach so that the interaction between the transport system and the economy which it serves can be simulated, and the effect of alternative time-staged investment strategies compared and evaluated. The selection of the appropriate investment strategy is left to the decision makers. The time-staged investment programme is developed in the following way

"The commodity flows estimated to move between nodes in the final year of the planning period are input to the transport model. The network the model will provide is that which will move the projected flow of goods for the final period at the least total cost to the economy, and yet utilise most of the capacity of the network as defined. By stepping back to the next planning period and submitting

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41. See Burns, R. E., An Applied Systems Approach for the Development of Regional and National Highway Systems in Under-Developed Countries. Unpublished Masters Thesis, MIT 1966.

the reduced commodity flows to the original network, a new and probably smaller network would result. The difference between this network and the ultimate network at the planning horizon would denote those physical facilities that should be built in the last period and their attendant construction costs. By repeating this process, the present day planning period would be reached and a construction plan denoted that could begin immediately. At the end of the five-year period, a re-assessment of commodity flows is made and new projections are made in the light of the information gathered in the past 5 years. The old planning horizon is then pushed out five more years and a new ultimate network is defined by the programme which is a function of the present network and the new commodity flow projections," Burns, (1966). This process is theoretically essential, for regional development objectives should be stated in terms of minimum and desired levels of growth rates to be achieved at 5 year intervals from the present to a horizon 30 to 40 years hence. "This long time span is required in part to permit proper accounting for the lives of major infra-structure investments; more importantly, it is necessary so that long-run shifts in goals and in the regional distribution of population and economic activities may be correctly weighed in establishing near-term development programs. Such near-term goals will specify such objectives as G. N. P, per capita income and its distribution and the composition of final demand and production by region" Fromm, (1965). Once these objectives have been integrated into a "long-range, dynamic development plan, showing the broad allocation of resources and production among industries and between islands over time to the horizon, the plan may be used to provide the basic long-run framework on which the near-term plans are to be hung, to ensure that the latter plans are consistent with long-term objectives" Fromm (1965).

The approach described has a number of failings:

- It is almost entirely theoretical and idealistic for "long-range planning of industry or agriculture is rarely delineated in a manner which the transport economist can use in this time perspective" Fromm (1965). This is certainly true of the Caribbean islands at present, where none of the development plans exceed a 5 year time period, although forecasts of the expansion of the tourist industry have recently been made to cover a 10 year period.[42]

- It requires the use of a mixed linear-integer programming model, which selects only those transport investments which minimise the capital, maintenance and operating costs of the total transport system and thus ignores alternative investment strategies which could result in a higher benefit-cost ratio and also an improved resource flow requirement over time.

These objections lead to an alternative approach where the full range of investment options must be considered, one by one over multiple time periods to the horizon. As "facilities provided in the present affect future transport costs, inadequate consideration of future needs and improper specification of capacity today can engender wasteful expenditure of resources tomorrow" (Fromm 1965). The need to consider both the long and short term development of the region where possible is clearly stated.

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42. See "The Future of Tourism in the Eastern Carribbean," H. Zinder & Associates, May 1969.

The application of the linear programming transport model, developed in the preceeding chapters, was therefore reconsidered in a dynamic situation where the flow of trade was assumed to change over time.

3.2.2 Dynamic Optimization

3.2.2.1 The Model Applied to a Dynamic Situation

The transport model was applied to the 5 port, 24 route problem described in Appendix I. A range of trade flows were input to the model to describe a changing intra-regional trade flow pattern over time.

Table 3.11 illustrates the values of "a_{ij}" selected. The results obtained when using this data are given in Table 3.12 where the port constraint values used as input data are also given.

A sensitivity analysis of the solution obtained for year 0 resulted in the following expression:

$$Z = -4299.\Delta S_2 - 2753.\Delta S_3 + \sum_{\text{All } i,j} \pi_{ij} . a_{ij}$$

ASSUMED TRADE FLOWS OVER A 5 YEAR PERIOD

Flow/ Year	0	YEARS 1	2	3	4	5
a_{12}	4008	NO CHANGE				
a_{13}	4862	5000	5200	5400	5600	5800
a_{14}	3156	3200	3400	3600	3800	4000
a_{15}	865	NO CHANGE				
a_{21}	2806	3000	3200	3400	3600	3800
a_{23}	23972	26000	29000	32000	35000	38000
a_{24}	45760	NO CHANGE				
a_{25}	8266	8400	8600	8800	9000	9200
a_{31}	11					
a_{32}	5974					
a_{34}	10539					
a_{35}	0	NO CHANGE				
a_{41}	19655					
a_{42}	201360					
a_{43}	12397	13000	14000	15000	16000	17000
a_{45}	3642					
a_{51}	7					
a_{52}	1201	NO CHANGE				
a_{53}	1475					
a_{59}	31					

TABLE 3.11

where those terms which are irrelevant to transport investment are ignored. The options available to a transport planner in year 0 are therefore:

- To do nothing
- To increase the capacity of port 2
- To increase the capacity of port 3
- To increase the capacity of both ports

A solution for each of the first three options was determined and the model was re-run for subsequent years using the data given in Table 3.11. The results of this exercise are given in Table 3.12 The characteristics of these solutions may be summarized as follows:

- The cost of transport operation can only be reduced by investing in those facilities which have simplex multipliers greater than zero
- A new transport facility must become available when the existing facilities become inadequate but might be justifiable once its associated simplex multiplier exceeds zero.

SOLUTION TO 5 PORT, 24 ROUTE TRANSPORT PROBLEM

STRATEGY	NO CHANGE[x]	CAPACITY OF PORT 2 INCREASED TO 230					PORT 3 INCREASED TO 50	
YEARS	0	1	2	3	4	5	1	2
COST £ (M)	1.22938	1.22956	1.25276	1.26166	1.27463	INADEQUATE SOLUTION	1.23892	INADEQUATE SOLUTION
Port 1 (24)	23.5	23.36	24	24	24		24	
Port 2 (209)	209.0	212.6	215.0	216.4	218.2		209	
Port 3 (48)	48.0	48.0	48.0	48.0	48.0		50	
Port 4 (230)	221.2	221.1	224.4	225.8	227.6		221.4	
Port 5 (20)	19.2	16.0	16.4	17.5	19.4		19.5	

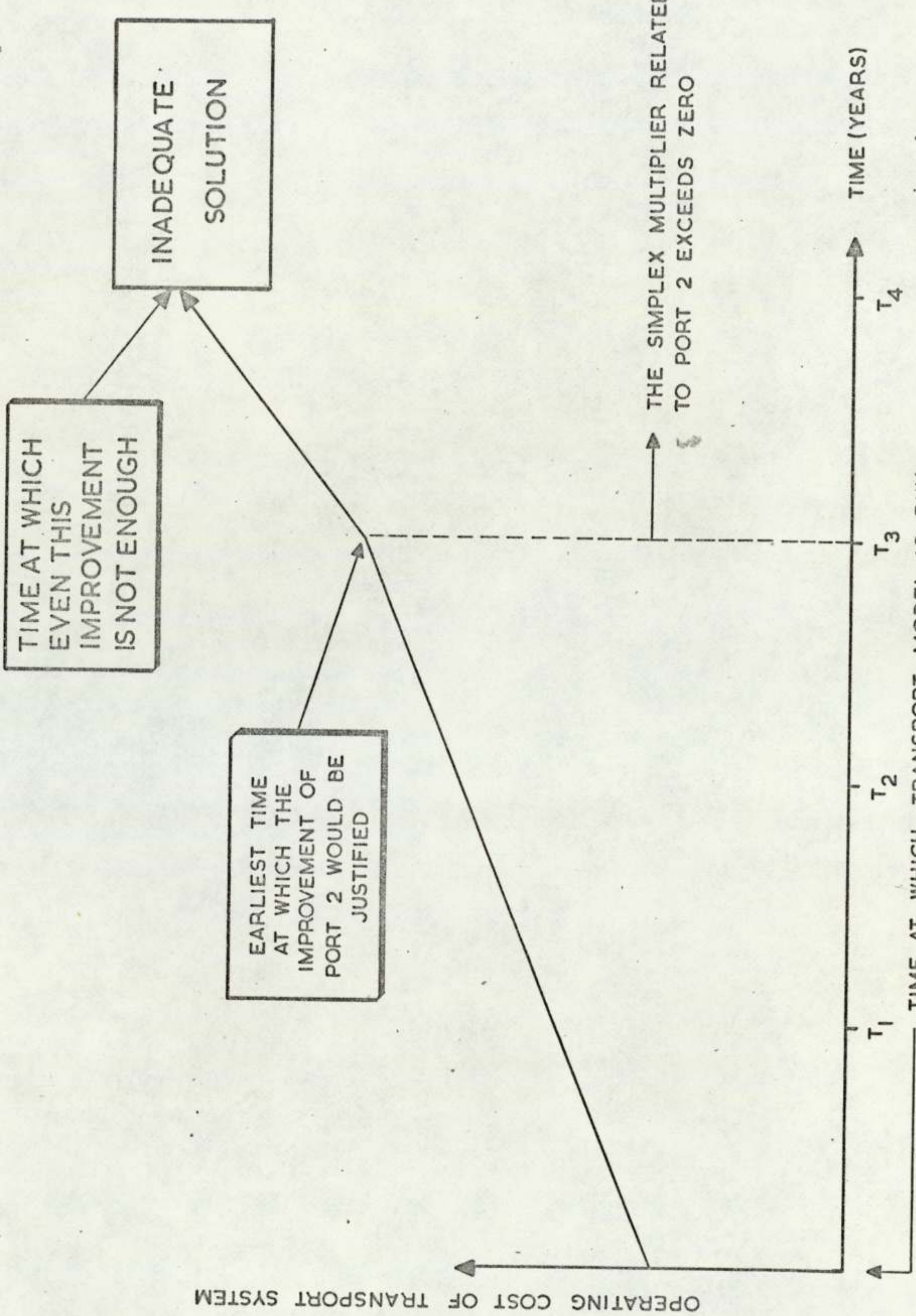
TABLE 3.12

[x] The Base Year Solution

- Different investment strategies have different solution characteristics in terms of the routes chosen and the range of trade flows over which the solution remains feasible
- Different routing patterns may have repercussions within the region, which cannot be measured by the model
- The behaviour of the system with future trade flows is not given

The first two criteria can be used to generate a range of construction sequences for each port improvement. Figure 3.18 illustrates the time frame within which a port improvement must occur.

The earliest point in time at which an improvement in port 2 could be justifiable is when its associated simplex multiplier exceeds zero. The latest point in time at which $\Delta S2$ must become available is when the system becomes inadequate, and can no longer carry the traffic for which it was designed.



A PORT IMPROVEMENT TIME FRAME

Fig.3·18

The third and fourth points confirm the need to evaluate the effects of every investment strategy. Changes in route structure might affect the markets of regionally based industries which might subsequently affect the growth of each island's economy. Similarly, the repercussions of each investment on the regional transport system and the economy in which it is made must also be determined before the full implications of each investment strategy can be considered. Those investments which create a demand for resources which exceed those available will not, of course, be considered. This point is illustrated by Table 3.13 which lists a hypothetical set of investment proposals which are assumed to be derived from sensitivity analyses of solutions to the transport model. If it is assumed that the present social value of each strategy can be determined, then the strategy chosen would be that which satisfies the limits on resource flows while having the highest value.

CHARACTERISTICS OF INVESTMENT PROPOSALS

INVESTMENT	PRESENT SOCIAL VALUE	RESOURCE FLOWS			
		YEAR 1	YEAR 2	YEAR 3	YEAR 4
$\Delta S2$	400	x	x	x	
$\Delta S2$	350		x	x	x
$\Delta S3$	600	x	x		
$\Delta S3$	750		x	x	
$\Delta S2 + \Delta S3$	500	x	x	x	
$\Delta S2' + \Delta S3'$	430		x	x	x
ANNUAL RESOURCE FLOW LIMITS		......	......	......	......
BUDGET LIMIT EQUALS .... OVER THE 4 YEAR PERIOD					

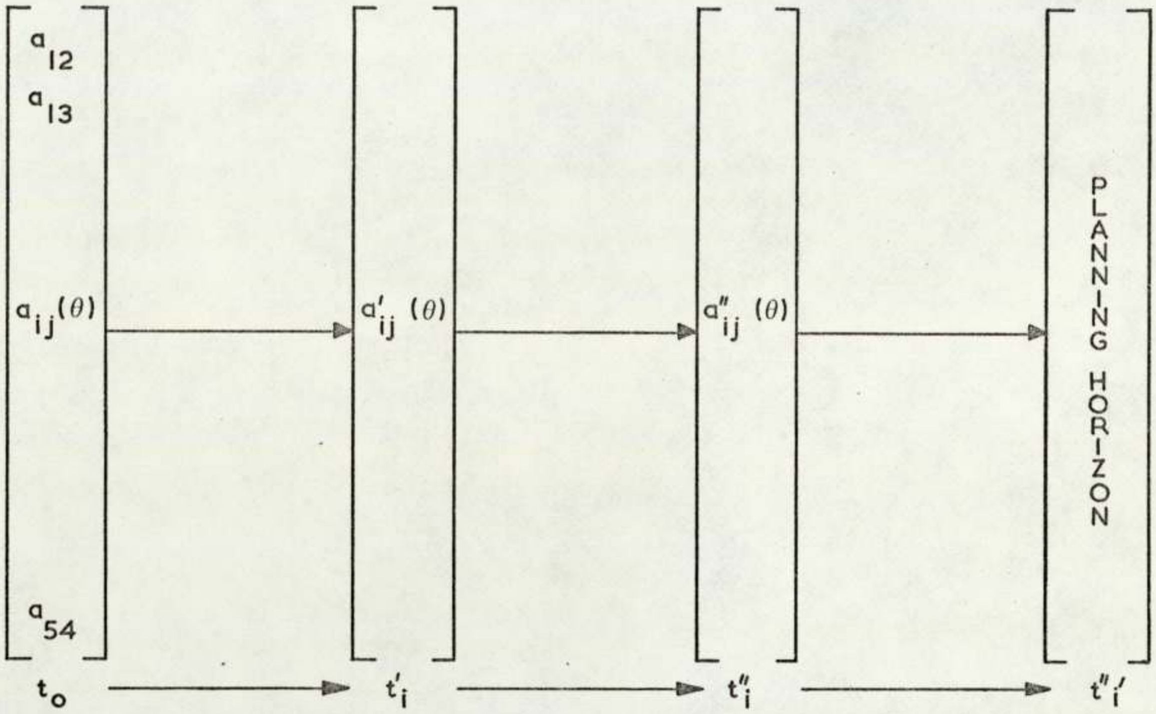
TABLE 3.13

The fifth point is of the utmost importance for, "inadequate" consideration of future needs and improper specification of capacity today can engender wasteful expenditure of resources tomorrow" Fromm, (1965). As each investment programme may result in a solution whose network characteristics change with increases or decreases of trade, the identification of the points in time at which new port facilities should be considered, becomes important. Thus, as those flows and those ports which are relevant to transport investment can be identified by sensitivity analyses, the timing of improvements to the existing transport system can be determined by running the model with projections of the sensitive flows.

A parametric linear programming approach to this problem was adopted where, for each investment strategy, each relevant commodity flow was assumed to increase with theta (θ) as follows:

where	$a_{ij}(\theta)$	=	$a_{ij}(1 + \theta\alpha_{ij})$
	a_{ij}	=	the exports of cargo from island "i" to island "j" in the base year
	$a_{ij}\ (\theta)$	=	the export of cargo from "i" to "j" in year θ
	θ	=	the number of years from the base year
	α_{ij}	=	the annual rate of increase of "a_{ij}" between ports "i" and "j"

If "α_{ij}" can be determined for all (i, j) then the behaviour of the transport system over time can be simulated in a limited number of computer runs and the approximate timing of investment projects identified. This would result in a significant saving over a year-by-year simulation of each system with each strategy over the planning period. Thus, if at year "t_i" a major investment is expected to be made in a particular island, then its effect on intra-regional trade and on the solution of the model will have to be re-determined. Thus, changes to the vector of trade flows are assumed to occur in the manner indicated in Figure 3.19.



Trade Flow Changes with Theta Figure 3. 19

At times t_o, $t_i^{'}$ and $t_i^{''}$ a new route enters the basis, a solution becomes infeasible, or the effects of investments in one or more islands become significant. The constant terms α_{ij}, can be any value, either positive zero or negative, because, over time, each trade flow in volume terms may change at a different rate, this rate being determined by (α_{ij})[43].

The process of observing the transitions that occur as the right hand side of the linear programming problem is changed continuously from a_{ij} to $a_{ij}{'}$ is called parametric linear programming, because the right hand side is considered to be a parameter of the system.

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43. The rate of change of the non-sensitive terms might be identified by using an intra-regional input-output approach. This point has not been investigated.

One further point needs to be made here. Every time the linearity assumption is broken, a re-calibration of the "α_{ij}" values becomes necessary, because intra-regional trading patterns will change due to changes in the characteristics of the transport system.

New investment strategies identified from this approach may be postulated so that the effect of the long term development plan may be considered over the current short-term development plan. For example, consider that the following results of sensitivity analyses on a number of solutions have been obtained (Table 3.14)

TIME	SENSITIVITY ANALYSIS	CHANGE
$(t_o - t_i')$	$\Delta Z = \pi_1 \Delta S_1 + \pi_2 \Delta S_2 + \sum_{i,} \sum_{j} \pi_i \cdot a_{ij}$	Zero
$(t_i' - t_i'')$	$\Delta Z' = \pi_1' \Delta S_1 + \pi_2' \Delta S_2 + \sum_{i,} \sum_{j} \pi_i \cdot a_{ij}$	Solution Change (the α_{ij} are re-calibrated)
$(t_i'' - t_i''')$	$\Delta Z'' = \pi_1'' \Delta S_1 + \pi_2'' \Delta S_2 + \sum_{i,} \sum_{j} \pi_i \cdot a_{ij}''$	Industrial Investment in Island A

FORM OF SENSITIVITY ANALYSES Table 3.14

Assume that as a result of industrial investment in island A, intra-regional trading patterns are modified and the handling capacity of port 1 has to be increased to cater for the increased trade, then the fact that S_1 will increase by ΔS_1 in year t''' can be fed back for simulation over earlier time periods, to determine the need or otherwise to invest in ΔS_2.

But this approach can only be justified if the linearity assumption applies, which in turn implies that:

- the shippers views on route selection do not change
- the quantity of each commodity available at each source exceeds aggregate demand.
- the purchase price of each commodity from each source does not change in the eyes of the buyer
- the demand for intra-regional imports increases linearly

To examine the first point, the parametric L. P. approach was applied to the problem described in appendix K. Over a 3 year period it was observed that, while the allocation of commodities to routes changed continually, route changes, and more importantly, the service frequency over arcs did not significantly change. Table 3.15 illustrates a sample of the results taken from appendix K. As the major changes in the number of ship-journeys completed occurred in routes 6, 12, 17 and 19, it was only pertinent to look at one or more of the arcs served by these routes.

Thus, Table 3.15 suggests that the shipper will be indifferent to minor changes of service, (that is, the shipper will not decide to use another mode of transport). This is because the ships are assumed to call at equal intervals of time. Where route changes occur, journey time between certain ports could be affected significantly[44] although waiting time might remain the same. In such a case the linearity assumption becomes invalid. A shipping company would certainly not modify its sailing schedule every few months, as changing trade flows over certain arcs upset the optimality conditions. In such a case, an optimal or near optimal schedule could be maintained which would meet expected fluctuations in levels of forecasted trade throughout the year.

ARC(ij)	ROUTE	YEAR 1	YEAR 3	T_{ij}^{x}(YEAR 1)	T_{ij}^{x}(YEAR 3)
1, 2	NS_{24}	22.0	22.0	13.4	12.3
	NS_{12}	1.47	4.01		
	NS_{16}	3.64	3.64		
2, 4	NS_{24}	22.0	22.0	1.67	1.70
	NS_{19}	0	4.36		
	NS_{17}	23.03	27.64		
	NS_{6}	173.4	163.4		

^{x} Waiting time at port between visits, assuming equal spacing of journeys, calculated from $365/\sum NS_k$

ROUTE CHANGES OVER TIME Table 3.15

Further consideration of the second point suggests that the linearity assumption would still be justified if the aggregate flow of commodities was approximately linear, even if the quantity

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44. Consider a route serving ports 1, 2, 3, 4, 5 on the outward journey and returning in the reverse order where the journey time equals 1 day between ports. If this route is replaced by one serving ports 1, 4, 5 on the outward journey and ports 5, 4, 3, 2, 1 on the return journey then, even if the journey time is the same for both journeys, travelling time between ports 1, 2 and 1, 3 will differ, even though the average waiting time may be the same.

of particular commodities from certain islands was limited. A measure of judgement is therefore required in applying the approach in a practical situation.

No information about the purchase price of commodities in individual territories was obtained. The significance of the price in the buyers criteria for purchasing particular commodities would have to be investigated in a practical situation. Rhomberg, (1965) has shown that the influence of price changes on trade flows takes more than three years to make itself fully felt. In practice, the significance and trends in prices of significant commodities would need to be investigated.

The fourth point was examined in relation to the island of Dominica[45]. Now the major commodities concerned in intra-regional trade can be broadly classified as food products and the products of light manufacturing industries. Table 3.16 shows the growth in demand for the main imports to Dominica. Over the period 1959 - 1965 the growth in imports of the commodities listed, while fluctuating from year to year, could be said to increase linearly in the long term, with one exception. Imports of copra oil dropped sharply in 1966 due to the islands investment in its own manufacturing facility.

The linearity assumption given in terms of the four points discussed above would clearly need to be checked before the use of the P. L. P. approach was contemplated. Should the linearity of each aggregate trade flow prove reasonable in the long term, then a year by simulation of each investment strategy should not be necessary.

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45. For the reasons stated in Section 3. 2. 6

Commodities	Quantity						Value (c.i.f.)				
	Unit	1959	1960	1961	1962	1963	1959	1960	1961	1962	1963
Food, Drink and Tobacco							$'000	$'000	$'000	$'000	$'000
Butter, Cheese and Milk	'000lb	421	491	571	769	872	213	237	289	412	413
Butter substitutes	'000 lb	222	231	223	270	345	97	101	99	121	157
Fish and fish preparations	'000 lb	853	1, 000	854	930	1, 112	303	358	313	345	415
Flour, wheaten	'000 lb	6,717	5, 525	5, 907	6, 662	6, 915	553	495	503	610	692
Rice	'000 lb	769	844	779	1, 110	1, 042	91	100	93	136	135
Liquor	'000gal	63	70	87	80	66	271	305	359	360	298
Meat and meat preparations	'000 lb	435	672	719	1, 046	1, 105	249	322	422	568	538
Oils, edible	'000gal	77	72	78	69	70	217	200	238	232	208
Sugar & sugar preparations	'000 lb	4,906	4, 989	4, 824	4, 830	4, 956	504	531	503	511	607
Tobacco	'000 lb	101	132	156	73	117	100	112	128	79	106
Textiles	-	-	-	-	-	-	593	660	740	794	679
Machinery	-	-	-	-	-	-	1, 137	759	682	952	698
Manures	ton	2,899	2, 468	2, 869	3, 220	5, 372	407	320	364	431	684
Metals and their manufacturers	-	-	-	-	-	-	606	753	599	719	618
Footwear	'000 pr	97	135	104	146	137	220	283	222	353	307
Oils, not edible	'000gal	1,167	868	1, 286	1, 222	1, 505	362	280	430	351	330
Soap	'000 lb	556	616	513	605	595	144	157	153	181	183

MAIN IMPORTS, 1959-63 TABLE 3.16

Source: Annual Trade Report, Dominica, 1968, page 23.

3.2.2.2 The "parametric" model applied

To illustrate the application of this approach, the problem described in appendix K was run with, for simplicity, a few flows which were assumed to increase over time (θ) and where the growth rate of these flows was assumed to be 5% per annum.

A sensitivity analysis of the extreme case solutions derived by the model when using the above data with an increasing right hand side (θ increasing) resulted in the following sets of equations.

θ	SENSITIVITY ANALYSIS
0 ↓	$\Delta Z = -2321.S_5 + \sum_i \sum_j \pi_{ij} . a_{ij} + 6273.T_{51}$
3.08	$\Delta Z = -1805.S_1 - 3299.S_3 - 829.S_5 + \sum_i \sum_j \pi_{ij} . a_{ij} + 8079.T_{51}$

Results of sensitivity analyses. Table 3.17

At $\theta > 3.08$ the solution became infeasible. (Fig 3.20). A sensitivity analysis of this final feasible solution indicated the investment options to be the various combinations of S_1, S_3 and S_5. Due to the integer nature of each transport facility (i.e. one wharf or no wharf), such combinations as $\Delta S_1 + \Delta S_3$ may not be of value to the region over the time period considered. That is, if ΔS_3 is added, the existing capacity of port 1 could be adequate for the levels of trade forecasted over the time period considered[46]. The various

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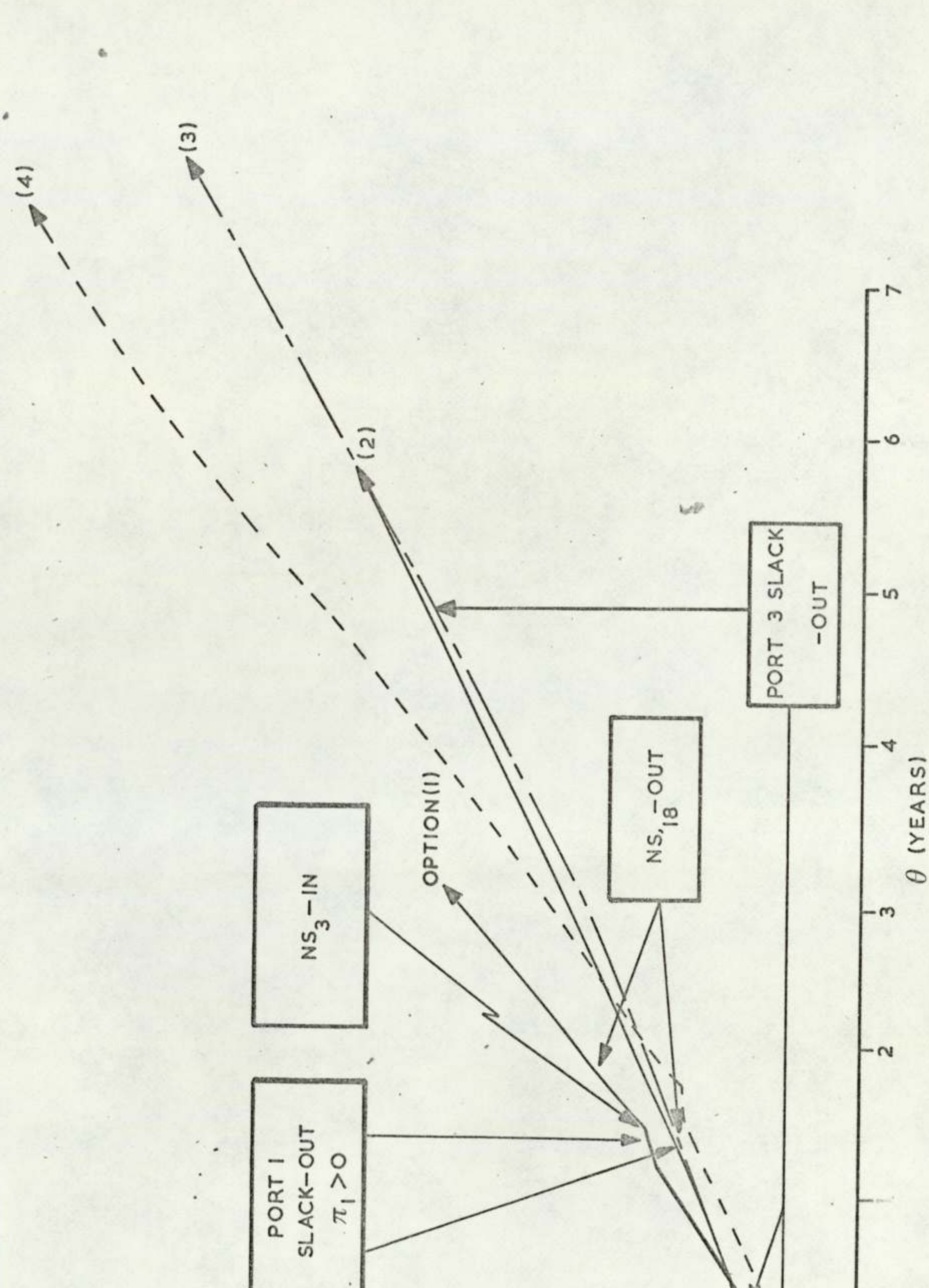
46. It can be seen from Figure 3.20 that the capacity of port 1 is adequate for $\theta \leq 5.8$ when $\Delta S_3 = 10$ is added.



TRANSPORT SYSTEM OPERATION WITH θ INCREASING

Fig.3.20

alternatives may be identified in subsequent runs of the computer programme. For purposes of illustration, the following investment options were run with the parametric linear programming model.

OPTION	INVESTMENT
1	THE BASE CASE
2	$\Delta S3 = 10$
3	$\Delta S1 = 10$; $\Delta S3 = 10$
4	$\Delta S1 = 10$; $\Delta S5 = 10$

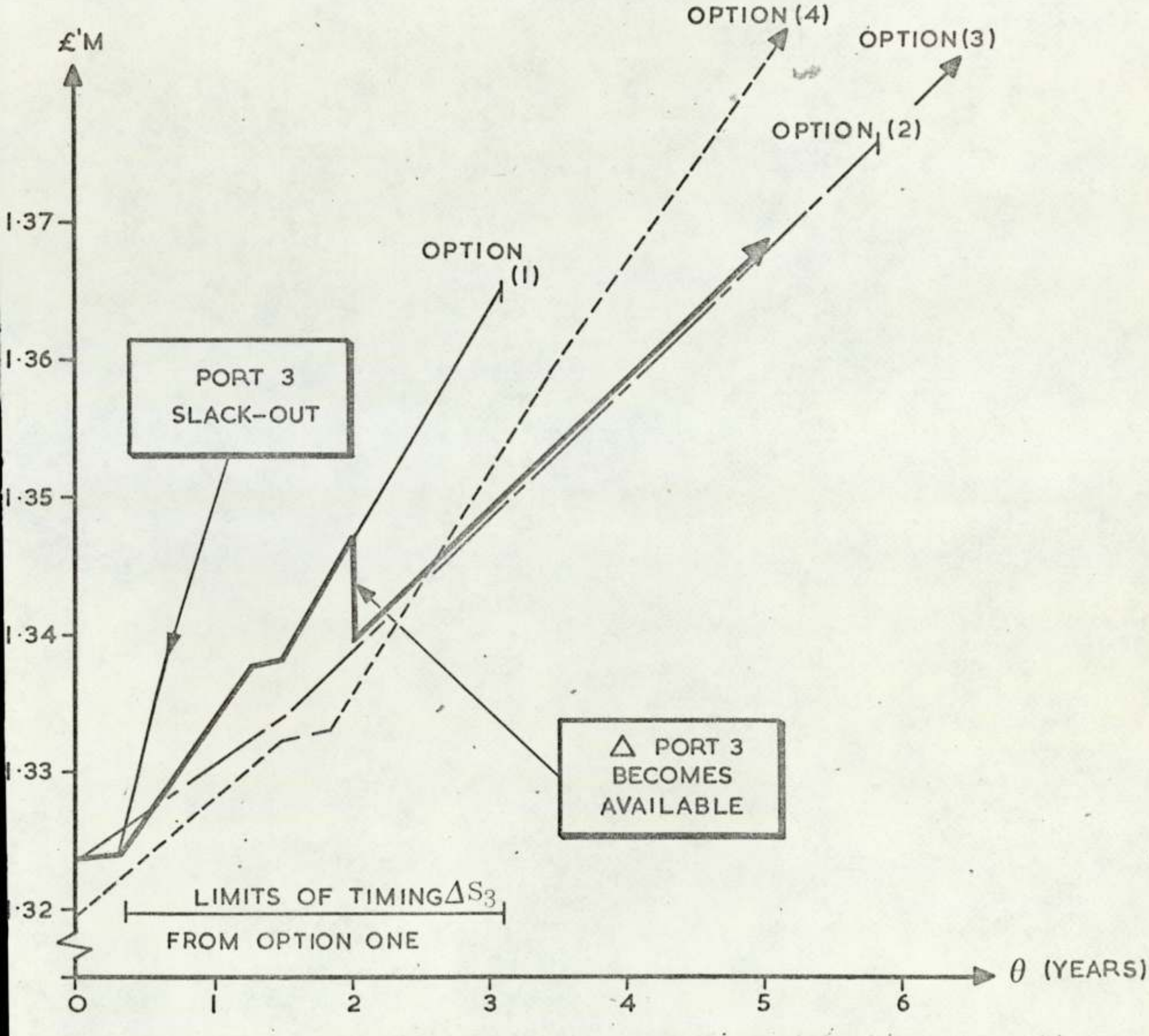
TABLE 3.18

The results of these runs are illustrated graphically in Figure 3.20 and illustrate the values of θ at which investment strategies 1 & 2 become infeasible. If the planning period extends over 5 years a whole range of investment strategies can be postulated within the limits set by the criterion that investment is only contemplated when:

- The simplex multiplier associated with a port or ship exceeds zero
- The solution becomes inadequate
- Investments postulated satisfy the available budget

Figure 3.21 illustrates the cost of operating the transport system if ΔS_3 becomes available in year 2. It also shows that ΔS_3 could become available at any time between the limits illustrated.

