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CARIBBEAN MARITIME TRAFFIC MODEL

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CARIBBEAN MARITIME TRAFFIC MODEL

6. Appendix

6.1 Model Formulation of CEPAL (1982)

6.2 Output of a Mixed-Integer Programming Model

1. Definition of the Problem

A model is being used as a representation of parts of the real world. It underlines relationships, which are in the focus of interest, and leaves out those aspects, which are presumed to be less important. So the qualification and performance of a model can only be evaluated against the background of the issues under investigation. Thus, reality is structured in a more or less abstract way, depending on the aims to be followed. Consequently, a most important step of modelling is to be clearly define the environment, which should be modelled and the issues, i.e. the quantity and quality of information, which should be provided by the model's outcome.

1.1 Importance of Ship Transport in the Caribbean

It is a natural consequence of the geographical situation that transport services between the nations of the Caribbean are provided by air and maritime carriers. Passenger transport is carried out by air except for ferry boat connections between Trinidad and Tobago and in the Virgin Islands. Hucksters who accompany their cargo by sea usually have to sign on as crew. Commodity transport is shared by airlines and maritime carriers. As maritime shipments take the major part and since the possibilities of substituting transport facilities seem to be limited, we will focus here on maritime transport only, and assume furthermore that there is no feedback between the two transportation modes, i.e. a change in the maritime transport system will not affect demand for air transport services and vice versa.

Economic development in the Caribbean where most countries' per capita income falls within the spectrum covered by the LDC category is closely related to the level of the transportation system. Transport lines are the arteries of economic life and have to be adjusted appropriately to avoid suppression of economic impulses [1/]. Thus, improvement

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1/ It is argued by some authors that transportation investments are able able to create economic impulses. Experience has shown however, that this argument should not be over-emphasised.

of the Caribbean freight transport facilities may be regarded as an integrated part of economic development policy. Comparing freight volumes and port infrastructures in the Caribbean[2/] one hardly can draw the conclusion, that there is a complete lack of facilities preventing the carriers from applying modern transportation technology. Many of the countries have deep water ports and shoreside facilities to load/unload medium sized or even large ocean vessels, and some of them are well equipped for container or Ro/Ro traffic. Thus the comparatively low standards of maritime transportation cannot be argued to be the consequence of an underinvestment in Caribbean ports. Regarding the situation realistically, the reasons for inefficient maritime transport activities predominantly are the lack of organization and co-ordination in using the capital equipment or to put it into the context of planning, the lack of operations logistics.

In maritime transport, logistic problems occur with two respects: first, dispatching/loading/unloading/storing problems have to be solved in the ports, yielding the port specific costs of cargo processing and vessel operating; secondly, there are vessel type/routing decisions to be made affecting the shipping cost at sea. Solving the port related logistic problems is only possible if a careful analysis of all Caribbean ports has been performed. This is not the aim of the present study, which will be restricted to the second type of problems, taking the costs of operations in ports as given. This means that we try to find out a pattern of shipment routes for different ship and cargo types, which, if implemented, could help to reduce transportation costs considerably.

1.2 Intraregional and Interregional Shipments

Selecting from the various definitions for "the Caribbean", it is convenient for the present purpose to follow the definition used in the UNCTAD/SHIP/506 UNSHIPRO Report (1982), which considers the

2/ See Wickenden, 1983.

twenty-four countries of the Caribbean listed below in Table 1. Venezuela has been introduced into the Intra-Caribbean transport pattern, because there are relatively strong trade relationships between the countries usually defined to be Caribbean[3/] proper and Venezuela. Some Caribbean countries (Turks and Caicos, Puerto Rico, Cayenne, Anguilla) have been aggregated and it may be useful for a transportation study to disaggregate the transport flows of these countries again, or to assign them to other countries according to geographical considerations. Other islands which are not integrated in the Intra-Caribbean transport pattern might be considered for separate listing because of existing transportation activities (Aruba, Curaçao, Bonaire). So it can be useful to slightly modify the Intra-Caribbean shipment survey of Table 1, if a detailed insight into some specific interrelationships shall be given. Table 1 shows that transport movements are highly asymmetric, i.e. originating traffic may differ considerably from destinating countries and the use of their ports for transhipment purposes.

On the other hand, there are very strong interrelationships between Caribbean and non-Caribbean countries. In a rough approach to the Caribbean maritime traffic problem, one could presume these flows and the associated interregional vessel routes to be fixed exogenously, because decisions on these routes are made outside of the Caribbean. There may be an interest, however, to study possibilities for feeder services provided by extraregional ocean lines. Taking such additional services of extraregionally operating carriers into consideration may remarkably change the traffic volumes, which are handled by the intraregional carriers. This mutual influence between inter- and intraregional traffic flows and the routing of vessels has to be taken into account. Table 2[4/] shows the volumes of interregional transport activities shown in Table 1. Note that there is a strong asymmetry of traffic flows, again, so that this seems to be an intrinsic characteristic of Caribbean transport patterns, which must be considered when developing routing models.

3/ See Wickenden, 1983, Table 1.

4/ See Appendix B.

Country	Originating Intra-caribbean Mar.Transport	Destinating Intra-caribbean Mar.Transport
1. Antigua	5 710	110 739
2. Bahamas	4 300	541 887
3. Barbados	23 623	340 116
4. Belize	11 252	4 733
5. Br.Virgin Isl.	30	18 076
6. Cayman Isl.	712	95 112
7. Cuba	34	517 396
8. Dominica	8 972	95 076
9. Dom. Republic	555 003	691 680
10. Grenada	9 025	29 373
11. Guadeloupe	66 810	755 750
12. Guyana	747 511	494 576
13. Haiti	1 477	120 019
14. Jamaica	391 809	2 338 773
15. Martinique	201 689	75 578
16. Montserrat	7 930	5 440
17. Nethlds. Ant.	2 128 077	24 998 333
18. St. Kitts	794	24 228
19. St. Lucia	17 560	57 363
20. St. Vincent	23 439	26 610
21. Surinam	403 967	941 801
22. Trin. & Tobago	2 579 145	1 204 404
23. US Virgin Isl.	18 080	19 137
24. Venezuela	28 310 978	910 272
25. Other Caribb.	31 604	213 188
Total Intra-caribbean	35 549 531	35 549 531

Table 1: Intraregional Transport Volume /metric tons/ 1980.
Source: CARINTRA (1982)

1.3 Data Base and Restrictions

The shipment data of Tables 1 and 2 have been taken from origin/destination matrices for the intra and interregional maritime freight transport, which are existing for the years 1978, 1979 and 1980 and will be updated in the future through the Caribbean Shipping Information System (CASIS). In these tables, the traffic flows are broken down into five cargo categories.

Technical port characteristics are available through the handbook on Caribbean ports, published by the Caribbean Shipping Association. Furthermore, it seems to be possible to collect data on port charges and on the average waiting time of vessels of berthing space.

On this basis figures for port operating costs of different ship categories can be constructed. By supplementing these data by information concerning operating speeds, number of members of the crews, operating costs on sea and investment expenditures for the vessels considered it is possible to construct cost figures for the sea transport of cargos and of moving idle capacities.

If this data base has been provided, it is possible to construct a model which represents the transportation activities on the average. This means that the data base does not allow for solving time scheduling problems, which are very essential in case of seasonal oscillations of cargo demand/supply. Furthermore, it does not allow for a more specific view of time costs of vessels waiting for operation in the ports, which quite naturally will vary with the number of ships arriving at the port. So it will not be possible to model peak load traffic. In the case of maritime freight transport, peak loads may partly be balanced by longer storage times of cargo and hence this problem may not be as crucial as it is in the case of passenger transports. Nevertheless, the problem is relevant for the transport of agricultural products, and should be handled as an option of the model. This means, that in case peak load traffic data are provided, the model should be capable to find a satisfactory solution as well.

1.4 Issues of Shipment Modelling in the Caribben

Given the average data on the yearly base of traffic demand, port costs and vessel costs, the Caribbean Maritime Traffic Model (CMTM) should be able to tackle the following problems:

1. Analyse, which part of intra-Caribbean maritime freight transport can be assigned to interregionally operating carriers.

2. Find a good split between large-vessel and small-vessel transportation modes for the transportation demand remaining after having been solved (1.)

3. Determine the capacities required for intra-Caribbean operation, i.e. the minimum number of vessels of large and of small type, which are necessary (on the average) to satisfy transportation demand.

