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STRATEGIC PLANNING OF FREIGHT TRANSPORTATION IN BRAZIL: METHODOLOGY AND APPLICATIONS

Part 4

SPECIFYING DATA FOR THE STAN SYSTEM: REQUIREMENTS, CONCEPTS, SOURCES AND ESTIMATION PROCEDURES

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ABSTRACT

This is the final report of the cooperative project *Strategic Planning of Freight Transportation in Brazil*, carried out jointly by the Centre de Recherche sur les Transports of the Université de Montréal, the Pontifícia Universidade Católica do Rio de Janeiro and GEIPOT, the National Transportation Planning Company of the Brazilian Ministry of Transportation, with the financial support of the International Development Research Centre (Canada). The report consists of five parts:

Part I	Project Summary
Part II	Methodology: The New Contributions
Part III	The STAN System
Part IV	Specifying Data for the STAN System: Requirements, Concepts, Sources and Estimation Procedures
Part V	Applications.

Part IV describes the data that is required as input to the strategic planning system. The sources are specific to Brazil, while the concepts and the estimation procedures are general in nature and, therefore, of broader interest and applicability.

KEY WORDS: Multimode Multiproduct Freight Transportation,
Network Optimization Models,
National/Regional Strategic Analysis and Planning of Freight Flows,
Interactive-Graphic System.

RESUME

Ceci est le rapport final du projet de coopération *Strategic Planning of Freight Transportation in Brazil*, réalisé conjointement par le Centre de recherche sur les transports de l'Université de Montréal, la Pontifícia Universidade Católica do Rio de Janeiro et GEIPOT, l'agence de planification nationale du ministère des transports du Brésil, avec le support financier du Centre de recherches pour le développement international (Canada). Le rapport a cinq parties:

Part I	Project Summary
Part II	Methodology: The New Contributions
Part III	The STAN System
Part IV	Specifying Data for the STAN System: Requirements, Concepts, Sources and Estimation Procedures
Part V	Applications.

La partie IV décrit les données qui doivent être fournies au système stratégique de planification. Les parties concernant les sources de données sont spécifiques au Brésil, tandis que les concepts et les procédures d'estimation sont générales.

MOTS CLES: Transport multimode multiproduit de marchandises,
Modèles d'optimisation de réseaux,
Planification stratégique nationale/régionale,
Système interactif-graphique.

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CHAPTER ONE

GENERAL CONCEPTS ABOUT DATA

Information is fundamentally important to any decision making process. Its validity and quality, as well as its timely update and easy accessibility, contribute significantly to the proper use and success of any planning and decision making method.

Much attention has therefore been devoted during the design and development of the STAN system to the proper definition of the information requirements. A considerable amount of effort also went into the compilation of the data sources available and into the collection, reconciliation and analysis of the data that would be used for the various Brazilian applications.

The chapters of Part IV are dedicated to the presentation of the main criteria used to define the type and characteristics of the data necessary for use with STAN in the analysis of strategic planning scenarios and to the illustration of the various manipulations that were required to transform the available information into usable data.

Specifically, this chapter presents these fundamental criteria and definitions and briefly explores the issue of maintaining and updating a STAN database in Brazil. In the following chapters, the applications of these criteria are described and the work carried out during the project to collect, correct and analyze data is illustrated by using the pilot application of STAN concerning the South-East region of Brazil. The first three chapters parallel Chapters 4 and 5 of Part II and are concerned with the definition and computation of the network data for the rail, road, ports and navigation modes. Finally, Chapter 5 examines issues related to the definition of products and the specification of the origin-destination demand matrices.

The importance of Part IV goes beyond its being a documentary of the huge amount of work accomplished during this project. We have described in Parts II and III the various elements of the STAN model and system and have thus implicitly specified the data requirements. The description of how actual data selections and functions fitting are used in this context may be of great instructional interest when new applications of STAN are contemplated. The description of the applications in PART V also contributes toward this end.

1.1 DATA REQUIREMENTS

Data requirements are usually defined in order to permit a meaningful representation and analysis of the system under study. This definition, which may be quite broad but precise, is constrained however by the availability of the data, by the requirements of the modeling and algorithmic approach and, also, by the anticipated efficiency of the solution and evaluation methods within the available computer-based system. It is, in fact, a multi-stage continuous process, that implies choices (e.g. the "modes" in STAN) during the development of the planning system.

STAN requires data describing the components of the multi-modal transportation network (modes, nodes, links, transfers) and their attributes (vehicles, lengths, capacities, unit costs, associated functions, etc.), and information specifying the multi-commodity transportation demand that is to be carried on this network: the amount of each product to be moved, on the permitted modes, from each origin to each destination.

The first step is the definition of a data base for a new application, is to divide the region under study into traffic zones, and to associate a centroid to each zone. Zones are generally defined according to several criteria, such as homogeneity, concordance with natural boundaries and compatibility with the main available statistical sources. For the Brazilian applications, we have adopted GEIPOT's zone definitions, which are sufficiently close to the zone subdivision proposed by IBGE in order to allow the use of the informations offered by this most important data source in Brazil.

The zones defined by GEIPOT served to subdivide the South-East region, while outside this region several groups of zones have been aggregated into, so called, *external zones.* To specify the external zones, we have generaly retained GEIPOT's zones that have significant trade flows with points inside the South-East region. The other zones have subsequently been aggregated around them.

The network data consists of various transportation modes, of the nodes and links which make up every modal subnetwork and of intermodal transfers at nodes. The network representation should retain sufficient detail in order to obtain a meaningful representation of the actual transportation system and to allow realistic strategic scenario analyses to be performed. On the other hand, all characteristics that do not significantly influence the outcome of such studies should not be included in the network model. Thus, road intersections and rail stations are modeled as simple nodes, while transfers may be used to represent important rail yards. Ports are either modeled as subnetworks or as transfers, depending on their importance.

The network in STAN consists of the most improtant data elements that achieve a strategic representation of the actual transportation system. Thus, only nodes and links with significant impact at this level of planning should be included: nodes and links which contribute to a meaningful graphical representation, nodes where transfers have to be defined or which help identify operationnally important links, etc. In such a representation, some abstraction is present: most of the small rail yards and most nodes of the road system, as well as most of the secondary links of the road network are not present in the network model.

The network representation is even more schematic outside the main region of the study. The role of this *external network* is to carry the traffic between the zones of the region and the external zones, while insuring that this traffic enters and exits the region at the proper nodes and follows realistic paths inside the region.

The external network is built along the following lines. Once the external zones are defined, the main boundary points are identified for the movements on each mode and are then linked to the centroids of the external zones. In general, only links that represent major transportation infrastructure, such as most rail lines and national highways, are considered in this phase. Links that represent secondary elements of the transportation system are then added to insure a connected network. Observed traffic flows may be successfully used in the determination of the links to include in the external network. This process usually results in a network which is quite dense close to the main region and which thins out as one is further away from the region's boundaries.

The network for the South-East region application has been defined based on a rather detailed network representation developped by GEIPOT (1980a). This network has subsequently been aggregated, simplified and updated according to the preceding ideas and by using various data sources: DNER for the road; the three main Brazilian rail companies, RFFSA, FEPASA and CVRD, for the rail subnetwork; PORTOBRÁS for ports and SUNAMAN for the navigation mode. A list of the data sources used during this phase of the project appears in the References section of this chapter.

In order to complete the network specification, various attributes have to be defined: the characteristics of the typical vehicles that transport each product on each mode, physical characteristics and unit costs for the transportation, energy and delay parts of the cost function for each link and transfer, as well as functional forms for the relations that quantify the delays due to the congestion effects observed on the links and transfers of the network. This exercise has required long, arduous and often frustrating efforts, sometimes due to the lack of homogeneity among the data sources and often due to lack of data.

Data that permits a meaningful visual representation of the network has also to be included: spatial coordinates for nodes, demarcation lines for the national and regional boundaries, as well as for significant natural (such as rivers or mountain ranges) or artificial (large hydro-electric works for example) geographical features, etc.

The demand for transportation is represented in the STAN system by origin-destination (O/D) matrices containing the quantity (in tons) of each product that has to be moved between the centroids of the network.

Building origin-destination matrices is a formidable task that could not have been successfuly accomplished without existing data within the short time and limited budget available for the project. We were fortunate in this respect, as

GEIPOT already had built such O/D matrices and made them available for the project. These matrices were then updated and aggregated according to the network definition of the South-East region application. In particular, and in order to insure the realisation of this phase of the project within the available ressources, only 8 of the 29 products defined in GEIPOT's studies were chosen for validation purposes. These products were chosen based on their importance and impact on the transportation system in the South-East region. Each represents either a major production/consumption commodity in the region, or an important import/export product. In either case, these products generate major flows on the links of all modes present in the region. These products are: iron ore, steel products, coal, cement, fertilizers, soya oil, soya grain, soya meal.

For each product, either an exogeneous modal split is specified, or the assignment is performed on the multi-modal network according to a chosen mesure of generalized cost. When the first alternative is chosen, the O/D matrix for each product is to be separated into as many matrices as necessary to represent the demand for a given mode or a subset of modes used for the product.

The availability of observed traffic flows on each of the modes may be of great value, both to determine the modal split and for validation purposes. Equally valuable in this context are the knowledge of the input/output structure of the region's economy and the capability to infer future demand requirements. We examined, although briefly, all these issues and we illustrate these efforts in the following chapters.

1.2 UPDATING THE DATA

During the project, a considerable amount of effort was dedicated to the compilation of the data sources available and to the collection, reconciliation and analysis of some of this data, with a dual purpose: validation and as definition of a "base year", against which future scenarios could be compared. It was generally judged at that time that all this information and experience in building the data base should not be lost and hence, since it is expected that STAN will continue to be used in Brazil, that the base year data base should be preserved and regularly updated.

A data base updating procedure requires the establishment of procedures which are exogerious to the STAN software. This issue was therefore discussed during the project, but no definitive action was taken. We feel, however, that updating the data base is an important issue and we would like to make a few observations on the subject.

It may be worthwhile to emphasize the distinction between updating the data base and defining a scenario. The first activity aims to keep the information used in the data bank to reflect the actual state of the transportation system as close as possible to the reality. A scenario describes a hypothetical situation that one desires to evaluate and compare with the actual state of the system as present in the data bank.

All elements of the transportation system may evolve in time: the multi-modal network and its attributes, the operating policies and various costs of the diverse agents operating in the system, the demand for transportation. To reflect these modifications into the data bank, several data sources have to be used. Also, the required effort may significantly vary according to the type of data. A systematic procedure that gathers the necessary information from the different data sources and systematically channels this information for updating the STAN data base is a desirable future development.