This approach only identifies, from an initially assumed value of "α_{ij}" for all (i, j):



ALTERNATIVE OPERATING STRATEGIES

Fig. 3·21

- The time at which a particular facility improvement could become available
- The time at which a particular facility improvement must become available

Thus, two problems remain. That of determining the correct value of α_{ij} for a given network alternative and that of selecting the exact time at which to initiate an improvement.

3.2.2.3 The Determination of Alpha, the annual rate of increase of a_{ij}, equal to α_{ij}.

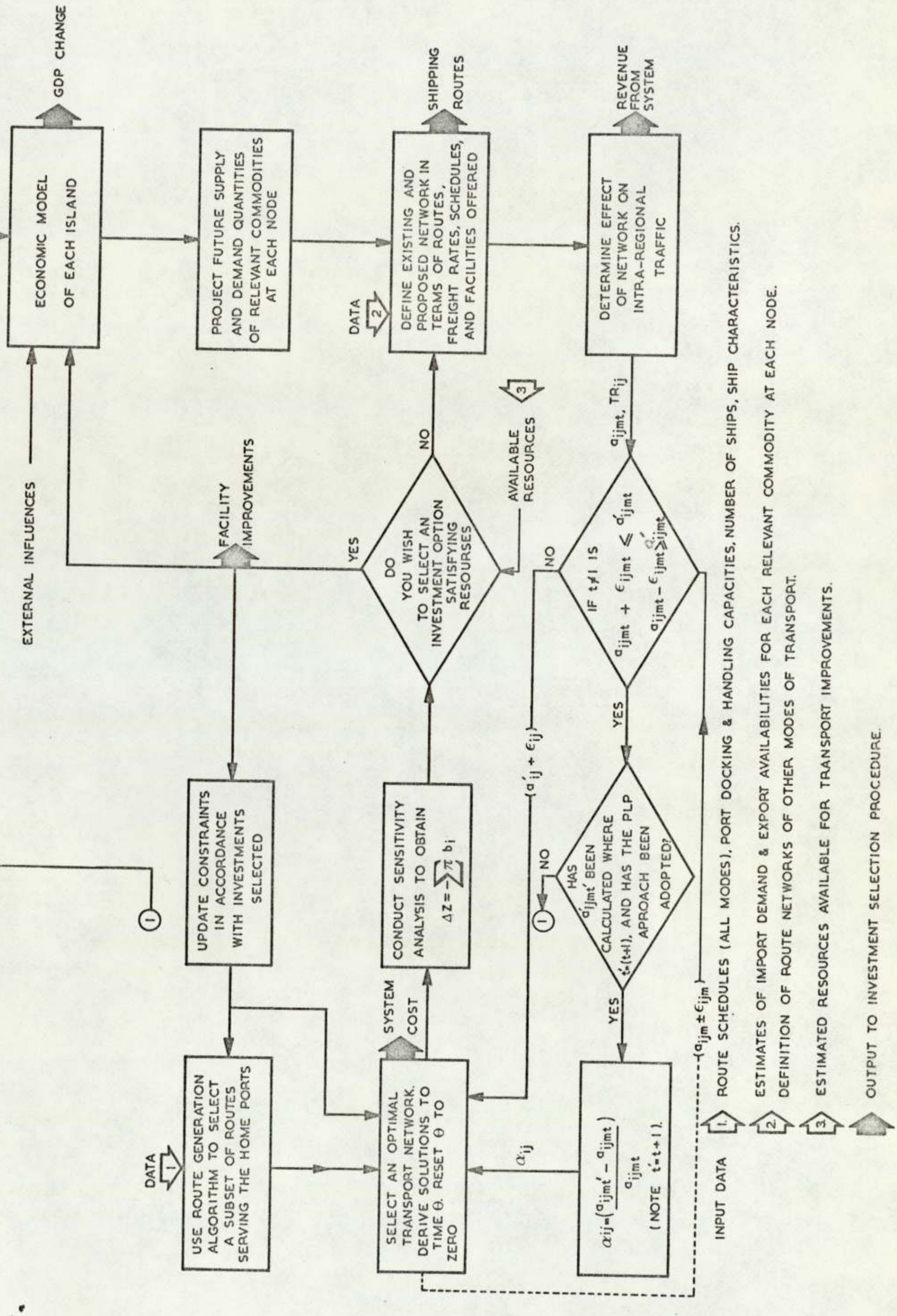
To determine α_{ij} for all (i, j), the approach illustrated in Figure 3.22 was derived from figure 3.16.

1) Starting in the base year the relevant commodity flow data would be input to the transport model and the route generation algorithm. A subset of shipping routes would then be derived for input to the transport model.

2) A solution to the model would now be obtained for year zero (the base year = t_o)

3) The transport network would now be defined in terms of the shipping schedules, freight rates, and the facilities offered over each route.

4) The effect of the multi-mode transport network on intra-regional trade flows would now be determined for the year the network becomes operational. If the resulting flows do not upset the optimality of the initial solution each islands sales in year "t_o" can be computed. The effect of the same network on intra-regional trade can now be determined for year "t_1".



TRANSPORT PLANNING ACTIVITIES

Fig.3·22

5) The difference between the flows computed for each of the two years simulated enables the growth rate of each islands commodity flows, in aggregate, to be determined for the network in question, providing values for α_{ij}.

6) The transport model is now run over a multiple time period, and the value of θ noted when those π_i exceed zero for those b_i defining transport facility constraints. (port docking and loading capacities and ship capacity)

7) A sensitivity analysis of the solution will identify the affect on the cost of transport operation of changes in the capacities of the transport facilities through an equation of the form:

$$\Delta Z = - \sum \pi_i \, b_i$$

where b_i refers to the facility constraints. Theta is reset for subsequent runs with new values of alpha.

8) If the reduction in ΔZ from an investment in transport facility improvements does not appear to be potentially worthwhile a new value of α_{ij} must be calculated (5) and the approach repeated. (Recalibration of the α_{ij} is necessary because the linearity assumption no longer applies. For example, a route change may have occurred).

9) Where improvement is potentially justifiable, an investment option may be selected and steps 2-8 repeated.

3.2.2.4 The Timing of Investment Projects

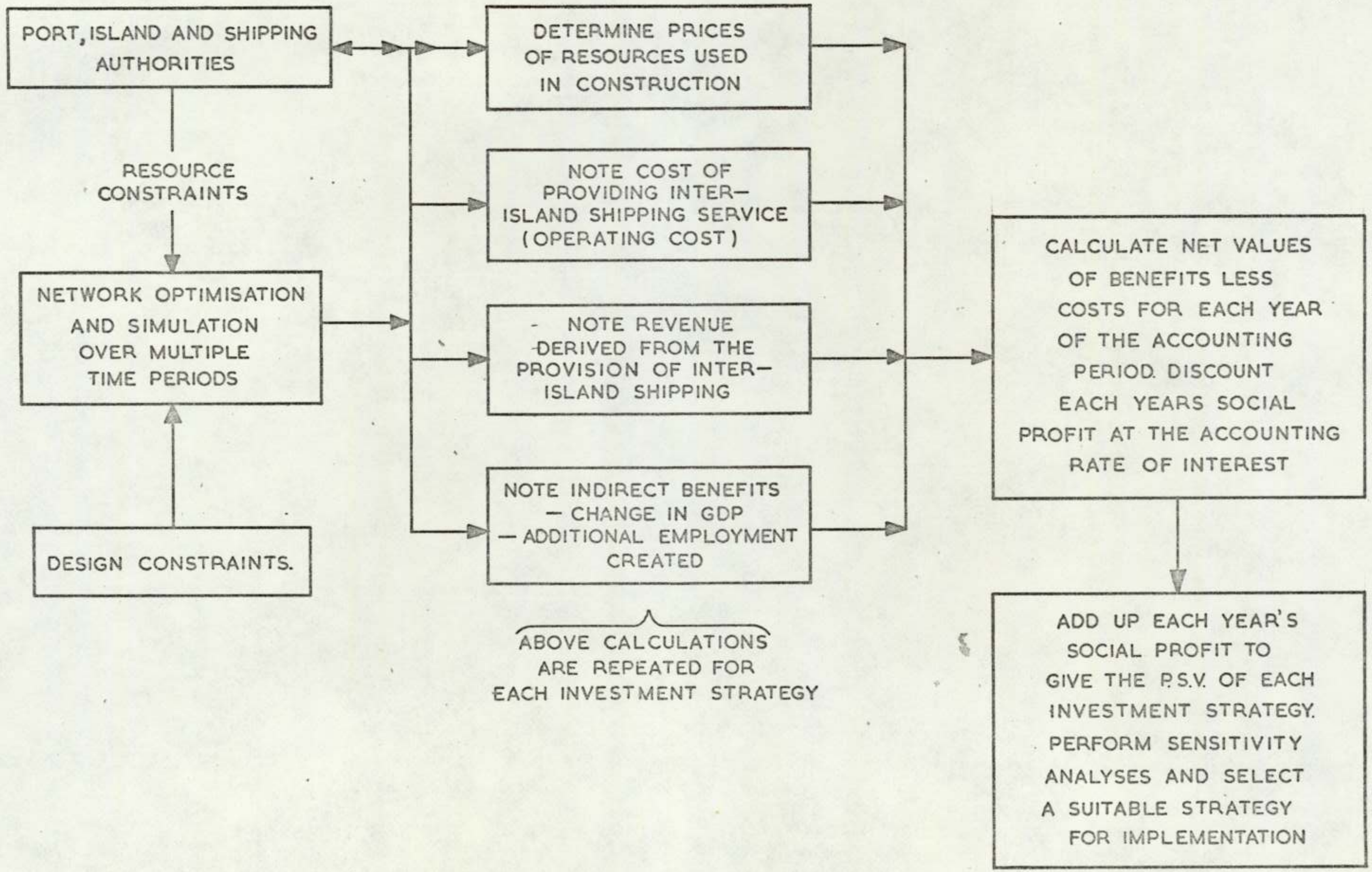
As each island is autonomous, it is assumed to decide on the size and timing of port investment. Figure 3.21 illustrates the form of the output where investment in the i^{th} transport facility may prove worthwhile. Thus, this method results in a few transport investment strategies where:

- the requirement for transport facility improvement is defined within specified time limits
- the revenue to be derived from the transport system is known
- the cost of operating the transport system is known
- the network associated with each strategy is known
- the cost of the facility improvement is known

Hence nearly all the information required to identify an optimal time-phased transport investment strategy is available, as can be seen from Figure 3.23. To identify the exact timing of investment projects "the appropriate procedure is to calculate the present social value, not only on the assumption that the project will be begun (in year "t"), but also on one or two alternative assumptions about the starting date (allowing for reasonable expectations about the techniques that will then be available, changes in the prices for inputs and outputs, and so on)". (O. E. C. D., 1968).

3.2.2.5 Conclusions

This approach does not ensure that the successive solutions converge. In practice, inspection of the various networks generated will ensure convergence. This is not such an unwieldy approach, for investment made to satisfy current transport needs, automatically creates excess capacity which can be utilised to meet future needs, due to the integer nature of transport investment. Hence, at any given time, investment options will be limited due to the excess capacity in parts of the system created by previous investment. The approach also assumes that shippers will react immediately to changes in route structure. This factor could, no



OPTIMISATION ROUTINE (FINANCING AUTHORITY)

Fig 3.23

doubt, be incorporated, but as we are concerned with transport investment planning, a long time frame is automatically assumed. Thus, short delays of the type referred to become insignificant in such a time frame. Hence, this approach allows long term development plans to influence transport planning when they become available. If the growth of trade is not approximately linear, a year by year simulation of network improvements must be adopted instead. This alternative approach is also shown in Figure 3.22.

Before this approach can be adopted, two problems must be solved. Those of determining:

- the effect on intra-regional trade of a change in the characteristics of the transport system
- the commodity needs and availabilities at each node in the network

3.2.3 The Forecasting of Intra-Regional Trade

3.2.3.1 Introduction

A method of forecasting changes in intra-regional trade resulting from changes in the transport network is the first problem to be solved. The second, is that of predicting the future location and level of supply and demand for each commodity and is assumed to be the responsibility of the regional or island economic planners. They would select a number of possible industry locations, and the transport planner would, for each choice, determine the resulting cost of transport operation and provision to satisfy the resulting demand for inter-island transport.

3.2.3.2 The Effect of a Network on Intra-Regional Trade

If it is assumed that reasonable predictions of the future location and level of supply and demand for each commodity can be obtained from the regions economic planners, then the effect of the network on intra-regional trade should be determinable if:

- the transport network for the year in question can be defined in terms of the cost and performance characteristics of each node and each link
- in general, commodities are shipped according to some economic rationale
- the cost and performance characteristics of the transport system can be related to the identified rationale
- commodities are homogenous, i.e. all commodities within each group must be perfect substitutes

Now the transport model will determine the performance characteristics of the transport system in such terms as:

- the cost of shipping a ton of cargo from port "i" to port "j" over route "k" for all ports i, j in the network
- the journey time and frequency of service provided over each link

Information on the such facilities as refrigerated space for perishable commodities can be obtained from a knowledge of the facilities offered over each route served.

The fact that commodities are sometimes shipped according to an economic rationale is indicated by a study, made in Japan, "on the prices shippers are willing to pay for different types of transport services, where time is by far the major and in some cases the only criterion. The study covered a dozen important commodities and indicated, for example, the following prices actually paid for a saving of one ton/hour:" (Adler, 1967).[47]

Dairy Products	0.35	$ U.S.
Fresh Fish	0.21	"
Vegetables	0.20	"
Fruit	0.14	"
Minerals	0.10	"

Thus, the cost and performance characteristics of the transport system can be related to the shippers economic rationale commodity by commodity. This is because different commodities have different transport needs, which involve, to the shipper, different costs and performance characteristics. "Complicating the whole analysis is the fact that for route and modal selection, price and not the cost of transport is the relevant factor"(Burns, 1969.) One must, therefore, assume the pricing conditions over time, and from a knowledge of the proposed transport system determine the cost to the shipper of exporting each commodity over alternative routes provided by the proposed network.

Burns, (1969) states that this measure of cost to the shipper can be defined in terms of five components:

- waiting time
- travel time
- travel time variability
- probability of loss, and finally
- the cost or price of traversing a link

"Each commodity is then given a preference vector, defining the value placed on each of the five components of the link-performance vector. The product of these two vectors provides a measure of the "friction of space" for each commodity. For instance, the preference vector for a high value, light-weight

47. This statement is assumed to mean that a shipper will pay, for example, an additional 0.35 S U.S. per ton shipped, for a saving of 1 hour in total journey time.

commodity will put a relatively high weighting on the probability of loss and on travel time, and a relatively low weighting on the price or cost of traversing a link. If this preference vector is combined with a link performance vector having a high probability of loss and a long travel time, the resulting friction factor will be high. The same link performance vector combined with a commodity preference vector with a low value placed on probability of loss and travel time, as would be the case for coal or other ores, would produce a much lower friction factor. Thus, the high value commodity might travel by air, and the low value commodity by rail. In other words, that routing over the network is chosen which minimises total friction as defined above. This allows specific attention to be given to the prediction of modal choice" (Burns, 1969.) In using this method to determine the shipper's choice of transport mode between two ports in a transport network, a calibration of the model is required to ensure that the shipper's choice is reproduced in practice[48].

48.

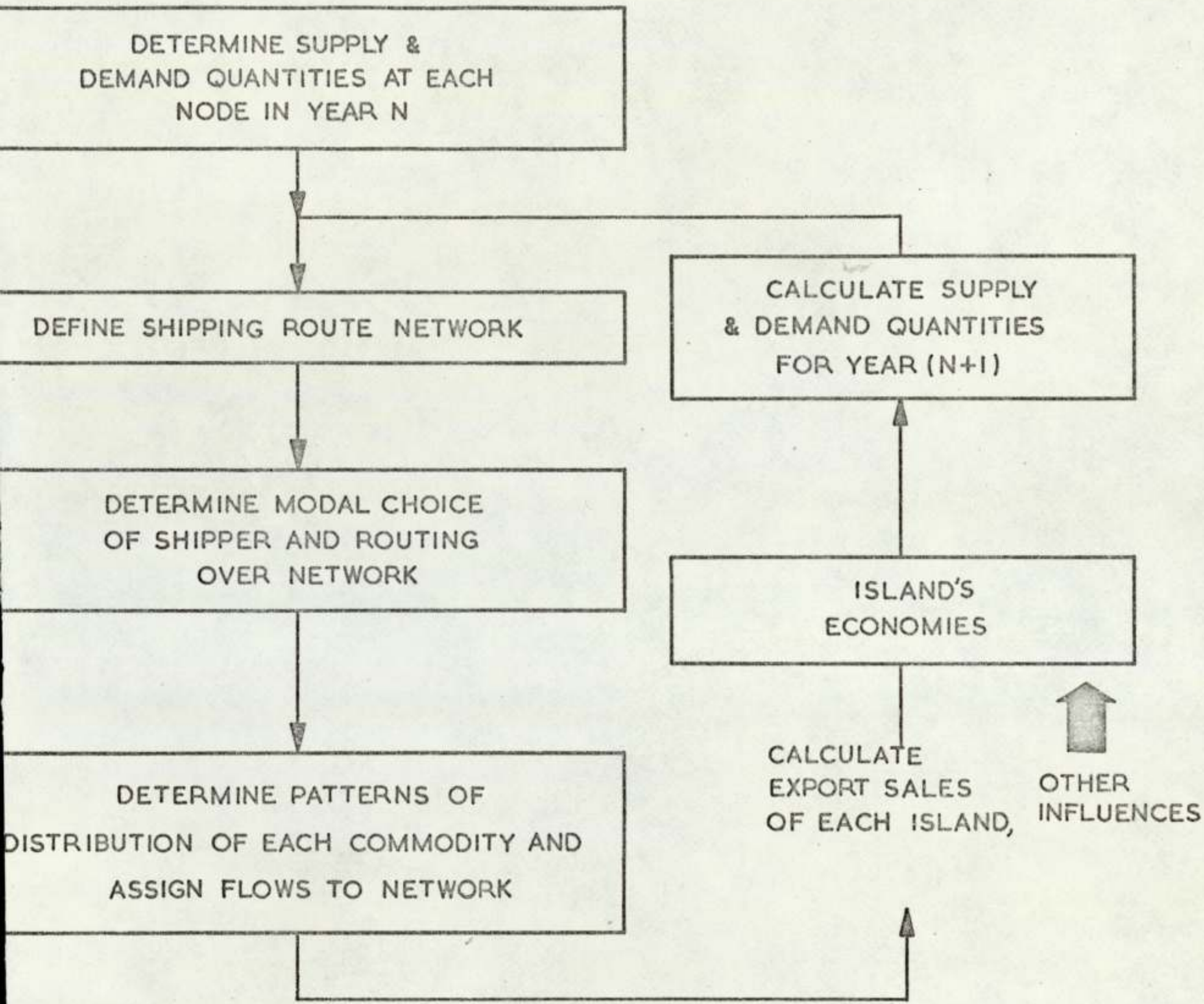
An alternative approach was used by Kuhn and Lea, (1969) in undertaking a land based transport study, where flows were assigned "to the transport system links on the basis of minimum costs as perceived by the shipper or user". The output consisted of flows and costs by vehicle type for each link in the system and overall systems performance measures. The model was calibrated for Dahomey in the following way.

- The flow of each commodity over each link was determined from data, which defined the supply of, and demand for, each commodity at each node, by using the "minimum cost as perceived by the shipper or user" criterion
- The calculated flow of each commodity was compared with the actual flow of the commodity as indicated by 1967 traffic estimates . A weighting factor was then applied to each link so that a re-run of the modal choice and distribution model would reproduce the actual flows.

Finally, the performance of the buyer at each node, in purchasing commodities from a number of sources of supply, can be determined in terms of the cost of the product to the buyer from each source. Where imperfect market knowledge exists or where the buyer would prefer one source to another, the commodities would have to be re-classified to overcome the homogeneity assumption. The pattern of intra-regional sales can then be determined, commodity by commodity. As each flow is determined, it can be assigned to the network. Thus, each trade flow can be determined in volume terms. Finally, the pattern of intra-regional sales determined by the model can be used to determine each island's industrial revenue, so that supply and demand quantities in the subsequent time period can be estimated. The whole process is summarised in Figure 3.24.

Thus, it would seem that the shippers rationale can, in general, be identified in quantifiable terms, and can then be reflected, commodity by commodity to the characteristics of the transport system proposed. Thus, the pattern of intra-regional movements over a network should be determinable for a subsequent year, commodity by commodity, using these so called "distribution" models, if the demand (need) and supplies (availability) of each commodity can be determined for the year in question.

It can be seen that the total flow over any one link could be used to determine an appropriate freight structure for the network in the subsequent time period, if freight charges could be determined by the Regional Transport Commission. The derived total flow values could also be used to "examine the effects of investment other than



THE EFFECT OF A NETWORK ON INTRA-REGIONAL TRADE

Fig. 3·24

new construction or the improvement of a link" (Burns, 1969.) For instance, a shipping cost-model might consider an improvement in operating performance which would modify the cost of operation (V_k). Similarly, investment in new ships could be reflected as changes of V_k fed into the linear programming transport model which, in turn, will be reflected in the design solutions determined by the transport model.

One further point remains. No account has been taken of other trade generating factors. In the Caribbean, tourism is a major contributor to economic growth. A major portion of tourist expenditure goes to pay for imports, and in the eastern Caribbean this expenditure is estimated to rise from the £20M sterling in 1967 to £58M sterling in 1972[49]. This may cause the network of trade flows, to, from, and within the Caribbean to change. Thus, the effect on each islands import needs created by other trade generating factors must also be reflected in the model of each islands economy, which is used to estimate the demand for transport.

The foregoing discussion suggests that the approach to transport investment planning illustrated in Figure 3.24 will only be possible if each relevant islands demands (for imports) and available supplies (exports) can be predicted in terms of each relevant commodity from:

- The envisaged expenditure on transport investment for each year
- The export sales for each island, commodity by commodity as estimated for the previous period from a knowledge of the transport network characteristics in that period

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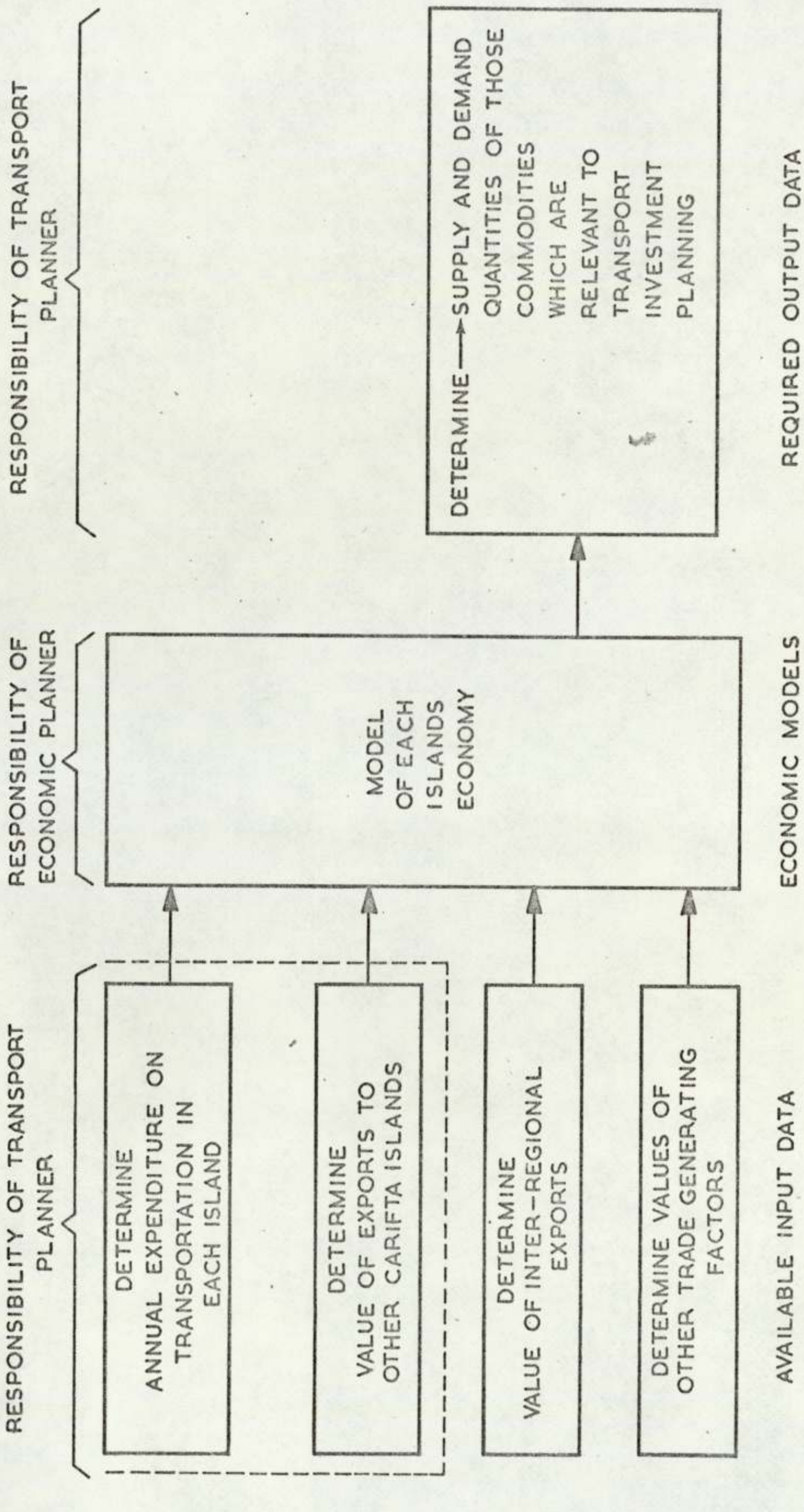
49. See "The Future of Tourism in the Eastern Caribbean, H. Zinder & Associates, May 1969, page 71.

- The estimated tourist expenditure in each sector of each islands economy
- Any other trade generating factors

While the first factor could be determined after exercising the linear programming transport model, and the intra-regional export sales of each island could be determined by the modal choice/distribution model approach described, the inter-regional export sales and other factors would be determined by the island or regional economic planners.

Thus, the problem becomes one of forecasting the import needs and export availabilities (at each port) of each island, in volume terms, from the input data supplied by the island economic planners. The problem is summarised in Figure 3. 25.

This figure shows that the transport planner must provide the data inputs shown for each year of the planning period. He must also convert what data is available from the islands' economic planners, who may already have economic models of their island's economies, into the supply and demand quantities and values of those commodities which are relevant to transport investment planning in the region.



THE FORECASTING OF SUPPLY AND DEMAND

Fig.3·25

3.2.4 Methods of Forecasting Intra-Regional Trade

There are several methods of forecasting trade flows between regions. The objective of these methods is "to show, in a quantifiable manner, the structural relationships between regions, so that the effect of an autonomous shock may be traced to, and through, the "n" regions under consideration" (Tiebout, 1968).

The original approach due to Isard, (1953) was developed to illustrate, not only the inter-industry relationships by region, but the inter-industrial and inter-regional relationships of a country. The framework of such a multiregional model was discussed in section 4.2 of Appendix A.

Although there are a variety of input-output models they can be broadly classified into "pure" interregional models, "balanced" inter-regional models and "gravity" models.

The pure inter-regional model has been particularly useful for determining national implication of regional projections for it is implemented "by aggregating a number of regional tables" (Miernyk, 1967).

"The transactions table of such a model shows, not only the sales of a given industry to all other industries in the region, but also the sales of that industry to all other industries in the other regions in the system", (Miernyk, 1967). If the appropriate data could be acquired for such a model, "it would show how changes in final demand for the products of one region generate impulses that are transmitted to other regions" (Miernyk, 1967).

"A balanced regional model is constructed by disaggregating a national input-output table into its component regions", (Miernyk, 1967), and is therefore particularly useful for determining regional implications of national projections.

A gravity model was developed by Leontief, (1963) for the purpose of determining regional flows and has been described as a gravity model in the sense that the structure of the model is not unlike the usual gravity models of the physical sciences.

The model concerned "tries to explain regional flows by considering the attraction of a volume of demand at a point and the sales push of a volume of supply from a given centre. All other forces are estimated through a coefficient evaluated from one set of observed values of the system. The coefficient thus may include the effect of distance, cost and other factors. The basic limitation, of the model is that it does not allow regional substitution", Ghosh, (1968).

In these approaches a set of pure trading coefficients for regional flows has been assumed constant. There is no valid reason for assuming that inputs which are substitutes must come from one area in preference to another. If a commodity is produced in many regions purchases by other regions will be determined by a number of factors. The supplies from different regions are always potential substitutes and sources of supply may be changed if these conditions change. Secondly, there is no reason to anticipate that as final demand changes, all regions will expand or contract outputs of any national industry in fixed proportion, as implied by the use of invariant allocating coefficients. To overcome the problems of substitution an interesting variation of an inter-regional model has been developed by Moses, (1960). He has blended inter-regional input-output analysis and a linear programming technique to make an empirical study of regional comparative advantage in the United States. In this study, trading patterns as well as regional outputs and requirements of all goods are determined while allowing for the introduction of alternative production techniques and substitution (between regions) into input-output analysis.

This differs from the normal transportation study, where the supply (availabilities) and demands (import requirements) at each node of a network are specified, as well as the cost of node to node transportation.

3. 2. 5 The Selection of an Intra-Regional Forecasting Model

3. 2. 5. 1 Introduction

If the case could be made that in some islands there is not a very sensitive relationship between transport investment strategy and the growth rate of intra-regional trade, then much of the complexity of transport planning could be removed. This is certainly possible within CARIFTA, where the revenue derived from intra-regional trade in some islands represents a small part of their total income. Thus if an island's intra-regional trade is small in relation to its total trade, the effect of alternative networks on intra-regional trade might be minimal[50]. When it is not, (the degree of significance has yet to be established) a trade flow forecasting model must be used. Section 3.2.3 outlined the requirements which must be satisfied by any intra-regional forecasting model (or models) in that it (they) must forecast the flows[51] which would occur in practice, should the postulated network be implemented. That is, in forecasting intra-regional flows, the model must, directly or indirectly:

- respond to the economic rationale which explain the movements of each commodity over a network. This implies substitution of products between sources and assumes the homogeneity of each product
- respond to the previous years industrial revenue and be usable for economic planning purposes
- respond to investment in transport facilities

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50. This statement also assumes that the effect of transport investment on the demand for transport is also insignificant.

51. Section 2.3.2 stated that an intra-regional transport system may have to carry:

- Re-exports or transhipment goods due to a distant country**
- Re-exports or transhipment goods due to an intra-regional island
- Domestic exports
- Exports due for transhipment**

In the double asterisked cases, the transhipment port would be regarded as the demand or supply point. For example, where imports to Antigua from outside the region, travel via the port of Barbados, then Barbados would be regarded as the supplier of the transhipped commodities.