4. Generate the routes for the ships of different categories.

5. Generate cost data and operating times for each route and for the total transportation pattern.

6. Represent important parts of the current status quo and allow for a comparison between that situation and patterns generated by the model.

7. Allow for putting in specific routes and vessel types exogenously.

8. Allow for an easy sensitivity analysis (modification of input data).

9. Allow for on-line dialogues between the planner and the model.

10. Visualize the model's outcome by moving symbols on a VDS (video display screen: either the computer's monitor or a TV screen).

11. Make the model implementable for small to medium sized computers (256 K-Byte core memory; 5M - Byte peripheral memory as require-

2. Modelling the Caribbean Shipping Problem

2.1 A Total View

Remembering the issues for modelling, CMTM may be classified as a combined multiclass routing/assignment problem. The model should generate routes for different ship classes, assign ships to these routes, and finally assign cargo to the ships according to the given demand pattern. Written as an optimization model, it would consist of the following elements:

minimize {transportation costs}
X
subject to:

{demand constraints}
{ship capacity constraints}
{port capacity constraints}
{route feasibility constraints}
{technical constraints}
{nonnegative integer or
zero-one properties of some elements of X}

X: Vector of transportation activities, which is to be optimized.

2.2 Decomposition of the Total Model

As there seems little chance to apply total programming methods, we try to simplify the model's complexity by breaking down the bulk of simultaneous relationships into a sequence of small sub-problems. As one issue of modelling is to allow for dialogues beween model and planner, this decomposition should be performed in a way that the outcome of each sub-problem is meaningful from the planners point of view and gives him the chance to control the computation process on line, i.e. to modify input data and check the sub-problem's results without being

forced to run through the other parts of the model. Facing the issues of modelling and the structure of Caribbean freight transport, we establish three principles of decomposition:

(a) Decomposition of traffic categories

Caribbean maritime freight transport may be divided by:

(i) interregional ocean liner transport (vessel > 2000 grt)

(ii) intraregional large vessel transport (500 grt < vessels ≦ 2000 grt)

(iii) intraregional small vessel transport (vessels ≦ 500 grt).

If the specific transportation costs of each category are not highly interdependent, then it is justified to calculate the transport problem for each category separately. On the other hand, of course there are interrelationships, between these modes, stemming from the demand side: determining the traffic volume of one category will influence the traffic volumes which are left to the other categories. It will be shown in the following sections that these demand induced interrelationships can be handled by decomposition.

(b) Decomposition by origins (destinations)

The search for good routes, the assignment of ship capacity and the computation of the related route/ship patterns may be simplified considerably by constructing sub-problems (for each category of (a)), which start from a given origin of each potential roundtrip. So every routing problem may be handled separately. If shipping routes are closely interrelated, the decomposition by origins leads to an oversimplification of the problem. Therefore, this instrument of decomposition will be used:

- generally for category (i), only, and
- optionally for categories (ii) and (iii).

(c) Decomposition by cargo types

If ships may be loaded with different types of cargo, very difficult problems arise for the dispatching of ships in ports and the assignment/scheduling of loads in the ships' storage. Undoubtedly, these problems must be solved, if one tries a microscopic modelling of the single activities carried out in the ports for operating the cargo. As we are concerned here with a more macroscopic perspective however, which should help gain insights into the freight transport pattern of the whole Caribbean including it's vessel fleet and it's transportation demand in total, it seems justifiable for a first approach to ignore this tedious problem and to presume that every ship is loaded with ohne type of cargo or that there is a fixed combination of cargo types to be loaded on the vessels. So the model will be run of every cargo type separately, or, if a fixed proportion of cargo types is being assumed, a splitting by cargo types is no longer necessary.

The concept of the modelling sequence is shown in Figure 1. In modelling step I, only interregionally operating lines are considered. The planner's input consists in selecting ports of the Caribbean which may be consedered for service by long distance lines, characterised by OD-pairs. The outcome of this step consists of route changes of interregional carriers, which would economically benefit the Caribbean the traffic volume (which is shifted from intraregional to interregional carriers and vice versa) and the related transportation costs.

Model II computes the routes for intraregionally operating large vessels, the number of vessels required and the related transportation costs. The user has to put in the ports which are capable of operating large vessels and the cost data. Furthermore, he optionally may put in ports which are considered for improved shore handling facilities, and fixed OD-relationships or fixed routes, respectively, if there are specific regional aspects which the model does not intrinsically include.

Model step III finally concerns the traffic flows served by intraregionally operating small vessels. Naturally all ports of the Caribbean are to be considered now and an exogenous fixing of OD-pairs and routes is only justified by particular interest of the planner.

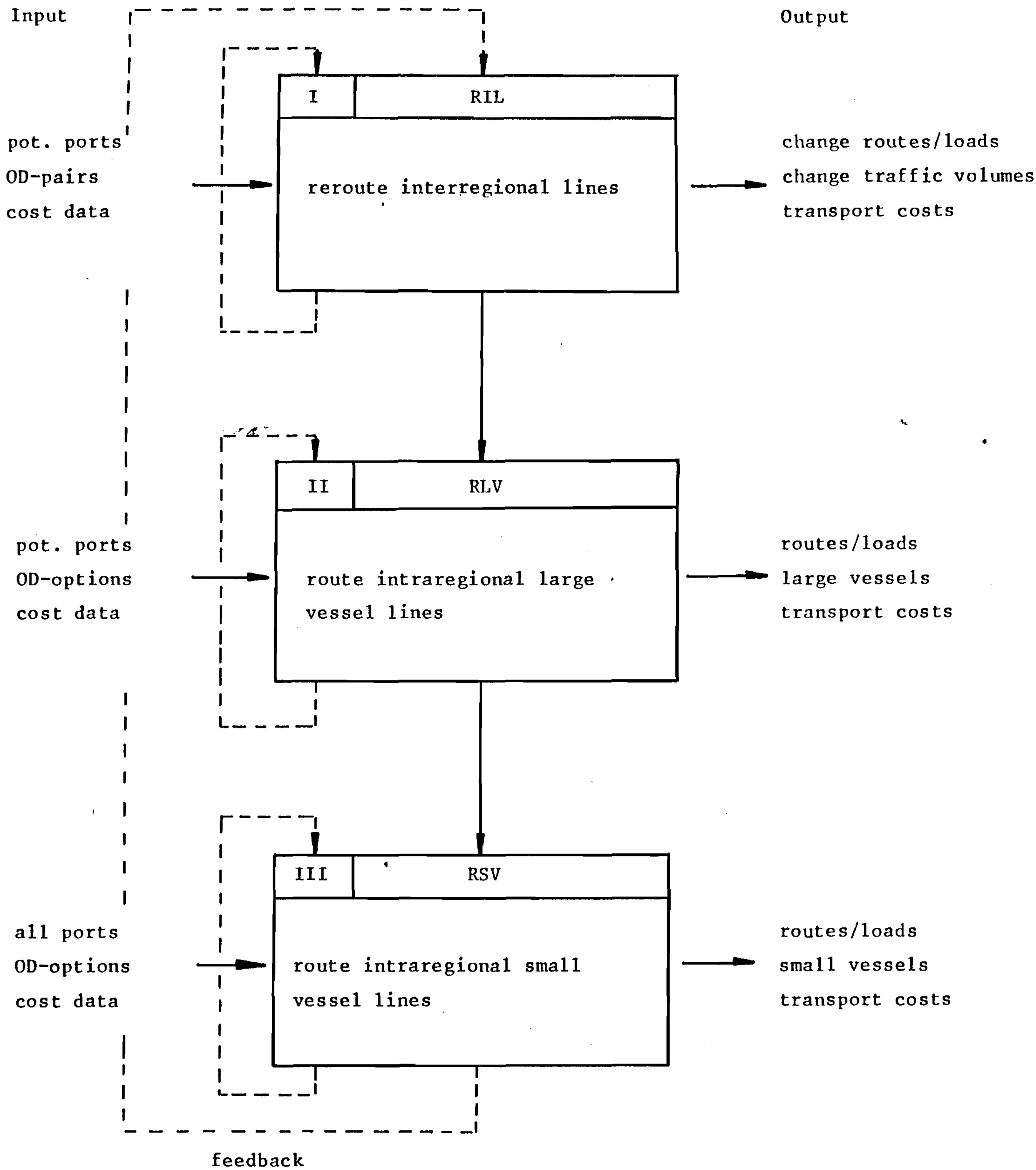


Figure 1: Model Sequence of CMTM

Comparing CMTM to total programming approaches, it is obvious that CMTM focuses on a good representation of the routing problem, simplifying the assignment problems involved, while total programming approaches focus on assignment, taking a limited number of routes as given. The idea behind CMTM is therefore that routing problems are much more important for representing the network of intraregional traffic links than assignment problems are.