The supply side data is relatively easier to collect and maintain. Modifications to the network infrastructure (new facilities, improvement of old ones, etc), to operating policies (different types of trains, priorities, prefered transportation mode for certain products, etc), to costs (e.g. national energy policies), to the transportation technology (such as vehicle types), etc. are generally quite conspicuous and may be obtained from the same sources used for building the initial data base: GEIPOT, the Ministry of Transportation, DNER (roads), RFFSA, FEPASA and CVRD (rail), SUNAMAN (navigation), PORTOBRÁS (ports), etc.

The evolution of the demand for transportation may, however, be more difficult to follow. The Brazilian economy is extremely dynamic, both in its production profile and the magnitude of its output. While a number of products display quite stable behaviour (steel products, iron ore, coal, ...), some others (coffee, citric products, ...) present variations in the amounts produced and are subject to the evolution of the international markets. Finally, a third group (grains, ...) display significant modifications in the producion patern with the opening of vast new production areas.

To keep track of these changes in the demand several information sources may be used. IBGE periodically collects data concerning industrial and agricultural production, at the zone level. These zones are roughly equivalent to those defined by GEIPOT. Input/output analysis may then be used to update the total productions and attractions of zones that, together with appropriate hypotheses, may then be used to estimate O/D demand matrices. It may be useful to note that STAN offers matrix balancing procedures that may be helpful in this respect. For specific products, additional data may be found in the concerned ministries (e.g. Ministry of Agriculture for agricultural products), in state agencies (e.g. SIDERBRAS for steel products), from national associations of producers (e.g. the National Association of Cement Producers), etc.

We would like to conclude by mentionning that we are aware of two major efforts in building and updating O/D matrices. The first, by the transportation group of the Institute for Technological Research of São Paolo, aims to obtain O/D demand matrices, for the year 1985, for the main products moved in the state of São Paolo. The second, undertaken in GEIPOT, has a similar aim, but at a national level.

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ACRONYMS

ABRACAVE	Associação Brasileira de Carvão Vegetal (Brazilian Coal Association)
ANFAVEA	Associação Nacional dos Fabricantes de Veículos Automotores (National Association of Motor Vehicles Industry)
CACEX	Carteira do Comércio Exterior (Foregn Trade Office)
CDI	Conselho de Desenvolvimento Industrial (Industrial Development Council)
CFP	Comissão de Financiamento da Produção Agrícola (Agricultural Production Financing Comission)
CIEF	Coordenação do Sistema de Informações Econômico-Fiscais (Economic-Fiscal Information System Coordination)
CNP	Conselho Nacional do Petróleo (National Petroleum Council)
CONSIDER	Conselho Nacional de Siderurgia (National Steel Products Council)
CVRD	Companhia Vale do Rio Doce (Vale do Rio Doce Railway Company)
DNER	Departamento Nacional de Estradas de Rodagem (National Departement of Roads)
DNPM	Departamento Nacional de Produção Mineral (National Department of Mineral Production)

FEPASA	Ferrovias Paulista S/A (Paulista Railways S/A)
GEIPOT	Empresa Brasileira de Planejamento de Transportes
IBGE	Fundação Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics)
PORTOBRÁS	Empresa de Portos do Brasil S/A (Brazilian Ports Enterprise)
RFFSA	Rede Ferroviária Federal S/A (Federal Railways Network)
SIDERBRAS	Siderurgia Brasileira S/A (Brazilian Steel Products)
SRF	Secretaria de Receita Federal (Federal Receipts Secretariat)
SUNAMAN	Superintendência Nacional da Marinha Mercante (National Superintendence of Merchant Marine)

CHAPTER TWO

RAIL NETWORK DATA

This chapter is dedicated to the presentation of the main issues related to the specification, collection and analysis of the data required for the various modes that use the rail infrastructure. The chapter is organized as follows: we first examine the requirements for the representation of the physical network, followed by those associated to the specification of the link physical attributes, to the computation of the unit cost figures and to the definition of the typical car types for each product and mode. We conclude this chapter with the presentation of typical cost and delay functions for the rail mode, in a form suitable for direct use in STAN.

2.1 THE NETWORK

The representation of the rail network, included in the multi-modal network used by STAN, closely reflects the topology and characteristics of the actual rail transportation system in the South-Est region of Brazil. To achieve this objective, the network representation retains:

- Most of the rail tracks in the region;
- The main track characteristics that determine different operating procedures: the various gauges (three in our case: large, metric and narrow), double or single track, and the electrification of the line; Specific *modes* have been used to represent these infrastructure types;
- The transfer points between gauges and between electrified and diesel track,

the most important intermodal transshipment points, the most significant rail stations and yards, etc.

The starting point of the procedure to build the STAN representation of the rail network was the railway network defined by GEIPOT (1980a). This basic network has subsequently been updated following information from:

- The annual operational plans of the subregional administrations of RFFSA for the years 1980 and 1981 (RFFSA 1980c, 1981);
- The graphical illustration of the Brazilian railway system published by RFFSA (1982);
- The FEPASA Chart (FEPASA 1978);
- The VALE DO RIO DOCE (CVRD) Schematic Network.

In addition to the direct representation of the track lines as links and that of the selected stations, yards and transfer points, etc. as nodes, links have been defined according to the various modes that model the multiple gauges and tractions modes encountered in the Brazilian railway system: metric, large and mixed gauge, diesel and electric traction. Moreover, to each direction of travel corresponds a dedicated link. These modifications follow the specifications of the rail model described in Chapter 4 of Part II: only unidirectional, mode dedicated links are allowed in the network. Consequently, when analysing the line utilization or when computing the over-the-line delays, the total traffic on all parallel links between two given nodes has to be compared to the capacity of the line.

Several connectors were also introduced to realistically model the main entry and exit points of the product flows into and out of each zone. Connectors are normally used to link the centroids, where all traffic originates and terminates, to the transportation network. Consequently, when a zone's centroid is linked to the network via one connector only, all traffic has to follow it. This obligation may introduce significant distortions in the paths used for some products and thus into the estimation of congestion, delay and cost measures for some parts of the network. This effect may be especially important when the zone is relatively large, covering several municipalities.

Several connectors were thus defined for each zone. For each product, one rail station is chosen to represent the origin/destination of the flow of product in the zone. This station is chosen as the node which generates or receives the largest volume of the given product according to the rail origin/destination demand matrix presented in Chapter 5. A connector is then introduced between this station and the centroid of the zone with a zero transportation cost for the given product and an "infinite" cost for the other products. Naturally, the same station may be selected for several products, when appropriate.

These concepts are illustrated in Figure 1, which displays the representation of the rail network in the zone centered around the city of Belo Horizonte, in the state of Minas Gerais. The map of the zone and its rail network appears in Figure 1a, while Figure 1b displays the resulting STAN network.

The STAN network model retains the topology and main characteristics of the original rail network. Several modes represent the different gauges used in the network (modes *a* and *b* represent large gauge links, modes *d* and *e* metric links, etc.) and the intergauge transfer points are retained. The representation is also an abstraction of the real network and thus discards numerous stations (e.g. the eleven stations between Matozinho and Cap. Eduardo) whose strategic impact on the routing of freight is not significant.