3.2.5.2 Substitution of Products between Sources

Both pure and balanced inter-regional input-output models suffer from the use of constant regional coefficients, where trading patterns are assumed to remain stable for all levels of output. Thus, the possibility of substitution between regions is removed which, in turn, prevents these models from responding to changes in the transport network. These considerations rule out the use of both pure and balanced inter-regional models for the forecasting of intra-CARIFTA commodity flows. In the gravity model the possibility of regional substitution is also prevented by the use of constant coefficients which are based on one set of observed values. Both the inter-regional model developed by Moses, and the combined input-output/distribution model discussed in Section 3.2.3 allow the possibility of regional substitution. The distribution model, once calibrated, should faithfully allocate each commodity from point of supply to point of demand, if the economic rationale governing the movements has been faithfully captured. Thus, this model takes into account the conditions of imperfect competition which prevail in the Caribbean in respect to inter-island trade[52]. This fact is not recognised in programming models of the type developed by Moses, for they only consider the minimisation of the combined cost of production and transportation for each commodity. In discussing models of this programming type, Ghosh, (1968) states that these models are "not realistic in assuming that a minimisation of total costs is the objective. This would be a realistic situation if we had conditions of perfect competition and each region had minimised its own procurement costs. One may assume that each regional unit is trying to achieve a local optimum. Conditions of perfect competition do not exist." Thus, a regional optimum

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52. Appendix A, 4.2.6 states that the "low level of trade ... is also in part, due to artificial impediments to trade within the region; to ignorance about trading possibilities; and to failure to exploit opportunities for diversifying the area's productive activities"

may not automatically lead to a local optimum".

This leaves the combined input-output/distribution model as the only model to use which satisfy the first of the criteria listed.

3.2.5.3 Economic Planning within Carifta

To be useful for economic planning, an economic model must replicate the performance of each island's economy through the instrument variables available to the island governments. In discussing the methods used in the islands at present O'Loughlin, (1966) states that "the G.D.P. at factor cost is projected, sector by sector ... to indicate desirable growth rates for the accomplishment of specific plans in the context of possibility for the economy concerned". In this type of model a certain set of objectives is specified such as a given rise in income or employment or a given reduction of a balance of payments deficit, and the model is used to determine the most appropriate policy means to achieve these objectives. O'Loughlin, (1966) also states that national income statistics have been prepared by the University of the West Indies for several islands and that the continuation of this work is being given to the respective statistical departments in each island. This will enable the aggregate national income approach to be combined with input-output methods in planning economic development.

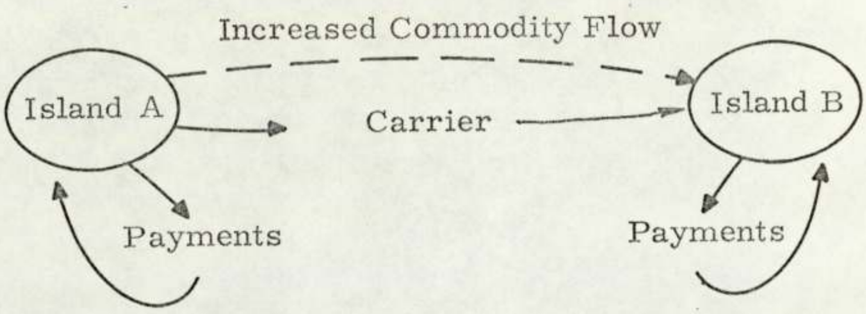
Now all the intra-regional forecasting models surveyed in Section 3.2.4 assumed that if final demand is given, then an input-output model will serve to determine the demand for intermediate products and capital goods (including imports) and its solution will provide for a mutually consistent set of production levels by economic sector, and imports for the whole economy. The variables in the model are the levels of final use, production and imports of each group of commodities. The levels of final use may be based either on exogenous variables such as Government policy variables, or on the outputs and incomes of the preceding time period. The demands for intermediate products and imports are determined from the solution of the model.

The advantage of the input-output method is that, "instead of a single equation for total supply of goods and services and their use, there is an equation for each sector of production. Similarly, the use of capital, labour and imported materials is estimated separately for each sector instead of on an aggregate basis. Input-output models therefore take into account the effect of changes in the composition of demand and output in estimating the requirements of such entities as capital, foreign currency and skilled labour, in contrast to aggregate models, which assume - for instance, in the projection of capital requirements, a single overall capital - output ratio"(Meier, 1964).

3.2.5.4 Investment in Transport Facilities

Investment in additional ports or shipping facilities will alter the production requirements of the transport industry. That is, the purchases by the transport sector, from the other sectors of an islands economy will be affected. Within an input-output model, these changes will correspond to changes in the technological coefficients of the processing sector (the transport columns). Similarly, network improvements resulting in cost savings to the carrier (operating the shipping service) will tend to alter the production needs of the transport sector of the island from which the shipping service obtains its requirements.

Another effect of a network improvement is to modify the amount of transport purchased by shippers[53]. This would result in an additional payment pattern to the transport sector by each industry, resulting in changes to the transport row of the input-output table. To which of the two islands concerned should these payments be allocated? In the case of the movement depicted in Figure3.29 both islands should stand to gain.



Payment Patterns Figure 3.26

- Additional payments will be made to the transport sector (the port) by each exporting industry (Shipper) in island A
- Island B will benefit similarly and
- The shipping company (the carrier) will benefit

In the latter case, this payment will be recorded in the island from which the carrier operates. This revised payment pattern could probably be determined by discussion/survey techniques or by comparative studies in advance of an envisaged investment. The manner in which network changes can be traced through an economy is illustrated in Figure 3.27 .

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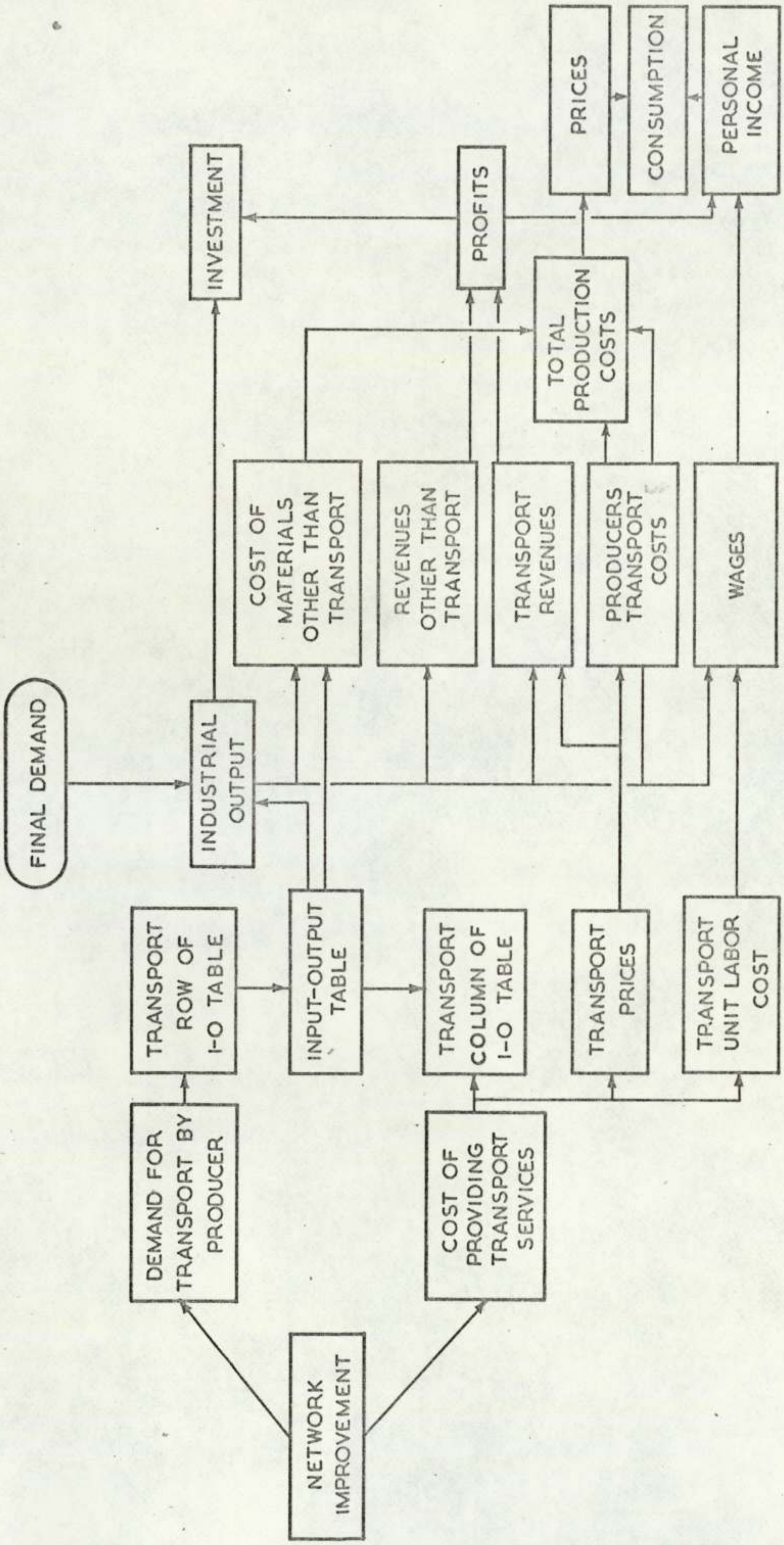
53. The conference systems would tend to prevent freight rate changes but refrigeration, alternative routes and other facility improvements could have the same effect.



SOURCE: ROBERTS, P.O., THE AMERICAN ECONOMIC REVIEW, MAY 1968, NUMBER 2, PAGE 354.

E MANNER IN WHICH NETWORK CHANGES CAN BE TRACED THROUGH THE ECONOMY.

Fig.3·27

It was not possible within the limitations of this study to pursue this point.

Thus, the combined input-output/distribution approach meets the requirements defined in Section 3.2.5.1. The relationship between these combined models, the input-output/distribution model and the linear programming transport model is as shown in Figure 3.28 which was derived from Figure 3.25.

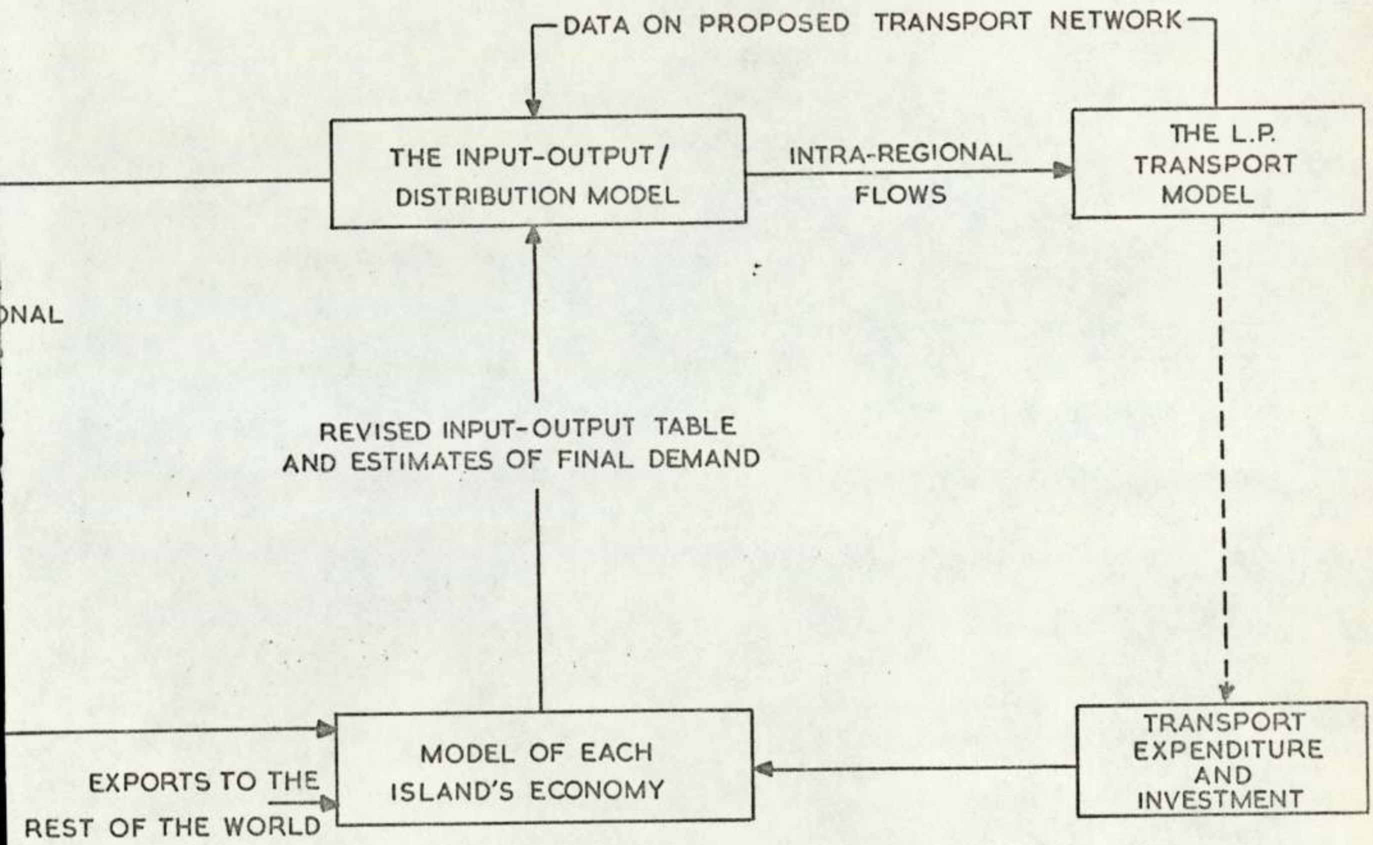
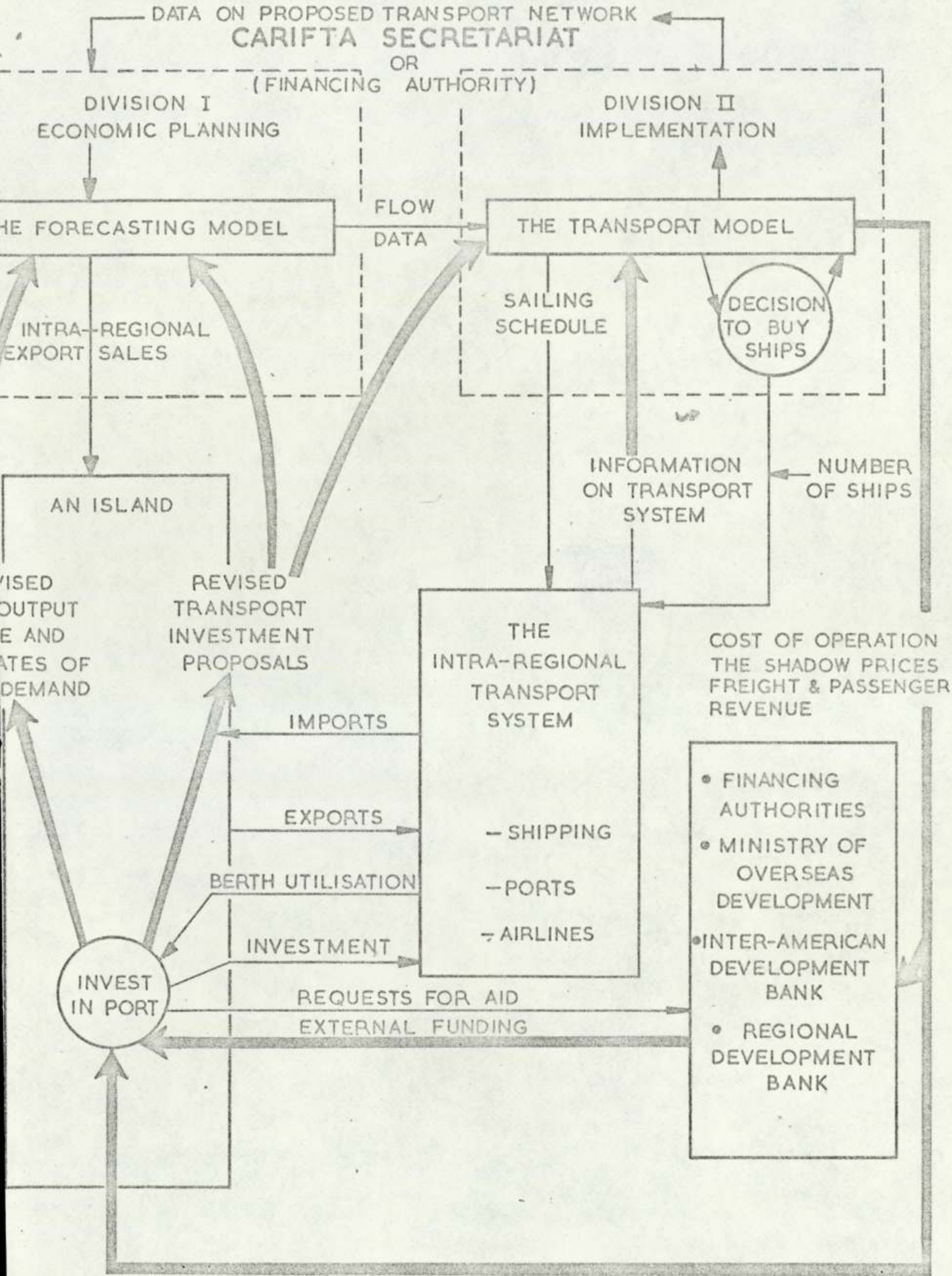


Figure 3.28

When Figure 3.28 is overlaid on Figure 3.12 of Section 3.1.3.6 the result is Figure 3.29 which suggests that a distribution model, when used in conjunction with the input-output tables of each island's economy could be used to forecast intra-regional commodity flows so that improvements to the transport system serving Carifta might be made. Each island's economic planners would estimate



THE DESIGN CYCLE.

Fig.3·29

the future revenue from exports as well as the other components of final demand. Their figures in aggregate would then be used by the transport planner within the Carifta Secretariat to determine:

- the import needs of each island in terms of the volume of each commodity by using an input-output model
- the export availability of each commodity in each island in terms of its cost per unit and the number of units available for export in the year in question

The modal choice and distribution models as described in Section 3.2.3 would then be used to determine the export sales of each island, commodity by commodity, for any defined transport network. In this way, the effect on the transport system of a selected course of development could be determined. Proof that the two activities above could be undertaken to the satisfaction of the transport planner is clearly required.

3.2.6 The Intra-Regional Forecasting Model

3.2.6.1 The Forecasting of an Island's Import Needs

The United Nations, (1966) state that because "the course of development is generally associated with the gradual substitution of domestic production for imports ... more of its imports are of the competing category". The difficulty with competing imports is that, to the extent that they are good substitutes for domestic production, the share of each in the total supply of the commodity may be variable and difficult to anticipate. In terms of input-output analysis, the direct and indirect inputs necessary to satisfy a given quantity of domestic output (X_i) may be quite substantial whereas an equal value of imports creates no demand for domestic output of any kind".

This can be illustrated by a simple example of a two industry open economy. The resulting equations can be given as:

$$M_1 + X_1 = a_{11}X_1 + a_{12}X_2 + Y_1$$
$$X_2 = a_{21}X_1 + a_{22}X_2 + Y_2$$

where

M_1 = the total imports of type 1 commodities

X_1 = the total output of industry 1

a_{12} = the amount of industry 1 output required per unit of industry 2 output

Y_1 = the final demand for type 1 commodities

If no imports are received

$$X_1 = a_{11}X_1 + a_{12}X_2 + Y_1$$

$$X_2 = a_{21}X_1 + a_{22}X_2 + Y_2$$

whereas if commodity 1 is imported and no domestic production takes place, then:

$$M_1 = a_{12}X_2 + Y_1$$

$$X_2 = a_{22}X_2 + Y_2$$

It is clear that if the demand for commodity 1 is imported then $a_{21}X_1$ is zero, i.e. there is no demand for domestic output from industry 1 and a reduced demand for domestic output from industry 2 - inputs from imports do not have indirect effects.

"The way in which substitution between domestic production and competing imports can be incorporated in a projection of the coefficient matrix depends upon the method of treating imports in the original table of the base year"(United Nations, 1966). Four basic methods are used.

3.2.6.1.1 The First Method

In the first of these methods, all imports are allocated in a single row to the consuming sectors, which generally include some of the final demand sectors. Hence the destination of imports to each sector must be known for this approach. As long as the imports recorded have no domestic counterpart this approach is acceptable, for the input coefficient matrix will be more stable than if substitution occurred. Where an import is "a good substitute for some domestically produced commodity" (United Nations, 1966) it is a competing import, and if substitution occurs between these two sources, as inputs to some third sector, will cause variance in the two input coefficients - from the competing import and from the domestic product - to the third sector" (United Nations, 1966). The projection of the import input coefficients - "can be treated in the same way as the projection of the other intermediate input coefficients. The same factors - essentially technological - which determine changes in the matrix of intermediate coefficients will determine changes in the import coefficients".

3.2.6.1.2 The Second Method

In the second method, "all imports are distributed along the row of a similar domestic sector" which means "that flows contain imported and domestically produced elements without distinction"[54]

54. Domestic inputs and competing imports to an industry must be in the same row to ensure the stability of the coefficient. Substitution between the domestic product and its foreign counterpart will not affect their joint input to a third sector which is technically determined. Thus, the technical coefficient is likely to be more stable than either the domestic input coefficient or the competing import coefficient.

This approach overcomes the problem of unstable coefficients but the presence of non-competing imports in the rows may give rise to inaccurate estimates of output requirements when the inverse matrix computed from this version of the table is post-multiplied by a bill of goods comprising final domestic demand and exports" (United Nations, 1966). This is because "inputs from imports are allowed to have indirect effects which they do not have" (Barna, 1963). "To avoid this error one has to change the final bill of goods by redefining each entry as containing domestic final demand plus exports minus imports. But this, in effect, means specifying in advance part of the solution (the level of imports) which one wishes to compute"(United Nations, 1966). Mathematically, the balance equations can be expressed by the relation

$$M_i + X_i = \sum_j a_{ij} \cdot X_j + Y_i$$

Hence

$$X_i = \sum_j a_{ij} \cdot X_j + (Y_i - M_i)$$

where all terms are as previously defined.

To form the coefficient matrices in this type of table one can either use the sum of all imports and domestic output as the denominator, or if the total imports are known for each row, "they may be entered with a negative sign in the final demand quadrant, so that the value of the row total equals domestic output"(United Nations, 1966). Expressed mathematically these coefficients are respectively:

$$a'_{ij} = \frac{X_{ij}}{X_j + M_j} \quad \text{and} \quad a_{ij} = \frac{X_{ij}}{X_j}$$

where

a'_{ij} and a_{ij} = the amount of sector i's output needed to produce a unit of "j"

X_{ij} = the demand by sector "j" for part of the output of the i^{th} sector

X_j = the total output of industry "j" excluding imports.

Only the second case (a_{ij}) can be justified, for in the first there is "no necessary relation between changes in total supply, which may be confined to imports, and changes in domestic inputs. Furthermore, this instability will affect the value of every coefficient in any column where significant substitution between imports and domestic production takes place" (United Nations, 1966).

3.2.6.1.3 The Third Method

In the third method, only "competing imports are distributed along the rows of the corresponding domestic sector (to ensure stable input coefficients) while non-competing imports are distributed along a separate row. "All intermediate flows thus consist of domestic production plus competing imports, and the total of the latter are entered as a negative column in the final bill of goods." In this case it is again necessary to specify the actual import requirements in any computation". The United Nations (1966) suggest that "this can be done more accurately with competing imports" .... "Frequently, however, the quantities of imports are related to the (unknown) levels of output of the corresponding domestic sectors. In this case, it is sufficient to specify the proportions which imports will form of the total supply of that sector".

The basic equations used with method 3, based on the standard open input-output model is as follows:

$$X_i = \sum_j a_{ij} \cdot X_j + Y(h)_i + E_i - M_i$$ [55]

or $$-a_{i1} X_1 - a_{i2} X_2 - \ldots\ldots (1 - a_{ii})X_i \ldots a_{in}X_n = (Y(h)_i + E_i - M_i)$$

where $Y(h)_i$ = the home final demand (i.e. final demand less exports)

E_i = the exports from the i^{th} sector

Other parameters are as previously defined.

From the base year data, the equation below can be derived where the quantities of imports are related to the (unknown) levels of output of the corresponding domestic sectors. That is:

$$M_i = k_i \cdot X_i \text{ then}$$

$$- a_{i1}X_1 - a_{i2}X_2 \ldots (1 + k - a_{i1})X_i - a_{in}X_n = Y(h)_i$$

where $(1 + k - a_{ii})$ represents the diagonal element. By making the appropriate adjustment to each diagonal element in the input coefficient matrix, (inputing the appropriate value of "k") it is possible to compute the level of competing imports as part of the solution to the problem if Y_i and E_i are input to the model. By summing all imports vertically in each column, each column sum can be used to provide an imported inputs coefficient for the sector. In addition, non-competing imports F are determined from the

55. This model is described by Cameron, B., "Inter-sector Accounts, 1955-56" Economic Record, April 1960, page 271.

equation:

$$F = \sum_i f_i \cdot X_i + Y(f) \quad \text{where}$$

f_i = the non-competing imports input coefficient into the i^{th} industry

$Y(f)$ = the final demand for non-competing imports

This would allow both competing and non-competing imports to be recorded, and satisfies the stability condition for the input coefficients in the processing sector. It may however suffer from aggregation error. Cameron, (1968) suggests that "purchases by final demand may be finished goods of a physically different type from intermediate purchases, while purchases by sector "i" are goods in process which may also be physically different from purchases of class "i" by the sectors "j". Such physical difference is likely to be matched by a difference in import coefficients." [56]

Accordingly, Cameron, (1968) sub-divided the imports in any cell "i" in "the competing imports row into three categories; direct purchases by final demand; purchases by the i^{th} industry for its own use; and the residual which comprises purchases by all other industries "j". The resulting hybrid model is an attempt to reduce aggregation error, and yet is relatively economical of data.

"The justification for distinguishing imports of commodity "i" for use in sector "i" from other imports of "i" is based on two

56. These views are confirmed by Eleish, G, Barna (1963) who states that "if all new production is substituted for imports which were purchased by the final demand sectors, this will not require the introduction of any changes in the technical coefficients of the productive sectors. But if the new production is substituted for imports purchased by particular sectors, this obviously will necessitate a change in the input coefficients of these sectors".

propositions. First, any industry which expands its output in order to substitute for imports is often likely to import more inputs slightly earlier in the productive process, e.g. the replacement of car imports by an expansion of car production may result in greater imports of electrical components, or an import-substituting expansion of cloth production may result in greater imports of yarn. Second, the crudeness of the commodity classification is often such that these products of successive processes - cars and parts, cloth and yarn - are included in the same commodity classification. Hence, if we are to understand what is happening to imports, say, in the textiles (yarn-cloth) group, it is desirable to distinguish the component commodities, since textile imports (i.e. yarn) bought by the textile industry may be rising while textile imports (i.e. cloth) bought by non-textile industries are falling. "(Cameron, 1968).

As before, non-competing imports are given by:

$$F = \sum_i f_i X_i + Y(f)$$

where the parameters are as previously defined.

Direct purchases by final demand are given by $Y(m)_i$. Purchases by the i^{th} industry for its own use are assumed to be proportional to output. That is:

$$M_{ii} = m_{ii} \cdot X_i$$

where

m_{ii} = a combination technical-market share coefficient

M_{ii} = competing imports of the i^{th} type to the i^{th} industry

Now the sales to other industrial users of the i^{th} type from home production are given by the equation:

$$\left[X_i \, (1 - h_{ii}) - (Y(h)_i + E_i) \right]$$

That this is so can be seen from the diagram below.

$X_i \, (1 - h_{ii})$ → $(Y(h)_i + E_i)$

HOME PRODUCTION of the i^{th} sector less internal needs

FINAL DEMAND FOR HOME PRODUCTION

$X_i \, (1 - h_{ii}) - (Y(h)_i + E_i)$

SALES TO OTHER INDUSTRIAL USERS

PURCHASES FROM THE i^{th} SECTOR

Figure 3.30

Purchases ($\hat{M}_i$) by other industries "j" are assumed "to have a constant share of the sales of "i" to other industrial users". Cameron, (1968). That is:

$$\hat{M}_i = \hat{m}_i \left[X_i \, (1 - h_{ii}) - (Y(h)_i + E_i) \right]$$

where

$$\hat{M}_i = \sum_j \hat{M}_{ij}$$

$\hat{m}_i$ = a market share coefficient

h_{ii} = the input coefficient of home produced sales of commodity "i" to the i^{th} industry

Clearly, home production has the rest of the market so that:

$$Y(h)_i \quad = \quad (1 - m_{iy})Y(h)_i$$

because

$$= \quad Y(h)_i + Y(m)_i = Y(h_i) + m_{iy}\, Y(h)_i$$

where

$Y(h)_i$ = home final demand

m_{iy} = a market share coefficient

$Y(m)_i$ = $m_{iy} \cdot Y(h)_i$

That is, "final home demand for home-produced output is related to total home final demand"(Cameron, 1968). Other parameters are as previously defined.

From the above, competing imports have been divided into the three categories given in the equation

$$M_i \quad = \quad M_{ii} + \hat{M}_i + Y(m)_i$$

where it is assumed that, "if exports are recorded net of re-exports ... no export demand directly requires competing imports". Cameron, (1968). Now in a standard open input-output model

$$X_i + M_i = \sum_j a_{ij} \cdot X_j + Y_i + E_i$$

Hence $X_i + Y(m)_i + M_{ii} + \hat{M}_i = \sum_j a_{ij} \cdot X_j + Y(h)_i + Y(m)_i + E_i$

$$\therefore X_i^*(1 + m_{ii} + \hat{m}_i - \hat{m}_i \cdot h_{ii}) - \sum_j a_{ij} \cdot X_j^* = \left[(1 - m_{iy})Y(h)_i + E_i^*\right] (1 + \hat{m}_i)$$

If X_1^* is calculated from exogenously specified $Y(h)_i$, E_i^* and the base year coefficients, then imports can be calculated from the equation:

$$M_i^* = m_{ii} \cdot X_i^* + \hat{m}_i \left[X_i^* (1 - h_{ii}) - (1 - m_{iy}) Y(h)_i + E_i^* \right] + m_{iy} \cdot Y(h)_i$$

where X_i^* = the total output of industry "i" in the year (*) specified

M_i^* = the total imports of type "i" commodities in the year (*) specified

This approach, which uses three separate coefficients m_{ii}, $\hat{m}_i$ and m_{iy} to calculate the level of imports, may be contrasted with the simpler form of method 3, where imports are summed to a single figure to derive the single coefficient "k_i", which is then used to determine the imports M_i^* from the equation

$$M_i^* = k_i \cdot X_i^*$$

The value of each formulation in forecasting the import needs of an economy depends on the availability of data and the validity of the associated assumptions.

3.2.6.1.4 The Fourth Method

In this method, all imported goods are identified by industry of origin and by industry of destination. Competing and non-competing imports are identified and the latter relegated to a row at the foot of the table. "This is equivalent to the preparation of two tables - one for domestic flows and one for imported products . . . . . An immediate advantage of this method is that information about import substitution in particular elements can be accurately incorporated in the table. Thus a domestic flow matrix can be constantly revised, so that the problem of substitutability can be minimised." If imports are non-competing, they can be aggregated by column 3 as in Method 1, or if competing they can be aggregated by row and treated as in Method 2. The differences between these methods of recording imports can readily be seen from Figure 3.31.

"If, during the period of the projection, it is known that domestic production will begin of goods hitherto not produced in the economy, it will be necessary to add the appropriate rows and columns to the input coefficient matrix"(United Nations, 1966). Within the Caribbean, it might be possible to obtain the input structure of such not-yet-existing industries from the other islands where such industries have already been introduced. Alternatively, specifications of the particular industrial units to be set up might be used to derive the input coefficients for the new industry.