2.3 Interregional Shipments

The RIV routine for rerouting interregionally operating vessels checks whether there are opportunities for transport cost savings by shifting intraregional traffic between interregional ocean lines and intraregional carriers. Note that cost savings are computed from the macro-economic point of view, i.e., it is not possible to check in which way the profitability of the respective shipping business is affected (to answer this question additional data on cargo rates charged and idle capacities are needed).

The RIV routine runs as follows (see Figure 2): the planner starts the routine by putting in the OD-pairs originating or terminating outside the region (e.g. North America/South America; Asia and Central America/Europe, Africa, Middle East; North America/Port-of-Spain) with the property that one port of the Caribbean is either an OD-point or an (actual or considered) interim stop on an extra-Caribbean route. The model's data bank contains an array of potential ports for intra-Caribbean stops for the liner in question. These potential ports are being checked successively for providing cost savings compared to the intraregional shipping service. This means that the costs of the ocean line in question are computed (including sea operating, port operating and capacity costs, see Section 4.6) and subtracted from the costs of the intraregional transport system, which are read from a matrix of shortest intraregional cost distances. This matrix will be initially filled with estimated data of the present transportation service and then updated by the results of the following routines RLV and RSV. The heart of the computing procedure is the "Savings Method" which is described in Section 4.2 .

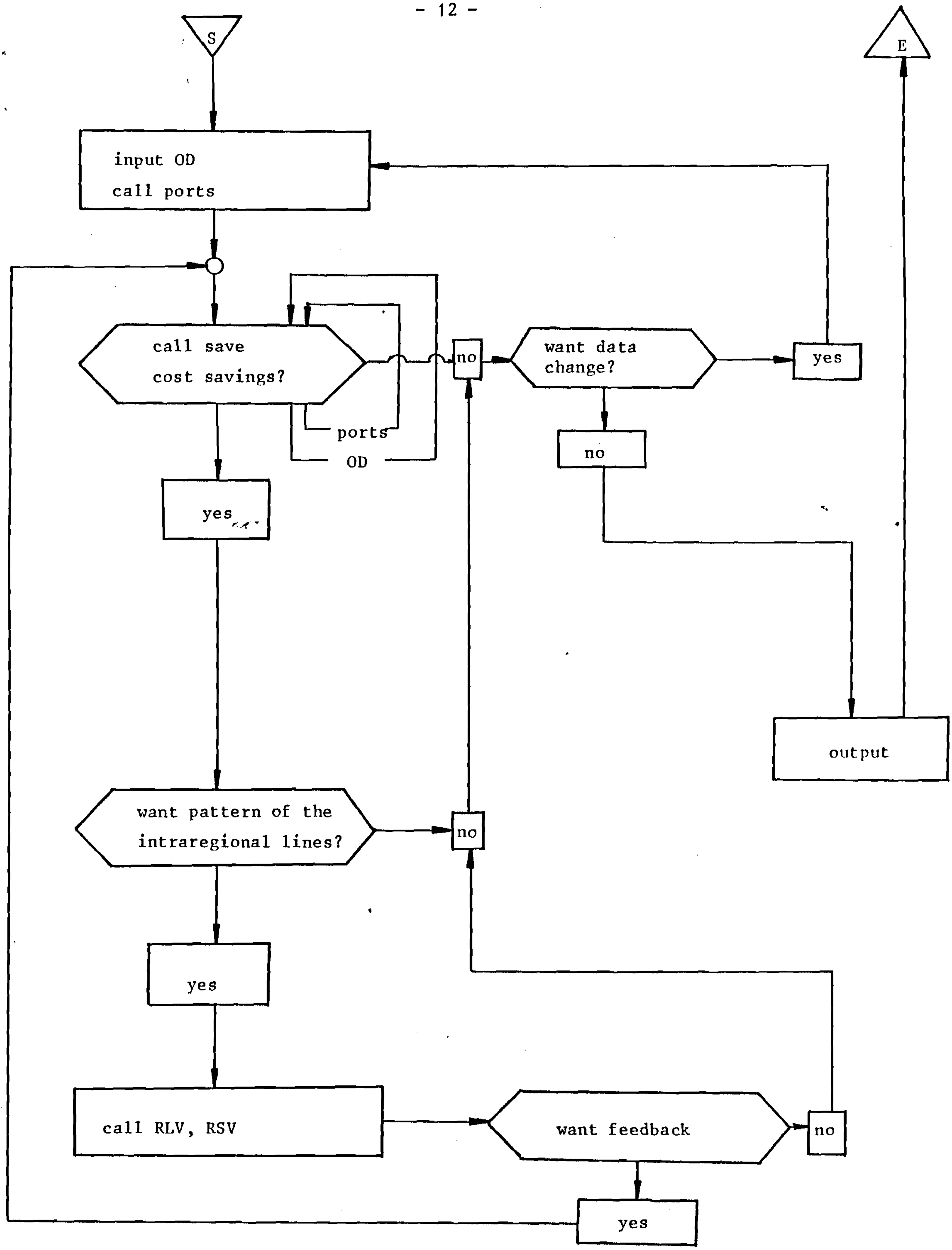


Figure 2: Flow Chart of the RIV-Routine

Figure 2 exhibits a rough flow chart of the computation process for the RIV routine. It shows the model's working procedure, if the planner is on-line. An off-line procedure differs from this chart in that the active responses of the planner are excluded.

It should be noted as a matter of course that the planner may leave out the RIV routine by taking the extraregional liner traffic as given inputs to his planning problem.

2.4 Large Vessel Intraregional Shipment

The model RLV for routing the large vessels which are operating intraregionally is started by putting in input options such as fixed OD-pairs or routes. The flow matrix (matrix of intraregional maritime transports of the cargo type chosen) and the ports which ar capable of or considered for operating large vessels are read from the data bank (see Figure 3). If the planner is interested in a feedback with the previous model RIV, the flow matrix has to be updated, because RIV output consists of proposed shifts of transport volumes between ocean liners and the intraregional transport system.

In the following step the MULTISAVE routine is applied to design a pattern of economically efficient routes for intraregional large vessels. This routine starts by linking all ports of the port array, such that the initial routes consist of direct connections, only (except for the fixed options). In the following process the routine tries to reduce transport costs by successively linking short routes together and creating longer roundtrips. Note, that the cost comparison includes the costs of small vessel transport which are read from a matrix of shortest cost distances for small vessels generated by the following model RSV (initialization may be done by putting in the estimated cost of present small vessel service). Note further, that the routine may be started with solutions of preceeding runs, if it is used for several times in a feedback process. The routine ends if further links yield no additional cost savings.