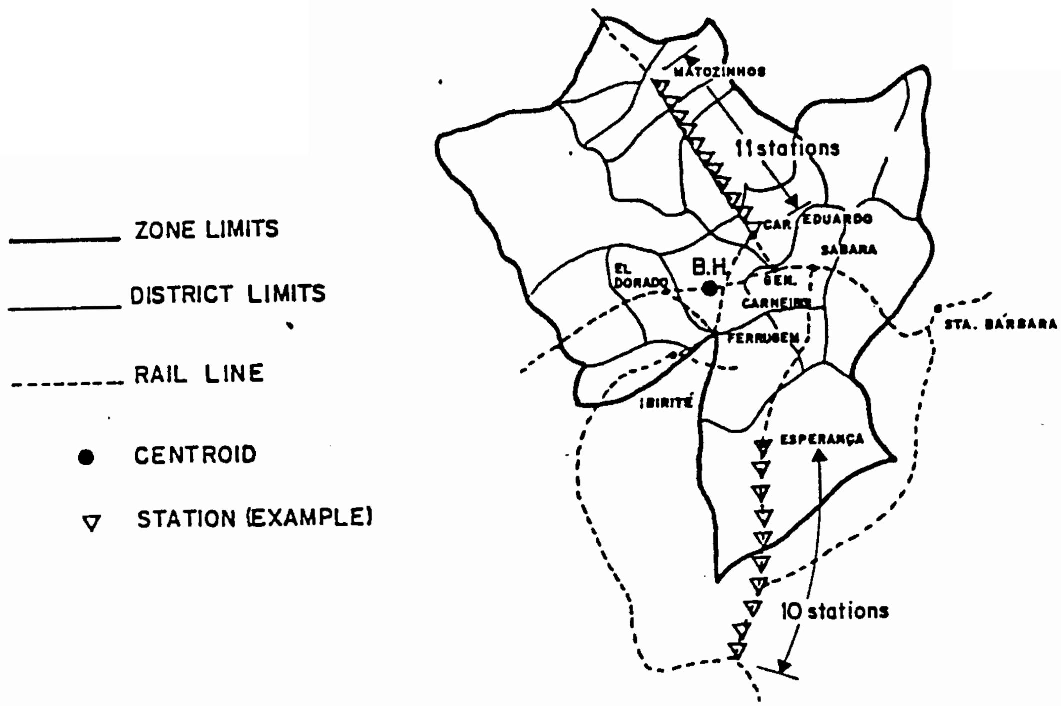

Figure 1a The Belo Horizonte Zone

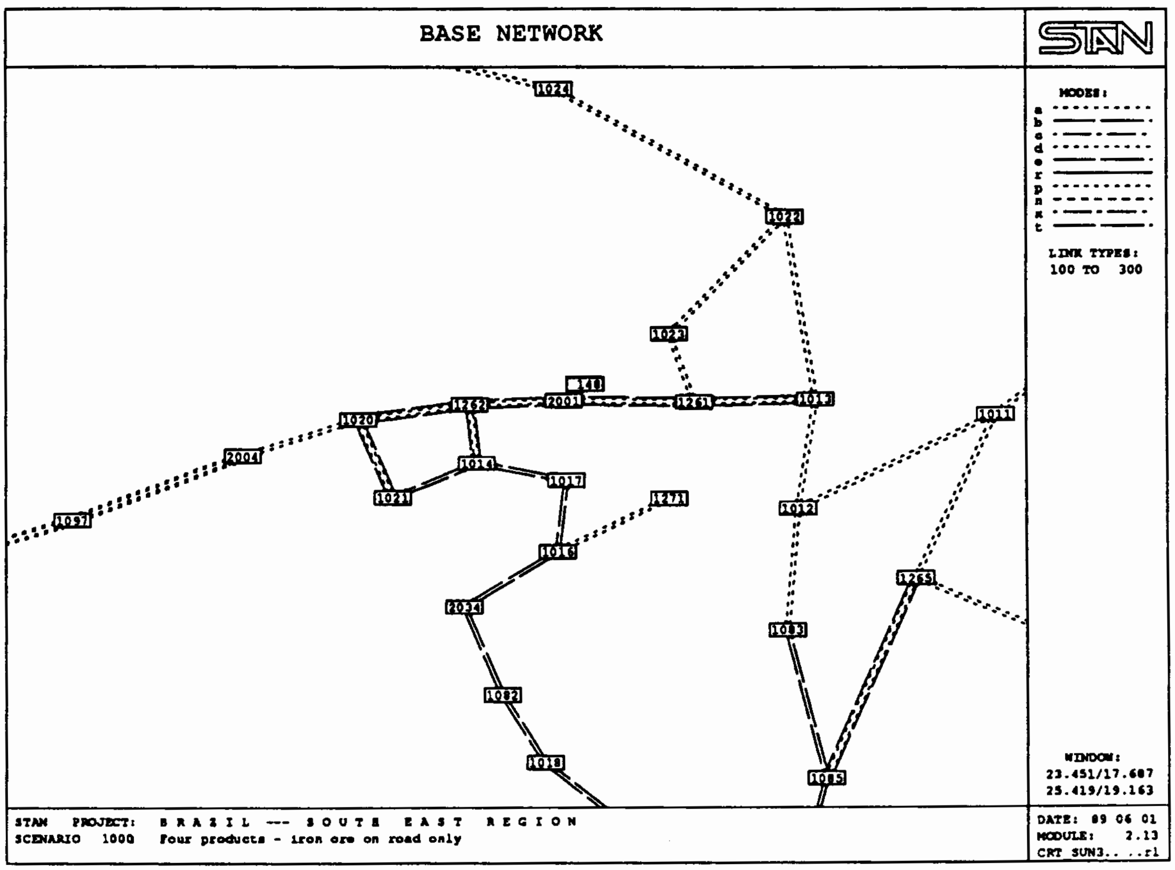

Figure 1b The STAN Rail Network

Figure 1 Example of Rail Network Modeling

Here, the station Belo Horizonte (node 2001) has been selected as the origin/destination point for the traffic of steel products and has been connected to the zone's centroid. The station Cap. Eduardo, which is another important loading point for steel products in the zone, is not linked to the centroid since it handles less volume. Consequently, all traffic of steel products will transit through the node Belo Horizonte. For iron ore, however, the corresponding origin/destination is the node Ibirité (node 1016). From this example, it may be easily seen that a concentration of all the flows through the Belo Horizonte station could have induced significant deviations in the estimation of the routings for iron ore out of the Belo Horizonte zone.

The external network for the pilot application in the South-East region, has been build following the ideas presented in Chapter 1, combined with the observed utilisation of the rail network (RFFSA, 1980b).

2.2 LINK ATTRIBUTES

To compute the various costs associated to the transportation of freight, one needs to know the characteristics of the vehicles and convoys used to move freight, the associated traffic volumes and the characteristics of the facilities the freight is moved through. For rail links, these characteristics have been aggregated into the following four attributes: *length, capacity, traction factor, energy consumption factor.*

2.2.1 Link Length

The length of the links of the rail subnetworks have been taken directly from the documents describing the Brazilian rail companies:

- The annual operational plans of the subregional administrations of RFFSA for the years 1980 and 1981 (RFFSA 1980c, 1981);
- The graphical illustration of the Brazilian railway system published by RFFSA (1982);
- The FEPASA Chart (FEPASA 1978);
- The VALE DO RIO DOCE Schematic Network.

The link length is used, among other things, to compute the *free running time* (FRT) of the link. This measure, required for the computation of the delay on the link, represents the time it takes a train to travel through the link when no congestion exits. Generally speaking, only one class of freight train is used in Brazil and the usual procedure for the computation of a link's FRT, is to use the speed of the heaviest train possible. This data was available, for most links, from the preceding data sources. When the free travel time was not available, it was evaluated by means of the average speed for the heaviest train, estimated by using the lengths and FRTs of neighbouring links.

Since the links in the STAN representation of the Brazilian rail network generally cover several links in the networks used by the rail companies, the length data had to be aggregated accordingly. This observation is valid for all link attributes.

2.2.2 Link Capacity

Link capacity is traditionally defined as the maximum number of trains that may travel through the link during the planning period. Several factors determinantly influence the capacity of a link: its physical characteristics (single or double track, length, number of siddings, signalization, etc.), the relative proportions between passenger trains and the various classes of freight convoys traveling on the link, the operating (dispatching, meeting, overpassing, etc.) rules governing movements on the link, etc.

Moreover, link capacity is not a simple constraint that cames into effect only when traffic reaches a certain level. It is, in fact, closely related to the phenomena of link congestion and increasing over-the-line travel delays: beyond a certain congestion threshold, link travel times increase rapidly with the volume of traffic, which makes the line unatractive for travel before its capacity is reached.

For railways, the link capacity thus represents an important operational constraint that often restricts the utilization of the rail network by certain commodities, either because the network is already too congested to accept new flows, or because the delays are unacceptable for the given commodity type. One thus finds an important literature dedicated to the analysis of rail line capacity under various physical and operational hypotheses, both for operational and tactical planning levels.

This type of analysis is, however, beyond the scope of a strategic model. As presented in Chapter 4 of Part II, the model of the rail network used in STAN integrates the capacity of the links into over-the-line delay formulae. An estimation of these capacities had therefore to be found.

The Brazilian rail companies estimate the capacity of a single track rail line by using the traditional Colson formula:

$$CAP = 2\, K_1\, K_2\, \frac{1440}{S^+\, S^- + \Phi}$$

where

CAP :	Capacity of the link;
K_1 and K_2 :	Percentage of effective capacity, accounting for the maintenance of the line and the presence of passenger trains;
1440 :	Minutes in a day;
S^+ and S^- :	Siding to siding time (e.g. travel time between two consecutive sidings) in the two directions of travel possible on the link;
Φ :	Signalization time.

Companies generally prefer to allow themselfs a safety margin, by underestimating the line capacity. Thus, they generally use the travel times of the heaviest train type when applying this formula.

For RFFSA and FEPASA, the capacities for single track links are computed by using Colson's formula and are directly available in the data sources we already mentioned. The data for the CVRD network has been supplied directly by the company. At our knowledge, a line performance calculator has been used to compute this data.

In the South-East region there are also a number of double track lines, on which a significant passenger train traffic may be observed. The Colson formula does not apply to these lines. Instead, the capacity of each directionnal link may then be determined by the minimum headway between two consecutive trains (computed as the longest siding to siding time for the heaviest train), corrected for the occupancy of the line by passenger trains:

$$CAP = K_1 \frac{1440 - T_p}{S_{\max} + \Phi}$$

where

CAP : Capacity of the link;

K_1 : Percentage of effective capacity, accounting for the maintenance of the line;

$S_{\max}$: Maximum siding to siding time = minimum headway;

Φ : Signalization time.

T_p : Occupancy of the line by passenger trains.

This formula has been used to compute the capacity of most of the double links in the RFFSA network in the South-East region.

2.2.3 Link Traction Factor

All flows in the multi-modal multi-commodity assignment network model are measured in tons. To compute the delays and costs associated to traveling on the links of the network, these measures are locally, for each link, transformed in an equivalent number of trains.

We have presented and analyzed in Chapters 4 and 7 of Part II the *by product* approach used in STAN to perform this transfomation: for each product, the total (product and vehicle) tonnage traveling on the link is divided by the weight of the average train of the given product that may be operated on that link. This *traction factor* is computed as the product of a link specific characteristic β_a and of a factor particular to each commodity α_p. The utilisation of two factors is motivated by our aim to adequately model, at the strategic level of planning, the effect of real rail operations where the specific train services that are run on the network, their composition, the mix of engines assigned to each train type, the physical characteristics of the links, etc., represent only some of the important elements that determine the relations between the number of trains and the volumes of freight traveling on a given link.

There are several equivalent ways of computing the link and product traction factors. One such method is presented in Chapter 7 of Part II, while a second one is decribed in this section. The choice of method should be guided by the availability of data and the operating characteristics of the system which is represented. When, as in the South-East application, the infrastructure characteristics and the operating policies vary significantly among subregions (due to different companies that own various parts of the network, to varying track qualities, to mountainous terrain, etc.) the following method seems more appropriate.

The β_a, the link traction factor, is defined as the ***total tonnage hauled by the typical engine associated with the link.*** This information is directly available in the FEPASA and CVRD data. For RFFSA, the information available in the annual operations plans of the four subregional administrations (SR-2, SR-3, SR-4 and CSP-3.2) present in the South-East region was used in the following procedure:

- Collect the route, frequency and engine mix for all train services run in the region;
- Plot the train services on the STAN rail network;
- Observe the train distribution on the links of the network and define for each link its typical engine as the engine the most frequently used on the link;
- Determine, from the RFFSA line classification, the ***traction profile*** of each link; if the link is made of several RFFSA segments, chose the profile of the most critical segment as the profile of the link;

- Identify, for each link, the traction factor for its typical engine, given the traction profile of the link.

To illustrate this procedure, on the link Barão de Vassouras - Barra do Pirai (of the SR-3 subregion) one observes 5 engines SD-38, 3 SD-40 and 17 engines of type U23-C. Thus, the U23-C is the typical engine for this link and, for the traction profile of the link, its traction factor is of 4400 tons. For the very few links, where all the necessary information was not available the traction factor of a neighbouring link with similar characteristics was used instead.

The traction factor associated with each product, α_p, is defined as the *number of engines used to haul a typical train loaded with the given product.* This factor was approximated, following an analysis of the trains scheduled to transport the products over the network. It results from this analysis that almost all products are moved by general purpose trains hauled by two engines. Iron ore, however, is transported by unit trains hauled by three engines. These figures were used as product specific traction factors.

2.2.4 Link Energy Consumption Factor

Energy consumption varies according to the length and geometry of the rail line, the total load hauled and the traction mode. An energy consumption factor is thus defined for each link of the rail subnetwork. This factor is measured in litres per ton-kilometre (l/TK) for the links where diesel engines are used and in kilowatts-hour per ton-kilometre (Kwh/TK) for links with electric traction.

CVRD made available fuel consumption rates for the links of its network. This data was obtained by using a train performance calculator. CVRD do not operate electrified lines.