This method, assuming its extensive data to be accurate, is the most searching of the approaches. A model[5] may be formulated to use the data, where, in this case, the non-competing imports are assumed to be aggregated. That is, the non-competing import columns (1, 2.....n) have been summed to give $f_i X_i$ for each i^{th} column (1, 2...... n) in the following example.

Output levels can be determined from the equations:

$$X_i = \sum_j a_{ij} \cdot X_j + Y(h)_i$$

Given these output levels, imports are determined by:

$$M_i = \sum_j m_{ij} \cdot X_j + Y(m)_i$$

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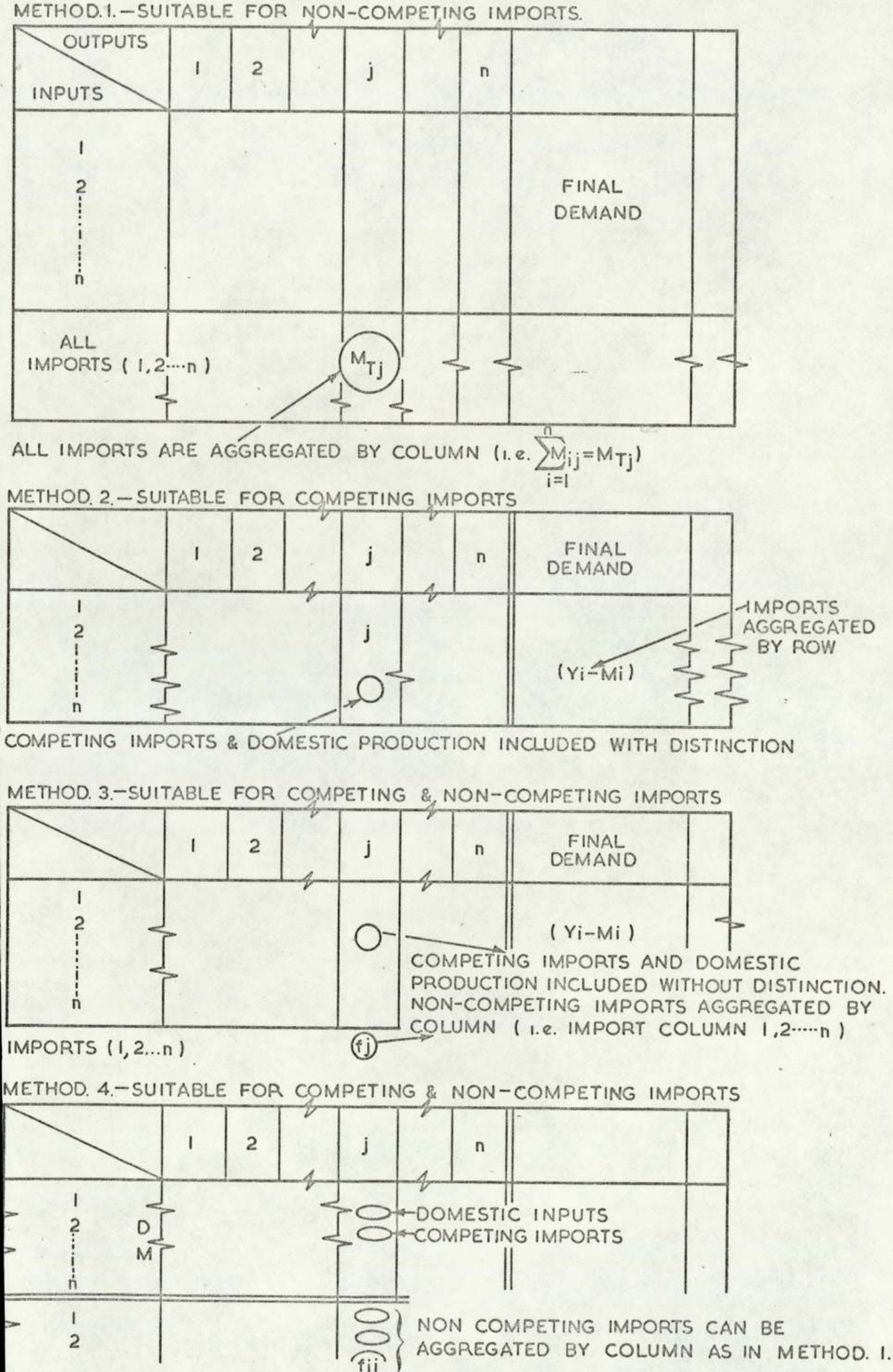
57. This description is similar to that given by Cameron, B. Input-output Analysis and Resource Allocation, Cambridge University Press, 1968, pages 28 and 29.



ALTERNATIVE METHODS OF RECORDING IMPORTS

Fig.3·31

where

a_{ij} = the input coefficient of home produced "i" into "j"

m_{ij} = the input coefficient of imported "i" into "j" derived from the base year input-output table

$Y(h)_i$ = the final demand for home produced commodities of the i^{th} type

$Y(m)_i$ = the final demand for imported but competing commodities of the i^{th} type

In addition, non-competing imports F are determined by the equation:

$$F = \sum_i f_i X_i + Y(f)$$

where

f_i = the non-competing imports input coefficient into the i^{th} industry

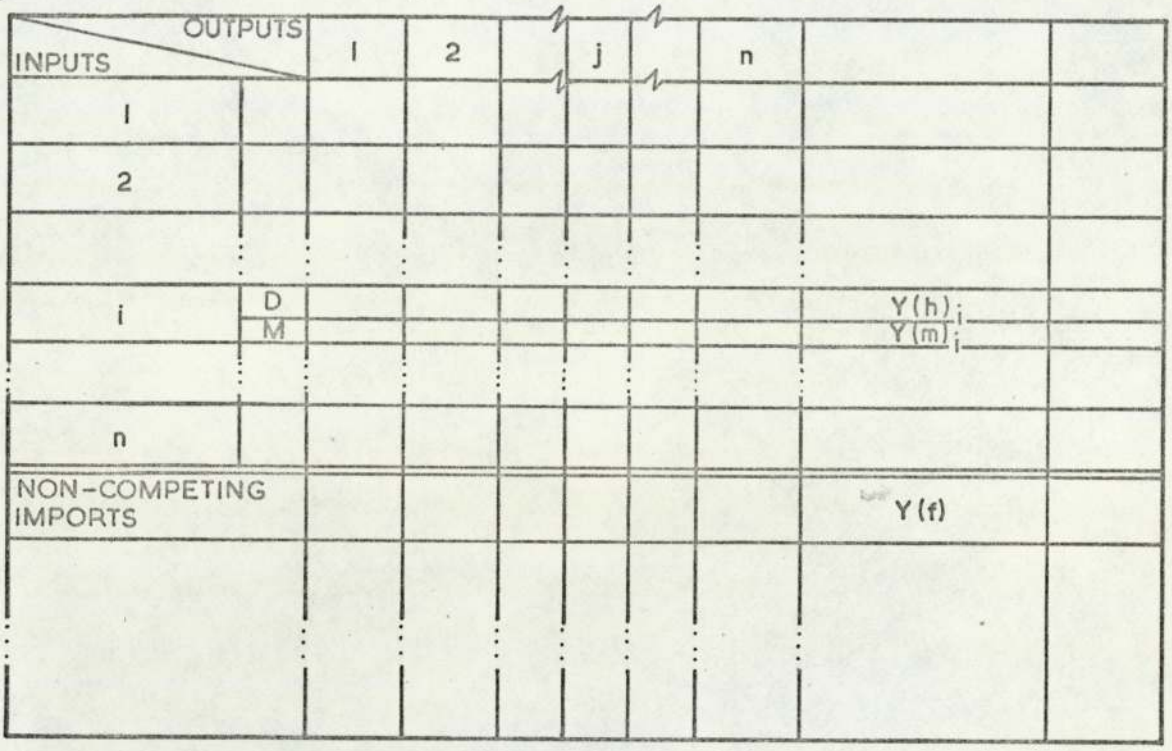
$Y(f)$ = the final demand for non-competing imports

Each of these parameters are illustrated in Figure 3.32.

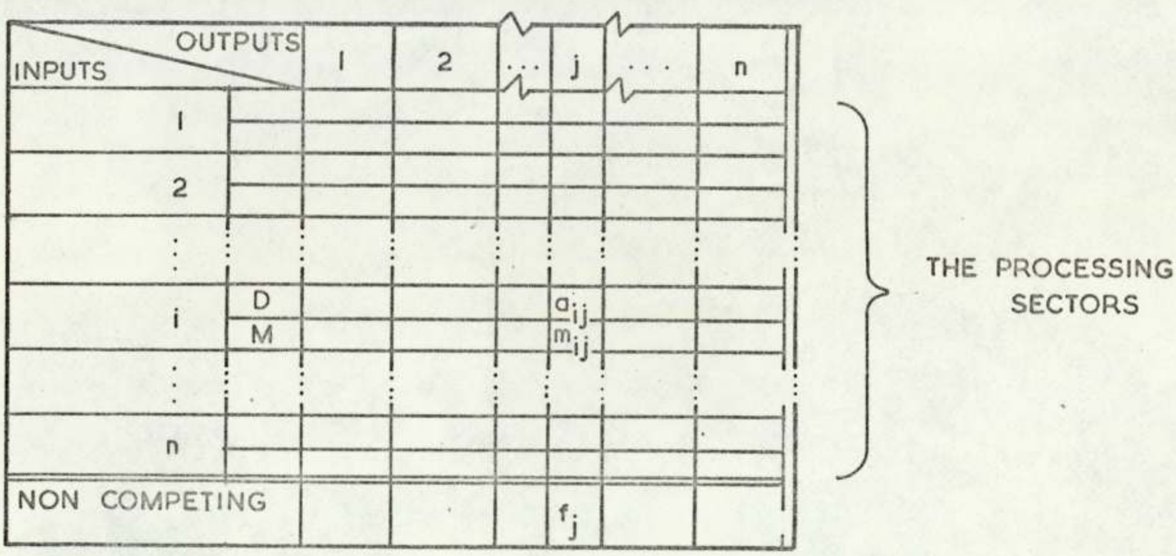
Conclusion

Only methods 3 and 4 allow both competing and non-competing imports to be recorded in the input-output table.

An examination of these two models suggests that they are



THE TRANSACTIONS TABLE



THE INPUT COEFFICIENT TABLE

THE TRANSACTIONS & INPUT COEFFICIENT TABLES

Fig.3·32

basically the same. That is:

$$X_i = \sum a_{ij} X_j + Y_i + E_i - M_i \text{ in both models}$$

while

$$M_i = \sum m_{ij} \cdot X_j + Y(m)_i \text{ in method 4 but}$$

$$M_i = m_{ii} X_i + Y(m)_i \text{ in the hybrid model}$$

The latter determines the import level $\hat{M}_1$ as a constant share of the sales of "i" to other industrial users, while method 4 determines $\hat{M}_i$ from $\sum_{i \neq j} m_{ij} \cdot X_j$. As the sales of X_j determine the sales of X_i then the two approaches are basically similar if X_i and X_j are interdependent, (they are normally assumed to be in an input-output table), although in the hybrid model, final demand for imported commodities is assumed to remain some constant proportion of home final demand, while in method 4 both $Y(h)_i$ and $Y(m)_i$ are exogenously determined. Either of these methods may prove adequate for the forecasting of imports if:

- estimates of final demand are sufficiently accurate
- the input-output coefficients are predictable over the forecasting period

3.2.6.2 The Forecasting of Exports

The export availability of each commodity is determined by the domestic production capability of each island, its own needs, and that islands position in international trade. "Considerable differences in the growth of exports are noted when countries are grouped by their position in international trade, size of domestic market, and degree of price inflation. - The commodity composition of exports is a further factor influencing the differences in export growth. A country's position in international trade depends on its share in world markets for its major exports and the relative importance of major exports and of minor exports in its total exports." (De Vries, 1967). Clearly, a detailed analysis of each island's domestic production capability and of specific world markets and their growth would be necessary if export levels are to be derived for the final demand vector. Several alternative levels of exports could be assumed around a value determined from a time-series analysis of past data. This approach would seem reasonable in the short to medium term analysis of transport investment alternatives. Indeed, Dudly Seers, the distingusihed U.N. planning economist has stated, in discussing the Caribbean that "export income is comparatively stable - in terms of both price and volume - from year to year."[58] (Demas, 1965). However, projections of external demand could go very far wrong because demand conditions for a country's exports abroad might be subject to sudden change. While this particular limitation is accepted, Dudley Seers' approach seems to suggest that export income could be forecast in the short to medium term. Thus, three questions remain, if one assumes that projections of final demand can be made:

- Can one of these input-output models be applied to the economies of those islands within CARIFTA to forecast their import needs in terms of each sector?

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58. The reason for this is almost certainly due to the British Commonwealth Sugar Agreements which guarantees "to the members of the West Indies Sugar Association, an overall quota of 900, 000 tons (84% of average annual exports), which can be sold at preferential prices in Canada or the United Kingdom. This total includes a negotiated price quota of 725, 000 tons. The remaining 16% of production is sold locally to the United States and to Canada. The price is at present £43.5 per ton, to which is added a fixed element of £1.5, replacing the old Colonial Preference Certificates, and a variable element, at present £2.5 which varies from £2.5 to zero inversely to the world price of sugar"(West India Committee, 1970).

- Can these sector forecasts be disaggregated into homogenous commodity groups in value terms?
- Can these value forecasts be converted into imports by volume in terms of each commodity group and can Carifta imports be separated from inter-regional imports ?

To answer these questions, the island of Dominica[59] was selected because data on this island was readily available.

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59. Dr. Cracknell of the Overseas Development Administration (O.D.A) suggested that data on this island might answer the questions posed by my study.

3.2.6.3 An Input-Output Model for Dominica

The Basic Table

The format initially selected for the collation of the input-output data on the economy of Dominica, is illustrated in Figure 3.36. By dividing the export column into those due for Carifta and exports to the Rest of the World, the repercussions on the economy resulting from a change in the level of intra-CARIFTA exports (modified by a change in the transport system) will be determinable. The reasons for allocating each sector to either the processing sectors or final demand are given in Appendix L.

3.2.6.3.1 The Sectors Defined in Commodity Terms

Now the sector of destination of imported commodities, as given in terms of the S.I.T.C[60] in the Annual Trade Statistics is unknown. Clearly, a definition of each sector in terms of commodities produced might solve the problem. As no such definition could be obtained, the author used the export statistics and Bartell, (1965) to define each sector of the economy in commodity terms. The result of this exercise is illustrated in Table 3.19 where the sector accounts served the purpose of identifying export commodity groups in terms of each sector. While the majority of figures are reconcilable, those figures relating to the banana industry are not. An analysis of the sector accounts and the export statistics, given in Table 3.20 shows the poor correspondence between the two sources.

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60. Standard International Trade Classification

INDUSTRY PROCEDURE \ INDUSTRY PURCHASING	A	B	C	D	E	F	G	H	I	J	SAVINGS & INVESTMENT	HOUSEHOLDS	PROFIT APROPRIATION	GOVERNMENT	EXPORTS TO:– CARIFTA	EXPORTS TO:– THE REST OF THE WORLD	TOTAL GROSS OUTPUT
BANANA INDUSTRY (A)	PROCESSING SECTORS										FINAL OUTPUT OF PRODUCTION SECTORS						
OTHER EXPORT AGRICULTURE (B)																	
DOMESTIC AGRICULTURE (C)																	
CONSTRUCTION & ENGINEERING (D)																	
MANUFACTURING (E)																	
DISTRIBUTION (F)																	
TRANSPORT (G)																	
FINANCE & INSURANCE (H)																	
SERVICES (I)																	
RENT OF DWELLINGS (J)																	
SAVINGS & INVESTMENT	PRIMARY INPUTS TO PRODUCTION										PRIMARY INPUTS TO FINAL DEMAND						
HOUSEHOLDS																	
PROFIT APPROPRIATION																	
GOVERNMENT																	
IMPORTS OF SERVICES																	
IMPORTS OF GOODS																	
TOTAL GROSS OUTLAY																	

THE FORMAT OF THE INPUT–OUTPUT TABLE FOR DOMINICA

Fig.3·33

SECTOR Source: Sector Accounts, (Bartell), 1965 Receipts from the rest of the world using 1962 sector accounts		COMMODITIES Source: Annual Trade Report, 1962 Exports to the rest of the world, using 1962 export statistics $'000 f. o. b.			
BANANA INDUSTRY		Total Value	Carifta Value	Commodity	S.I.T.C.
	4317.5	4858.9	-	Bananas	051-03.01
OTHER EXPORT AGRICULTURE					
Copra	430.5	430.5	430.5	Copra	22
Fresh Citrus	272.0	272.0	-	Oranges, tangerines, limes & grapefruit	051-01.01/ 02.02
Cocoa	137.8	144.7	-	Cocoa beans, Spices	07
Other	57.9	61.6	61.6	Fruit & Veg. excluding bananas & Lime juice	05
		11.86	11.86	Animal Oils & Fats	41
		10.96	-	Misc. food preparations	09
		3.8	3.8	Other	02, 04, 24, 29
OMESTIC AGRICULTURE					
None		None	-	Fishing & Livestock	
ONSTRUCTION & ENGINEERING					
None		None	-	Housing Construction & Improvement	
ANUFACTURING					
traw Products	46.0	46.0	25.9	Floor Matting	657
ime Juice	1173.8	1176.7	4.7	Lime Juice	053-04.07/.12
ssential Oils	481.8	481.8	5.6	Essential Oils & Perfume	55
		4.3	2.7	Misc. Manufac- tured articles	81-85 & 89
		3.7	-	Metalliferous Ores & Scrap	28
ISTRIBUTION					
uvenirs, etc.	32.5	36.6	13.1	Personal Effects of Travellers	93

DEFINITION OF SECTORS IN TERMS OF COMMODITIES PRODUCED
TABLE 3.19

YEAR	SECTOR ACCOUNTS*	EXPORT** STATISTICS
1961	4638	4784
1962	4318	4875
1963	4739	5417

TABLE 3. 20

Sources:

*National Income Statistics, Dominica, 1961-64, I. S. E. R.

**Abstract from Annual Trade Report, 1968 for Dominica, 1968, p. 22

Information on each sector was used, in conjunction with the 1962 trade statistics[6/] to allocate imports to each sector. The result of this exercise is illustrated in Figure 3.34which shows the close correspondence between the authors estimates of the imports to each sector and the estimates taken from the sector accounts. (Bartell, 1965). In practice, this information would be available in each island, the commodities entering each sector being defined by the statistician who prepared the sector accounts. It can be seen that the imports to the banana industry could not be separated from other export agriculture. In some cases, the distribution sector imports both consumer goods and other materials destined for other sectors. An important piece of information - the degree of dependence of the various sectors on these imported products - is lost. For example, part of the imports of S. I. T. C. 63 consists of casks, hogsheads and barrels (S. I. T. C. No. 632-02. 01); clearly an input to the bottling industry (part of the manufacturing sector). Competing imports are those goods which are the same as those manufactured locally. These were identified by comparing import and export data in the Annual Trade Report (i. e. those which are

6/. Given in Appendix L.

SECTOR ACCOUNTS AND IMPORT STATISTICS COMPARED

SECTOR ACCOUNTS		SECTORS		IMPORTS	
CRIPTION OF IMPORTS	VALUE		VALUE	DESCRIPTION	COMMODITY (S.I.T.C)
TILIZERS AND OTHER PLIES →	656.9	BANANA INDUSTRY & OTHER EXPORT AGRICULTURE -Bananas -Animal oils & fats -Copra -Cocoa -Lime -Pickles & condiments -Fruit & vegetables	219.698	Animal oils and fats largely copra and coconut oil	41
			431,174	Fertilizers manufactured	56
			189.894	Insecticides, fungicides, weedkillers, etc.	599-02
TILIZER, INSECTICIDE, . →	244.8		1.878	Lime for agricultural use	661-01.01
			65.475	Implements and tools for agriculture	699-12.01 699-12.09
			908.000		
ING SUPPLIES →	3.3	DOMESTIC AGRICULTURE	3.337	Fishing Nets	655-06.02
			3.300		
CT IMPORTS →	2109.1	CONSTRUCTION & ENGINEERING -Home construction -Construction of banks and super-markets -Expansion of electric power and lime processing industries -Engineering and maintenance of vehicles and buildings	4.442	Paints and enamels	533-03.01)
			5.084	Asphalt cement putty mastic paints	)* 533-03/04)
			19.944	Veneer sheets and fibre boards	631-018.03
			12.816	Builders woodwork, flooring materials, etc.	691-058.08
			9.883	Felt roofing	655-01.01
			267.023	Building materials, largely cement	66*
			53.527	Structural parts	699-01
			951.750	Machinery other than electric	71
			622.309	Transport equipment	73
			80.332	Sanitary, plumbing, heating and lighting	81
			12.641	Portable electric tools	721-12
			2109.800		
CT IMPORTS OF RAW ERIALS →	420.9	MANUFACTURING -Local crafts -Electricity generation -Cigarettes -Rum processing -Baking and bottling -Processing lime -Matting -Essential oils -Misc. manufactured articles -Metal ores and scrap	356.821	Unrefined beet and sugar cane	061-01*
			36.237	Raw molasses	061-01*
			2.874	Natural rubber	23
			0.678	Pulp and waste paper	25
			4.908	Synthetic plastic materials in	599-01
			2.937	Gravel, clay, stone and metallic minerals	27-03/04
			19.611	Salt, coarse and rock.	272-05.01
			0.362	Stone and crude non-metallic minerals	272-08 & 19
			1.200	Mineral tar and crude chemicals	52
			420.600		

Fig.3·34

SECTOR ACCOUNTS AND IMPORT STATISTICS COMPARED (cont'd)

CTOR ACCOUNTS		SECTORS	IMPORTS		
PTION OF IMPORTS	VALUE		VALUE	DESCRIPTION	COMMODITY (S. I. T. C.)
ECT IMPORTS	8969.7 →	DISTRIBUTION	3,137,844	Food and live animals less (061-01*)	0
			439.096	Beverages and tobacco	1
			347.548	Wood, lumber and cork	24
			2.396	Textile fibres, cotton jute and hemp	26
			14.253	Fine salt	27-05.02
			0.374	Stone for industrial uses	272-11
			5.846	Seeds for planting bulbs cut flowers	29
			349.556	Petroleum and petroleum products	3.1.3
			1.716	Gas natural and manufactured	3.1.4
			39.588	Acids alcohol and organic compounds	51
			17,352	Dyeing, tanning and colouring materials	53*
			302.795	Essential oils and perfume materials, e. g. soap	55
			45.809	Starches, glues and other chemical materials	59*
			5.641	Leather and leather manufactures	61
			219.740	Rubber manufactures - car and lorry tyres, etc.	62*
			147.461	Wood and cork manufactures	63*
			518.725	Paper paperboard and manufactures	64*
			689.739	Textile yarn and fabrics	65*
			49.871	Non-metallic mineral manufactures	66*
			10.623	Silver, platinum, gems and jewellery	67
			269.252	Non-ferrous metals-rods, plates, tubes, etc.	68
			331.791	Manufactures of metal-pots and pans, etc.	69*
			75.008	Batteries accumulators and electrical appliances	72*
			149.240	Furniture	82
			884.150	Clothing and footwear	84 and 85
			553.258	Watches, clocks, etc. and misc. manufactured articles	86*and 89
			114.787	Commodities and transaction - unclassified	9
			8,723.500		

Fig.3·34(Cont)

SECTOR ACCOUNTS AND IMPORT STATISTICS COMPARED

SECTOR ACCOUNTS		SECTORS	IMPORTS		
CRIPTION OF IMPORTS	VALUE		VALUE	DESCRIPTION	COMMODITY (S.I.T.C.)
ECT IMPORTS OF GOODS RCHASED ON HOLIDAYS) OAD)	90.3	HOUSEHOLDS	63.869	Radio batteries, radio sets and radiograms	721-02.01 & 04.01/2
			41.045	Travel goods, handbags, etc.	83
			104.900		
ORTS OF GOODS	393.7	GOVERNMENT -Telephones -Electricity -Hospitals	6.194	Glassware for laboratory use	655-09.01
			222.274	Medical and pharmaceutical products	54
			1.158	Medical and surgical articles of rubber	629-02
			73.269	Electric generators, motors, etc.	721-01
			36.448	Medical and telephony equipment	721-05/06
			22.963	Control, medical and signalling equipment	721-08 and 11
			25.014	Electric cables	721-13
			3.230	Surgical medical and dental appliances	861-03
			390.550		

Fig.3·34(Cont)

given the same S.I.T.C. classification as the exported commodity). The result of this exercise is illustrated in Table 3.21.

The completion of these activities enabled the construction of the input-output table (Table 3.22), where competing imports are recorded below the figures in the row for domestic production, while non-competing imports have been aggregated and are given in a single row at the foot of the table. The structure of this table is based on the fourth method of recording imports in an input-output table.

3.2.6.3.2 The Data Derived for the Model

Input-output and import coefficient tables were calculated for the purposes of using method 4 to calculate the import needs of Dominica. These coefficients were derived from Table 3.21 and are given in Table 3.23.

The import coefficients were calculated from the equations:

$$a_{ij} = \frac{X_{ij}}{X_j} \qquad m_{ij} = \frac{M_{ij}}{X_j} \qquad f_j = \frac{M_j}{X_j}$$

where M_{ij} = the value of competing imports of type "i" to the j^{th} sector

M_j = the value of non-competing imports to the j^{th} sector

The large import coefficient for distribution merely indicates that home production is inadequate to satisfy final demand and so $1.464.X_d$ must be imported. An import coefficient was not calculated for the construction and engineering sector because a major portion of its imports are for domestic capital formation, and do not constitute imports to current production. Rather, they are imports to future production, their level being determined by the investment of households on residential dwellings, business and government, all of which are exogenously specified. A reconstruction of Table 3.22 would show imports to gross domestic capital

Origin Sector	Importing Sector	Commodity Description	SITC	Value $ (W. I.) (1962)	(1963)
Other Export Agriculture		Copra Oil	412-07	203507	202,500
Manufacturing ↕	Distribution ↕	Other Bakery Products	048-04.09	7368	6643
		Non-Alcoholic Beverages	111-01.09	2596	7481
		Cigars & Cheroots	122-01	58	500
		Lime Oil, Distilled	551-01.041	1700	-
		Bay Rum	552-01.01	807	273
		Carpets & Vegetable Matting	657-03	2501	1628
		Other Wooden Furniture	821-01.09	6359	8617
		Hats, Caps & Other Headgear	841-11	29106	42446
		Slippers & House Footwear	851-01	4962	4383
		Baskets, complete	899-12.01	904	993
		Other Articles of Basketware	899-12.09	659	-
		Toys & Games	899-15.09	27929	30310
		Other Preserved Fruits	053-01.09	9290	6434
		Citrus Peel	053-02.01	643	117
		All Other Preserved Fruits	053-02.09	2547	2088
		Jams, Jellies & Marmalades	053-03.01	3503	293
		Grapefruit Juice - in Containers	053-04.02	1078	433
		Orange Juice - in Containers	053-04.04	818	354
		Lime Juice, Raw	053-04.07	2800	-
		Lime Juice, Clear	053-04.11	10	87
		Vegetables	054-09.09	5407	5575
		Cocoa Beans	072-02	7748	3545
		Vanilla Spice	075-02.01	115	-
Other Export Agriculture		Cinnamon Spice	075-02.02	22	-
		Pickles, Condiments & Sauces	099-09.03	13589	15027
Distribution)		Lumber, Simply Sawn	243-03.01	11954	4496
Distribution)	Distribution	Bulbs, Tubers & Plants	292-06	393	1316
Manufacturing)	Households	Travel Goods	831-01	33843	17481
Manufacturing)		Handbags, Wallets, etc.	831-02	7202	11847

COMPETING IMPORTS TO EACH SECTOR
TABLE 3.21

1962 Receipts \ Expenditure 1962		Banana Industry	Other Export Agriculture	Domestic Agriculture	Construction & Engineering	Manufacturing	Distribution	Transport	Finance & Insurance	Services	Rent of Dwellings	Savings & Investment	Households	Profit Appropriation	Government	Rest of the World	Total Gross Output
Banana Industry Industry	D		13.0				37.5						75.0			4317.5	4443.0
	C																
Other Export Agriculture	D					585.5	286.5					26.3	22.6			898.2	1819.1
	C		203.5				47.6										
Domestic Agriculture	D					61.0	937.2						2975.8			-	3974.0
	C																
Construction & Engineering	D	15.4	5.4	9.5		83.4	34.5	198.7	11.8	11.3	604.9	4756.8	144.3		42.0	-	5918.0
	C																
Manufacturing	D						1626.3					50.8	167.4		45.1	1701.6	3591.2
	C						84.9						41.0				
Distribution	D	83.3	14.7	183.4	1535.6	204.9		525.6	8.0	32.8		241.8	11573.0		569.3	32.5	15004.9
	C						12.3										
Transport	D	681.0	105.1	113.9	51.4	37.3	192.0						244.0		41.5	114.5	1580.7
	C																
Finance & Insurance	D	121.0	28.2	7.1	24.9		132.2	74.2			80.0		266.9			-	734.6
	C																
Services	D	287.2	4.5		3.5	5.3	41.3	13.5			11.4		961.8		14.2	109.3	1452.0
	C																
Rent of Dwellings	D												3483.2			-	3483.2
	C																
Savings & Investment		85.3											836.6		1379.8	2873.5	5175.2
Households		989.5	367.1	2525.1	1487.3	1205.5	807.5	228.0	408.2	608.3				8420.7	3480.4	1515.9	22043.5
Profit Appropriation		1310.9	950.8	1125.0	431.5	610.4	147.8	334.1	142.4	584.1	2729.8					127.9	8494.7
Government		147.6	85.5	6.7	274.7	377.0	1792.4	220.1	5.1	8.5	57.1	99.5	938.6			2437.8	6450.6
Imports of Services		64.8	-	-	-	-	-	-	145.6	207.0	-	-	264.0	74.0	484.6		14128.7
Imports of Goods		656.9	41.3	3.3	2109.1	420.9	6824.9	-	-	-			49.3		393.7		
TOTAL GROSS OUTLAY		4443.0	1819.1	3974.0	5918.0	3591.2	15004.9	1580.7	734.6	1452.0	3483.2	5175.2	22043.5	8494.7	6460.6	14128.7	

THE INPUT-OUTPUT TABLE FOR DOMINICA, 1962 -

THE INPUT-OUTPUT TABLE FOR DOMINICA, 1962

TABLE 3.2?

SECTORS	A	B	C	D	E	F	G	H	I	J	B	F
Banana Industry (A)		.00826				.00597						
Other Export Agriculture (B)					.1850	.0455					.1291	.0079
Domestic Agriculture(C)					.01938	.1491						
Construction & Engineering(D)	.00414	.00344	.00240		.0262	.00549	.1257	.0210	.00907	.1738		
Manufacturing(E)						.2582						.0141
Distribution (F)	.0228	.00935	.0462	.4025	.0649		.332	.0136	.0264			.00204
Transport (G)	.1862	.0669	.0286	.01352	.0118	.0305						
Finance & Insurance (H)	.0332	.0179	.00179	.00652		.0210	.047			.0230		
Services (I)	.0784	.00286		.00919	.001673	.0066	.0085			.00328		
Rent of Dwellings(J)												
Non-Competing Imports(Goods)	.1810	.0262		*	.1330	1.464	-	-	-	-		

* An Import Coefficient was not derived.

INPUT-OUTPUT AND IMPORT COEFFICIENTS - 1962

TABLE 3.23

formation (part of final demand) separately from the recurrent expenditure of the construction sector.

Now the imports to any sector "i" can be calculated from the equations:

$$M_i = \sum m_{ij} \cdot X_j + Y(m)_i \quad \text{and} \quad F = \sum_i f_i \cdot X_i + Y(f)$$

where

$$X_i = \sum a_{ij} \cdot X_j + Y(h)_i + E_i = (I - A)^{-1} Y$$

Now Y can be divided into that part of final demand due to exports to the CARIFTA territories and the remainder. As the export income from CARIFTA forms a minor proportion of Dominica's total income, (Table 3.19) the interaction between the transport system and the economy of Dominica may be irrelevant to the forecasting of its imports. Where it is, import needs could presumably be forecasted using time series analysis supplemented by data on the changing needs of the economy concerned.