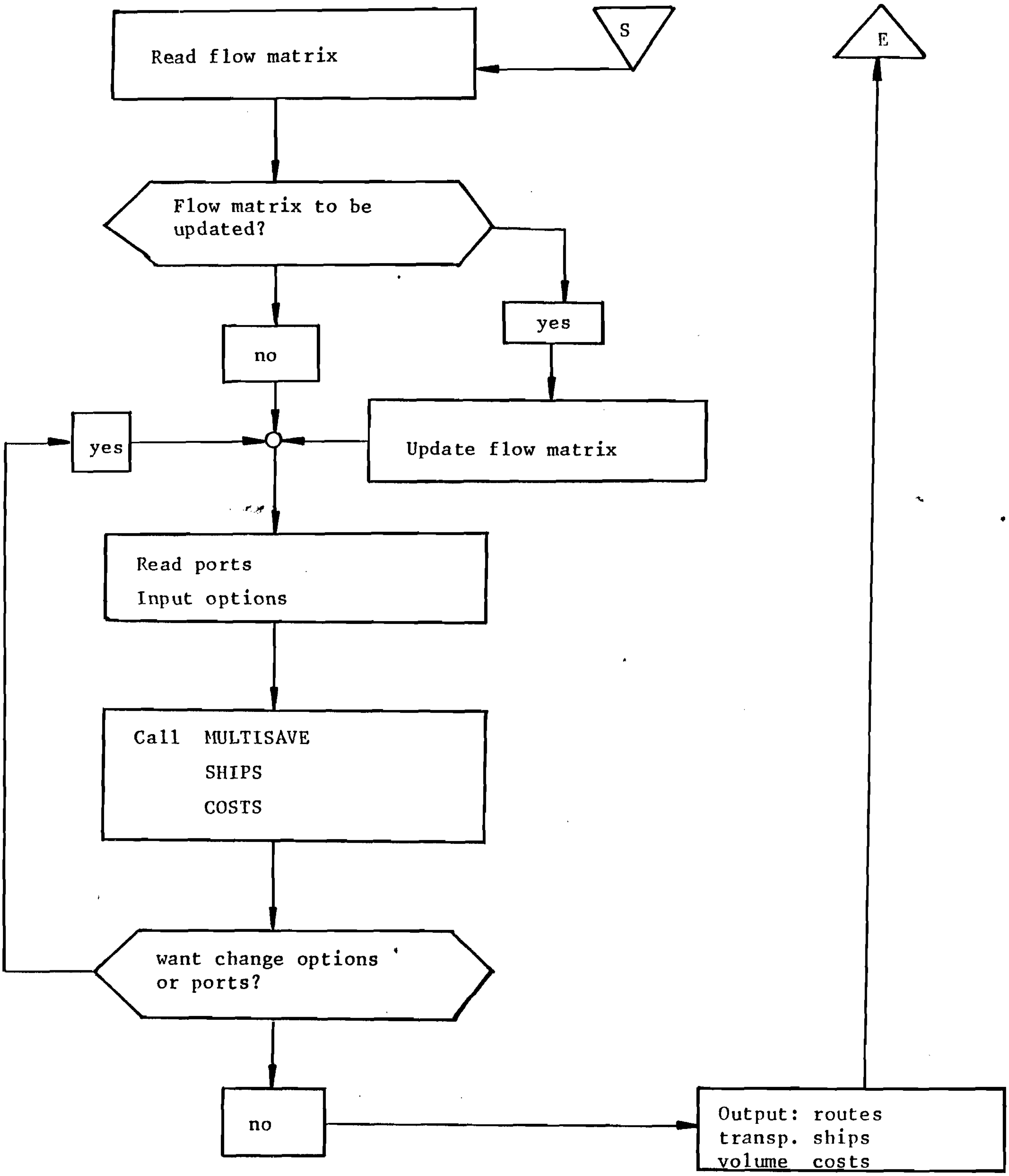


Figure 3: Flow chart of the RLV routine

During the MULTISAVE analysis, some subroutines are being called up with high frequency, such as the saving method, the ship assignment and the cost computation. These subroutines are described in Section 4. The model's output comprises the results on routes created, ships assigned, transport volumes served and the associated costs.

2.5 Small Vessel Intraregional Shipments

The RSV routine for generating routes for small vessel shipping is similar to the RLV algorithm. The differences between RLV and RSV are only:

- RSV is concerned with all ports of the Caribbean;
- RSV has to serve total transportation demand remaining after having run RIV and RLV;
- the search for route connections in the MULTISAVE subroutine will be limited by putting in maximal operation distances for small vessels.

The last restriction mentioned is intended to make sure that the computation process does not exceed a reasonable time span.

3. Modular Structure and Dialogue Capability

3.1 Requirements for Implementation on Small Computers

The basic requirement for implementing transportation models consists in a sequential run such that only a small part of the total data arrays must be worked on simultaneously. This requirement can be fulfilled by breaking down the bulk of model issues into independent subproblems, each of which requires the sequential solution of small and simple computation problems. For instance, if the RIV routine is in operation, then the only data needed from RLV and RSV can be con-

densed in form of a matrix of shortest cost distance of the size n x n, if n is the number of ports in the Caribbean. The RLV-routine only needs the shortest cost distances from RSV (n x n - matrix) and the final RSV-routine does not need any cost data from RIV and RLV, the linkage between RLV and RSV consists in the variation of transport flows at the very beginning of the RSV process, only.

Thus, the requirements for core/memory are relatively low, because the data arrays on routing patterns for all routines which are not acutally worked on, can be stored by peripheral memory. Small computers and personal computers have a basic memory of ca 128 K-Bytes which is extendable in most cases. For the modern machines there is no problem to assign a peripheral memory of about 5 M-Byte, which will be absolutely sufficient for operating the model. */

There is a further advantage of this model construction to be considered: it is a natural consequence of decomposition that the model will be programmed in a modular way, i.e. every submodel is independent of the other submodels. Furthermore, the subroutines which are used for the computation steps are separable and can be written as independent subprograms. This means: it is easy to modify elements of the model in the future, because this may simply be done by exchanging the modules concerned without influencing the total set up of the program. This is most important, because the data base may change or new issues may be generated in the future which call for an adjustment of the program.

3.2 Dialogue and Control

As can be seen by the flow charts of Figures 2 and 3, the model allows for interactive feedbacks between the planner and the model, such that the model can be used for a step-by-step mutual learning process, which leads to a better evaluation of input data and of the

*/ It must be noticed however, that computation on personal computers are time consuming compared to computers with larger capacities, which will be more convenient, if the model's total sequence is run with several feedbacks.

output generated. As most planners are not used to think in the Computer's terms, it is an important issue to provide a good representation of the model's outcome by intuitively understandable symbols on a monitor or TV screen. So the transport volumes on the links and the number of ships operating between each two ports can be represented graphically. This macroscopic view could be supplemented by graphics which give a microscopic view of onward traffic flow and routing for any selcted port of origin. This device improves the planner's control on the reliability of the detailed arrangements made by the model.

3.3 Optimality Property

The proposed solution techniques for CMTM may be characterised from the mathematical point of view as a "heuristic method". This means that there is no guarantee that the model finds the overall optimum solution in a finite (or even in an infinite) number of steps. This is of course unsatisfactory for a theorist. But there is, on the other hand, a chance for a limited control of the model's efficiency.

If the present situation (routes, vessels, costs) is taken as a reference point, then the improvements of the solutions generated by the model can be evaluated by computing the cost differences. So while the model cannot provide for the optimum solution, it can suggest steps in the direction towards this optimum. From the point of view of realism, one has to consider this a progress compared to methods which are able to compute proved optimum solutions for highly unrealistically modelled environments.

4. Basic Elements of Computation

4.1 Modelling the Network

A simple and efficient way of modelling ports and (potential) shipping links between the ports is to represent the ports by points in a coordinate system. We define an (x,y) coordinate system with an

arbitrary origin and a fixed scale (e.g.: 1 : 10,000,000). Thus each port may be characterized by a number and by its coordinates. It is possible then to calculate the distances between the ports by the formula

(4.1) $$d(i,j) = [x(i) - x(j))^2 + (y(i) - y(j))^2]^{1/2}$$

$d(i,j)$: Euclidean (≙ airline) distance between ports i and j.

If the average speeds and operating costs per mile are given for each vessel type, it is easy to derive the

- travel times
- operating costs on sea .

By applying the coordinate method it is possible, furthermore to select ports which are located in a defined corridor (needed for routines RIV and RLV) or in a defined circle (needed for routine RSV).

4.2 The Savings Method

(a) Basic Idea and One Depot Routing

The Savings Method has been developed for solving routing problems for regional waste disposal. By comparing the Savings Method to other heuristic techniques in experimental test runs the Savings Method came out to be the most efficient technique for problem types similar to the Caribbean intraregional maritime shipping problem, measured in terms of deviation from the actual optimum solution, computation time and CPU required for calculation*/

The Savings Method starts by assuming an originating point (called "depot" in the case of waste disposal modelling) is linked to each other node of the network, such that the number of routes is equal to the number of nodes. The total distance for this initial routing plan is then

*/

(4.2) $$D = 2 \sum_{i \in I} d(0,i)$$

I: set of nodes

0: originating node (depot).