The same information was also available (in $l/1000TK$) for the links of the RFFSA network. Some adjustments were however necessary, since the network representation and the RFFSA network do not coincide. When the links of the company's network cover several links of the model (a rather rare occurrence), each link in the model receives the same energy consumption rate as that specified for the RFFSA link. When, on the other hand, several RFFSA links are aggregated into one link of the model (the most frequent event), the energy consumtion factor of the aggregated link is computed as a weighted average of the fuel consumption rates of the real links. The weights of the formula are the lengths of the links:

$$C_a = \frac{\sum_{i=1}^{n} C_{a_i} L_{a_i}}{\sum_{i=1}^{n} L_{a_i}}$$

where

C_a : Energy consumption rate for link a, aggregated from n links of the RFFSA network;

C_{a_i} : Fuel consumption rate of RFFSA link a_i, $i = 1, ..., n$;

L_{a_i} : Length of RFFSA link a_i, $i = 1, ..., n$.

Fuel consumption rates were not available for the links of the FEPASA network and were therefore estimated by using a train performance calculator. Detailed line profile data and train characteristics, required by the calculator, were obtained from the company. A simulation of all the links in the FEPASA network would have been very time and resource consuming. Besides, this effort is not really required, since links with similar profiles generate very similar consumption rates.

A simulation of fuel consumption was therefore carried out for selected links of the export corridor between Uberaba and Santos. These links were:

Itapetininga	- Itapera
Itapera	- Itararé
Assis	- P. Prudente
P. Prudente	- P. Epitácio
Uberaba	- Araguari
Evangelio	- Passos
Samaritá	- Santos
Samaritá	- Juquiá

FEPASA classify the various link profiles into 29 types, numbered from 7 to 35. We aggregated these profiles into five classes and, by simulating the operations on the selected links, we obtained estimations of fuel consumption for each of these classes:

Profile Class	Fuel consumption ($l/1000TK$)
7 - 12	2.8
13 - 16	3.4
17 - 20	4.1
21 - 25	6.6
26 - 35	10.0

Each link in the FEPASA network received then the energy consumption factor that corresponds to its profile class.

Energy consuption figures for the electrified links were not available. FEPASA estimates, however, the equivalence between the two energy modes: one litre of fuel corresponds to 10.393 Kwh. We used this coefficient to transform the fuel consumption rate, obtained according to the profile of the line, into an electricity consumption factor for all links in the network where electric traction is available.

2.3 UNIT COSTS

Three different unit costs, operation, delay and energy consumption, are used in STAN to transform into a total system cost the measures of transportation activities on the links (and transfers) of the network. Operating unit costs are measured in Cr$ per train, car or ton - kilometre, delay unit costs in Cr$ per train, car and ton - hour and energy unit costs in Cr$ per litre or Kwh, for diesel and electric traction, respectively. In this section, the monetary figures are measured in 1980 cruzeiros.

Rail companies use very detailed accounting and costing rules. Yet, the required data for our applications often was not available in a directly usable form and it was even missing for certain situations. A number of hypothesis and aggregation rules have therefore been used.

Two main concerns guided our analysis. First, that all cost items may be similarly defined and available for all the transportation modes specified in the application and, secondly, that they have a direct bearing upon the final assignment of traffic.

It was thus decided that infrastructure and, in general, fixed costs should not be considered in the computations. Track maintenance expenditures have also been discarded, since the equivalent costs for the road mode are not usually asociated with costing for truck transportation (this is equally valid in the case of the infrastructure related costs).

The following cost items have been retained: fuel (electricity) consumption and lubrification (measured in Cr$/l or Kwh), crew (Cr$/train-km or Cr$/train-hour), equipment depreciation (Cr$/car (engine) - km or Cr$/car (engine) - hour) and equipment maintenance (Cr$/car (engine) - km or Cr$/car (engine) - hour). The choice of the particular cost items that are to be used in each application depends upon the avalability of the required data for all modes considered, according to the above mentioned principle of uniform treatment of modes.

Lubrification is usually taken as 10% of the fuel consumption cost, which is a company constant for a given year. As for the crew costs, they are often measured in $/train-hours and contribute to the delay costs. For our applications, however, we follow the accounting procedures of the Brazilian rail companies, and include them into the link operating cost. The equipment depreciation and maintenance costs associated with travel (as measured by the amount of car and engine kilometres performed) also contribute to the link operating cost.

When the value of equipment depreciation and maintenance is measured in time units, the unit costs are used to compute delay costs and are no longer link specific. Their derivation is, however, included in this section, since it depends upon each particular rail company. It is worth noting that in the applications presented in this report, there are no operating costs associated with tons, due to insufficient data availability. For the same reason, we did not use commodity specific delay unit costs to model product depreciation and inventory costs, time priorities, etc.

The computation procedures are slightly different for FEPASA and RFFSA. Data concerning cost figures was not available for the CVRD network. We use the RFFSA unit cost figures for the metric gauge links, since the CVRD network is in the same gauge.

The RFFSA Subnetwork

Cost related information in the RFFSA network is available in a yearly report (RFFSA, 1980a), where data is presented for the company and for each one of its administrative subregions (called SRs). The total number of production units (train-km, car-km, car-days, etc.), as well as the corresponding total and unit operating costs are given for the various items included in the costing proceduree of the company. For some items, depreciation figures are given as well.

The data which is best suited for our applications is that describing each subregion of the company. Several reasons justify this choice. First, the global company figures do not discriminate among gauges. Second, these figures are computed as network wide averages of the costs in each subregion. Then, since the RFFSA network is very heterogenous in infrastructure quality and maintenance effort, while the South-East part is certainly the best on both counts, the utilization of these global unit costs in the South-East region would significantly misrepresent the actual figures.

Unit costs are generally computed for each gauge and traction, according to the modes defined in the application. Tables 1 and 2 present the intermediary figures and the unit costs for some cost items in the metric and large gauges with diesel traction. Data from subregions SP-2, CSP3-2 and SP4-2 has been used to compute the figures for the metric gauge, while data from the SP-3 and SP4-1 subregions served the same purpose for the large gauge.

We have retained in these computations the discrimination that RFFSA introduces into the car maintenance costs, between the cost of the usual maintenance activities, measured in Cr$/car-km, and the costs of repairs, measured in Cr$/car-days. Car depreciation figures, on the other hand, represent the same total depreciation cost of the vehicles, measured both in distance and time units. The average fuel cost for the South-East region was evaluated at 12.09 Cr$/l.

Cost Item	SP-2	CSP3-2	SP4-2	Total	Unit Cost Cr$/Unit
Crew					
Cr$ * 10^3	301149	88831	321931	471722	
Train-km * 10^3	6031	2401	3673	12069	39,64
Engine Maintanance					
Cr$ * 10^3	457757	171995	90576	720328	
Engine-km * 10^3	14409	2778	3673	20860	34,50
Car Maintanance					
Cr$ * 10^3	202855	40166	103100	143266	
Car-km * 10^3	129850	27180	104330	131510	1,09
Cr$ * 10^3	132832	24865	57135	214832	
Car-day	21059007	502970	1472410	4081287	52,63
Car Depreciation					
Cr$ * 10^3	235244	95273	111528	206801	
Car-km * 10^3	129850	27180	104330	131510	1,57
Car-day	21059007	502970	14724110	4081287	50,67

Table 1 Unit Cost Computations - Metric Gauge, Diesel Traction (RFFSA)

Cost Item	SP 3	SP4.1	Total	Unit Cost Cr$/Unit
Crew				
Cr$ * 10^3	305954	15667	321631	
Train-km * 10^3	6802	188	6990	46,01
Engine Maintanance				
Cr$ * 10^3	1232729	39531	1272260	
Engine-km * 10^3	15192	280	15472	82,23
Car Maintanance				
Cr$ * 10^3	105330	107020	342350	
Car-km * 10^3	350959	21800	372759	0,65
Cr$ * 10^3	343636	98362	441998	
Car-day	2242306	1693080	3435386	112,31
Car Depreciation				
Cr$ * 10^3	340252	194952	535204	
Car-km * 10^3	350959	21800	372759	1,44
Car-day	2242306	1693080	3935386	135,99

Table 2 Unit Cost Computations - Large Gauge, Diesel Traction (RFFSA)

For the electric traction links, car related unit costs are assumed to be equal to their counterparts in the links with diesel traction. To compute the crew and engine related costs, data from the SP4-1 subregion was used for the large gauge links. For metric gauge links, the SP-2 region was used. Table 3 summarizes the unit costs for these cases.

Cost Item	Metric Gauge	Large Gauge
Energy (Cr$/kwh)	0.336	0.468
Crew (Cr$/train-km)	107,18	27,76
Engine-Mantenance (Cr$/engine-km)	49,89	41,65

Table 3 Some Unit Costs for Electric Traction (RFFSA)

The FEPASA Subnetwork

Cost data for the FEPASA network was retrieved from forcasted cost figures for the company for the year 1980. Data is presented for large and metric gauges and for diesel and electric traction modes. The fixed and variable part of each cost item is specified when appropriate, and all production is measured in vehicle units (car-km) only. The statistical yearbook of FEPASA (1980), supplied the total amount of a number of other production measures, such as train-km, engine-km, etc., performed during that same year.

The total cost for a specific cost item was then computed by using its variable cost and the corresponding total number of car-km, both figures available in the first data source. The unit cost, measured in the desired units, was then deduced by comparing this total cost to the corresponding production figure available in the second source of informations. Table 4 summarizes these computations.

Cost Item	Diesel Metric	Diesel Large	Electric Metric	Electric Large
Energy				
Cr$/l(kw)	13.64	13.64	0.47	0.47
Crew				
Cr$	158400504	15815140	72850721	9746840
Train-Km	4855392	802991	2977566	2593228
Cr$/Train-Km	32.64	19.81	24.47	3.77
Cr$/Car-km	0.83	0.81	1.31	0.38
Engine Maintenance				
Cr$	259547814	27028230	87191021	25202860
Engine-Km	13575896	4336036	6645975	4624663
Cr$/Engine-Km	18.90	6.23	13.12	5.45
Car Maintenance				
Cr$	259266984	—	88323588	41395233
Car-Km	190843981	19648321	55518001	26011028
Cr$/Car-Km	1.36	0.94	1.59	1.59
Car Depreciation				
Cr$	—	23170750	184969324	133968718
Cr$/Car-Km	2.86	3.10	3.33	5.15

Table 4 Unit Cost Computations - FEPASA

To compute the depreciation figures measured in temporal units (Cr$/car-days and Cr$/engine-days) the amount of car (engine) - days performed in the year was estimated by assuming that every car (engine) available in the FEPASA fleet worked the estimated 300 work-days of the year. The car depreciation figures were estimated by gauge, irrespective of the traction mode, for a production of 1280700 (3087900) car-days for the large (metric) gauge. Table 5 summarizes these computations.