The inverse of the domestic production coefficient matrix is given in Table 3.24. Each element in this matrix represents the quantity of output of sector "i" required directly and indirectly to satisfy one unit of final demand for sector "j". Accordingly, each column of the matrix shows the total dollar production, directly and indirectly required from the industry in that column for each dollar of delivery to final demand by the industry at the left.

For example, the output of the transport sector (G) depends upon the demand for:

TABLE 3. 24

SECTORS		A	B	C	D	E	F	G	H	I	J
Banana Industry	(A)	1.0007	.0086	.0004	.0029	.0022	.0071	.0027	.0002	.0002	.0005
Other Export Agr.	(B)	.0097	1.004	.0057	.0400	.1937	.0980	.0377	.0022	.0030	.0070
Domestic Agriculture	(C)	.0161	.0061	1.009	.0661	.0337	.1620	.0623	.0036	.0049	.0116
Construction and Engineering	(D)	.0312	.0133	.0073	1.0102	.0320	.0203	.1348	.0215	.0097	.1761
Manufacturing	(E)	.0269	.0103	.0158	.1107	1.0240	.2713	.1044	.0060	.0082	.0194
Distribution	(F)	.1043	.0398	.0612	.4289	.0928	1.0509	.4042	.0233	.0316	.0752
Transport	(G)	.1914	.0704	.0315	.0331	.0297	.0480	1.0202	.0013	.0016	.0058
Finance and Insurance	(H)	.0448	.0225	.0047	.0181	.0072	.0267	.0582	1.0007	.0009	.0262
Services	(I)	.0811	.0046	.0008	.0129	.0036	.0088	.0131	.0004	1.0004	.0056
Rent of Dwellings	(J)	0	0	0	0	0	0	0	0	0	1

INVERSE COEFFICIENT MATRIX (DOMINICA, 1962).

- homes, banks, etc. (construction sector)
- cigarettes, rum and other local manufacturers
- processed foods, textiles, etc. (distribution sector)

Thus, X_i, and hence imports, can be determined if:

- the value of Y can be determined by the island economic planners
- the import coefficients can be predicted with sufficient accuracy
- the value of E_i can be predicted with sufficient accuracy

3.2.6.3.3 The Derivation of Final Demand Estimates

The planning of each island's economy over a 5 year period is currently undertaken by projecting the G.D.P at factor cost by kind of economic activity. Data on changing technical coefficients, sectoral market prospects, past trends and other information is brought together to determine the growth rate of each sector.[62] Difference equations, which link an aggregate in one time period with an aggregate in another, are then used to determine the G.D.P of each sector to the end of the given time period. The total G.D.P will result from the sum of the sectoral projections. This total is almost equal to total household consumption expenditure, the remaining household income being derived from the government and the rest of the world accounts. As exports, government expenditure, and levels of investment and saving must also be estimated during the planning phase, then final consumption expenditure Y could be derived from:

- total G.D.P at factor cost
- government expenditure on each sector
- the investment expenditure in each sector

62. See O'Loughlin, National Economic Accounting, Pergamon Press, 1971, page 166

The estimated household consumption is then allocated among the sectors on the basis of previous patterns of household expenditure. The proportions of adjusted gross output of this sector for the years 1961-63 are given in Table 3.25. An estimate for total household consumption can be obtained by adding total G. D. P at factor cost to the estimated expenditure of the government sector on households (equal to 3480. 4 in Table 3.22). This figure must then be multiplied by 1. 09 because the remaining 8% of total household income (equal to 1515. 9 in Table 3.22) is derived from the rest of the world. Thus, it should be possible for the island's governments to derive estimates for Y_i from estimates of G. D. P, government and investment expenditure. The relationship between an input-output table and the estimates of sector G. D. P can be identified from Table 3. 26.

SECTOR \ YEAR	1961	1962	1963
BANANA INDUSTRY	.0048	.0035	.0034
OTHER EXPORT AGRICULTURE	.0012	.0011	.0011
DOMESTIC AGRICULTURE	.1412	.1402	.1342
CONSTRUCTION & ENGINEERING	.0062	.0068	.0066
MANUFACTURING	.0078	.0079	.0080
DISTRIBUTION	.5676	.5452	.5590
TRANSPORT	.0105	.0115	.0113
FINANCE & INSURANCE	.0102	.0126	.0121
SERVICES	.0457	.0454	.0442
RENT OF DWELLINGS	.1420	.1642	.1665
ADJUSTED GROSS OUTPUT *	20, 524	21,207	22,275

* TOTAL GROSS OUTPUT LESS SAVINGS

HOUSEHOLD EXPENDITURE COEFFICIENTS

TABLE 3. 25

Sector	1962	1963	1964	1965	1966	1967	1968
	ESTIMATES					PROJECTIONS	
Export Agriculture*	3618	4691	4770	4648	4312	4508	4703
Other Agriculture*	2918	2999	3089	3181	3277	3375	3475
Fishing & Livestock*	733	792	808	840	873	908	944
	1919	1912	2530	2190	2240	2580	2780
	1816	1287	1564	1589	1710	2075	2470
	955	1264	1618	1810	1780	1915	2080
	562	653	846	905	968	1036	1117
	551	542	574	604	634	665	699
	1192	1210	1236*	1329*	1438*	1542*	1672*
	2730	2911	2924	3070	3223	3384	3553

Current Prices in $000 W.I. to 1966. *Includes Hotels.

Sector Gross Domestic Product (Factor Cost)

Source : Dominica, Economic Survey & Projections, British Division, 1967.

Estimates of GDP per Sector (Dominica, 1962)

EXPENDITURE IN 1962 / 1962 RECEIPTS	Banana Industry*	Other Export* Agriculture	Domestic* Agriculture	Construction & Engineering	Manufacturing	Distribution	Transport		Services	Rent of Dwellings	
Depreciation											PRIMARY INPUTS TO FINAL DEMAND
Households	989.5	367.1	2525	1487	1206	808	228	408	608	-	
Gross Value Added	1311	951	1125	432	610	148	334	142	584	2730	
G.D.P. (Factor Cost)	2300	1318	3650	1919	1816	956	562	550	1192	2730	
Government											
Imports											
Total Gross Outlay											

PORTION OF AN INPUT-OUTPUT TABLE (DOMINICA - 1962)

SOURCE: National Income Statistics, Dominica, 1961-64, I.S.E.R., July 1965.

*The different sources use different sector definitions for Agriculture.

THE RELATIONSHIP BETWEEN AN INPUT-OUTPUT TABLE AND ESTIMATES OF G.D.P.

TABLE 3·26

3.2.6.3.4 The Derivation of the Import Coefficients

The main imports to Dominica are given in Table K9 of Appendix K. The input and import coefficients for the banana industry and other export agriculture were calculated from the sector accounts and are given in Table 3.23. The discrepancies suggested by the 1962 and 1963 import coefficients were investigated by comparing the non-competing imports to these sectors in 1962 and 1963. Table 3.27 indicates the results and suggests that an allocation error exists in the sector accounts, where the Banana Industry is importing some of the imports destined for other Export Agriculture. When the sectors were combined the resulting import coefficient appeared more reasonable.

YEAR	IMPORT CATEGORY	BANANA INDUSTRY	OTHER EXPORT AGRICULTURE	THE SECTORS COMBINED
1961	Competing	-	N.A.	N.A.
1962	Imports	-	0.129	0.0390
1963		-	0.112	0.0357
1961	Non-Competing	0.1538	0.1412	N.A.
1962	Imports	0.1810	0.0262	0.1351
1963		0.2462	-	0.1650

IMPORT COEFFICIENTS FOR AGRICULTURE

TABLE 3.27

The volume of imports to the combined sector in terms of the main imports to it is given in Table 3.28.

CATEGORY	COMMODITY	VALUE	VOLUME*
Competing Imports	Animal Oils	203, 507	196, 200 cu. ft
Non-Competing Imports	Animal Oils	16, 191	
Non-Competing Imports	Fertilizers	431, 174	136, 200 cu. ft

*Appendix (A) was used to derive these figures

IMPORTS TO AGRICULTURE

TABLE 3. 28

The main imports to the combined sector is given in Table 3.29.

Commodity	S.I.T.C	1962		1963	
		Value	Weight (lb)	Value	Weight (lb)
Animal Oils and Fats	41 less 412-07	16191*	25092	9015*	19,801
Fertilizers	56	431174	7211700	684565	12,036,500
Insecticides, Fungicides, etc	599-02	189894	N.A.	180672	N.A.
Lime	661-01.01	1878	140900	1732	147,900
Implements & Tools for Agriculture	699-12.01 699-12.09	65475	N.A.	49635	N.A.
TOTAL		704612	7377692	925619	12,204,201

*Non-competing imports

MAIN IMPORTS TO AGRICULTURE (COMBINED SECTORS)

TABLE 3.29

Clearly, the demand for transport is largely influenced by the demand for both fertilizers and animal oils, because the weight/volume ratios are approximately the same. (Appendix A).

When banana production was compared to fertilizer usage (Table 3.30) became clear that

- nearly a third of fertilizer imports were for use by sectors other than the banana industry
- banana output is related to the previous years imports of fertilizer (weather permitting!)

Year	Fertilizer Imports		Fertilizer Usage by Banana Producers[3]	Banana Exports (Production)[3] Tons
	Value[1]	Tons[2]		
1961	364	2869	1, 814 tons	28759
1962	431	3220	2, 351	28240
1963	684	5372	4, 337	30739
1964	N.A.	7540	6, 080	42232
1965	↑	4962	3, 862	49755
1966		4441	3, 832	43448
1967		6637	5, 322	46796
1968	↓	5825	4, 845	54911
1969	N.A.	7718	5, 832	57677

Sources:
1. Annual Trade Report for Dominica 1968, page 22
2. Table IV of a paper written by M. D. Kingston of the British Development Division in the Caribbean, entitled "Current Economic Situation & Prospects, 1971".
3. Table VII, taken from Source (2)

BANANA PRODUCTION & FERTILIZER USAGE

TABLE 3.30

Columns 3 and 4 of Table 3.30 should, however, be read in the light of the following comments: First, a bad hurricane in 1963 led to grants being made available. Imports of fertilizer more than doubled (7, 540 tons in 1964) and by 1965 banana output had increased enormously. The ending of the scheme saw a fall in imports of fertilizer in 1965 and lower output in the following year. A fertilizer credit scheme was then introduced by the Banana Growers' Association which increased fertilizer usage sharply in 1967 and output to 55, 000 tons in 1968.[63]

For the reasons given above, new import coefficients were calculated for fertilizer imports and for all imports to the combined agriculture sectors, where fertilizer imports are lagged by one year. The results of this exercise are illustrated in Table 3. 31.

Year	$'000 W.I. Adjusted Output	NON-COMPETING IMPORTS			
		$'000 W.I Fertilizer[1]	$'000 W.I. Other[2]	Import Coefficients	
				Fertilizer	All Commodities
1961	5536	320 (1960)	N.A.	0.0579	Data Unobtainable
1962	5210	364 (1961)	273	0.0698	0.1222
1963	5690	431 (1962)	241	0.0759	0.1182

*Output Less Imports   Sources: 1. Animal Trade Report for Dominica, 1968, page 22

2. Table 47

REVISED IMPORT COEFFICIENTS TO AGRICULTURE

TABLE 3. 31

63. This description is drawn from that given by M. D. Kingston in "Current Economic Situation and Prospects, 1971", British Development Division, Barbados, page 4.

It can be seen that import coefficients are somewhat more predictable than Table 3.27 suggested.

Thus, the demand for transport generated by fertilizer imports in year (n - 1) 1961 could have been determined from the general equation:

$$\text{Imports (weight)} = B_c \cdot D_{ic}\left[f_i X_i + Y(f)_c \right] \text{ if } X_i \text{ and } Y(f)_c \text{ are in constant prices}$$

where: $B_c = \frac{2869}{364}$ the weight/value ratio in 1961 (year $\left[n-1\right]$)

$D_{ic} = \frac{364}{364+273} = \frac{\text{The imported value of fertilizers in year(n-1)}}{\text{Fertilizer imports in year (n-1) + other imports in year "n" to sector one (in value terms)}}$

$f_i = \frac{364+273}{5210} = \frac{\text{Fertilizer imports in year (n-1) + Other sector imports in year "n" in value terms}}{X_i}$

X_i = 5210 = adjusted gross output of combined agriculture -

$Y(f)_c$ = final demand for commodity (c) (non-competing) (equal to zero in this case)

Thus, fertilizer imports = 7. 89(0. 571) 0. 1222 (X_i)

If the quantity and value of commodities imported to each sector remain in constant proportion to total imports and to sector output the calculation of the volume of imports to each sector (f_iX_i) should be possible. The calculation of B and D for fertilizer imports for the years 1959-1961 is given in Table 3. 32

YEARS	1959	1960	1961	1962	1963
B - Volume/Value Ratio[1]	0.335	0.363	0.371	0.352	0.370
(fi.Xi) - Sector Imports \$000[2]				637	672
Fertilizer Imports S'000	407	320	364	431	684
D - Proportion of Total Imports[3] (Lagged)				0.572	0.672

Sources:

1. Derived from Appendix A and Table K8 of Appendix K
2. Excluding competing imports, and based on sector accounts
3. Proportion of Fertilizer in the Total Imports of the Combined Sector

FERTILIZER COEFFICIENTS

TABLE 3.32

This analysis was repeated for each sector for the main imports (in volume terms) as identified from Table K8 of Appendix K. The construction and engineering sector was excluded from this analysis for the reasons previously stated. The results are given in Table K10 of Appendix K and are summarised here in Table 3.33.

It can be seen that the weight/volume (and hence the volume/value) ratio can change significantly, even over a 5 year period to allow accurate forecasts to be made. In such a case, the weight of imports forecast by the model can be corrected to account for such changes by using a transport elasticity for each group of commodities. A transport elasticity of this kind (e), states how the volume of commodities by weight (W) changes when the underlying quantity, the flow of commodities by value (V) undergoes a certain relative change.

Commodity Group	Weight/Value = Ratio (B_c)			Preparation of Sector Imports (D_c)		
	1961	1962	1963	1961	1962	1963
Animal Oils and Fats	2.99	3.49	4.56	N.A	2.54*	1.34*
Fertilizer	7.89	7.46	7.85	N.A	0.572	0.672
Unrefined Beet and Sugar Cane	9.6	9.4	8.2	N.A	0.848	0.861
Butter, Cheese and Milk	1.98	1.87	2.11	0.0388	0.0475	0.0481
Butter Substitutes	2.03	2.23	2.20	0.0133	0.0139	0.0182
Fish and Fish Preparations	2.72	2.70	2.68	0.0420	0.0398	0.0482
Flour	11.76	10.93	10.0	0.0675	0.0715	0.0805
Rice	8.38	8.16	7.72	0.0125	0.0157	0.0157
Meat & Meat Preparations	1.70	1.84	2.05	0.0565	0.0655	0.0625
Footwear	0.468	0.414	0.446	0.0172	0.0091	0.0123

* Non-Competing Imports

NON-COMPETING IMPORT RATIOS

TABLE 3.33

That is: $e = \frac{\frac{dW}{W_1}}{\frac{dV}{V_1}}$ for each year of $e_n = \frac{Wn/W_1}{Vn/V_1}$

The validity of this approach can be proved for $\left(\frac{W_1}{V_1}\right)V_n$ gives the weight W_n at "n" years assuming that $\frac{W_1}{V_1}$ does not change. It does, as illustrated by (e_n) so that (V_n) e_n should provide the correct tonnage flow after "n" years for each commodity.

Proof

$$\left(\frac{W_1}{V_1}\right) V_n \cdot \left[e_n\right] = \left(\frac{W_1}{V_1}\right) V_n \left[\frac{W_n}{W_1} \; \frac{V_1}{V_n}\right] = W_n$$

The same proof applies to a multi-commodity trade flow by value.

Finally, the values of the non-competing import coefficients (f_i) were calculated from the sector accounts and are given in Table 3.34.

Year \ Sector	Export Agriculture (the combined sectors)	Domestic Agriculture	Manu-facturing	Distribu-tion
1961	Statistics not available	0.0065	0.158	1.181*
1962	0.1222	0.0083	0.1330	1.410
1963	0.1182	0.0108	0.176	1.303

* Includes competing imports

NON-COMPETING IMPORT COEFFICIENTS

(MARKET PRICES)

TABLE 3.34

Again, these coefficients are based on market prices. Clearly, if the value of an imported commodity changes in relation to the value of its domestic counterpart, the coefficient will change.

Table 3.35 was used to revalue the non-competing import coefficients in terms of constant prices (1962)[64].

Year \ Sector	Export Agriculture	Domestic Agriculture	Manu-facturing	Distribution
1961	-		-	
1962	0.1222	0.0083	0.1330	1.410
1963	0.1242	N.A	0.1520	1.396*

*Due to the diversity of imported commodities to distribution, the value indices for 1962 and 1963 were used instead. Hence:

$$1.303 \left[\frac{\text{Value Index for 1962} = 164.2}{\text{Value Index for 1963} = 153.3} \right] = 1.396$$

These value indices were obtained from the Digest of trade statistics of the Leeward Islands, Windward Islands and Barbados. I.S.E.R., Dec. 1969, page 28.

NON-COMPETING IMPORT COEFFICIENTS

(CONSTANT PRICES)

TABLE 3.35

64. That is the 1963 import coefficient in 1962 prices is obtained by multiplying the 1963 coefficient by the ratio of the 1963 to 1962 weight/value ratios. For example, the 1963 input coefficient for manufacturing in constant prices = 0.152 from $0.176 \times \frac{8.64}{10.0}$

The foregoing discussion suggests that a model for forecasting the main imports to Dominica in constant prices may be formulated in the following terms.

$$X_i = \sum_j a_{ij} \cdot X_j + Y(h)_i + E_i \qquad \text{(Competing rows)}$$

where $Y(h)_i$ & E_i are exogenous inputs to the model, and can be obtained from the economic planners in the territory.

Competing imports $$M_i = \sum_j m_{ij} \cdot X_j + Y(m)_i \qquad \text{(Non-Competing Rows)}$$

while non-competing imports $$F = \sum_i f_i \cdot X_i + Y(f)$$

To forecast the volume of imports needed by Dominica in any year "n", the equations below are used.

$$\text{Imports (cu. ft)} = B_c \cdot \quad D_{ic} \cdot \left[(f_i \cdot X_i) + Y(f)_c \right]$$

where the coefficient f_i is assumed to remain constant.

3.2.6.3.5 The Forecasting of Exports

Data on the major exports, representing over 90% of total exports (in value terms), is given in Table 3.36 for the period 1959-1963. Commodities have been grouped in terms of the exporting sector.

SECTOR	COMMODITY	QUANTITY					
		UNIT	1959	1960	1961	1962	1963
Banana Industry	Bananas	'000 stems	2, 049	2, 407	2, 384	2, 374	2, 502
Other Export Agriculture	Citrus	'000 barrels	15	16	19	22	17
	Vanilla	'000 lb.	11	2	1	1	1
	Cocoa, Raw	'000 lb.	314	342	217	281	344
	Copra	'000 lb.	2, 192	2, 940	3, 244	2, 836	3, 336
Manufacture	Lime Juice	'000 gal.	402	335	365	246	131
	Bay Oil	'000 lb.	29	29	48	32	30
	Lime Oil	'000 lb.	20	27	33	32	35

Source: Abstract from the Annual Trade Report, 1968, for Dominica, page 23

MAIN EXPORTS, 1959-63

TABLE 3.36

An estimate of final demand (in value terms) for each sector cannot be derived without an estimate of the level of the sector's exports. Similarly, an estimate of the demand for transport (e.g. port handling capacity) cannot be made until an estimate of the volume of each commodity to be exported has been derived. Projections of the export agriculture sector have been published in terms of each commodity group.[65] These projections were compared with the actual exports of each sector over the period 1966-1970 in Table 3.37 This table shows that, in volume terms, bananas constitute the major proportion of Dominica's exports. Projections made by the island's planners are shown to be in error by up to 13% over the 3 year period from 1967-1969. The sensitivity of the solution of the transport model to such errors of data should clearly be tested.

3.2.6.4 The final model and its use

3.2.6.4.1 The Final Formulation of the Model

The general equation used to forecast non-competing imports of the c^{th} commodity in volume terms is given by:

$$B_c \cdot D_{ic} \cdot \left[f_i \cdot X_i + Y(f)_c \right]$$ where

B_c = the volume/value ratio in the base year for the c^{th} commodity

D_{ic} = the proportion of the i^{th} sector's imports represented by the c^{th} commodity

f_i = the imported proportion of the i^{th} sector's output

X_i = the adjusted gross output of the i^{th} sector

$Y(f)_c$ = the final demand for the c^{th} commodity (non-competing imports)

65. See Dominica, Economic Survey & Projections, British Development Division, 1967, page 4.

Sector and Commodity	Year	Weight		Volume('000 cu. ft)*	
		Projected	Actual	Projected	Actual
		'000 lbs.			
Banana Industry	1967	108, 400	111, 300	3975	4075
Banana	1968	113, 300	97, 100	4140	3560
	1969	118, 900	104, 900	4320	3840
	1970	125, 000	123, 000	4580	4510
Other Export Agriculture		Tons			
Copra	1967	600	491	45	36. 8
	1968	600	N. A	45	N. A
	1969	655	N. A	49. 1	N. A
	1970	789	N. A	59. 1	N. A
		'000 lbs.			
Cocoa Beans	1967	205	158	68. 6	52. 9
	1968	207	248	69. 4	83. 0
	1969	210	329	70. 3	110. 1
	1970	212	-	70. 5	N. A
		'000 lbs.			
Grapefruit	1967	3240	5569	118. 5	204. 0
	1968	3180	4697	116. 4	171. 5
	1969	3180	4391	116. 4	160. 5
	1970	3180	-	116. 4	-
		'000 lbs.			
Fresh Oranges	1967	489	775	17. 9	28. 4
	1968	594	762	21. 8	27. 9
	1969	742	696	27. 2	25. 5
	1970	814	N. A	29. 8	N. A
		'000 lbs.			
Mangoes	1967	343	262	12. 6	9. 6
	1968	356	309	13. 0	11. 3
	1969	367	361	13. 4	13. 2
	1970	380	-	13. 9	-
Total Exports	Year	Projected Volume		Actual Volume	%Error
	1967	4, 238, 000		4407, 000 cu. ft	3. 84%
	1968*	4, 350, 000		3, 850,000	13. 0%
	1969	4, 546, 000		4, 160,000	9. 3%

*Volume figures were derived from Appendix F

ACTUAL & ESTIMATED EXPORTS COMPARED

TABLE 3. 37

The corresponding equation for competing imports to the j^{th} sector is given by:

$$B_c \cdot Djc \left[m_{ij} \cdot X_j + Y(m)_c \right] \text{ where}$$

m_{ij} = the value of commodities of the i^{th} type imported to the j^{th} sector per unit output of that sector.

$Y(m)_c$ = the final demand for the c^{th} commodity

Hence, the model for Dominica may be derived from Table 3.38. because X_i can be calculated from the equation:-
$X_i = (I - A)^{-1} \left[Y(h)_i + E_i \right]$ as described previously under method 4.

Commodity	SITC	Category	B_c [66]	D_c	m_{ij}/f_i
Copra Oil (Gallons)	412-07	Competing	3.49	1.0	0.0390
Fertilizer (Tons)	56	↑	7.89	0.571	0.1222
Unrefined Beet and Sugar Cane	061-01		9.45	0.848	0.1330*
Butter, Cheese and Milk	02		1.872	0.0475	↑
Butter Substitutes			2.23	0.0139	
Fish and Fish Preps.	03	Non-Competing	2.70	0.0398	1.410
Flour			10.92	0.0715	
Rice			8.16	0.0157	
Meat & Meat Preps.	01		1.84	0.0655	
Footwear	85	↓	0.41	0.0091	↓
$Y(m)_i$ and $Y(f)_c$ equalled zero for the above					
*The stability of the coefficient is in doubt					

IMPORT COEFFICIENTS OF MAJOR IMPORTS (1961)

TABLE 3.38

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66. As the statistics available to the author were given in weight/value terms, B_c was assumed to be a weight/value ratio. Weight/volume relationships are constant. See Appendix A.

In May 1971 a letter was posted to the British Development Division in the Caribbean requesting data of $Y(h)_i + E_i$ so that the model could be tested for the period 1963-67.

A reply was received in mid-July, and confirmed that such data is available. In fact the letter stated that a sector by sector analysis of commodity imports by S. I. T. C sections should be possible because such data is now collected by computer. Unfortunately, the data required was not forthcoming but was offered, subject to a fee being paid for the time required to produce such data.

Because of the time required to produce this report, further work ceased, the testing of the model being left to some future date.

3. 2. 6. 4. 2 The Use of the Model

Section 3. 2. 6. 3 suggested that

- the export income of Dominica can be forecasted with a reasonable degree of accuracy in the short to medium term
- these estimates, when combined with the total forecast of G. D. P for these island can be used to derive total household consumption expenditure
- the above estimates, when combined with estimates of savings and investment, and government expenditure, can be used in conjunction with an input-output model to calculate the import needs of each island in terms of each commodity group in volume terms. This information, when input to modal choice, routing and distribution models will result in estimates of the volume of traffic

over the specified transport network, and the industrial revenue of intra-regional sales. Thus, economic planning could be integrated with transport planning with the data which is currently available within CARIFTA. It is assumed that the import row of the input-output table would be divided into imports of services, imports of goods from within CARIFTA, and imports of goods from the rest of the world. Imports from within CARIFTA comprise those imports from the rest of the world which are transhipped at a CARIFTA port for they determine the demand for intra-regional transport.

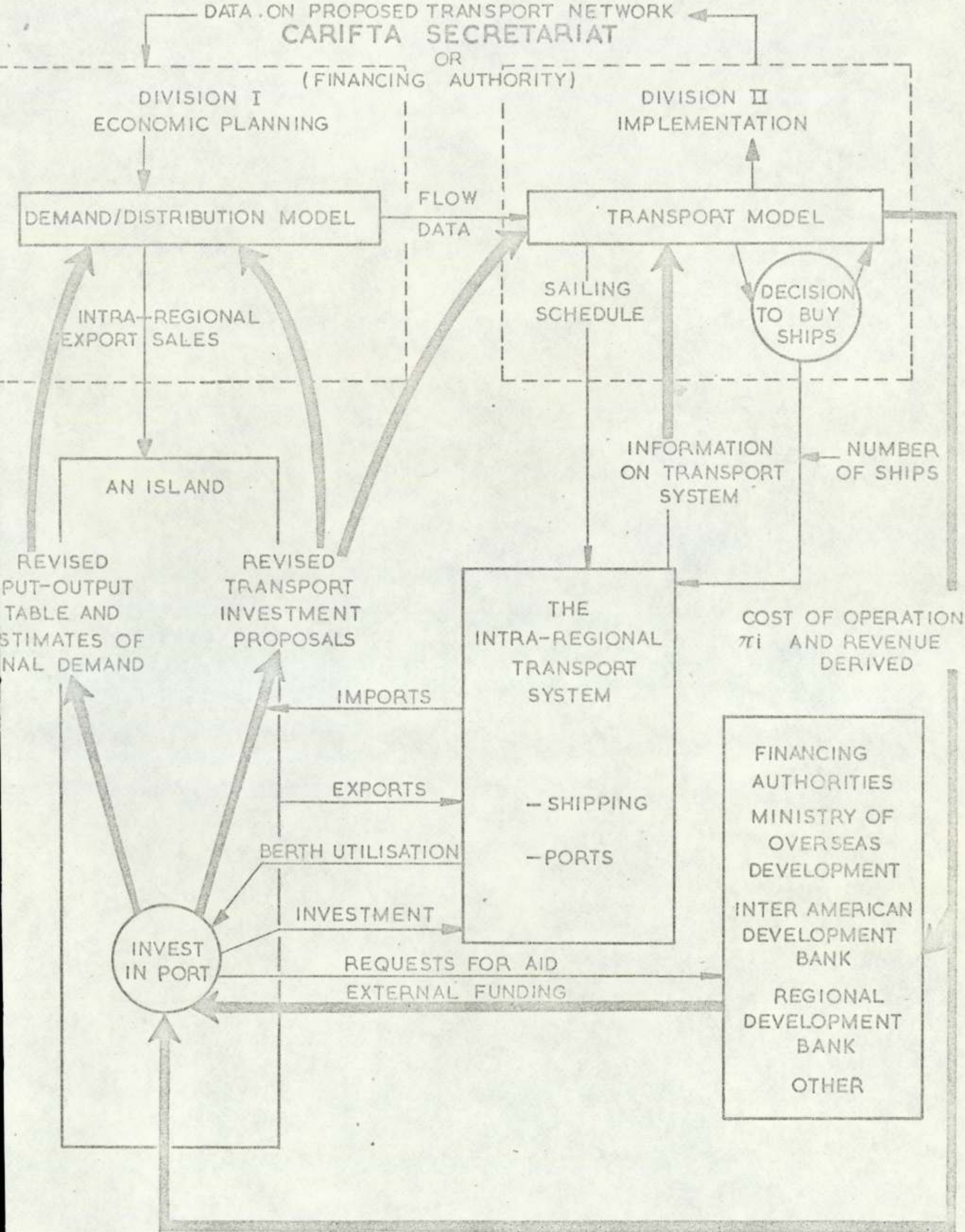
3.3 Optimisation

3.3.1 Introduction

At this stage, the objective of the systems engineer is to optimise the system. Armed with a model (or models), it should be possible "to compute the value of the economic criterion corresponding to different modes of operating the system .... Choosing the system which results in the most favourable value of the economic criterion is what is meant by optimisation." Jenkins, (1969).

3.3.2 A Systems Approach to Caribbean Transport Planning

The functioning of the basic approach developed in this study, to the design of improvements to the CARIFTA transport system, is illustrated in Figure 3.35. Current data on the transport system is fed into the transport model which derives a solution network, the feasibility of which is ensured by one or more iterations with the forecasting model. The effect of the feasible network on the growth of traffic over each link is now determined and the transport model



THE DESIGN CYCLE.

Fig. 3·35

run to time θ. At this point either a route change occurs or the solution becomes infeasible (indicating that facility improvement must be made if the demand for transport is to be satisfied). The procedure is then repeated for subsequent time periods. Figures derived by the model are passed to the island/port and/or financing authorities who decide on the size and timing of specific transport facility improvements.

Two variants of this approach have been developed. The first assumes that the Carifta Secretariat can coordinate the development of the transport system. In so doing, a form of decentralised decision making is adopted to allow complete autonomy of operation to each island/port authority. The second assumes that a financing authority has to consider requests for competing port improvement schemes and is free to decide on the allocation and timing of transport system improvements. In the latter case, the output from the models are fed into an optimisation routine to solve the problem.

Subsequent sections of Chapter 3 demonstrate the application of this approach to the improvement of a regional transport system.