The basic idea of the method is now to check step by step the possibilities of reducing distances by linking different routes together. If the end nodes of two different routes are i and j then a linking of these routes leads to a rotal reduction in routing distances of

(4.3) $$S(i,j) = 2\,[d(0,i) + d(0,j)] - d(0,i,j,0)$$

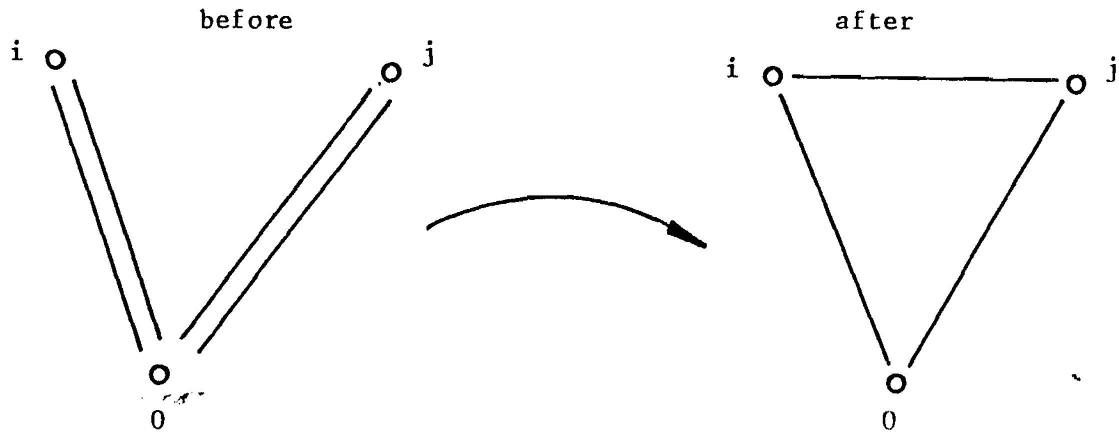
S(i,j): distance reduction by combining routes with end nodes i and j.

Figure 4 exhibits the effects occurring by route combination in the first step after initialization and in an intermediate stage of method processing.

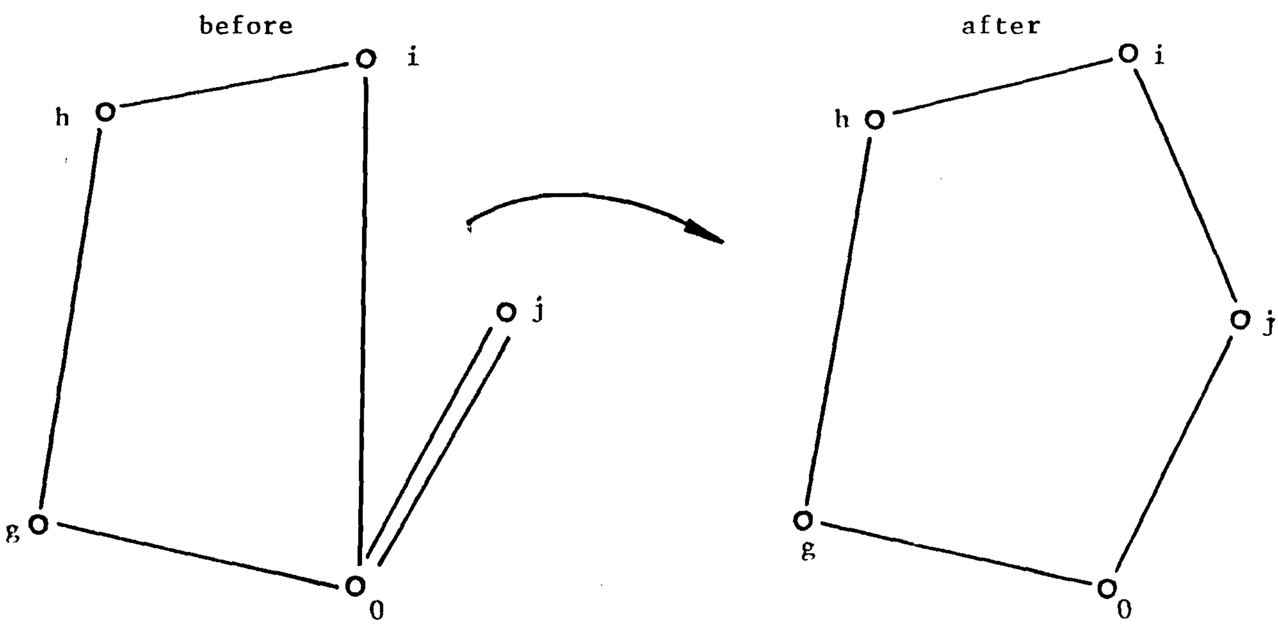
The savings value (4.3) is used as a criterion for the selection of pairs of end nodes (i,j) which are considered for a route combination. As a general selection rule the pair (i,j) associated with the maximal savings values is selected first, the pair (i',j') associated with the next best savings value is selected second, and so on. This means that the saving values (4.3) have to be sorted in descending order.

To conclude, the savings method can be described to consist of five steps:

- Initialize;
- Compute savings values;
- Sort savings values in descending order;
- Construct routes;
- Construct matrices of results (distances, costs).



a) Route Linking at the Beginning of the Process



b) Route Linking in an Intermediate Stage of the Process

Figure 4: Route Combination by Applying the Saving Method

(b) Computations in the SAVE Subroutine

The SAVE subroutine is called by RIV, i.e. the routine for rerouting interregionally operating ocean vessels. SAVE is basically being characterized as a simple cost comparison between a route directly connecting an extra-Caribbean region with a Caribbean port and routes which contain additional stops for carrying out intraregional transport services.

In the first step SAVE computes the savings values for all ports j which are considered for interim stops on a defined OD-relationships, when i denotes an origin or destination or interim port located in the Caribbean:

(4.4) $$S(i,j) = C(i,j) \cdot x(i,j) + C(j,i) \cdot x(j,i) - \bar{C}(i,j) \cdot x(i,j) - \bar{C}(j,i) \cdot x(j,i)$$

S(i,j): Cost saving by introducing interim stop j;

C(i,j): Transportation costs per unit of cargo for intraregional service between ports i and j;

$\bar{C}(i,j)$: Transportation costs per unit of cargo for ocean vessel service between ports i and j;

x(i,j): Transport volume which can be served maximally by ocean vessels between i and j.

The result of (4.4) consists in a list of ports which are considered for large ocean vessel service. In the following steps of computation the algorithm checks possibilities to combine some ports listed and to construct new routes. This can be performed by the one-depot savings method described in (a).

The cost terms C(i,j) are read from a matrix of shortest cost distances, which has been generated by the RLV and RSV-routines (or has to be initialized exogenously). The cost terms $\bar{C}(i,j)$ are being calculated by subroutines described in sections 4.4 - 4.6.

(c) Computations in the MULTISAVE Subroutine

The MULTISAVE subroutine is explained here in the extensive form as used in the RSV section. We have to consider all ports of the Caribbean and a matrix of transport relationship. The problem is to find routes and assign ships to these routes such that transportation demand is satisfied and cost of transportation are minimized. */ In developing a solution concept it is essential to remember that the transportation demands are highly asymmetric **/. This means that the savings method described in (a) cannot be applied without modifications.

In a rough outline the MULTISAVE algorithm works as follows:

STEP 1: Initialize. Generate direct connections between all ports of the list. Compute costs. Go to STEP 2.

STEP 2: Compute "forward direction savings values" for all end nodes of routes constructed. Select max. savings value subject to constraints of max. time and max. distance. Link selected routes forwardly.

STEP 3: Update "incremental transport matrix". All incremental demands served?
YES: Go to STEP 4.
NO: Go to STEP 2.

STEP 4: Generate output. End.

The heart of the procedure is incorporated in STEP 2. The basic idea is to successively construct forward routing schemes, i.e. to generate routes for one direction, starting at an originating node i and terminating at this node ***/. The cost comparison in this case

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*/ As to the optimality property see section 3.3.

**/ See section 1.2

***/ The linking procedure is comparable to the savings algorithm for the multiple depot case (see Paessens, 1981).

comprises the transport activities for the selected direction, only, (cost situation without minus cost situation with route combination). The demand/cost situation of the reverse direction is left for the actual cost comparison in STEP 2. The reverse direction will be taken into consideration when it is selected by the max. savings computation. A second essential part of the method is to construct an "incremental transport matrix" and to update it after each route determination. This means that the incremental transport matrix is identical to the matrix of intraregional transport flows at the beginning of the process. Then, after each route determination in STEP 2 the transport demands served by this route are subtracted from the predecessing demand values. As the demand values highly influence the transport costs the computation process will select routes first which are associated with high transport volumes and then successively turn to serve lower demand volumes. But note that this doesn't mean that the process selects routes strictly in descending order of demand values, as other important influencing factors taken into account are variable and fixed costs for vessel operations and costs of port services all of which affect the size of the cost per unit of cargo.