Cost Item	Diesel Metric	Diesel Large	Electric Metric	Electric Large
Engine Depreciation				
Engine-Days	81600	29400	22800	19200
Total Cost $* 10^3$	185118	23517	21797	46929
Cr$/Engine-Day	2268	800	956	2444
Car Depreciation				
Total Cost	546424489	60943197	184969324	133968716
Cr$/Car-Day	236.85	152.19	236.85	152.19

Table 5 Unit Cost Computations - Time Depreciation (FEPASA)

We finally present, in Table 6, aggregate figures for all the region for some unit costs. These figures are computed as averages over all companies and may be used for rapid approximations.

Cost Item	Diesel Metric	Diesel Large	Electric Metric	Electric Large
Crew Cr$/Train-Km	37.23	43.32	26.10	12.20
Engine Maintenance Cr$/Engine-Km	28.45	65.59	13.62	17.28
Engine Depreciation Cr$/Engine-Day	1800.00	2101.00	3403.00	4839.00
Car Maintenance Cr$/Car-Km	1.92	2.47	2.54	2.07
Car Depreciation Cr$/Car-Day	130.88	140.00	130.88	140.00

Table 6 Aggregated Unit Cost

2.4 ESTIMATION OF VEHICLE TYPES

Although in the assignment model used in STAN flows are measured in tons only, costs and delays are evaluated by using an equivalent number of vehicles (rail cars, trucks, ships) and convoys, when appropriate (e.g. trains). Typical or average vehicles have thus to be defined for each product and for each mode specified in a particular application.

A typical vehicle for product p on mode m, is defined by two characteristics: its empty weight, vw_p^m, and the average load of the given commodity it transports, w_p^m. These characteristics may be evaluated by the following general procedure (Leal et al., 1986):

- Given the total volume of product transported on the mode, V_p, and the total number of cars used to move it, n_p, the average load of the typical car is:

$$w_p^m = \frac{V_p}{n_p}$$

- The weight of the typical car when empty, is

$$vw_p^m = \frac{\sum_{i \in I_p^m} vw_i \, n_{ip}}{n_p}$$

  where, I_p^m is the set of available car types for product p on mode m, vw_i is the weight of car $i \in I_p^m$ and n_{ip} represents the total number of cars of this type used to transport the product on the current mode.

This general approach has been ajusted and adapted according to the data availability. We assumed, in particular, that for a given product on a particular track gauge, the characteristics of its typical vehicle will not significantly vary with the company or the traction mode. Even with this rather serious assumption, several cases had to addressed.

For several products, aggregate data about the total tonnage transported and the number of cars that did the transport, as well as a sample of individual cars, was available from a number of yards in the RFFSA network. By using this data, typical vehicles have been defined for the following products: mineral coal (metric gauge), cement and steel products (both gauges), iron ore (large gauge).

In several administrative subregions of the RFFSA network, origin-destination data indicated, for a number of products, the total tonnage transported, the total number of cars and the total capacity supplied for the transport. By using averages, the following typical cars could be defined: fertilizers, soya oil and soya meal for large gauge (from data of the SP4-1 - Saõ Paolo subregion), soya grain in metric gauge (SP4-2 - Bauru subregion) and fertilizers in the same gauge (using O/D data from the SR-2 - Belo Horizonte subregion).

The typical car for iron ore in metric gauge has been obtained form CVRD.

Data was not available for soya oil and soya meal in metric gauge and for soya grain in large gauge. We then computed, by using the characteristics of the typical cars for the products with estimates in both gauges, two proportionnal coefficients:

$$\gamma_w = \frac{\sum_p w_p^{metric}}{\sum_p w_p^{large}} \quad and \quad \gamma_{vw} = \frac{\sum_p vw_p^{metric}}{\sum_p vw_p^{large}}$$

We obtained $\gamma_w = 0.83$ and $\gamma_{vw} = 0.73$. We then used these coefficients to estimate the characteristics of the typical car on one gauge, from the equivalent measures on the other gauge. For example:

$$w_{soya-oil}^{metric} = \gamma_w \, w_{soya-oil}^{large} = 0.83 * 37.66 = 31.26 \; tons/car$$

and

$$vw^{metric}_{soya-oil} = \gamma_{vw}\ vw^{large}_{soya-oil} = 0.73 * 24.00 = 17.52\ tons$$

Tables 7 and 8 summarize, for the metric and the large gauge, respectivelly, the characteristics of the typical cars for each product. The utilization factor of each car, defined as the proportion of the car's capacity which is effectively used, is also given.

Cost item	Costs/Car-km [Cr/Car-km]	Total Cost	Production Unit	Volume of Production	Unit Cost
Fuel consumption					0.468
Crew	0.3754	9746.840	Train-km	2593.228	3.766
Engine Maintanance	0.9689	25202.860	Engine-km	4624.663	5.449
Car Maintanance	1.5914	41395.223	Car-km	——	1.592
Car depreciation	5.1503	133968.718	Car-km	——	5.150

Table 7 Characteristics of Typical Cars - Metric Gauge

Energy Source	1.60	1.00
Diesel	60.943.197	546.424.489
Electric	133.968.716	184.969.324
Total Cost	194.911.913	731.393.817
Car-days	1.280.700	3.087.900
Unit cost ($/Car-days)	152,19	236,85

Table 8 Characteristics of Typical Cars - Large Gauge

2.5 LINK COST AND DELAY FUNCTIONS

For each link (a similar approach applies for transfers) the generalized cost is computed as the weighted sum of the link *operating cost* ($FCLnn$), *delay* (FDLnn) and *energy consumption* (FFLnn) functions specified by the link *function class nn*:

$$generalized\ cost = \{b_1 FCLnn + b_2 FDLnn + b_3 FFLnn\} * \ product\ volume$$

where b_1, b_2, b_3 are the user defined weights.

A typical operating cost function, for product p on link a, is:

$$\{\ train\ unit\ operating\ *\ number\ of\ trains$$
$$+\ car\ unit\ operating\ cost\ *\ number\ of\ cars$$
$$+\ ton\ unit\ operating\ cost\ *\ number\ of\ tons\ \} * link\ \ length$$

$$= \{\gamma_c^t \frac{v_a^p + (v_a^p\ /\ w_p) * vw_p}{\alpha_p * \beta_a} + \frac{\gamma_c^w\ *\ v_a^p}{w_p} + \ \gamma_c^p(v_a^p\ + (\frac{v_a^p\ *\ vw_p}{w_p})\}l_a$$

where

- v_a^p : flow of product p on link a;
- w_p : quantity of product p that may be loaded into the corresponding vehicle p;
- vw_p : weight of an empty vehicle p;
- α_p : product traction factor;
- β_a : link traction factor;
- l_a : length of link a;
- γ_c^t : train unit operating cost;
- γ_c^w : car unit operating cost;
- γ_c^p : ton unit operating cost.

When the function is written in the prescribed form for STAN:

$$Total\ cost = unit\ cost * volume,$$

the unit cost becomes:

$$\{\frac{(1 + vw_p/w_p)\gamma_c^t}{\alpha_a * \beta_a} + (\gamma_c^w + \gamma_c^p\ vw_p/w_p) + \gamma_c^p\}\ l_a$$

or, by using the keywords available in STAN and described in Chapter 2 of Part III, (the unit costs are reputed to be in the first mode, product and mode-product user data) the final function is:

FCLnn = (((1.0 + VEHWGT / WBYVEH) * UM1 / (BETA * CONWGT))
+ (UP1 + UMP1 * VEHWGT) / WBYWGT + UMP1) * LENGTH

Similarly, a typical link delay cost function is:

$$\begin{aligned} &\{\ train\ unit\ delay\ cost\ *\ number\ of\ trains \\ &+ car\ unit\ delay\ cost\ *\ number\ of\ cars \\ &+ ton\ unit\ delay\ cost\ *\ number\ of\ tons\}\ \text{over-the-link-delay} \end{aligned}$$

$$= \{\gamma_d^t \frac{v_a^p + (v_a^p\ /\ w_p) * vw_p}{\alpha_p * \beta_a} + \frac{\gamma_d^w\ *\ v_a^p}{w_p} + \gamma_d^p(v_a^p\ +\ \frac{v_a^p\ *\ vw_p}{w_p})\}D_a$$

where

D_a : over-the-line delay on link a;

γ_d^t : train unit delay cost;

γ_d^w : car unit delay cost;

γ_d^p : ton unit delay cost.

When link a is a single track link, the polynomial delay function, defined in Chapter 4 of Part II, may be used:

$$D_a = \phi_0 l_a * (1 + \phi_1 * T_a + \phi_2 * (T_a/CAP_a')^{\exp})$$

where

$\phi_0 =$ 1/"*speed*",

D_a : delay on link a;

CAP_a : capacity of link a;

T_a : total train flow (both directions, all modes) on the link

and ϕ_1, ϕ_2, and exp are the parameters of the polynomial.

Once the equation is transformed in order to single out the unit cost part (similarly to the previous treatment for the operating cost function), the delay function may be written by using the STAN keywords (the unit costs are reputed to be in the second mode, product and mode-product user data, while the speed of the train appears in the third mode user data):

FDLnn = (UM2 * CONWGT * (1 + VEHWGT / WBYVEH) / (CONWGT
* BETA) + UP2 / WBYVEH + UMP2 * (1 + VEHWGT / WBYVEH))
* (LENGTH / UM3) * (1.0 + ϕ_1 * STRAIN + ϕ_2* (STRAIN / CAP) ^ ϕ_3)

Finally, a similar approach may be used for the energy consumption function for a product p on a link a:

$$\{weight\ of\ the\ engines\ for\ a\ train\ *\ number\ of\ trains$$
$$+\ weight\ of\ a\ car\ *\ number\ of\ cars$$
$$+number\ of\ tons\}\ link\ length$$

$$= \{\gamma_e^t\ \alpha_p \frac{v_a^p\ +\ (v_a^p/w_p)}{\alpha_p\ *\ \beta_a} + \frac{vw_p\ *\ v_a^p}{w_p} + v_a^p\}\ l_a$$

where

γ_e^t : weight of an engine for product p.

After the appropriate manipulation, the unit energy consumption function may be written in STAN keywords (the engine weight is in the third mode product user data) as follows:

FFLnn = (1.0 + UMP3 / (BETA * CONWGT)) * (1.0 + VEHWGT / WBYVEH) * LENGTH

Functions different from those presented in this chapter may be used in a STAN application. A similar manipulation should, however, be performed before the actual input to the system.