3.3.2.1 Data Collection

Information about the intra-regional transport network must be obtained as follows;

- Route schedules (all modes) including journey times, service frequency, travel time variability, probability of loss and freight rates quoted
- The handling and docking capacities of each port

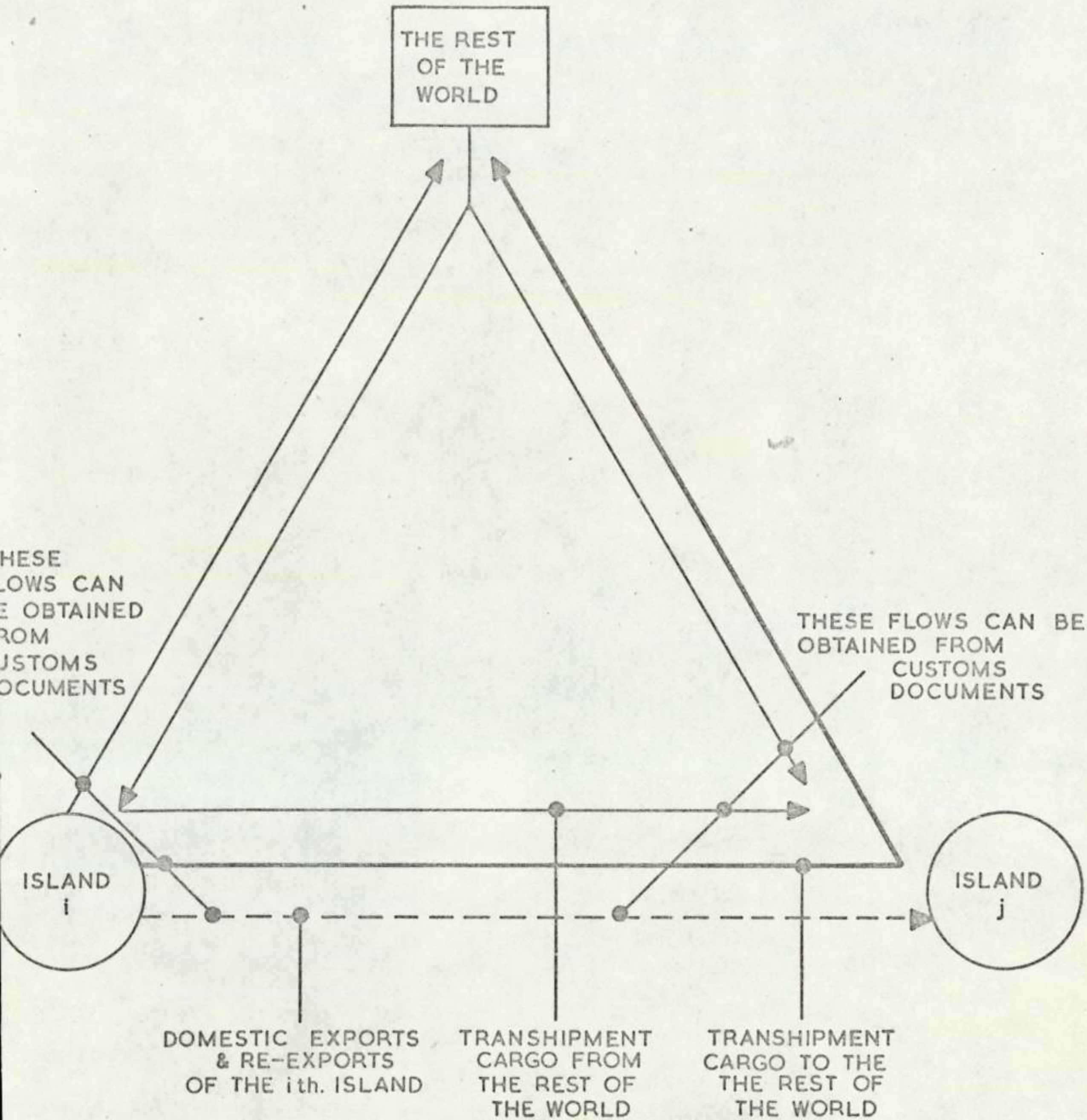
- The number of ships and their capacity in terms of refrigerated, general cargo space and passenger accommodation
- The origin and destination of commodity flows

In the last case, the yearly intra-regional flow of cargo (in commodity terms) can be obtained by sampling the ships manifests. The different categories of movement are illustrated in Figure 3.36. It is understood that inter-island Carifta cargoes are never transhipped. This particular flow category is therefore omitted.

Import and export transhipment movements could be identified by sampling the appropriate ships manifests. These movements are understood to be undertaken only by the Federal service.

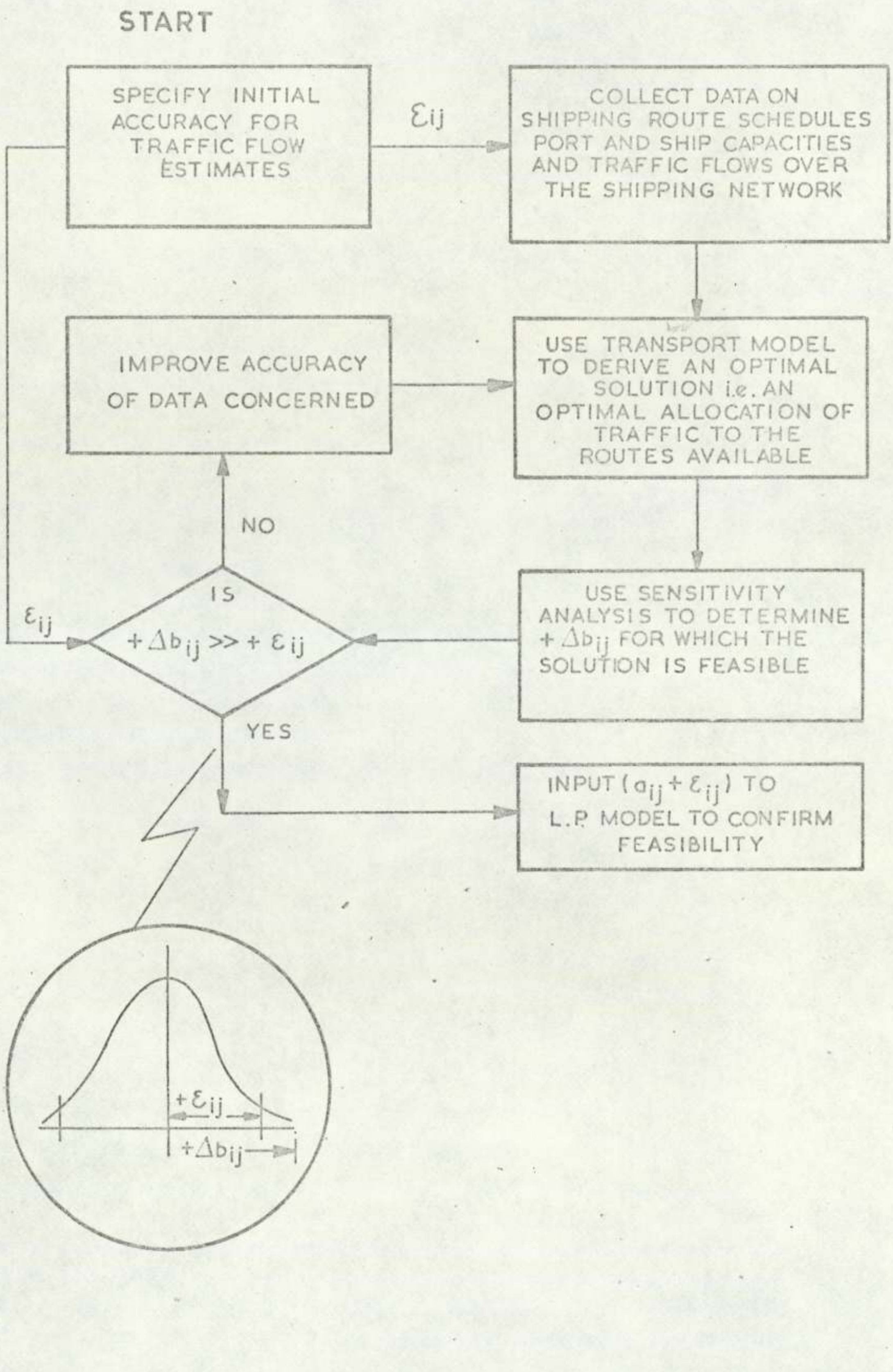
Domestic exports and re-export traffic is handled by air, schooners and the Federal service. The categories of cargo handled by the Federal service will be identifiable from the sample of the ships manifests. Sampling techniques such as the approach described in Appendix G may be used. A comparison of the customs documents (Annual Trade Report) will identify the cargoes carried by the air and schooner services (equal to the difference between the total recorded exports and the domestic and re-export cargo carried by the Federal service). The customs documents will also state the quantities of cargo exported (supply) and imported (demand) for each year.

Data on the existing shipping system is input to the transport model (Figure 3.37. The shipping routes, ship and port capacities are input to the model, the solution being constrained to the number of ship journeys per year which occur in practice. As the system is known to be feasible, then if a feasible solution results when estimates of traffic handled are input to the model, the estimates



CATEGORIES OF MOVEMENT

Fig. 3·36



DATA COLLECTION ACTIVITIES

Fig.3.37

must be reasonable approximations. These rough traffic flow estimates are input to the linear programming transport model. Only those flows to which the solution is sensitive need subsequently to be improved in terms of their statistical accuracy. Part of a typical result, taken from Appendix K, is given in Table 3.39.

TRADE FLOW	VALUE	ACCEPTABLE* LIMITS	ACCEPTABLE VARIATION
a_{12}	4008	0 to 5969	-100% to +48%
a_{13}	5200	0 to 13710	-100% to + 164%
a_{14}	3400	0 to 3642	-100% to +7%
a_{15}	865	0 to 10023	-100% to + 1058%
a_{21}	3200	2639 to 3570	-20% to + 11.6%
* Limits for optimal solution			

THE FORM OF THE OUTPUT FROM A SENSITIVITY ANALYSIS

TABLE 3.39

If the $\mathcal{E}_{ij}$ for each flow is equivalent to $\pm$ 10% then the accuracy of the asterisked flow must clearly be improved if $(a_{ij} \pm \mathcal{E}_{ij})$ is to be a realistic estimate for these flows (i.e. if a_{14} > 7% an infeasible solution would result).

3.3.2.2 The route selection procedure (Shipping)

The sequence of activities[67] is illustrated in Figure 3.38.

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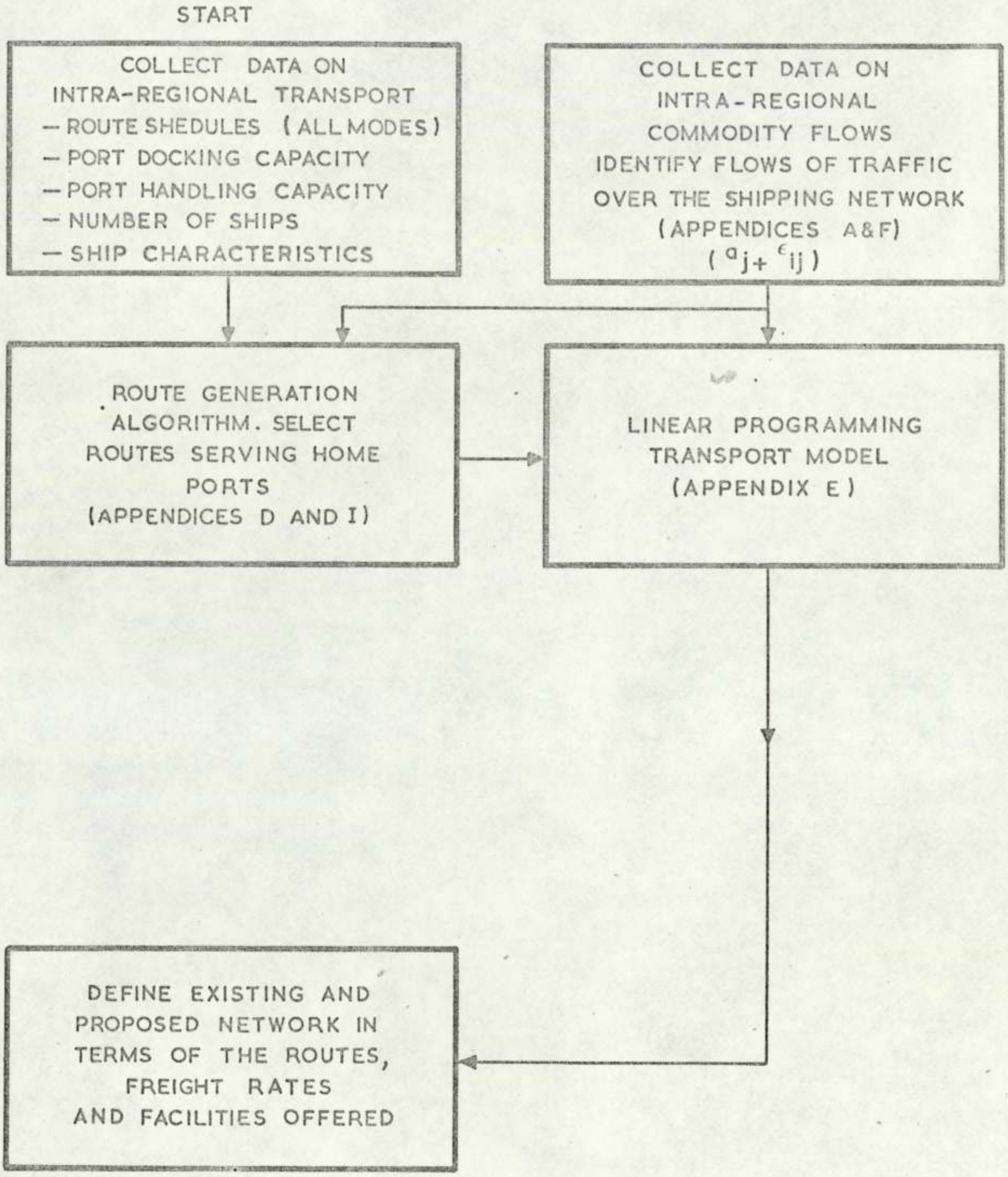
67. Details of each activity can be obtained by referring to the appropriate appendix.



THE ROUTE SELECTION PROCEDURE

Fig.3·38

The use of the route generation algorithms results in a subset of routes from which an optimal pattern of shipping routes must be chosen. The form of the output from the algorithm is as given in Table 3.40, taken from the results obtained for the 5 port problem described in Appendix H.

ROUTE NUMBER	NUMBER OF PORT	NUMBER OF PORT	NUMBER OF PORT	NUMBER OF PORT	MAXIMUM TONNAGE CARRIED OVER ANY ONE LINK	COST PER. JOURNEY (£)	JOURNEY TIME (DAYS)	MAXIMUM NUMBER OF JOURNEYS
	1	2	3	1	674·2	8916·8	7	46·9
	1	2	4	1	5713·0	10414·4	9	36·5
	1	2	5	1	559·3	8990·4	8	41·1

SOURCE : —— TABLE 5 OF APPENDIX I

FORM OF OUTPUT FROM ROUTE GENERATION ALGORITHM

TABLE 3.40

If it is assumed that each flow input to the linear programming model is equivalent to the actual flow plus the estimated error ($a_{ij} + \mathcal{E}_{ij}$) then the solution derived by the model will be feasible. If traffic is lower than estimated, the lower number of ship-journeys required will not significantly modify the total cost of transport provision[68].

Finally, the proposed network must be combined with the networks of the other forms of transport serving the region. This enables the total transport network to be defined in terms of the following:

- the routes served and their direction
- the cost or price of traversing a link
- the availability of particular facilities such as refrigeration, deck passenger facilities and cabin passenger facilities
- probability of loss
- waiting time
- travel time variability
- travel time

3.3.2.3 Network validation

The sequence of activities is illustrated in Figure 3.39. Import/export statistics (customs documents) will reveal the sources and destinations of cargo in any one base year.

The effect of the proposed shipping routes can then be estimated by determining:

- the cost to the shipper of exporting each commodity over the alternative routes provided by network

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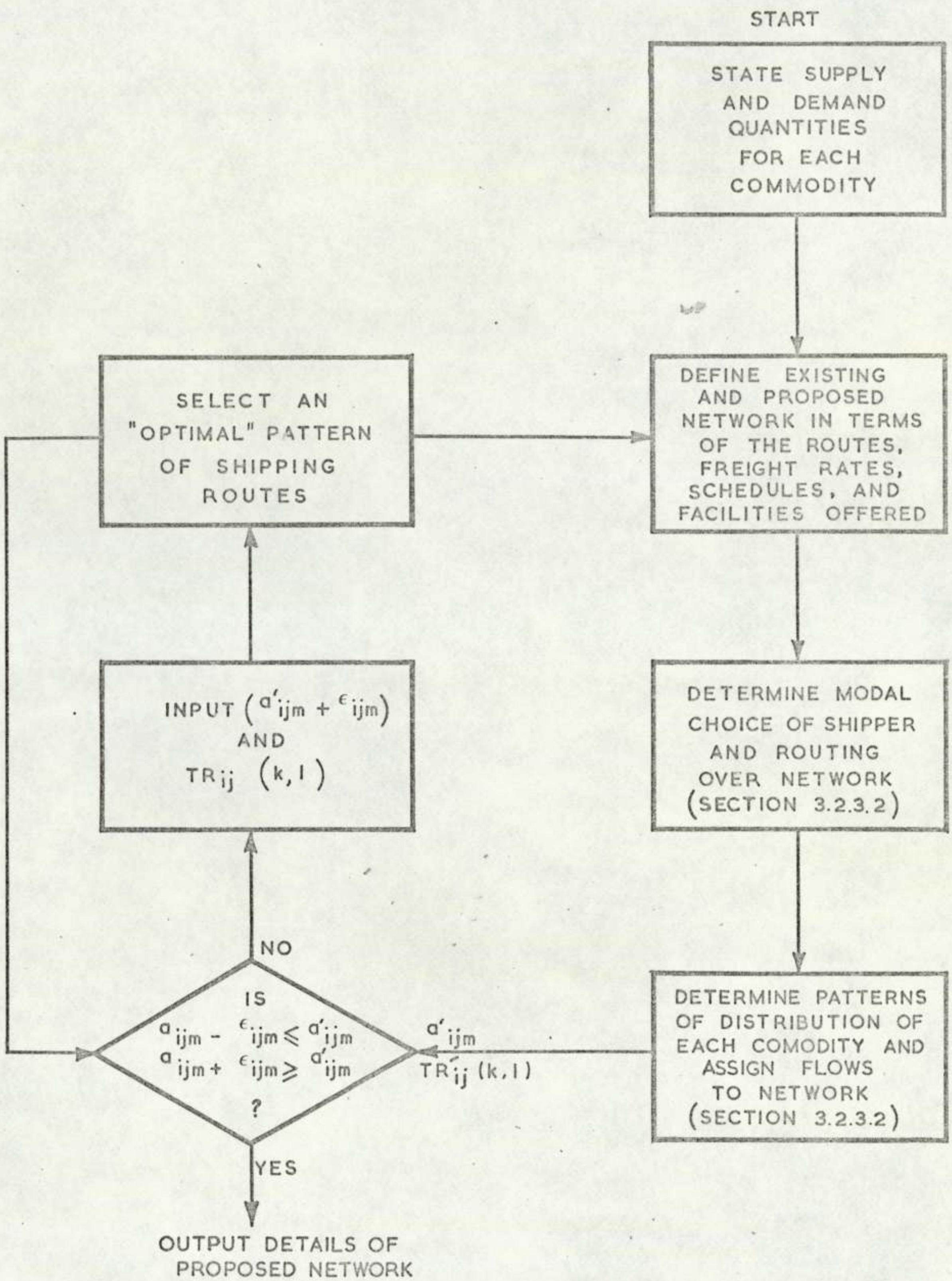
68. In experiments with the model described in Appendix J, it was found that route changes occur much less often than changes to the allocation of commodities to each route. This is because different routes have significantly different journey costs. Hence, changes in a_{ij} merely modified the number of journeys required between the ports concerned.



NETWORK VALIDATION

Fig.3.39

- the performance of the buyer at each node, in purchasing commodities from a number of sources of supply

The pattern of intra-regional sales can then be determined by minimising the cost of purchasing the required quantity of each commodity at each point of demand from the several sources available. As each flow is determined it is assigned to the routes available.

The sum of the flows over each route "k" of the "Federal" shipping service (mode m) is equal to a'_{ijm}. That is,

$$\sum_k a_{ijkm} = a'_{ijm}$$ for all "k" routes of mode "m" serving arc (i, j).

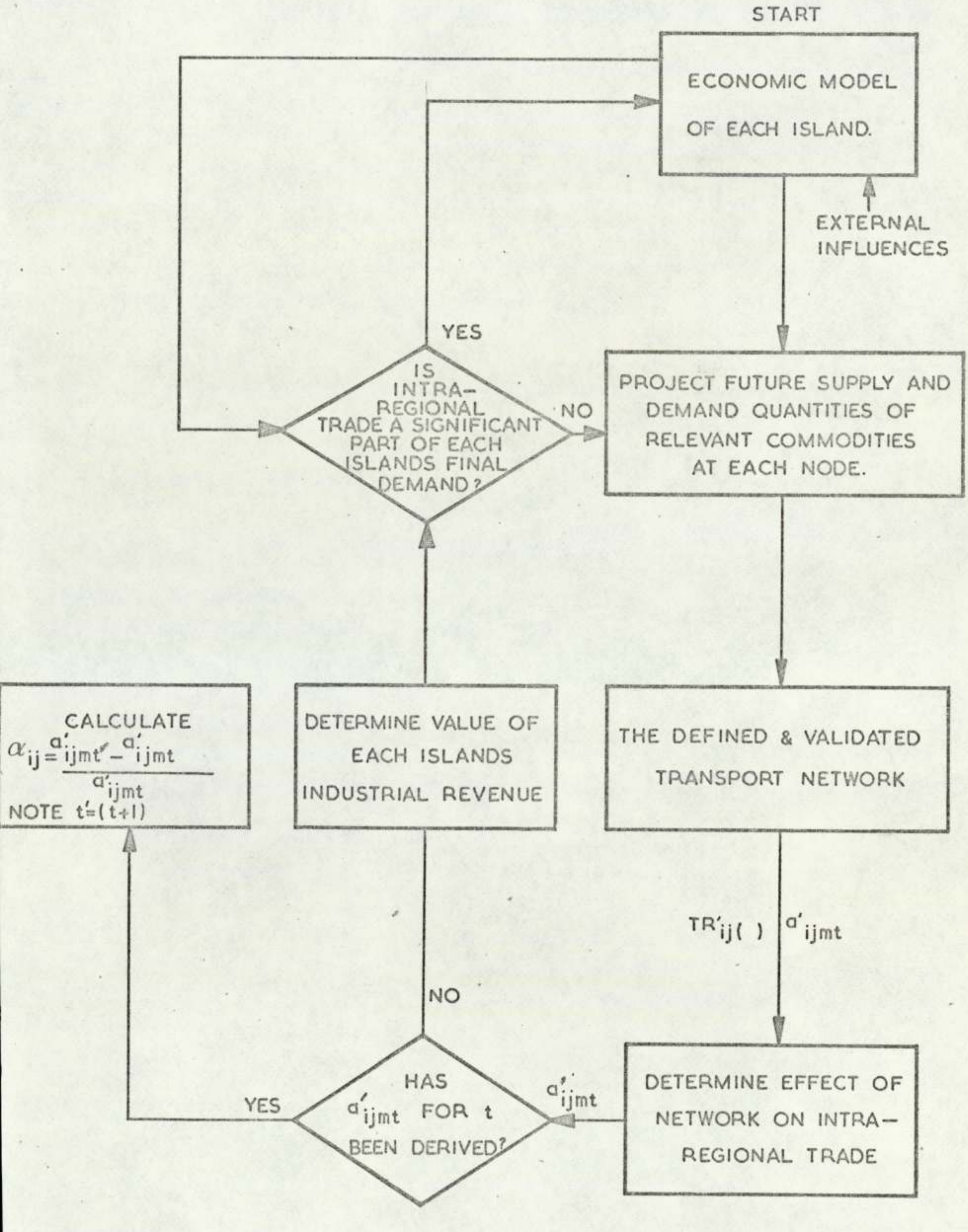
Where particular flows are transhipped between modes in completing the journey from port "i" to port "j", they are designated by $TR_{ij(\ )}$ where flow is defined by (i, j) and the arcs over which it is moved on another mode are designated in brackets after the (i, j) subscripts.

On completion of this activity, the validity of the network improvement generated by the L. P. model is checked. An analysis of the solution derived from the base year commodity data will show it to be 'optimal' and feasible for flow values equal to $(a_{ij} \pm \mathcal{E}_{ij})$. If this condition is not satisfied the flows of traffic over the improved network may be input to the route selection procedure to derive a feasible (and hence valid) network.

3. 3. 2. 4 The derivation of alpha

The sequence of activities is illustrated in Figure 3. 40

The volume of each flow over the shipping network obtained in the base year (equal to a'_{ijmt} as derived in Section 3. 3. 3. 3 for t = 0)



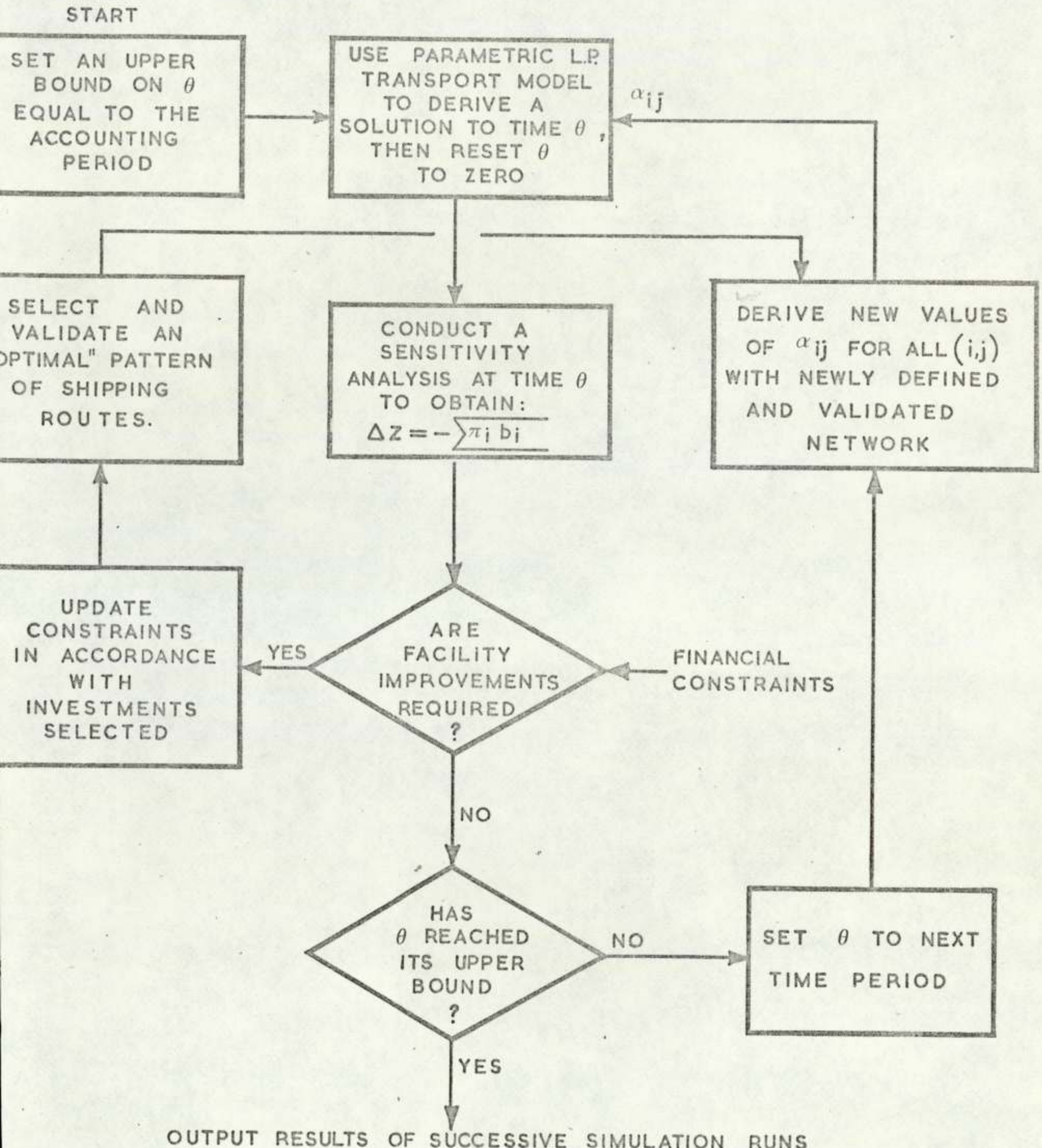
THE CALCULATION OF THE GROWTH RATE OF EACH FLOW

Fig. 3·40

is converted into value terms. The sales of each island can then be determined, commodity by commodity, until the total sales revenue of each sector of each island's economy has been derived.
Table 3.19 of Section 3.2.6.3 shows the exports of Dominica to both Carifta and the rest of the world. If the intra-regional sales of any island form a significant part of the final demand of that island, and if the major part of those sales have been carried by the shipping system, then changes in the characteristics of the shipping system may have a considerable effect on that island's subsequent demand for imports. In such a case, the island's economic planners would be asked to calculate the import needs of each sector in value terms, from which the future volume of those commodities forming part of intra-regional trade would be estimated. They would also be requested to estimate the availability of export commodities over the period required by the transport planner. These projections would account for expected changes in the economy of the country, such as new investment in industrial plant, estimated tourist expenditure, and export sales to the rest of the world. (When import needs are not significantly affected by the intra-regional shipping network, simple projections of each island's import needs might be made in conjunction with the island's economic planners). The effect of the defined network on intra-regional traffic can now be determined for year (t + 1). If there are no constraints on the (approximately) linear growth of trade between the N(N-1) nodes of the network, then alpha may be calculated.

3.3.2.5 Simulation of a network over multiple time periods

To determine the effect of the proposed network over multiple time periods two approaches may be adopted. The first assumes an approximately linear growth of traffic between nodes in a network over short periods of time, the second is a year by year simulation



THE P.L.P. APPROACH TO NETWORK SIMULATION

Fig. 3·41

of the network and so ignores the linearity assumption.

To initiate the first approach, an upper bound is placed on θ equal to the accounting period. The derived values of alpha (α_{ij}) are then input to the parametric linear programming transport model.

The output of a typical run, taken from Figure K . 1 of Appendix K is given in Figure 3.42 It can be seen that a route change occurs at $\theta = 1.45$. A sensitivity analysis of the solution at the value of θ will result in an equation of the form:

$$\Delta Z = - \left[\pi . S + \pi \ . \ P + \pi \ . \ SH + \text{Other Terms} \right]$$

where S = the vector of docking capacities

P = the vector of port handling capacities

SH = the number of ships available to the region

This information, together with that concerning the cost of shipping, revenue derived, the routing pattern and number of journeys scheduled can be considered by those authorities[69] concerned with transport facility improvement. If the simulation of one or more improvements is requested, a new optimal network is derived, together with new values of α_{ij}, and the process is repeated. If no improvements are postulated, new values of α_{ij} are derived for the new pattern of routes given by the PLP model, and the procedure is repeated.

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69. The ports, the Carifta Secretariat and/or external funding authorities.