The sequential selection process for the routing in STEP 2 is illustrated by Figure 5.

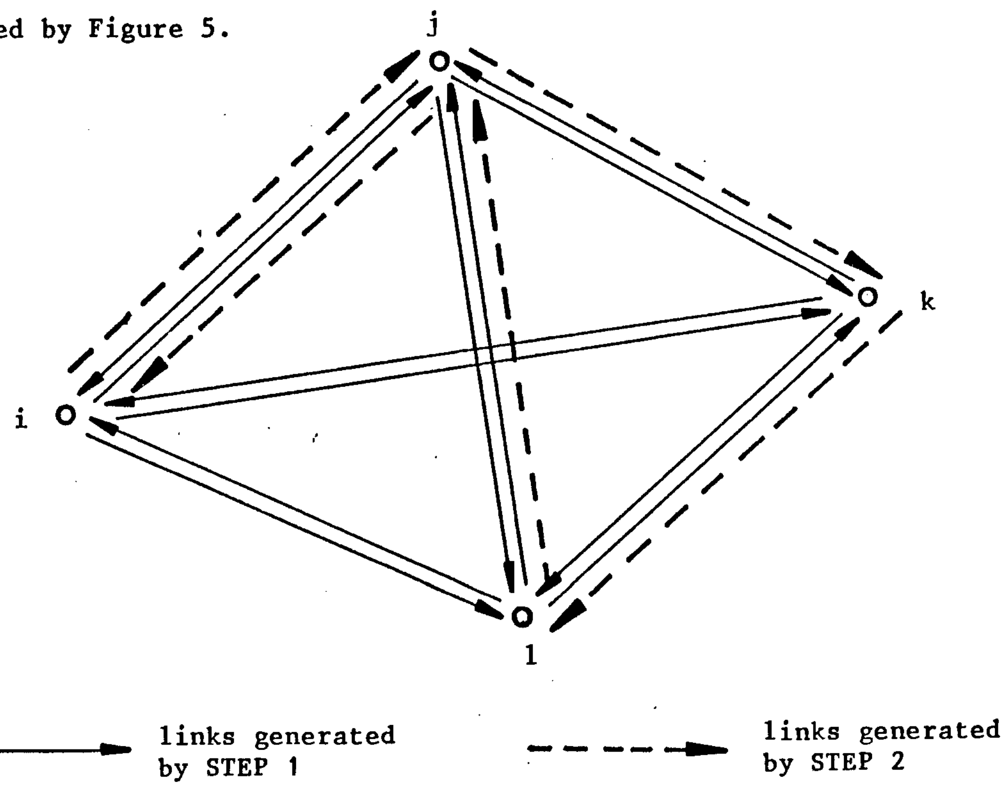
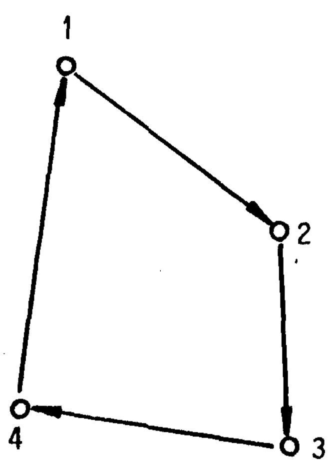


Figure 5: Generating routes by MULTISAVE.

Figure 5 shows that the initially generated routes (thin lines) are successively substituted by longer directed routes (dotted lines).

4.3 Link Capacities for Combined Load/Unload Activities on the Roundtrips

As deliveries can be made from each node to all other nodes of a specific route the problem of assigning ships and loads to a route is by no means a trivial one. Take for instance the situation illustrated by Figure 6. Suppose a route is combing nodes 1,2,3,4. Then the minimum capacity required to serve the demand along this route can be calculated in the way shown in the column "Min.Cap." in Figure 6. But there



Link	Min. Cap.	Max. Cap.
(12)	$L_{12} = X_{12} + X_{13} + X_{14}$	$L^*_{12} = L_{12}$
(23)	$L_{23} = X_{13} + X_{23} + X_{14}$	$L^*_{23} = L_{23} + X_{21}$
(34)	$L_{34} = X_{14} + X_{34}$	$L^*_{34} = L_{34} + X_{21} + X_{31}$
(41)	$L_{41} = X_{41}$	$L^*_{41} = L_{41} + X_{21} + X_{31}$
Requ. Cap.	$\text{Max.}\{L_{12},L_{23},L_{34},L_{41}\}$	$\text{Max.}\{L^*_{12},L^*_{23},L^*_{34},L^*_{41}\}$

Figure 6: Link Capacity Problem

could exist a possibility for picking up loads in ports 2 and 3 which are destinated for port 1. In this case the capacity required would have to be extended according to the column "Max. Cap.".

There is no problem involved in this loading/unlodading schedule, if the number of ships required for "Max. Cap." equals the number of ships required for "Min.Cap.". But if this is not the case the combinatorial problem arising can be tedious, indeed. Several possibilities should be checked before deciding on the way to proceed:

- Are there technical constraints (ships, ports), which help to reduce the number of combinations for loadings/unloadings?
- Is the approximations quality good enough, if the cost of the "Min.Cap." and "Max.Cap." solutions are compared and the cost minimal solution is selected for the further process?
- Could a modified version of the CEPAL-model, a network assignment algorithm (see Le Blanc and Rothengatter, 1983; 1984) or an optimization method for stockage problems (see Le Blanc, 1982) be applied efficiently for solving these combinatorial subproblems?

Of course the most simple way would consist in introducing a cost comparison step similar to the savings method, but this point needs further consideration before developing a programming code.

4.4 Number of Vessels for a Roundtrip

Let $d_s^r(i,j)$ be the number of days on sea on route r between ports i and j and $d_p^r(i)$ the number of days for waiting in line and for operation in port i.
Then,

$$(4.5)\qquad \sum_{(i,j)\,\varepsilon\, L_r} d_s^r(i,j) + \sum_{i\,\varepsilon\, I_r} d_p^r(i) = d^r$$

L_r: set of links on route r; I_r: set of ports on route r;

is the number of days for one roundtrip on route r. If D is the total number of days per year for which a vessel can be operated, then

(4.6) $$D/d^r = u^r$$

is the frequency of vessel service on route r. Multiplying this frequency by the vessel capacity C_r we get the transport volume which can be served by one vessel per year on route r, T_v^r. Dividing the required capacity on route r, C^r, by T_v^r results in the number of vessels V^r required to serve the transportation demand on route r.

(4.8) $$C^r/T_v^r =: V^r.$$

4.5 Cost Function

The transport costs incurred by maritime shipments consist of

- fixed costs for investment (annuity) and for the crew (yearly salaries),
- variable costs of sea operation,
- variable costs of port operation.

It is necessary to collect port data (average waiting time, operation time, port charges) and ship data to construct cost functions differentiated by ports and vessel types. Some examples are given in Lundstrom (1976), which give an idea on the relationships between vessel types, distances, cargoes and transport costs.

5. Conclusion

A concept for modelling the intraregional Caribbean Maritime transports has been developed, which focuses on the interdependent routing problems which arise in interdependent intraregional transport systems. The routing and associated assignment problems are solved by decomposition and sequential solution of subproblems.

It is proposed to apply heuristics instead of total programming techniques, because the heuristic approach allows for constructing a computation sequence which yields improvements over the status quo and can be implemented on small computers and provide possibilities for on-line dialogues between model and planner. The mathematical instruments required for this analysis are rather simple and easy to understand. These advantages come at the cost of not being certain that the computations actually reach a global optimum.

While this may be disappointing from a purely theoretical point of view it has to be pointed out that on the other hand, the model is able to tackle problems which the transport planner in the Caribbean is strongly confronted with and leaves him the chance to understand and to control the procedures. An appropriate comment to the issue at hand is a statement by Kenneth E. Boulding: "Mathematics in any of its applied fields is a wonderful servant but a very bad master". It is in this spirit of constructive pragmatism that the present work lays a useful basis for the planning of Maritime Transport in the Caribbean.