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CHAPTER THREE

INFORMATION ON THE HIGHWAY MODE

3.1 DEFINITION OF THE HIGHWAY NETWORK

In the pilot application of the STAN system, the highway network contained in the Transportation Operating Plan (GEIPOT, 1980a) was adopted for the Southeast Region, according to the characterization of the study area. In order to face the difficulties resulting from the unavailability of complete and reliable data on all the transportation network and to simplify the assignment of freight, only a subnetwork was selected, with the aim of transporting more than 80% of the demand of the analyzed products and of selecting all highway segments with flows exceeding 500,000 t/year. The procedure adopted for this selection of the basic network produced a classification of origin-destination pairs, according to the increasing order of freight generation/attraction, based on the freight routes identified by direct surveys developed by the Transportation Operating Plan (GEIPOT, 1980a). As far as possible, alternative routes were also considered, both for possible improvements in their physical characteristics, and for prospects of structural changes in transportation demand. It should be noted that the DNER subdivision of highways into links and the DNER recording of highway inventories was adopted in this study, in order to facilitate access to this information.

For the highway mode, the identification of centroids makes it possible to differentiate between pich up and delivery, which is local and almost exclusively done by truck, and long-distance transportation. Such a differentiation depends upon the level of flow concentration; for example, the soya bean production which may be stored either in farms, or in municipal or in state storage centers. Although the Transportation Operating Plan (GEIPOT, 1980a) had identified 4699 O/D pairs served by highway routes, only the 417 which had a level of spatial aggregation larger than municipalities (that is, larger than the size of traffic zones) were selected for the present application. These 417 O/D pairs with road transportation represent more than 80% of the total demand.

Connector links are required to allow traffic to and from the centroids to the transportation network. In general, these connectors are specific to each mode permitted for the centroid in the network. For the road mode, connectors are defined as exclusive for this mode, with a length which represents the average distance of freight collection in the area of the centroids. As to regular links, they suite straightforwardly represent the road segments according to the STAN specifications.

Therefore, the highway transportation network was defined in terms of the location of the nodes and links, the latter being road sections connecting nodes according to the topology of the network. Nodes represent both highway (alternative routes) and intermodal (transshipment) junctions and points where changes in the physical characteristics of the highways occur. The interregional interchanges were assured by the definition of a relatively sparse external network, outside the study area. In total, the road network selected for the pilot application of the STAN system covers an extension of approximately 80,000 km, with 1600 links.

3.2 ATTRIBUTES OF THE HIGHWAY NETWORK

The attributes of the highway network correspond to the information on nodes and links contained in the data base of the STAN system. This information may be used in the specification of the cost functions associated with the transportation, or in the graphical representation of the transportation network. There are three free variables for the user, both at a level of nodes and links; for links these variables were used to store the classification of highway sections by their physical characteristics.

The links are identified by the triplet "origin node-destination node-mode", whether they are connectors or not. To specify cost functions, the principal attribute used is the length of the road section, since the function class already indicates the link classification. Despite the fact that capacity had been estimated, according to the Highway Capacity Manual (TRB, 1985), as the maximum number of vehicles for the desired level of service, no capacity restriction was assumed for cargo assignment on the road mode. This, apparently strong, hypothesis assumes that the cargo surplus in the railway and waterway modes will be captivated by the roadway, which insures the existence of the solution of the assignment problem. However, capacity should be considered in 'a postiori' analyses where critical road sections are identified. The energy consumption coefficient, in liter per gross ton transported, was introduced in a more aggregate form directly into the cost function specific for a given set of physical characteristics of links.

In addition, the link type is considered as an attribute of the link, and is used for plotting or listing of selective subgraphs of the network. For the highway network, the link type indicates the jurisdiction of the road (federal or state) and the simplified classification of the road type as paved or unpaved. It is important to note that this attribute cannot be used to specify cost functions, because of the computer implementation.

The road sections were classified according to their geometry and rolling track characteristics, which are the variables determining the transportation cost functions adopted in the pilot application of the STAN system. The criteria for classifying the roads were based on the experience obtained in the Research on the Interrelationship of Highway Costs - PICR (GEIPOT, 1980b), which carried out a systematic monitoring of about 35,000 km of road during a period of five years.

In PICR it was established that other than the type of rolling track (paved or unpaved), the roads are characterized by the geometry of the vertical profile, the geometry of the horizontal alignment and the maintenance state of the rolling track. The variables quantifying these characteristics were selected so as to discriminate roads according to their quality and their maintenance characteristics; they were aggregated in order to facilitate the statistical analyses in which the correlations between vehicle operating costs and the roads on which they travel were established. In addition, these variables can be measured by high production equipment and instruments. The following are the variables used for the classification of highway sections:

- RF (Rise plus Fall) corresponds to the average of the absolute values of all road grades, weighted by the road length (m/km).
- ADC (Average Degree of Curvature) corresponds to the summation of the central angles of road horizontal curves, divided by road length (ọ/km).
- QI (Quarter-car Index) characterizes the roughness of the rolling track according to the movements of the vehicle rear axle in relation to its body (counts/km).

Despite the limitations and imperfections of these measures, admitted during the development of PICR, they still represent the state-of-art.

Maintenance State			
Paved Roads		Unpaved Roads	
Classification	QI Range (Counts/km)	Classification	QI Range (Counts/km)
Good	QI<45(30)	Good	QI<100(90)
Regular	45<QI<70(60)	Regular	100<QI<140(120)
Bad	70<QI(90)	Bad	140<QI(180)

Geometry			
Vertical Profile		Horizontal Alignment	
Classification	RF Range	Classification	ADC Range
Level	RF<15(15)	Little Sinuous	ADC<20(15)
Undulated	15<RF<30(25)	Middle Sinuous	20<ADC<70(45)
Mountainous	30<RF(40)	Very Sinuous	70<ADC(80)

Table 1 Qualitative and Quantitative Definitions of Road Section Classification Factors (Typical values betwwen parentheses)

In addition, variation intervals were established by associating qualitative evaluations to the variables that determined the road classification, thus reflecting the reliability of the available information and facilitating the process of updating this mass of information. Table 1 (GEIPOT, 1984a) shows the correspondence between the qualitative evaluation, normally assuming three values - high, middle and low, and the variation interval of each variable and typical value within this interval. It is important to note that this correspondence is subjective, since the correlation between the subjective classification made by roadway technicians of existing road sections or designed sections and the average values of the QI, ADC and RF variables was not investigated.

The data base used for the characterization of the highway network corresponds to the DNER inventory, which contains information obtained in the field survey carried out from 1978 to 1979. The data making up this inventory consists of two types of information: identifying information, that characterizes the road by the elements that identify each component section; and information that qualifies the road by some quantifying elements and by the qualitative evaluation of the road maintenance state. The data structure identifies information for the road, for each section, and for each kilometer, as well as information on structures and special occurences. The information included in the highway classification was: section length; type of layer and its maintenance state; transversal incline of terrain; number of curves per kilometer with a radius below 100 m; incline and length of slopes in each road section. Therefore, for the above mentioned length and type of link data, the information contained in the DNER inventory was used.

The inexistence of a direct correspondence between the information contained in the DNER inventory and the variables determining the classification of the road sections posed a problem. Due to this, it was necessary to design a method for evaluating QI, ADC and RF based on inventory data. As to the simplified subdivision of the links into paved and unpaved, it was possible to obtain it directly from the inventory, based on the pavement type of each section. It is believed that the above mentioned methods will be unnecessary in up-to-date versions of the highway inventory, since there is a consensus in accepting the variables QI, ADC and RF as information capable of characterizing a road.

For the state of the rolling track, the method adopted consisted of calculating the QI for each road section and then making the corresponding qualitative evaluation. The maintenance state of the rolling track is marked in the DNER inventory, for every kilometer, as in one of three levels: good, regular or bad. However, because these data are qualitative, it was necessary to use the typical value of each range, shown in Table 1, in order to obtain an estimate of the weighted average for the total length of the section. It is important to observe that caution has to be show when using this 1978-1979 inventory information in the 1980 application, since there are significant value variations along time, which were not considered here, due to the inexistence of any other information source.

For vertical geometry, two classification alternatives were identified, based on information in the DNER inventory. Initially, the transversal incline of the terrain was considered according to four levels (5, 20, 50 and 70%), for each kilometer of road. The average values were weighted by the total length of each section and, then, were classified into level (20%), undulated (from 20 to 50%) and mountainous (70%). All values were determined according to DNER criteria. However, because the road profile may not be related directly to the transversal incline of the terrain, this classification was abandoned in favor of calculating the RF factor according to its own definition. The information on the total slope length, available in the DNER inventory, is split up by levels of incline, ranging from 3% to 12% by intervals of 1%. As to the two extreme levels, representing slopes under 3% and above 12%, average inclines, of 1.5% and 12% respectively, were assigned for the purpose of calculating RF. The RF estimation consists of the summation of incline levels multiplied by their respective slope lengths in meters, divided by the total length of the section in kilometers. It is noteworthy that, as anticipated, differences between the classification according to transversal terrain incline and according to RF calculations were observed for the Southeast Region.

Finally, for horizontal geometry, the information in the DNER inventory does not contain the central angles of the existing curves in each section, making a direct ADC evaluation impossible. Thus the option was to correlate the ADC value with the number of curves with a radius under 100 m, which was the only available information on horizontal alignment, and with the RF value of the road profile. The ADC functions were determined by means of linear regression techniques, based on inventory information for some road sections, whose slopes and curves had already been measured by PICR, and for which the respective ADC and RF values were available. The best fitness (R^2=0.64) was obtained by using the following equation:

$$ADC = 8.304 + (81.328*NCKM) + (2.480*RF)$$

where NCKM is the number of curves with a radius under 100 m in the road section.

It is important to note that the correlation hypothesis between the horizontal alignment and the road profile was satisfactory, because of the RF coefficient and the order of magnitude of this variable (10) in relation to NCKM (1).

Based on the evaluation of point estimates of the variables determining vertical (RF) and horizontal (ADC) geometry for each road section, the classification of these sections according to the qualitative factors shown in Table 1 was carried out. Such an aggregation of point estimates into variation intervals reduced the imprecision of the estimates, principally for ADC. Contrary to what happens with the maintenance state of rolling track, it is coherent to consider this classification of road geometry as stable along time, unless improvement projects are introduced.

The classification of road sections in terms of geometry and maintenance state was recorded in the three free user data fields associated with each link in the STAN data base, according to the typical value of the variation interval of each determinant variable. In addition, the option was made to use the beta coefficient, which is another link attribute, to classify the rolling surface into paved and unpaved, even though it has also been included in the identification of the link type. Therefore, the data base to be used by the STAN system provides, for the highway mode, the inventory information on the selected road network. It is to be noted that these variables were not used in the specification of the cost functions, since different functions were specified for the different sets of physical characteristics of the road sections.

This determination of road network attributes corresponds to a proposal for the application of the STAN system in the Southeast Region, and represent basic concepts in the definition of the data base contents. These concepts may be modified, as may be required in the context of the assignment algorithm and as a result of the application of the STAN system.