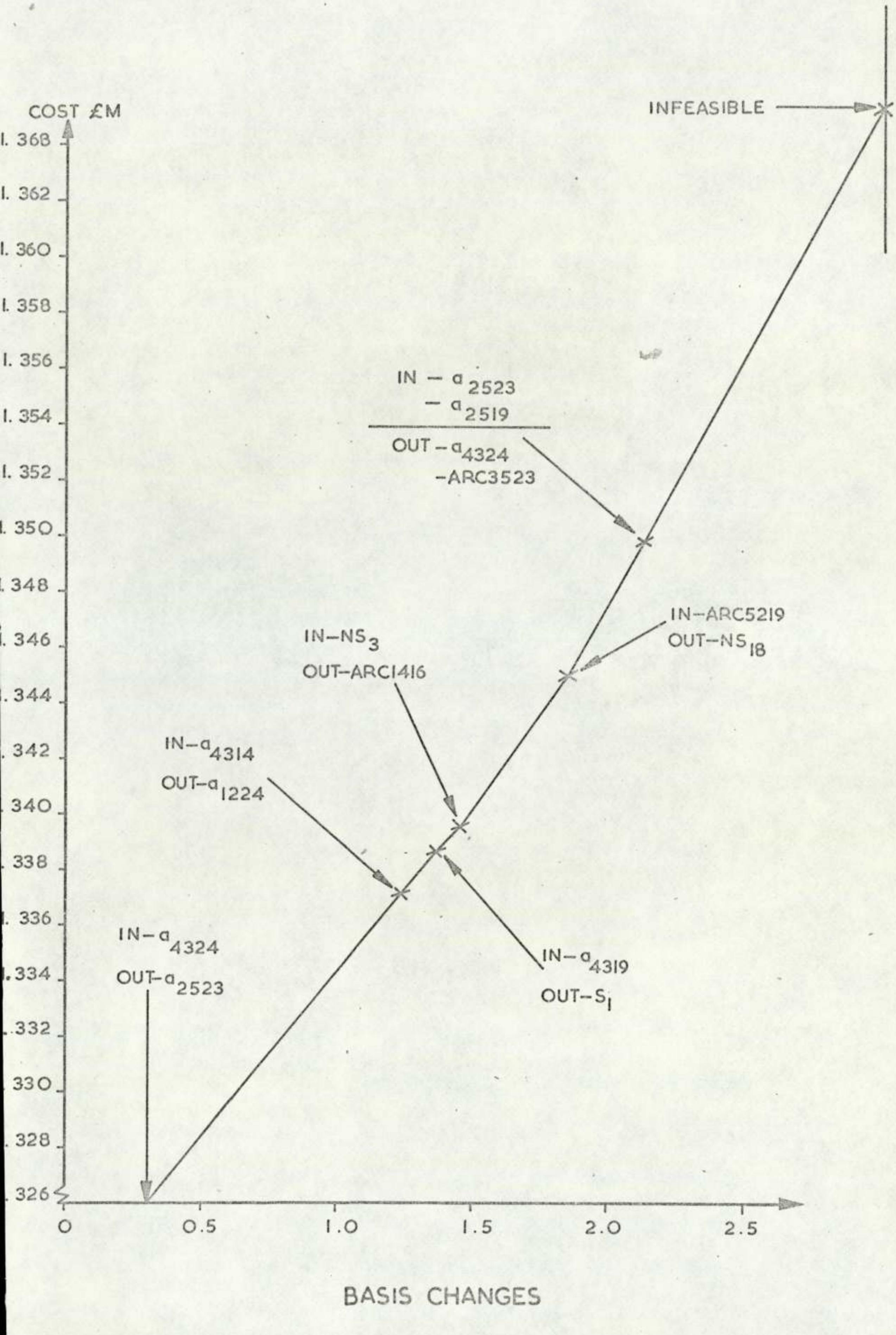
COST £M
INFEASIBLE
1.368
1.362
1.360
1.358
1.356
1.354
1.352
1.350
1.348
1.346
1.344
1.342
1.340
1.338
1.336
1.334
1.332
1.330
1.328
1.326
IN − a_{2523}
− a_{2519}
OUT − a_{4324}
−ARC3523
IN−ARC5219
OUT−NS_{18}
IN−NS_3
OUT−ARC1416
IN−a_{4314}
OUT−a_{1224}
IN−a_{4324}
OUT−a_{2523}
IN−a_{4319}
OUT−S_1
0
0.5
1.0
1.5
2.0
2.5
BASIS CHANGES

Fig. 3·42

Where the linearity assumption does not apply, the flow of traffic is estimated for each year of the planning period. The sequence of activities is illustrated in Figure 3.43 which shows that a new pattern of shipping routes is selected whenever the optimality conditions are violated or when the simulation of specified transport facility improvements is requested.

3.3.2.6 The timing of transport facility improvements

Two approaches have been developed. The first assumes that the Carifta Secretariat can co-ordinate the development of the transport system, while allowing complete autonomy of operation to each island/port authority. The second assumes that a financing authority has to consider requests for competing port improvement schemes and is free to decide on the size and timing of transport system improvements.

3.3.2.6.1 The First Method

On completion of the several simulation runs requested, each transport authority[70] will have decided on the size, type, and timing of those transport facility improvements under their control. Port authorities will have noted (from the information fed to them) how particular improvements in their facilities will modify port revenue.

The usual method of appraisal is to assess the total flow of costs and benefits from the proposed improvement and compare this with the flow of costs and benefits which would arise if no improvement

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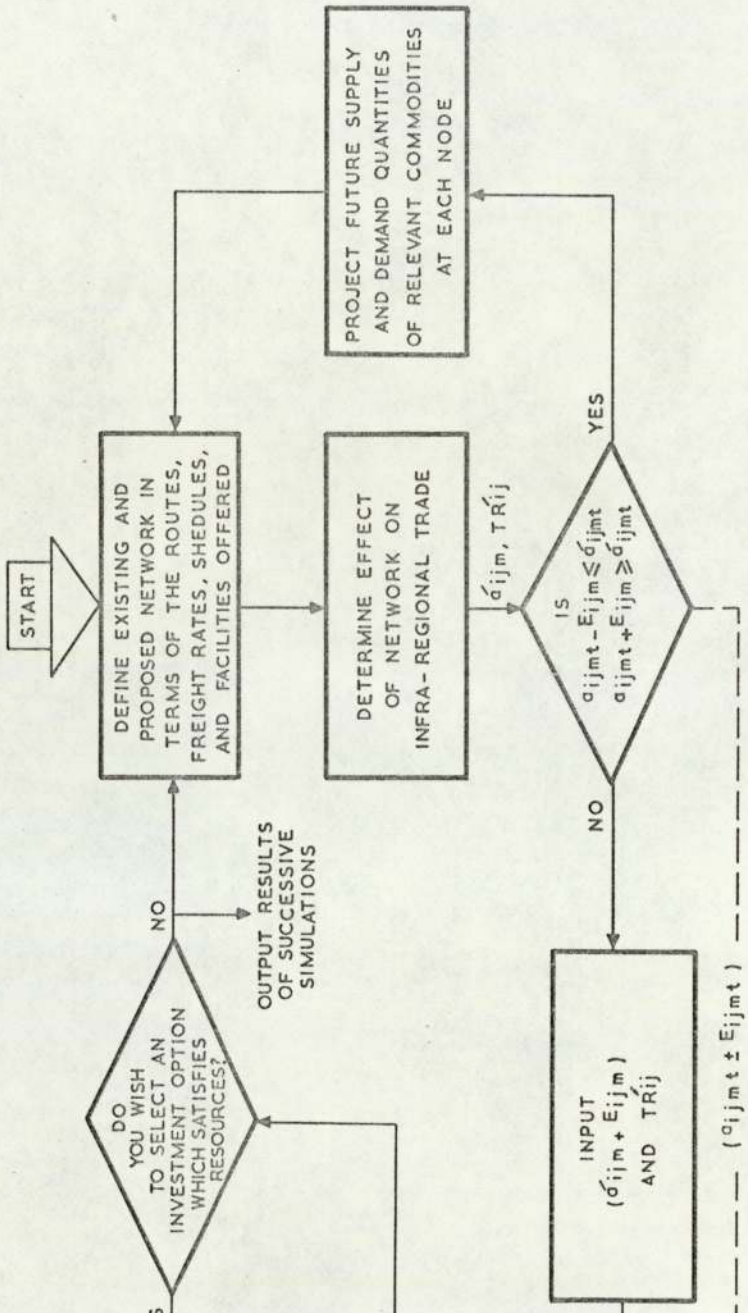
70. The island/port authorities and the Carifta Secretariat.



THE YEAR BY YEAR SIMULATION OF A TRANSPORT NETWORK.

Fig.3·43

was made. The difference between the costs and benefits, with and without the development, can then be compared using either a net present value (NPV) analysis, with a fixed discount rate, or by carrying out a discounted cash flow (DCF) analysis to determine the internal rate of return. In very simple cases it may be helpful to look at the ratio between the first year return (benefits less increases in operating cost) and capital cost.

If no improvement was made, traffic would eventually be diverted to other ports, and exports might be inhibited. The port authorities could assess the costs of diversion or inhibition and include these in their cost-benefit analyses. There seems little point in doing so if the purpose of the study is to avoid the likelihood of such a situation, where it is only necessary to determine the correct timing for the improvement and to show that it is justified.

The typical sequence of activities required in any N. P. V. calculation involving port improvement is illustrated in Figure 3.44

Thus, the choice of investment and its timing would be made by the relevant port authorities. The Carifta Secretariat will also have been able to assess the relative merits of providing additional shipping, within the constraints imposed by particular port facilities.

3.3.2.6.2 The Second Method

The output from the simulations of the network(s) over the planning period[71] will provide, to the financing authority, the information required to derive an optimal transport investment strategy.

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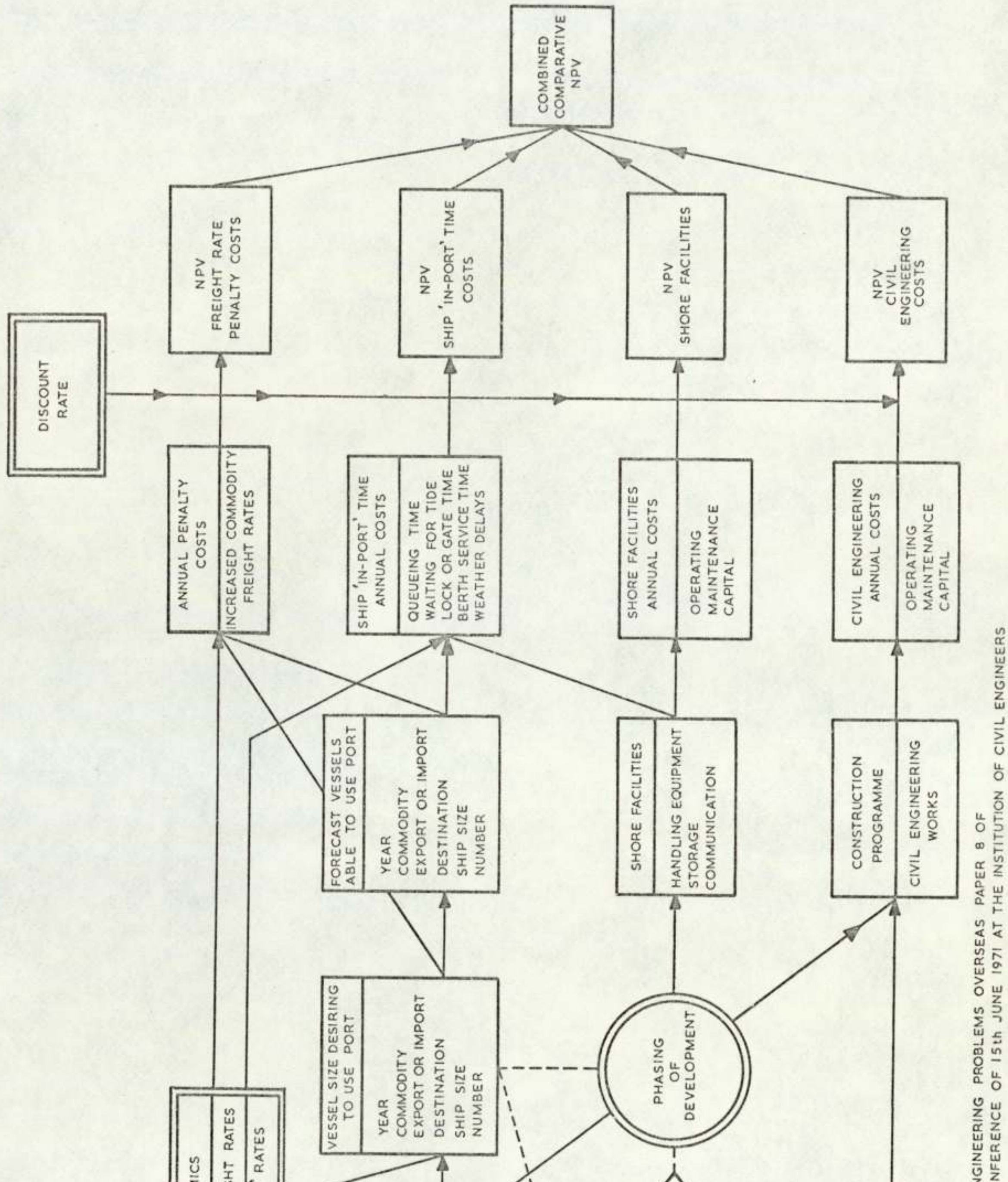
71. Described in Section 3. 3. 3. 5.



THE SEQUENCE OF ACTIVITIES IN PERFORMING AN NPV CALCULATION

Fig.3·44

Firstly, early sensitivity analyses of one or more solutions will generate results of the form given in Table 3.41.

Theta (θ)	Equation derived from sensitivity analysis
0 (Base Year)	$\Delta Z = -\ 2321^{*} \ .\ S_5$ + Other Terms
1.4 (Route Change)	
1.6 (Route Change)	
3.08 (Infeasible)	$\Delta Z = -\ 1805^{*} \ .\ S_1 + 3299^{*} \ .\ S_3 + 829^{*}.S_5$ + Other Terms

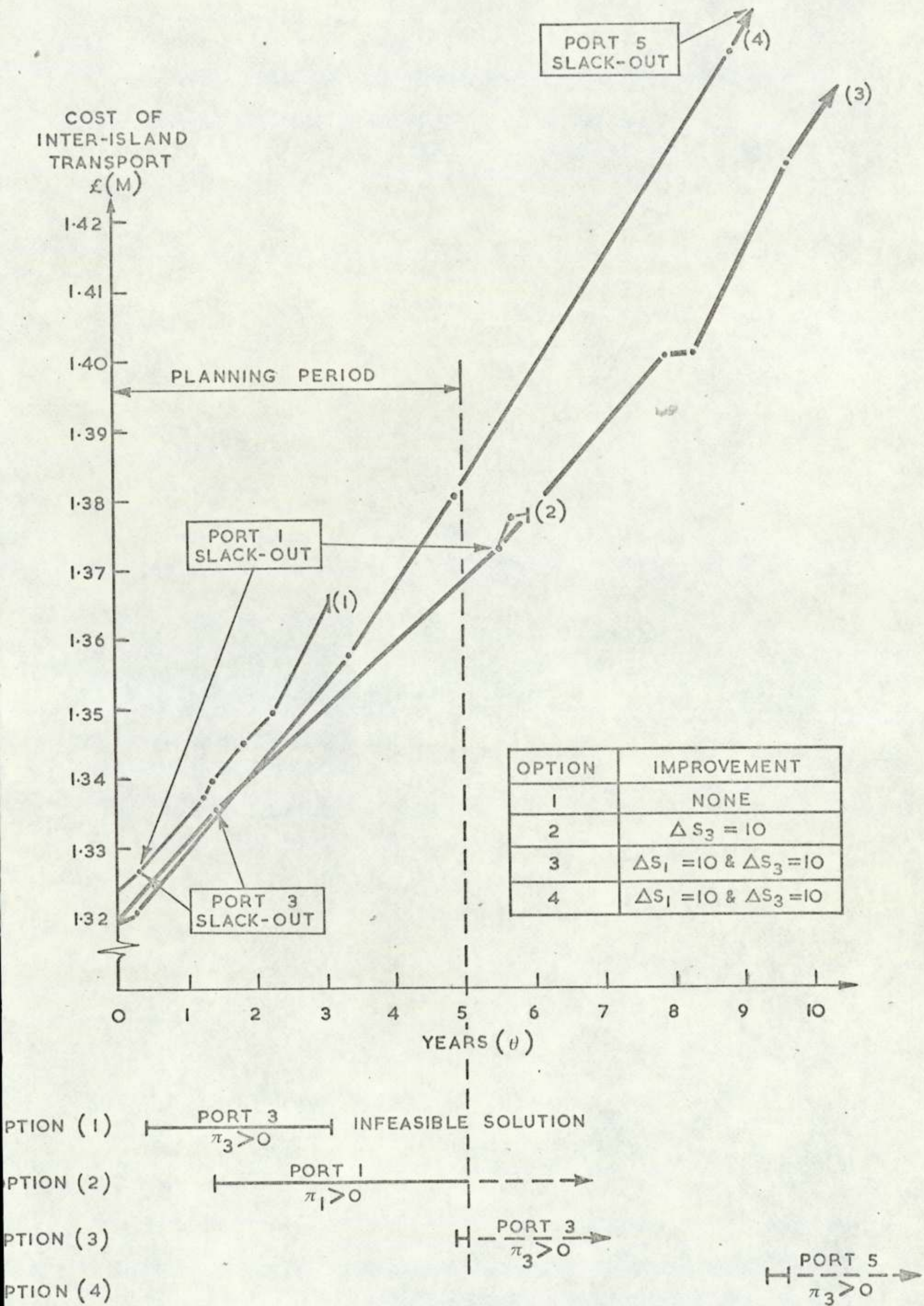
Source: Taken from results given in Section 3.2.2.2
* Simplex Multipliers

RESULTS OF SENSITIVITY ANALYSES

TABLE 3.41

The simplex multipliers identify those facilities which, if separately improved, would reduce the cost of inter-island shipping. These results indicate the range of investments to be the various combinations of those facilities identified by the simplex multipliers.

Secondly, one or more simulations of each combination of improvements requested may be carried out for the finance authorities. The results of such an exercise are illustrated in Figure 3.45 although the results of separately investing in ports 1 and 5 are not shown.



SOURCE: FIGURE 3.20 OF SECTION 3.2.2.2.
THE TIMING OF FACILITY IMPROVEMENTS

Fig. 3·45

It can be seen that additional port facilities must be made available by year 3, if the system is going to be able to carry the traffic throughout the 5 year planning period. Also, if port 3 is improved (ΔS_3 = 10), the need to improve port 1 disappears. This is due to the integer nature of transport investment (i.e. one wharf or no wharf).[72] By carrying the simulation to "infeasibility" in each case, the effect of future (essential) investment on short term investment planning can be identified. For example, if investment in port 3 is contemplated, it can be seen that an improvement in port 1 must be made at the end of the fifth year. Thus, the effect of the (essential) investment in port 1 on the need to invest in port 3 can be determined in subsequent runs of the model.

On completion of these activities the financial authorities will have identified a limited number of investment strategies. For each investment strategy the approach will also have identified the time period in which particular facility improvements must become available.

This information, when combined with estimates of the cost of facility improvement, and data concerning the availability of resources for improvement, can be used to derive a subset of improvement options for further evaluation. Table 3.42 illustrates a method of postulating a range of construction periods for each facility improvement which satisfies the completion times given in Figure 3.45.

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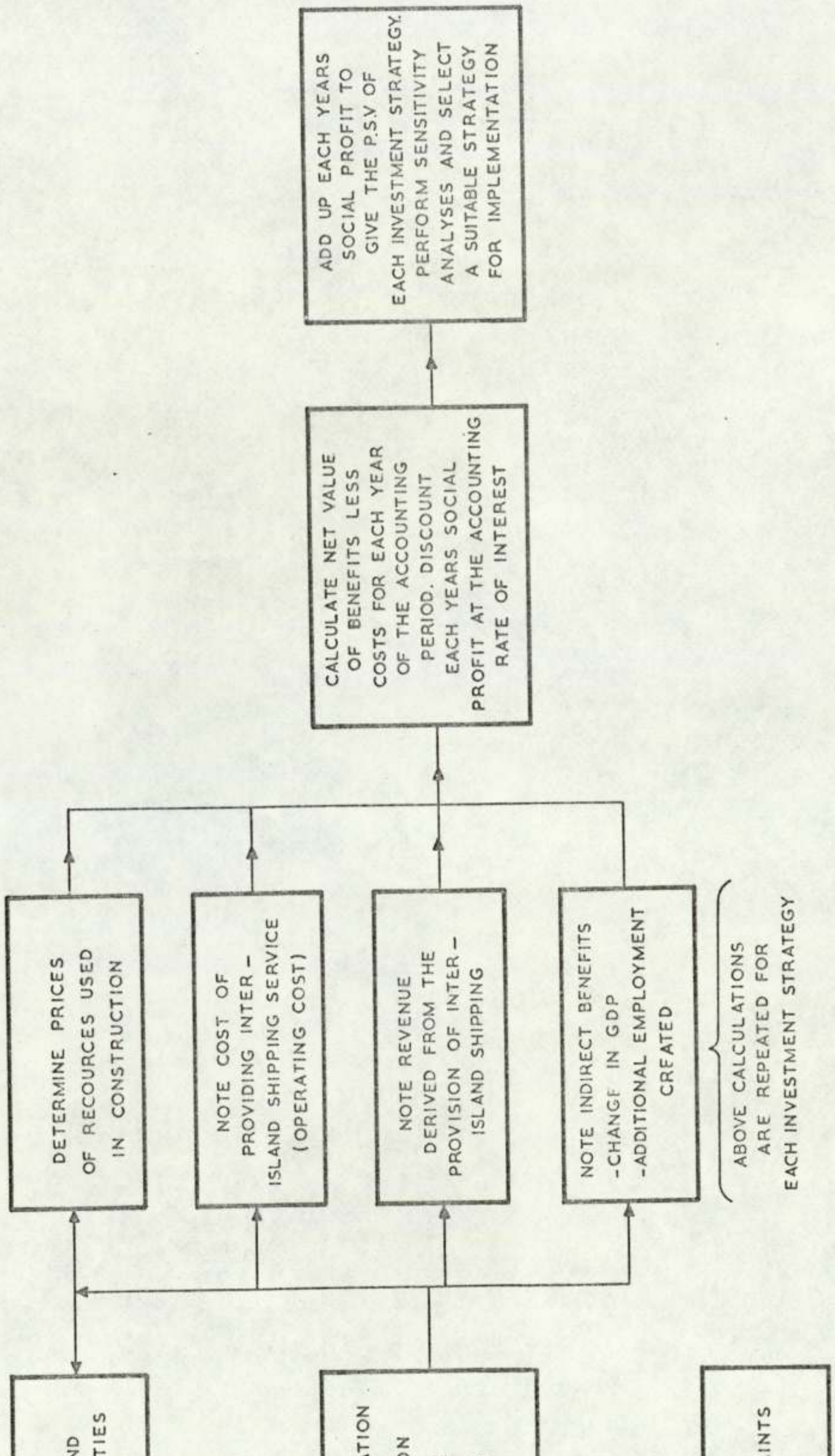
72. If the capacity of port 3 is increased, certain ships will tend to use port 3 and need no longer visit port 1.

IMPROVEMENT	RESOURCE NEEDS PER YEAR					P.S.V
	1	2	3	4	5	
S_3	x	x				.....
S_3'			x	x		.....
S_1	x	x	x			.....
S_1'		x	x	x		.....
$\Delta S_3 + \Delta S_1$	x	x	x			.....
$\Delta S_3 + \Delta S_5$		x	x	x		.....
LIMIT ON RESOURCE FLOWS	x	x	x	x	x	
BUDGET LIMIT OVER 5 YEAR PERIOD = ...						

EVALUATION OF IMPROVEMENT OPTIONS

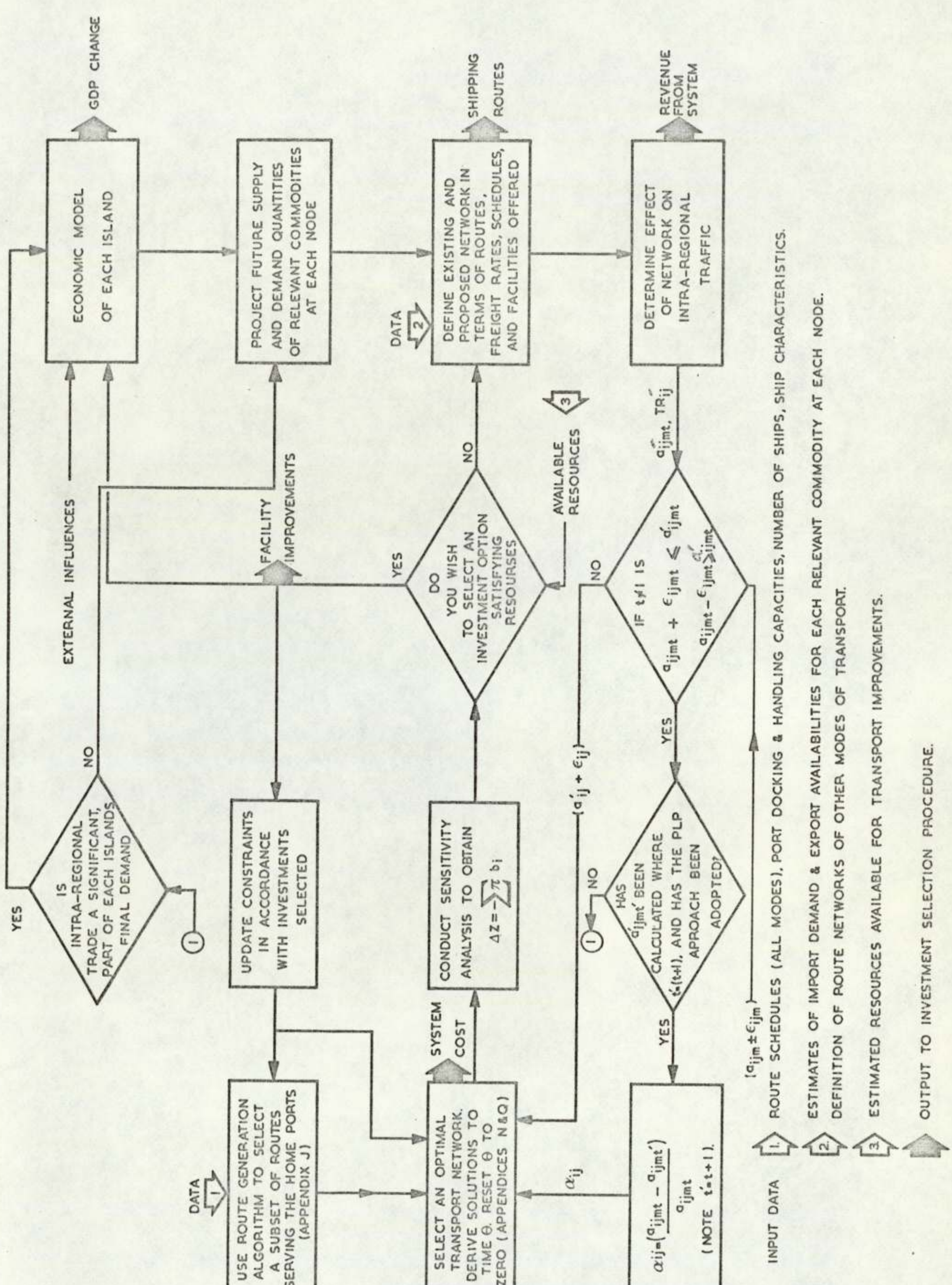
TABLE 3.42

The present social value (PSV) of those strategies satisfying the availability of investment funds over time can now be estimated. The strategy(s) with the highest PSV(s) would be selected for final evaluation. The sequence of activities required to compute the PSV of each strategy is illustrated in Figure 3.46. It can be seen that the information necessary to derive the PSV of each investment strategy can be derived from the application of the systems approach which implies the co-operation of the port and shipping authorities concerned. Following data collection the sequence of activities concerned in completing the design cycle is as illustrated in Figure 3.47.



OPTIMISATION ROUTINE (FINANCING AUTHORITY).

Fig. 3·46



TRANSPORT PLANNING ACTIVITIES

Fig. 3.47

3.3.2.7 Final selection

A detailed evaluation of the remaining alternatives must now be conducted before the final selection of a system alternative. Three important considerations have to be investigated.

- The sensitivity of the economic criterion to assumptions made in the design
- The sensitivity of the economic criterion to changes in the parameters near the optimum
- The effect of uncertainty in the forecasts of the environment in which the system will have to operate [73]

If, on completion of these activities, it is found that the overall economic criterion "is smooth with respect to changes in the design parameters, then this information tells us that a wide range of systems is acceptable, each with a value of the economic criterion that is roughly the same as that of the "best" system. This constitutes a good design", (Jenkins, 1969). However, if small changes in the design of the system have a marked effect on the overall economic criterion, then the design is a bad one, since one cannot be absolutely certain that the assumptions, on which the design was based, are valid.

---

73. These can include assumptions made in deriving the overall economic criterion. The value of this criterion can be significantly affected by:

- the inclusion or exclusion of certain specific categories of benefits and costs
- the choice of interest rate and period of economic life
- the exact form of the criterion in different circumstances
- the treatment of risk
- the projection of prices, and
- the problems of measurement

Now the objective of this study was to develop a methodology for deriving a time-staged transport investment programme for Carifta. It is therefore important to reconsider the methodology to ensure that system solutions derived will not be too sensitive to:

- Assumptions made in the design
- Changes in the parameters near the optimum
- Forecasts of the environment in which the system will have to operate

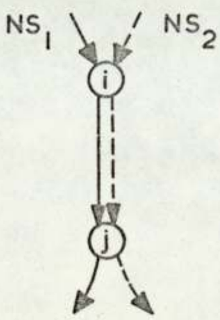
3.3.2.7.1 Assumptions made in the design

These are as follows:

- All vessels under the jurisdiction of the Carifta Secretariat operate within the region
- All such vessels operate liner services
- Each island is served by one port
- Passenger movement is ignored
- Freight rates are constant
- The make-up of the cargo remains constant, voyage after voyage
- Ships call at each port at equal intervals of time

None of the assumptions invalidate the methodology although minor changes are necessary in some cases. Where an island is served by more than one port, the relationship between the import/export trade of the island and the share of each port in it has to be established for forecasting purposes. Where passenger movement is relevant, minor changes to the formulation of the transport model are necessary. The necessary changes are given in Appendix L.

Where freight rates can be varied, the transport model is invaluable in that the marginal cost of transport provision is directly obtained from the solution in the form of the shadow prices. These can be used as a guide to future freight rates if every rate is to show a margin over operating costs. Changes in freight rates can also be reflected in the modal choice and distribution models which enables the relationship between an island's economy, traffic carried and transport system revenue to be explored. In a region trading largely in agricultural products, seasonal variations in the supply and of particular commodities will undoubtedly occur. The transport model could be run for each season of the year if seasonal fluctuations in traffic volume were identified. The last assumption affects the calculated average waiting time at a port before a ship calls. Figure 3.48 illustrates the case where a shipper in port "i" in exporting to "j" is served by two shipping routes. If $NS_1 = 20$ and $NS_2 = 10$ then the model formulated states that the average waiting time for an export consignment is $\left[365/\sum NS_k \right]$ days. This statement is clearly only valid if the number of ship-journeys over each route are scheduled to occur at equal intervals of time. If the two journeys have different journey times, the waiting time will increase and decrease over time, as the two ship-schedules move in and out of phase. Where there are a large number of ships and routes in a region, this fluctuation will be but a ripple about the average waiting time, and the constraint will be valid. Where, for example, only two ships serve the region, then the waiting time for particular categories of exports may be critical. In such cases, a lower bound (equal to the desired number of journeys) may be placed on each route selected as optimal, to ensure that the waiting time for such commodities will not be exceeded. In practice, the sensitivity of any solution to the expected changes in the average waiting time would identify the robustness of the design.



Two Routes
FIG. 3.48

3.3.2.7.2 Parameters affecting the optimum

An analysis of those investment strategies selected for final evaluation should normally be conducted, to identify those variables to which the economic criterion is sensitive. No such analysis would be necessary if this systems approach was used, for the simplex multipliers derived in solving the transport problem identifies the variables and their relative importance. The result of such an analysis might suggest that a small improvement in the docking capacity of a particular port could significantly reduce the cost of inter-island transport provision.

3.3.2.7.3 Forecasting errors and their effect on the system

A simple sensitivity analysis of the solution network will identify those trade flows to which the solution is sensitive in each year. The sequence of activities described in Section 3.3.3.2 can then be performed to see whether changes in these flows will significantly modify the system improvements recommended.

The objective of these sensitivity analyses is to:

- Identify those parameters which are cost sensitive
- Guard against systems with very sharp optima for such systems are "assumption" sensitive
- Design system improvements which are insensitive to minor changes in the assumptions
- Avoid the dangers of sub-optimization

The last point is the most serious, for if each port authority is allowed complete autonomy of operation, sub-optimisation is a real possibility. The only solution might be to derive the optimal sequence of improvements and then to persuade each port to adopt the optimal strategy.

At this stage of the study, the author received a report[74] in which some short term solutions to the problems of the regional shipping service were recommended. It was therefore decided to use the L. P. transport model to evaluate the system improvements recommended in the report although they were short term improvements. (The L. P. model is primarily a tool for devising a time-phased transport investment programme).

The mathematical formulation of the model is given in Appendix L, together with the data used and the results obtained. Only cargo handling capacity, journey frequency and ship capacity constraints were included, because other factors developed in the general model were not considered in the report.

The authors of the report were asked to undertake an investigation of the economic aspects of the operation of the vessels run by the West Indies Shipping Service with particular reference to the:

- Possibility of alternative ship schedules
- Potential for increasing revenue
- Possibility of reducing costs
- Suitability of the present vessels

A model of the recommended transport system was formulated so that conclusions drawn in respect to its operation could be evaluated.