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6. Appendix

6.1. Model Formulation of CEPAL (1982)

In mathematical terms, the objective of the model is to minimize

$$Z = \sum_{l} b_l y_l + \sum_{ijkl} c_{ijkl} x_{ijkl} + \sum_{jikl} c_{jikl} x_{jikl}$$

subject to the constraints

$$- y_l + \sum_{ijk\}l} x_{ijkl} \leq 0 \qquad \text{for all } l \qquad (1)$$

$$- y_l + \sum_{jik\}l} x_{jikl} \leq 0 \qquad \text{for all } l \qquad (2)$$

$$\sum_{l} x_{ijkl} = q_{ijk} \qquad \text{for all } ijk \qquad (3)$$

$$\sum_{l} x_{jikl} = q_{jik} \qquad \text{for all } jik \qquad (4)$$

$$\sum_{l\}ijk} y_l \geq F_{ijk} \qquad \text{for any } ijk \qquad (5)$$

$$\sum_{l\}jik} y_l \geq F_{jik} \qquad \text{for any } jik \qquad (6)$$

where i is a port in Latin America;
j is a port in Japan;
k is a type of cargo;
l is a shipping service consisting of a particular type of ship plying a particular round voyage itinerary;

Note: The character } is used to mean "is an element of".

b is the long-term round voyage operating cost per shipping ton of a vessel while at sea;

c is the cost per shipping ton of loading, discharging and operating a vessel while in port;

F is a minimum frequency of service, measured in shipping tons per time period;

q is a quantity of cargo offered for carriage, measured in shipping tons, that must be transported;

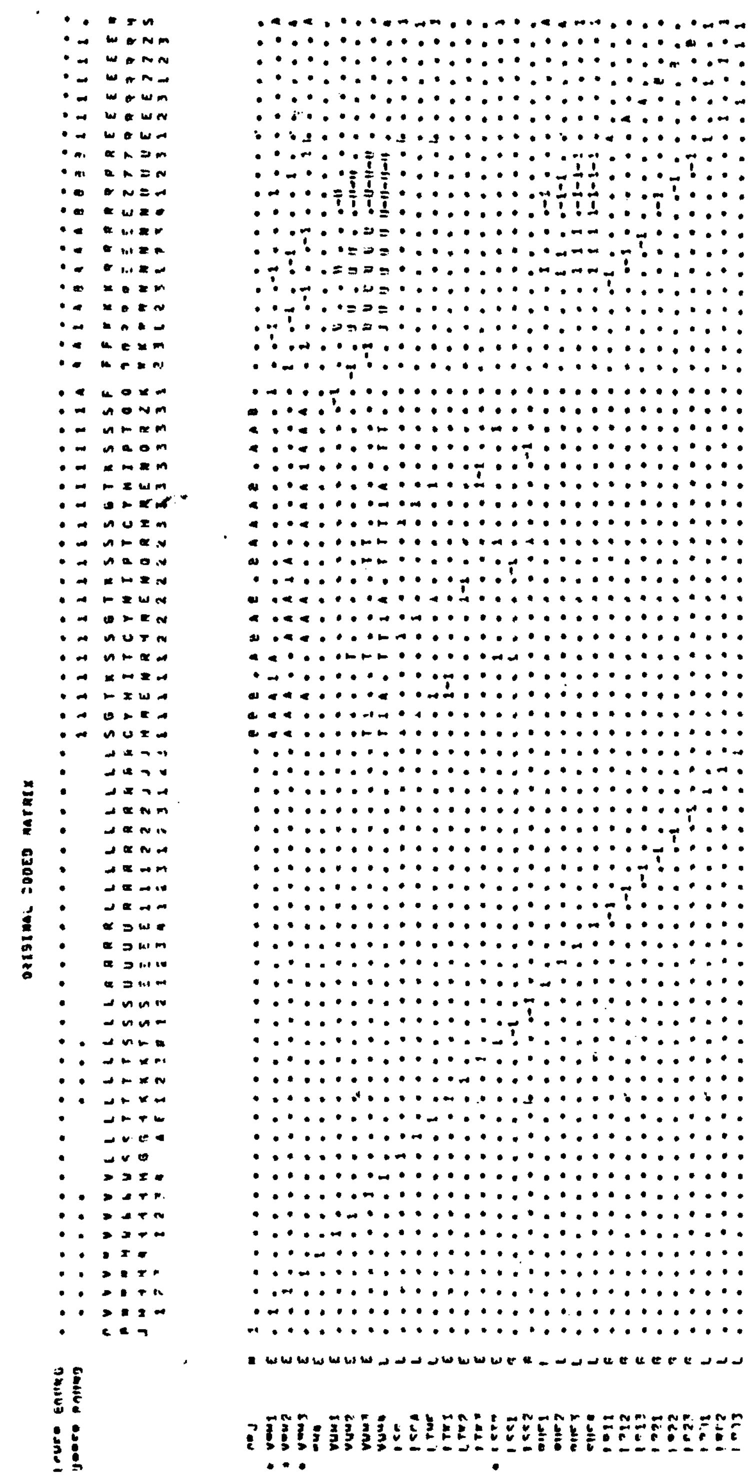
x is the quantity of cargo, measured in shipping tons, that the model assigns to a particular service;

y is the capacity, measured in shipping tons, that the model assigns to a particular service in order to transport all of the cargo quantities assigned to that service.

The model optimizes the capacities for particular service types (y_1) and the quantities of cargo of type k which are assigned to the services 1 on transportation relationships from i to j (x_{ijkl}). The intraregional routing problems are not solved and important characteristics of intraregional transport are left behind, to keep the approach simple. So the model could be used to solve subproblems, such as the capacity/ assignment problem addressed in section 4.3.

6.3. Output of a Mixed-Integer Programming Model

a) Structure of the Program by Rows



E,L,G mean equal, less, greater

A,B,T,U characterize the size of coefficients

b) Mixed-Integer Solution (IT: integer variables)

SECTION 1 - ROWS

PRIMAL-DUAL OUTPUT

NUMBER	..NAME..	AT	..ACTIVITY..	SLACK ACTIVITY	.LOWER LIMIT	.UPPER LIMIT	DUAL ACTIVITY	.INPUT COST.	REDUCED COST
1	OBJ	BS	72.28737	-72.28737	NONE	NONE	-1.00000	.	-1.00000
2	VMH1	EQ	3.00000	.	3.00000	3.00000	8.78866	.	8.78866
3	VMH2	EQ	7.00000	.	7.00000	7.00000	7.96392	.	7.96392
4	VMH3	EQ	8.00000	.	8.00000	8.00000	7.50000	.	7.50000
5	MHA	BS	.	.	.	.	.	.	.
6	VUH1	EQ	.	.	.	.	8.78866	.	8.78866
7	VUH2	EQ	.	.	.	.	7.96392	.	7.96392
8	VUH3	EQ	.	.	.	.	7.50000	.	7.50000
9	VUH4	UL	5.00000	.	NONE	5.00000	90.00000	.	90.00000
10	ISC	BS	1.00000	.	NONE	1.00000	.	.	.
11	ISCA	BS	1.00000	.	NONE	1.00000	.	.	.
12	LTHE	BS	1.00000	.	NONE	1.00000	.	.	.
13	LTK1	EQ	.	.	.	.	-380.23196	.	-380.23196
14	LTK2	EQ	.	.	.	.	-340.74742	.	-340.74742
15	LTK3	EQ	.	.	.	.	7.50000	.	7.50000
16	LSTP	EQ	1.00000	.	1.00000	1.00000	-5.75000	.	-5.75000
17	LSS1	BS	1.00000	1.00000	.	NONE	.	.	.
18	LSS2	BS	.	.	.	NONE	.	.	.
19	PUF1	UL	2.00000	.	NONE	2.00000	.32216	.	.32216
20	PUF2	BS	-.86082	3.86082	NONE	3.00000	.	.	.
21	PUF3	UL	1.00000	.	NONE	1.00000	1.87500	.	1.87500
22	PUF4	BS	1.00000	.	NONE	1.00000	.	.	.
23	LP11	LL	.	.	.	NONE	.	.	.
24	LP12	LL	.	.	.	NONE	.	.	.
25	LP13	BS	8.13918	8.13918	.	NONE	.	.	.
26	LP21	LL	.	.	.	NONE	.	.	.
27	LP22	BS	17.13918	17.13918	.	NONE	.	.	.
28	LP23	LL	.	.	.	NONE	.	.	.
29	LPC1	BS	1.00000	.	NONE	1.00000	.	.	.
30	LPC2	UL	1.00000	.	NONE	1.00000	.	.	.
31	LPC3	UL	1.00000	.	NONE	1.00000	.	.	.