3.3 IDENTIFICATION OF HIGHWAY VEHICLES

As described in Chapter 2, Part II, in the STAN system, vehicles are associated to products transported on a given mode, and may be used to specify those transportation costs which are independent of the tonnage transported as, for example, the cost of vehicle depreciation. Vehicles are defined according to their cargo capacity and gross weight and one vehicle is associated to each product-mode combination. In addition, the STAN system permits to combine vehicles into "convoys" to be defined in terms of total gross weight, used principally in the representation of waterway convoys and trains.

The definition of road vehicles, for the pilot application, differentiated two utilization factors for selecting the typical vehicle and determining its transportation capacity. The utilization of each vehicle type, available in the fleet, represents the proportion in which the transportation of a given product is distributed among the different classes of road vehicles. The capacity utilization factor represents the ratio between the actual load per trip and the nominal cargo capacity of each vehicle class. These factors are fundamental in establishing an equivalence between the tonnage transported and the number of vehicles used. They also permit the evaluation of the vehicule costs for the network links.

The determination of the two utilization factors was based on data contained in a sample of about 11,000 commercial vehicles surveyed by GEIPOT in the period from May, 1982 to April, 1983, through the project "Study on Freight Highway Transportation" (GEIPOT, 1984b). This information was collected by means of questionaires mailed to transportation operators selected at random all over the Brazilian territory. This constitutes the most complete sample of available information on the operation and on the fleet used by freight highway transportation in Brazil. However, the size of this sample is relatively small and, as a consequence, its representativeness cannot be taken without reservation. The average response rate obtained during the data collection was of only about 25% of the mailed questionaires. The total of the mailed questionaires, corresponded to 0.1% of the commercial vehicles inventoried in the country in 1979. It is also important to note that most of these responses were obtained from transportation companies, which could imply a bias in the obtained sample, given the high rate of individual truck ownership. However, the statistical tests carried out during that project, insured that the influence of this problem was negligible for the observed variables.

Before determining the utilization factors, the data was classified in different categories of vehicles and products, in order to simplify its analysis and maintain the aggregation level of the information appropiate for the use of the STAN system.

In general, road freight vehicles were classified, according to their size and net cargo capacity, into light, middle and heavy trucks, while sometimes also including middle-heavy trucks. This classification does not follow any established pattern, however, and there are variations between studies in the limits considered for each class.

While developing the STAN data base, the classification adopted was the one used in the model employed for the calculation of vehicle operating costs, so that the parameters concerning vehicles be compatible with the parameters concerning the cost of their operation.

According to this classification, the different categories into which commercial vehicles are subdivided correspond to the following capacity ranges for net cargo:

- Light trucks	less than 4.0 tons;
- Medium trucks	from 8.0 to 15.0 tons;
- Heavy trucks	from 24.0 to 29.0 tons;

It may be noted that these ranges are not continuous. As in the sample used there were cases situated between the intervals, it was necessary to aggregate the data and to classify these vehicles into the corresponding weight range.

Data was classified according to product type, only in terms of the product groups considered in the pilot application of the STAN system (see Chapter 5): soya beans, soya meal and oil, fertilizers, cement, coal, iron ore and metallurgical products. Data concerning soya beans, fertilizers, coal and iron ore could be classified directly, since they were already included as such in the sample considered. Data for cement and metallurgical products were included as different subgroups of these products, so it was necessary to "a priori" aggregate these. The group classified as cement was composed of data for white cement and portland cement, and the group classified as metallurgical products covered data for steel, concrete reinforcing bars, pig iron and several metallurgical products.

The fleet utilization factor is defined as the percentage each vehicle class is used to transport a given product, and is one of the major parameters for the definition of the road typical vehicles. The distribution of freight among the several vehicle categories allows to associate delays and costs to the links of the network.

In the present study, the determination of this factor was based on a sample of actual observations on the operation of freight road transportation, where the following variables were considered:

- vehicle gross weight;
- vehicle nominal capacity;
- cargo carried each trip;
- cargo carried by month;
- monthly kilometres travelled with cargo;
- monthly kilometres travelled empty.

From these variables, those selected for the calculation of the fleet utilization factor (since they best characterize the transportation operation) were:

- cargo carried by month;
- monthly kilometres travelled with cargo;
- cargo * monthly kilometres travelled with cargo;
- monthly kilometres travelled with and without cargo;
- cargo * monthly kilometres travelled with and without cargo.

This set of variables was evaluated separately for the different vehicle classes and products considered in the project, and the averages corresponding to each of these classes were determined.

These variables were also analyzed in terms of direction of the circulation of products in the Southeast Region. Consequently, the data was also classified for the following routes: routes within and out of the Southeast Region, routes that come in and out of the region, total of routes in the region, total of routes in the country. The decision was made, however, not to use the data for any specific route, since it resulted from disaggregations of the sample and would have reduced the number of observations (see Table 2 - GEIPOT, 1984b), making any inference based on such data unreliable. For this reason, only the data set for all the routes in the country was used.

The variable considered as the most representative of the fleet utilization, since it represents the combined effect of the freight transported and of the distance travelled, was the tonnage of each product transported monthly. Only loaded vehicles were considered.

So, according to the definition presented above, the fleet utilization factor is obtained as the fraction associated with each product multiplied by the monthly distance travelled with cargo by the different vehicle classes. These factors are summarized in Table 3 (GEIPOT, 1984b), together with the corresponding monthly amount of ton-km performed for each product.

According to these data, the utilization of the road vehicle fleet involves, for all products, a more substantial participation of heavier vehicles, the smaller ones representing the smallest part in terms of the total ton-km done by month. For almost all of the analyzed products, the data indicate that heavy trucks transport

Route Product	Soya Bean	Soya Meal	Soya Oil	Char-Coal	Mineral Coal	Iron Ore	Cement	Metal. Products	Fertilizers	Total
Total of Region	19	17	33	68	10	206	210	201	102	866
Within the Region	12	16	24	68	10	206	205	185	87	813
Coming into Region	6	-	-	-	-	1	7	1	21	36
Leaving Region	1	1	3	-	-	-	4	9	14	32
Outside Region	146	42	9	3	2	38	130	41	90	501
National Total	165	59	42	71	12	244	340	242	192	1367

Table 2 Number of Vehicles Observed in the Sample by Route and Product

Product / Vehicle	Soya Bean	Soya Meal	Soya Oil	Charcoal	Mineral Coal	Iron Ore	Cement	Metal. Product	Fertilizers
Light Trucks (Gas)	1.0 (61,090)	- -	6.9 (199,335)	6.9 (45,619)	- -	- -	4.5 (180,542)	2.8 (62,600)	12.0 (405,286)
Light Trucks (Diesel)	0.3 (15,600)	5.6 (114,180)	18.2 (524,426)	11.5 (75,600)	3.5 (142,560)	19.0 (2,522,955)	11.9 (472,731)	8.2 (183,012)	6.3 (212,347)
Middle Trucks	14.4 (837,662)	29.7 (765,637)	22.4 (643,477)	81.6 (537,138)	26.8 (1,081,500)	57.3 (7,309,488)	27.7 (1,104,426)	36.3 (811,296)	30.9 (1,047,163)
Heavy Trucks	84.3 (4,904,052)	64.7 (1,666,875)	52.5 1,508,440)	- -	69.7 (2,816,000)	23.7 (3,029,562)	55.9 (2,231,795)	55.7 (1,178,096)	50.8 (1,720,511)

Table 3 Fleet Utilization Factors (%) and Monthly Production (Ton-km)

more than 50% of the total monthly ton-km. The only exception is iron ore since, according to the sample used, medium trucks move almost 60% of all the iron ore transported monthly.

The vehicle capacity utilization factor is defined as the ratio between the load actually transported by the vehicle and its nominal cargo capacity. This is the factor that determines the quantity of freight that may be assigned to each vehicle.

As in the case of the fleet utilization factor, the effective capacity of road freight vehicles was determined based on some of its operating characteristics. From the available variables, those representing the technical characteristics of the vehicles were considered more relevant for this case:

- vehicle gross weight;
- nominal cargo capacity;
- cargo transported per trip.

These variables were also evaluated separately for the different vehicle classes, products and routes considered in the pilot application, and the averages corresponding to each of these classes were determined.

Much dispersion was observed in the data for light and medium trucks, with very high values for some standard deviation values. This dispersion was expected, however, since the vehicle classes did not present a continuous distribution in their respective weight ranges. The aggregation also resulted in values larger than those predicted for the nominal cargo capacity of light trucks, with the average found for the other classes within the expected intervals.

A comparison between the predicted values for this variable and the respective average values found in this study, by vehicle class, is presented below:

Vehicle Type	Predicted Cargo Capacity(tons)	Cargo Capacity Found(tons)
Light Trucks (Gas)	Up to 4.0	6.3
Light Trucks (Diesel)	Up to 4.0	5.9
Medium Trucks	From 8.0 to 15.0	12.8
Heavy Trucks	From 24.0 to 29.0	25.1

It is worth to recall that these averages are for the aggregated data of all the routes in the country.

Therefore, according to their definition, the utilization factors for the vehicle capacity are computed as the ratio between the freight load transported per trip and the nominal freight capacity of the vehicle. Table 4 (GEIPOT, 1984b) shows a summary of these factors, together with respective values of the typically transported loads and net capacities. In addition, Table 5 (GEIPOT, 1984b) shows the average gross weight observed for each vehicle class, for each of the selected products.

According to this data, heavy trucks exhibit a higher utilization of their cargo capacity per trip than medium-size and light trucks. Heavy trucks also exhibit, for the various products, more homogeneous values of the utilization factors of their cargo capacity, followed by medium-size trucks. It is also observed that the utilization factors for light trucks are the lowest found among the several vehicle classes, and are those that present the greatest variation for the different products.

Based on this information, the specification of the road vehicle for each product may follow one of two alternative hypotheses. In the first hypothesis, the vehicle

Vehicle / Product	Soya Bean	Soya Meal	Soya Oil	Charcoal	Mineral Coal	Iron Ore	Cement	Metal. Product	Fertilizers
Light Trucks (Gas)	89 (6,045/6,791)	- -	72 (4,300/6,000)	96 (6,000/6,250)	- -	- -	79 (5,341/6,770)	32 (6,045/4,750)	100 (6,919/6,919)
Light Trucks (Diesel)	100 (6,500/6,500)	74 (2,405/3,250)	94 (6,633/7,050)	94 (6,635/6,750)	95 (7,300/7,700)	125 (9,500/7,625)	86 (4,620/5,396)	73 (3,647/4,993)	90 (3,444/3,811)
Middle Trucks	99 (12,407/12,950)	99 (14,005/14,077)	93 (10,796/11,790)	99 (11,506/11,682)	80 (11,650/14,500)	99 (11,806/11,895)	91 (11,673/12,881)	90 (10,938/12,209)	97 (12,547/12,881)
Heavy Trucks	100 (24,959/25,011)	100 (25,007/25,107)	99 (26,460/26,643)	- -	97 (23,333/24,000)	100 (25,000/25,000)	94 (24,044/25,451)	90 (22,030/24,476)	100 (25,294/25,176)

NOTE: The values within parentheses correspond to the ratio between the typical load and the vehicle capacity.