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74. An Economic Investigation of the Operation of the M. V. Federal Maple and the M. V. Federal Palm, I. S. E. R., 1964.

3.3.2.7.4 Possibility of alternative ship schedules

In their report,[75] the I.S.E.R recommended that the first vessel should operate the present schedule, only accepting those northbound cargoes which could be worked without overtime, while the second vessel was restricted to the collection of passengers on the southbound leg of the revised journey between St. Kitts and St. Lucia (Fig. 3.49). The reasons given for these recommendations were as follows:

- The cost per journey of each defined route is significantly affected by the categories of cargo carried. If passengers only are carried, no fees in respect of pilotage, tonnage, wharfage, or berthing can be levied,[76] the only costs incurred being launch hire, harbour dues and "entry and clear" costs (given as less than $50 in the report)

- By collecting southbound passengers only on the St. Kitts - St. Lucia leg, the time saved was available for loading time in each port northbound without incurring overtime costs.

The implications of the above, in terms of the final formulation of the transport model (Section 3.1.2.4) are as follows:

- The objective function only contains one cost/journey figure for each defined route. In practice the figure would include pilotage, tonnage and wharfage dues where cargo ships were envisaged.[77] To include the possibility of a ship stopping at a port to collect passengers or cargo as an option

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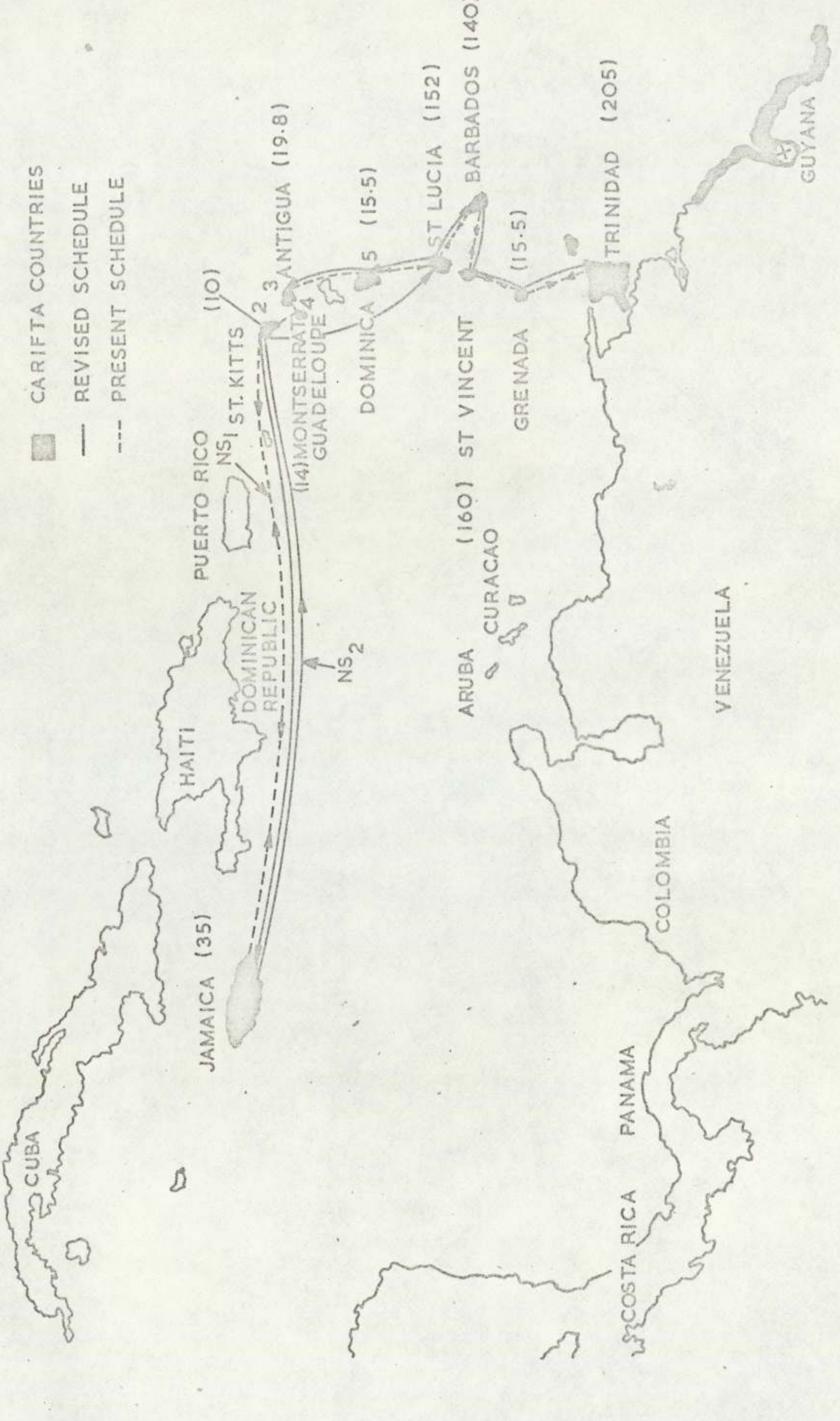
75. An Economic Investigation of the Operation of the Vessels M.V. "Federal Maple" and M.V. Federal Palm, I.S.E.R., 1964, pages 21, 22.

76. The only relevant data concerned Voyage 16 of the Federal Maple in 1962 when the cost of discharging 14 tons of cargo was $2,853 (W.I) and the costs of pilotage, towage and berthing charges in Trinidad, which amounted to $385 per visit.

77. These figures were not available for the case described in Appendix M.



SHIPPING ROUTES RECOMMENDED BY I.S.E.R.

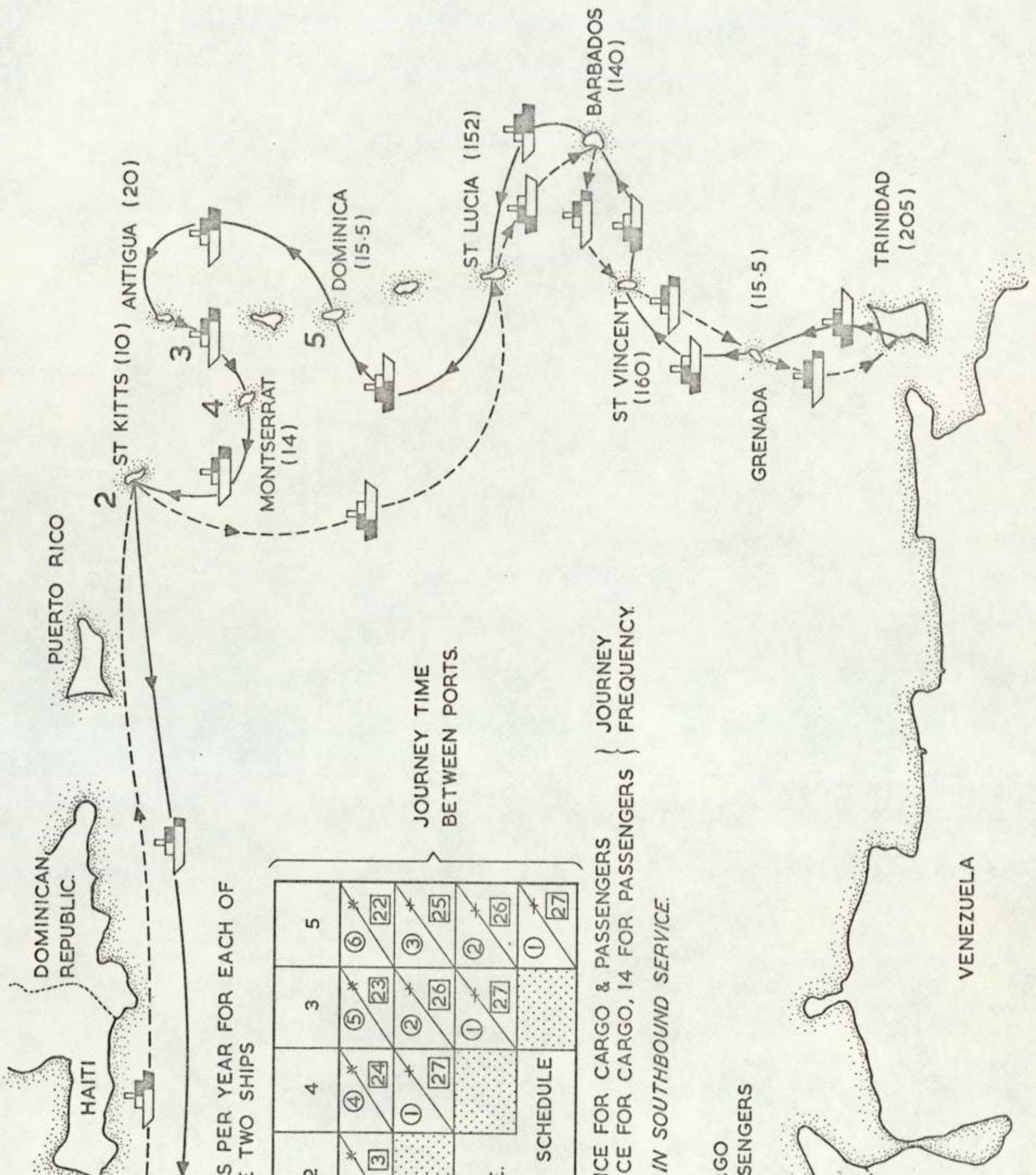
Fig. 3·49

in the programme would involve combined linear-integer programming. An inspection of the results obtained in one or more runs of the L. P. model may prove to be adequate in selecting this possibility in most cases

- The minimum frequency of service selected by the I. S. E. R. for ports northbound from St. Lucia to St. Kitts was 28 days for the round journey because "the agents in Trinidad appeared to consider a regular schedule to be valuable and it is agreed that it has been a very significant factor in increasing not only passenger business but also in increasing cargo business". (I. S. E. R., 1964).

Applying these criteria together with the routes selected and other data used by the I. S. E. R to the transport model, different results were obtained. Full details are given in Appendix L, although the results are summarized in Figure 3.50. These show that:

- Both ships should be assigned to route 2, the number of journeys required being determined by the demand for passenger transport between Grenada and Trinidad
- Only one ship need call for cargo at northbound ports above Dominica if the 28 day service was acceptable. The saving in pilotage, towage and wharfage costs should be traded off against the cost of overtime (if any) incurred by the other vessel. Similarly, only one ship need carry cargo on the southbound journey from Jamaica to St. Lucia.
- Only one ship need visit Jamaica
- Journey time is ignored in the L. P. model



A SOLUTION TO THE CARIBBEAN TRANSPORT PROBLEM.

Fig. 3·50

This last factor, if significant, could dominate route selection, for it is the main difference between the schedules recommended by I. S. E. R and the model. This point is illustrated in Figure 3.50 where the journey time between ports is given together with the journey frequency. When this information is compared to the original schedule recommended by I. S. E. R (Figure 3.49) it can be seen that over arcs (1, 3), (1, 4), (1, 5), (2, 3), (2, 4), (3, 5) and (4, 5) waiting times and/or journey times differ. The schedule recommended by I. S. E. R is almost the same in that one ship follows the present schedule every 28 days while 14 days later, the other ship follows the proposed schedule. In this way, passengers in ports 3, 4 and 5 can either take an anti-clockwise trip lasting 25-27 days or wait 14 days for the second ship for a journey of 1 to 3 days. For northbound cargo from the same ports, that cargo which would incur overtime working, has to accept the 28 day service, against the present 14 day service. A further improvement would result if the route schedules illustrated in Figure 3.51 were adopted. The resulting journey times on a 28 day service being as illustrated, although passengers and cargo have the option of a 14 day service with longer journey times.[78] If the 14 day service could be dropped, only one ship need visit Jamaica, the other ship being allocated to a new route. Both passengers and cargo still have to take an anti-clockwise trip lasting 25-27 days or wait 14 days for the second ship for a journey time of 1-3 days. On the other northbound route, journey times from ports south of St. Lucia, to northern ports are shorter to Jamaica.

Table 3.43 shows the costs of ship operation for the alternative schedules discussed.

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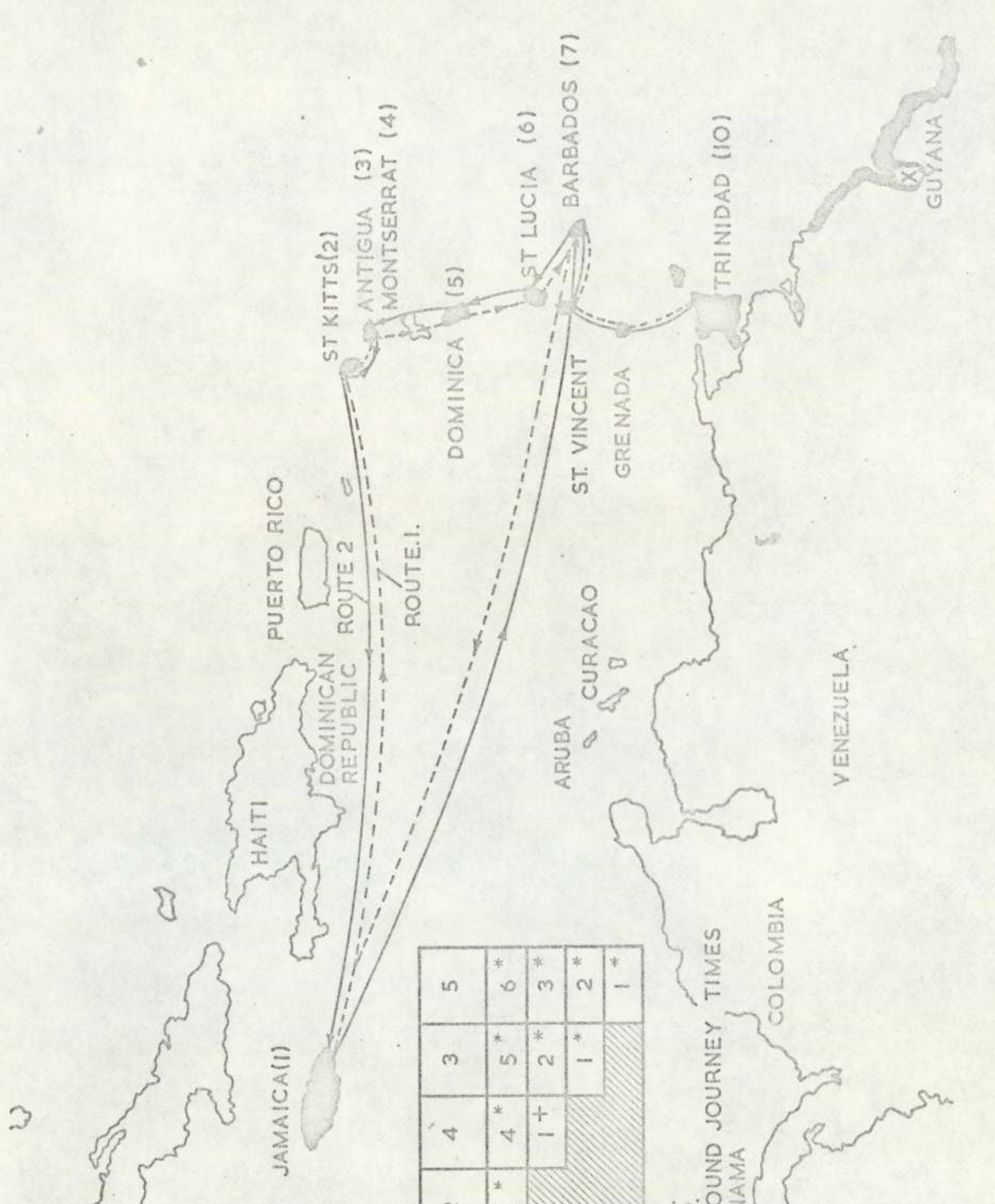
78. This would incur pilotage, wharfage and towage costs at each port visited.



PORTS	2	4	3	5
1	3 *	4 *	5 *	6 *
2		1 +	2 *	3 *
4			1 *	2 *
3				1 *

ROUTE SCHEDULES RECOMMENDED BY EASAM'S

Fig.3.51

	PRESENT	I. S. E. R.	EASAMS
Variable Costs	$ 237, 500	233, 200	191, 200
Fixed Costs	842, 000	842, 000	842, 000
TOTAL	1, 079, 500	1, 075, 200	1, 033, 200
The derivation of these costs is given in Appendix M.			

ANNUAL COSTS OF SHIP OPERATION

TABLE 3. 43

This table suggests that a further reduction in the cost of transport system operation would result if every possible route schedule could be considered by using the route generation algorithm and transport model as previously proposed. It can be seen that the effect of route changes on the cost of transport provision is small. Thus, route changes could well be preferable to investment in particular facilities. The use of the model would again evaluate such alternatives.

The model showed however, that the schedules recommended by I. S. E. R could be further improved, even when using their own route selection criteria, if the total system approach recomended in this study were adopted.

3.3.2 7.5 Potential for increasing revenue

- The allocation of passengers shown in Figure 3.53 confirms the recommendation that concessionary fares could be introduced in the under-utilised section of the voyage. However, route schedules should be modified to improve the utilisation over each link.
- The four principles[79] on which a tariff should be based are as follows:
  - Every rate should show some margin over operating costs, i.e. no cargo should be accepted at less than full handling charges
  - Necessities of life, i.e. rice cereals should be carried at a rate consistent with the first principle
  - Development materials, principally building materials, agricultural machinery, turbine and engineering equipment should be carried at a minimum rate consistent with the first principle; and
  - All other cargoes should be carried at a rate based on the principle of what the traffic will bear

If the Association (Carifta) uses the present schedules, then the passenger and freight rates should be as given in Table 3.44 which is based on the first of the four principles above.

Only Antiguan passenger fares have been calculated for comparison with those existing.

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79. These principles were laid down by Professor Kierstead in his report entitled "Inter-Territorial Freight Rates and the West Indies Shipping Corporation" (Undated).

Ports Served	Freight Rates[1]		
Antigua to:	Existing	Calculated[2]	Calculated[3]
Jamaica	31.9	518.0	831.0
St. Kitts	17.0	31.1	50.0
Montserrat	17.0	20.6	33.5
Dominica	21.9	56.6	91.0
St. Lucia	27.2	102.2	165.0
Barbados	31.8	150.2	242.5
St. Vincent	36.5	131.6	211.0
Grenada	41.5	164.2	265.0
Trinidad	46.2	210.0	347.0[4]

1. The derivation of the calculated fares is described in Appendix S.
2. Based on the existing subsidy. See Appendix M.
3. Based on the total cost of transport provision.
4. $V_k / C_{kp} \triangleq \$8$ (W.I), the only link over which the marginal cost is applied.

EXISTING AND CALCULATED PASSENGER FARES COMPARED

TABLE 3.44

It can be seen that the present structure of inter-island freight rates bears little relation to the cost of transport operation and/or provision, a fact suggested by I.S.E.R., (1964). They recommended a + 15% increase in the rates (some rates would increase by less and some by more than 15%). Refrigerated cargo in particular could probably carry a substantially higher increase within one twelve month period and 10% in the following year. The increased rates recommended for passenger fares (20% in the on-season and 10% in in the off-season) does nothing to correct the imbalanced fare structure illustrated in Table 3.44. Even when the fare structure is supported by the existing level of subsidy, the recommended increases fall far short of the desired (assuming transport demand to remain constant).

One danger of increasing the freight and passenger charges lies in the competition, which comes from two sources; trans-oceanic vessels and the inter-island motor vessels and schooners. The former deliver goods from the United Kingdom and Canada to the islands, but do little inter-island trade. In the latter case, "it appears that the centralisation of importing and retailing in the hands of a few major firms, favours the use of the vessels of the West Indies Shipping Service, which can carry larger consignments and command more favourable insurance rates (in some cases, schooners cannot command cargo insurance)". (I. S. E. R., 1964). In the case of passengers, the air fare between most points in the Eastern Caribbean is lower than the fare on the ships, but for holiday makers and others the averageper night rate on the ships is substantially lower than one would pay in a resort hotel ashore of equivalent comfort. The effect of such increases on the demand for transport is more difficult to assess.

3.3.2.7.6 Possibility of reducing costs

- Recommendations in respect of the above would identify those factors significantly affecting journey costs. For example, the bunker costs per journey were deduced from the annual total and the number of journeys.

3.3.2.7.7 Suitability of the present vessels

- The L. P. model was simplified by aggregating refrigerated and general cargo. As a result, no conclusions can be drawn except that the model could include the consideration of this type of cargo with a corresponding increase in the number of variables

- The reduction in the cost of transport provision resulting from an increase of passenger capacity could be considerable. An examination of Figure 3.50 shows that greater ship utilisation would result from the increase. (A recommendation by I. S. E. R). Alternative routes could also be postulated to further increase ship utilisation.

- Data could not be acquired in time to test the suitability of the present vessels. In a client sponsored study, data on the proposed vessel would be input to the model and the results compared with the existing vessels

These conclusions all concern the day to day operation of the existing system and do not highlight the prime use of the model, which is to derive an optimal time-phased transport investment programme for the region. They do, however, illustrate the fact that the model can be used with the limited data that is available within the region.

3.4 Control and Reliability

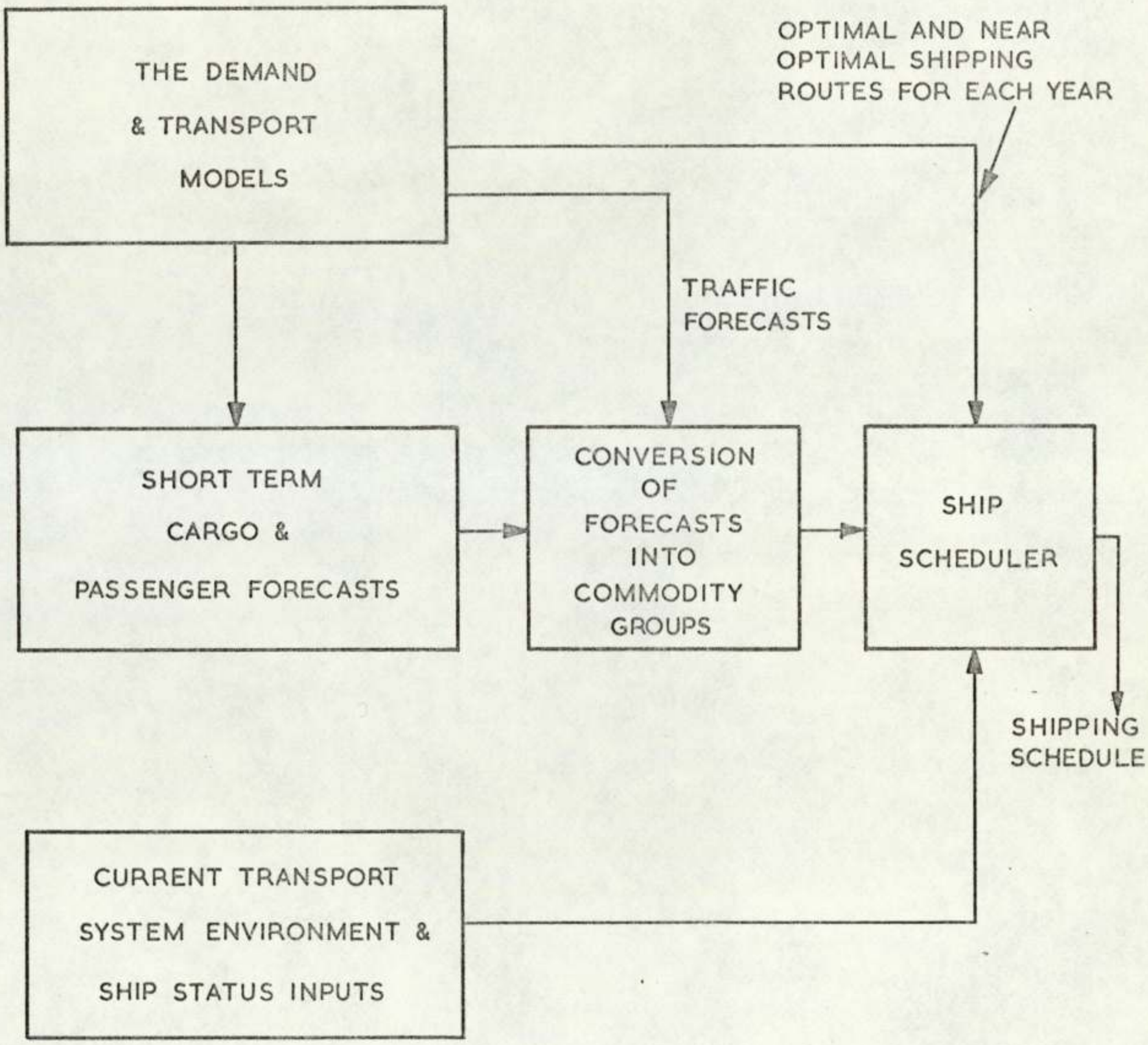
A system will not realise the most profitable design conditions without a control system. The reliability of a system is also important. If a system can still operate when parts of it have failed (due to dock strikes or equipment breakdowns) it is a better system than one which fails to operate when such events occur.

As previously stated, the linear programming model has been developed primarily for investment planning purposes. The model does not produce a day by day schedule for each vessel; it does produce the number of voyages to be made by each ship in a given time period. This is not a serious limitation because it is not necessary to determine exact schedules for several years (or quarters) in advance. The L. P. model is meant to indicate basic strategy and could provide inputs for a scheduling model or scheduler.

Given the routes by the model, the scheduler can attempt to keep the number of ship-journeys between origins and destinations close to the linear programming solution. The scheduler also has available to him, as a by-product of the linear programming solution, a relative cost coefficient for each route that is not in the solution. These coefficients give a measure of the desirability of each such route, which is useful in suggesting alternatives to the optimal solution.

In practice, control of the system in an operational environment would be exercised by the scheduler using the output of the L. P. model supplemented by short term market forecasts and other expected changes to the transport system environment. The envisaged process is illustrated in Figure 3. 52.

The short term scheduling process[80] does not concern the study (see Appendix A , Section 2.1.3) but system reliability does. The system improvements generated should be reliability tested by re-running the transport model to simulate equipment failure and other short term disturbances to the forecast environment.



THE DERIVATION OF SHIP SCHEDULES Figure 3.52

80. See Olson, C.A., Sorenson, E.E. and Sullivan, W.J., "Medium Range Scheduling for a Freighter Fleet", Bulletin of the Operations Research Society of America, 15, B-49, 1967, pages 565 to 582.

4 EVALUATION AND CONCLUDING REMARKS

4.1 Achievements

The basic aim of the study was to develop a methodology for deriving a time-phased transport investment programme for a group of developing countries, linked politically, economically and culturally, but separated from each other geographically. My external supervisor[1] emphasised that the methodology should, where possible, be generally applicable, although data on the Caribbean was to be used to verify the approach. It is therefore hoped that this report will be judged in relation to the above objectives. A secondary aim of the study was to produce a report which could be used by EASAMS' personnel in their work. As a result, the size of the thesis and appendices is somewhat larger than is conventional.

Chapters 2 and 3 describe:-

- the practical application of the techniques of systems engineering to the design of improvements to the transport system serving a group of developing countries relying largely on sea transport.

- a design methodology which incorporates decentralised decision making, where improvements to the transport system can be designed through the collaboration of the separate transport authorities without affecting their autonomy.

- a design methodology which enables the generation of a time-phased transport investment programme using parametric linear programming. As far as the author is aware, this is a new application of parametric linear programming.

To the author's knowledge, this is the first application of systems techniques to a transport system serving a region comprising several

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1. D.J. Cashmore

territories separated from each other by sea. The approach is also unique in that it uses the existing political, economic and decision making structure of the region studied, as well as the limited data available. Chapters 2 and 3 show the reader how:-

- The region's problems were identified in terms of a number of inter-related sub-problems.
- An overall economic criterion was developed which incorporated profit, cost, quality, performance, compatibility, flexibility, permanence, simplicity and time objectives.
- The solution to these sub-problems in terms of a number of improvement options were incorporated in the design method.
- The system and its relation to each island's economy was determined.

In so doing, the reader will see how techniques used in systems engineering have helped the author to structure the problems and generate solutions to them in this new area. Such an approach is of general applicability, and indeed has been applied in Algeria, where EASAMS' personnel are now completing a land-based transport study under the technical direction of the author. The approach described also solves the multi-port problem in that it identifies the relationship between the operation of a region's transport system and its component parts. Thus, when investment in certain facilities is suggested by the transport model, a detailed model of the port concerned can then be used to determine the form the improvement should take.

4.2 Shortcomings

The greatest mistake, in structuring the study initially, was to collect so much data. An over-ambitious programme of research was initiated. If the author had defined the problem in more detail before initiating data collection activities, a more efficient utilisation of time spent would have resulted. To collect traffic data in parallel with other activities is indeed contrary to the systems approach. The author's lack of knowledge of the approach at that time was to blame.

To undertake a study of the Caribbean when there was no prospect of ever going there, was bound to create difficulties. Postal communication with the area proved hazardous. In some cases replies took 3 months. The author is still awaiting replies to some letters! Information that was available in London was often incomplete. It was with great regret that the author was not able to test the input-output model of Dominica. The only data acquired was limited to a period of 3 years. Data on the ports was inadequate and could not be incorporated in the final transport model formulated for Carifta.

No attempt was made to test the modal choice and distribution models, although they form part of the methodology. Such models are already well developed. To develop such models for the Caribbean would have necessitated one or more visits to the area.

No mention is made in this report of a trade flow forecasting model developed by the author to forecast the volume of traffic between Carifta countries and various other countries. Such a model could be of value if the Carifta ships were to serve countries both within and outside Carifta. The model, based on a formulation due to Linneman[2] is almost complete. Its omission from this thesis was suggested by the University.

4.3 Directions for Further Research

The first requirement is, of course, to validate the application of the input-output model developed in Chapter 3.2 and secondly, to further test the transport model with data on the ports within the region. The degree to which network changes affect the input-output coefficients is also unknown.

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2. H. Linneman, An Econometric Study of International Trade Flows, North Holland Press, 1966.

The final requirement is, of course, to investigate the acceptability of the approach with the authorities concerned. The approach developed would be useless if it could not be applied.

One of the major differences between land and sea based transport is that in the former the transport network is fixed while in the latter it can change significantly. In a developing country, served only by land transport, where only one or two roads link each region, it may be possible to develop input-output models for each region, and then to use the output from each model as the input to the transport model.

The formulation below sets out to use only the same information that is required by the input-output model and so reduces the amount of data to be collected and the probability that data for one model implicitly contradicts data for another.

The model minimizes costs of production and transport subject to the following constraints:

- Regional commodity requirements must be met - these requirements are output from the input-output studies.
- Regional production capacities must not be exceeded - this data must be available to each region's planners.
- Present or envisaged links between regional centres must not be overloaded.

Formally: Minimize $z = \sum_h \sum_i \sum_j \sum_k a_{ijkh} ({}_kC_{pi} + {}_kC_{tijh})$

subject to $\sum_i \sum_h a_{ijkh}$ = demand for commodity k in region j

$\sum_j \sum_h a_{ijkh} \leqslant$ production capacity in region i for commodity k

$\sum_i \sum_j \sum_k a_{ijkh} \leqslant$ capacity of transport over route h

Where a_{ijkh} = the volume of commodity k transported from production centres in region i to demand centres in region j over route h.

$_kC_{pi}$ = unit cost of producing commodity k in region i.

$_kC_{tijh}$ = unit cost of transporting commodity k from region i to region j over route h.

If the three right-hand-sides of the constraints can be obtained, and the unit costs of production and transport can be estimated, then the a_{ijkh} terms will be chosen by the model to satisfy the objective function. The flows obtained can be checked by surveys of waybill data (if any) and the model "calibrated". Other constraints, such as maximum journey times, limits on vehicle fleets, etc. could be added if required. This model allows substitution of products between regions but only considers production plus transport costs as the criterion for shipment. As roads are fixed the value of the model could be considerable.

The compilation of this report has been a most enjoyable and rewarding experience. My sincere gratitude extends to all those people who made its production possible, particularly my supervisors who guided, criticised and encouraged me over a period of 3 years and to my company who sponsored the work in its entirety.

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