NUMBER	..NAME..	AT	..ACTIVITY..	.INPUT COST.	.LOWER LIMIT	.UPPER LIMIT	REDUCED COST
32	SCH1	IT	1.00000	17.00000	.	1.00000	99.72165
33	GYM1	IT	.	21.00000	.	1.00000	159.61340
34	THE1	IT	.	45.00000	.	1.00000	.
35	KTH1	IT	.	.	.	1.00000	389.02062
36	STP1	IT	1.00000	5.00000	.	1.00000	19.37371
37	SCH2	IT	.	32.00000	.	1.00000	95.89175
38	GYM2	IT	.	13.00000	.	1.00000	156.39175
39	THE2	IT	.	45.00000	.	1.00000	.
40	KTH2	IT	.	.	.	1.00000	348.71139
41	SPO2	IT	.	20.00000	.	1.00000	42.89175
42	STP2	IT	.	4.00000	.	1.00000	.
43	SCH3	IT	.	17.00000	.	1.00000	66.50000
44	GYM3	IT	1.00000	30.00000	.	1.00000	102.50000
45	THE3	IT	1.00000	35.00000	.	1.00000	295.00000
46	KTH3	IT	1.00000	.	.	1.00000	.
47	SPO3	IT	.	20.00000	.	1.00000	98.50000
48	STP3	IT	.	3.00000	.	1.00000	15.25000
49	SN73	BS	.88582	15.00000	.	1.00000	.
50	EAV1	BS	.16250	.	.	5.00000	.
51	EAV2	BS	.13918	.	.	5.00000	.
52	EAV3	BS	.22648	.	.	5.00000	.
53	VPM1	BS	.06250	.	.	1.00000	.
54	KPM2	LL	.	.	.	2.00000	.15964
55	KPM3	BS	2.93750	.	.	18.00000	.
56	PCM1	BS	2.00000	.	.	2.00000	.
57	PCM2	BS	.	.	.	10.00000	.
58	PCM3	BS	1.86382	.	.	11.00000	.
59	PCM4	LL	.	.	.	23.00000	2.70000
60	PZH1	AT	.	.	.	15.00000	.
61	PZH2	BS	2.86082	.	.	20.00000	.
62	PZH3	BS	.	.	.	21.00000	.
63	FPC1	IT	1.00000	.	.	1.00000	.
64	FPC2	IT	.	.	.	1.00000	.
65	FPC3	IT	1.00000	.	.	1.00000	.
66	FPZ1	IT	.	.	.	1.00000	.
67	FPZ2	IT	1.00000	.	.	1.00000	.
68	FPZ3	IT	.	.	.	1.00000	.

The problem exhibited in a) und b) consists of 36 variables (23 integers) and 30 constraints. Problems of this size can be solved easily by LP and optimal subset selection techniques. If there are thousands of rows and columns however, as would be the case for CMTM, then difficult problems arise as to data input and input control, aggregation and interpretation of output results and control of the optimization procedure (simplex or revised simplex method, decomposition possible by the method of Dantzig and Wolfe).

Table 2: Interregional Transport Volume /metric tons/ 1980
Source: CARINTRA (1982)

Origin \ Destination	1	2	3	4	5	6	7	8	9
1. Antigua	0	0	0	0	0	0	0	0	0
2. Bahamas	0	0	1	0	0	21	0	0	26
3. Barbados	0	0	0	0	0	0	0	0	11
4. Belize	0	0	0	0	0	0	0	0	72
5. Br. Virgin Is.	0	0	0	0	0	0	0	0	0
6. Cayman Is.	0	342	0	242	0	0	0	0	0
7. Cuba	0	2	0	0	0	0	0	0	0
8. Dominica	0	0	10	0	0	0	0	0	165
9. Dom. Rep.	485	0	3639	1317	1	252	0	1401	0

Origin \ Destination	1	2	3
10. Grenada	0	0	6
11. Guadeloupe	0	0	57
12. Guyana	0	0	0
13. Haiti	0	17	0
14. Jamaica	1431	376	5881
15. Martinique	0	0	18
16. Montserrat	0	0	0
17. Netherlands Ant.	0	160337	41
18. St.Kitts/Nevis	0	16	0

4	5	6	7	8	9
0	0	0	0	0	0
0	0	5	115	159	7
0	0	0	0	0	4
0	0	0	0	0	100
867	4	45008	332	1172	18097
0	0	0	0	0	5
0	0	0	0	0	0
0	0	0	0	0	257289
0	0	0	0	0	0

Origin \ Destination	1	2	3
19. Saint Lucia	977	0	2212
20. St.Vincent	0	0	3793
21. Suriname	0	0	0
22. Trin.+ Tob.	107721	134387	169907
23. US. Vir.Is.	0	0	0
24. Venezuela	125	245738	154551
TOTAL	110739	541327	340116

4	5	6	7	8	9
0	0	0	0	2451	0
0	0	3193	0	0	1
0	0	0	0	0	5193
2307	17814	32073	0	43241	89620
0	0	0	0	0	9
0	257	14560	516949	0	221076
4733	18076	95112	517396	9507	691680

Origin \ Destination	10	11	12
1. Antigua	0	4814	0
2. Bahamas	0	0	0
3. Barbados	0	107	0
4. Belize	0	0	0
5. British Virgin Is.	0	0	0
6. Cayman Islands	0	0	19
7. Cuba	0	0	0
8. Dominica	0	39	0
9. Dominican Republic	3587	34776	291

13	14	15	16	17	18
3	157	0	0	52	0
2	7	36	0	4	18
0	2844	256	0	43	0
0	3066	0	0	0	0
0	0	0	0	0	0
0	90	0	0	5	0
0	0	0	0	4	0
0	8280	0	0	0	0
20	4359	13793	1530	6846	4490

Origin \ Destination	10	11	12
10. Grenada	0	1	0
11. Guadeloupe	21	0	0
12. Guyana	0	601	0
13. Haiti	0	105	0
14. Jamaica	849	4541	3133
15. Martinique	109	200699	0
16. Montserrat	0	7873	0
17. Netherlands Ant.	0	12462	0
18. St.Kitts/N/A	0	54	0

13	14	15	16	17	18
0	622	112	0	0	0
56	2	34157	1314	18238	0
1	55732	458	0	0	0
0	224	625	0	0	0
42089	0	5287	106	1853	595
2	0	0	71	51	0
0	20	15	0	4	0
23	1150606	9337	0	0	0
0	9	0	0	0	0

Origin \ Destination	10	11	12
19. Saint Lucia	1549	761	249
20. Saint Vincent	0	0	0
21. Suriname	0	13144	0
22. Trinidad + Tob.	23258	49295	490029
23. U.S. Virgin Is.	0	0	0
24. Venezuela	0	415181	855
TOTAL	29373	755750	494576

13	14	15	16	17	18
17	2625	0	111	0	74
0	454	0	0	0	0
0	27477	6238	0	1	0
81912	261657	5243	2305	172415	19051
0	0	0	0	0	0
1719	820116	21	2	24798805	0
126019	2338773	75578	5440	24998333	24288

Origin \ Destination	19
1. Antigua	0
2. Bahamas	0
3. Barbados	0
4. Belize	0
5. British Virgin Is.	0
6. Cayman Islands	0
7. Cuba	0
8. Dominica	0
9. Dominican Republic	8984

20	21	22	23	24
0	0	643	0	40
0	0	13	0	4078
0	0	20206	1	4
0	0	8114	0	0
0	0	30	0	0
0	0	0	0	0
0	0	0	0	28
0	0	0	0	4
5822	171845	950	1532	286512

Origin \ Destination	19
10. Grenada	0
11. Guadeloupe	11
12. Guyana	0
13. Haiti	45
14. Jamaica	2673
15. Martinique	0
16. Montserrat	0
17. Netherlands Antilles	0
18. St.Kitts/N/A	0

20	21	22	23	24
0	0	8284	0	0
189	3	454	8168	796
0	0	502583	0	186454
0	0	280	1	74
378	46486	136405	102	68764
0	66	74	0	371
0	0	18	0	0
0	0	69561	0	272181
0	0	715	0	0

Origin \ Description	19	20	21
19. Saint Lucia	0	1150	377
20. Saint Vincent	0	0	0
21. Suriname	0	0	0
22. Trinidad + Tobago	44977	19071	722056
23. US Virgin Is.	0	0	0
24. Venezuela	673	0	762
TOTAL	57363	26610	941801

22	23	24
4017	0	990
15974	0	24
297378	0	54536
0	9059	16934
9	0	18058
119079	257	0
1204404	19137	910272