Table 4 Vehicle Capacity Utilization Factors (%) plus Typical Loads and Net Capacities

Product Vehicle	Soya Bean	Soya Meal	Soya Oil	Charcoal	Mineral Coal	Iron Ore	Cement	Metal. Product	Fertilizers
Light Trucks (GAS)	11,068	-	10,500	10,067	-	-	13,122	8,780	10,815
Light Trucks (Diesel)	11,450	6,200	13,308	11,000	12,999	9,385	9,383	8,553	6,750
Middle Trucks	19,346	21,372	18,414	18,547	23,750	17,936	19,864	19,237	19,708
Heavy Trucks	40,007	40,014	42,214	-	37,333	43,375	40,113	39,288	40,294

Table 5 Gross Weight of Highway Vehicles (tons)

types are defined as those with the highest utilization in the fleet, whereas in the second hypothesis, the typical vehicles represent averages of the characteristics of each vehicle class, weighted by its fleet utilization factor. Although typical vehicles do not correspond to actual vehicles, the concept of typical vehicles was adopted because the assignment procedure considers the freight tonnage, vehicles being only an intermediary step in the evaluation of delays and transportation costs. Table 6 shows the transportation capacity and the gross weight of the typical vehicle for each product. It is important to stress the correction of the nominal vehicle capacity by means of the associated utilization factor, thus reflecting the typical loading of the vehicle.

	Characteristic	
Product	Transportation Capacity	Gross Weight
Soya Bean	22,907	36,657
Soya Meal	20,474	32,584
Soya Oil	17,816	29,434
Charcoal	10,536	17,094
Mineral Coal	19,641	32,841
Iron Ore	14,495	22,718
Cement	17,460	29,623
Metallurgical Products	15,921	28,635
Fertilizers	17,774	28,282

Table 6 Typical Road Vehicles

It is possible to identify three groups of typical vehicles according to the transportation capacity and gross weight ranges. One finds, in the extreme groups, soya bean, soya meal and mineral coal, using heavier vehicles, and iron ore and charcoal, with lighter vehicles. The remaining products are in the intermediary range. It is believed that there was a certain distortion for iron ore data, due to the fact that a large part of the cargo was transported by railway. The road vehicles surveyed reflected, therefore, only the freight movements between the mine and the railway stations or short-distance transportation. On the other hand, there was no indication of an influence of the link characteristics of the road network in the Southeast Region on the utilization of different types of trucks, such as restrictions to the traffic of heavy trucks on unpaved roads.

The determination of the number of vehicles required for transportation was performed independently of the total round trip. To obtain more consistent estimates of fleet needs, one may consider the empty return as an additional product in the transportation demand, or one may reduce the vehicle transportation capacity according to its trip routing. The assignment algorithm in the STAN system evaluates the number of vehicles by means of the ratio between the transportation demand and the vehicle capacity on each link of the transportation network. Even when the number of vehicles is not considered in the specification of the cost function, one may obtain these statistics at the end of the assignment, both at the level of links and by product- mode combination.

3.4 DEFINITION OF HIGHWAY COST FUNCTIONS

Generalized transportation cost is used as criteria in the assignment procedure, that is, the route selection is determined by the minimum cost path. Considering the user cost (tariffs, time opportunity, losses and dammages, etc.) in the modal split, refleted in the selection of possible transportation modes for the O/D matrices, the assignment should be based on the cost of supplying the transportation, either financial (operator) or economic (macroeconomic analyses). The base of the cost is, therefore, the unit cost by transported ton-km, so as to differentiate road sections according to their physical characteristics and traffic conditions.

The definition of the cost elements considers those that vary with the transported tonnage, whereas the fixed portion (for example, construction costs) is considered as a historical cost. Although part of the road maintenance cost depends on transportation flow, it was included in the fixed cost because its outlet programming is a function of the observed traffic in the previous period. Therefore, transportation cost basically represents the operating cost of road vehicles, reflecting the design characteristics and current maintenance state of the road. It should be stressed that the fixed costs, especially maintenance costs, should be evaluated after the determination of flows in the assignment process, to establish investment programs.

The assignment algorithm in the STAN system permits non-linear cost functions to be specified, in order to represent, for example, economies of scale or traffic congestion. Link capacity, in particular, may be considered in the cost functions as a freight quantity above which transportation costs increase and is given by a continuous function.

According to the decision of not specifying capacities for the road system, however, unit costs were considered to be constant. Also, normally, there are no congestion problems on Brazilian roads, except for sections close to urban centers. This congestion can be reflected through an additional cost associated to the nodes representing these urban centers, or through the creation of access links with non-linear cost functions. Both alternatives are difficult to calibrate, however. As to economies of scale, they were considered as inexistent for highway transportation, both in terms of tonnage, due to the small freight leads as compared to the vehicle capacity, and distance, due to the high incidence of empty back trips and short distance movements.

Three types of cost functions may be defined in the STAN system, operating, time and energy costs, which may be linearly combined to form the generalized cost used in the assignment algorithm. The vehicle operating cost, considered as the cost of supplying highway transportation, covers all these three types. However, in order to specify these costs it was necessary to estimate non-monetary quantities, namely, average speed, for the time cost, and the energy consumption, for the energy cost.

The delays and costs were determined as depending on road and vehicle class. In addition to paved and unpaved, roads were classified according to horizontal alignment (ADC), profile (RF) and maintenance state (QI), following the classification of the attributes of the transportation network (see Table 1). Vehicles, on their turn, represent light, medium-size, and heavy trucks, assuming that all three use diesel oil as fuel. Although the typical vehicles by product presented data for light truck using gasoline, their characteristics were not compatible with vehicles considered in the prediction equations for speed and fuel consumption. It is worth stressing that, even if the aggregations into road types and vehicles classes were subjective and based on experience obtained by PICR (GEIPOT, 1980b), they are traditional in strategic planning of the highway sector.

Profile / Horizontal Alignment	Level RF < 15		Undulated 15 < RF < 30		Mountainous 30 < RF	
	RF= 7	ADC=12	RF=27	ADC= 9	RF=32	ADC= 2
Little Sinuous	RF=13	ADC= 8	RF=20	ADC= 0	RF=57	ADC= 3
ADC < 20	RF=13	ADC= 2	RF=21	ADC=11	RF=34	ADC=17
	RF=15	ADC=20	RF=19	ADC=17		
	RF= 7	ADC=26				
	RF= 8	ADC=55*	RF=21	ADC=22	RF=34	ADC=35
	RF=12	ADC=60				
Middle Sinuous	RF=15	ADC=42	RF=23	ADC=70	RF=31	ADC=61
	RF=10	ADC=46				
20 < ADC < 70	RF=11	ADC=41	RF=18	ADC=47	RF=43	ADC=62
	RF=15	ADC=52*				
	RF= 5	ADC=57				
	RF=13	ADC=48*				
	RF=12	ADC=51				
			RF=30	ADC=101*	RF=49	ADC= 90*
			RF=26	ADC= 98	RF=31	ADC=118
Very Sinuous	RF= 8	ADC=83	RF=27	ADC= 77	RF=40	ADC= 72
			RF=21	ADC=119*	RF=42	ADC=225*
ADC > 70	RF=14	ADC=71	RF=21	ADC= 71	RF=67	ADC=190*
			RF=18	ADC= 99	RF=36	ADC=111
			RF=18	ADC= 86	RF=32	ADC= 90
			RF=30	ADC=154*		

(*) These sections were considered in the calculation of impedances in the cells with more than four observations.

Table 7 Road Sample

A random sample was used as data for the calculation of delay and cost values for the characteristics of existing road sections. In fact, the disaggregate information concerning the road section (sequence of slopes and curves) required to estimate fuel consumption and vehicle speed was obtained from a set of geometrical projects that was later classified according to ADC and RF ranges. In total, 44 road sections from the Southeast Region were selected, in an attempt to find as many sections as possible for each type of road. The distribution of geometrical characteristics for ADC and RF ranges for these road sections is found in Table 7. These sections were 6-km long, without cutting curves or slopes in their extreme points. This was considered sufficient for obtaining representative averages of ADC and RF indices. Three levels of condition were adopted for the road maintenance state, by means of the typical values of each range (see Table 1) in each selected section, since, in practice, it would be very difficult to obtain this data for several types of geometry, the information in DNER inventory being unreliable and out-of-date. Cost and delay values were, therefore, determined based on averages of maximum three sections, for each geometry type, for the different maintenance conditions, with monetary values in 1980 cruzeiros. The results by vehicle and pavement type were represented in a three dimensional matrix, representing the levels of horizontal alignment, profile and maintenance state.

The operating cost estimates were based on equations developed by the Research on the Interrelationships of Highway Costs (PICR), carried out by GEIPOT in the 1976-1980 period. The survey of user costs was aimed at obtaining correlations between each of the components of the vehicle operating costs and the characteristics of the roads they use. The data base was made up of records and information collected from accounting offices, storehouses and repair shops of the companies, or from personal notes of vehicle owners and measurements of routes used by those vehicles, so as to characterize them in terms of QI, ADC and RF. The corresponding equations were obtained through statistical analysis and regression techniques. Among the characteristics considered for the vehicles were their class (light, middle-size, or heavy), fuel type, age and monthly utilization (in km), as well as financial or economic prices parameters, such as fuel and tire prices. The operating cost components considered in these equations cover the following items: fuel, oil and grease consumption, spare parts, maintenance labor, washing, tire consumption, depreciation and interest, driver wages, licencing and insurance, administration charges, all in 1980 cruzeiros per kilometer. The results of these estimates are shown, in terms of total operating cost (average and standard deviation), in Tables 8 to 13, by truck class and rolling track type (paved and unpaved).

It was noted that, in general, the standard deviations are very small, on the order of 0.1% of the average value, with larger values only in extreme conditions of geometry and road maintenance, where the deviations were within a range from 3% to 25% of the respective averages. The following observations are relevant:

- Operating costs increase with the level of severity of road characteristics and with vehicle size;
- Costs for unpaved roads are higher than those obtained for paved roads;
- The variation of costs with their maintenance state is larger for unpaved roads than for paved roads;
- Costs for heavy trucks are more susceptible to variation with terrain profile than costs for lighter trucks;
- Costs for level roads are not significantly influenced by the variation in the degree of curvature;
- In very curved roads, the increase in costs with the degree of inclination of the terrain is much more notable than in roads with a more linear design.

Thus, the small variance in total operating costs, and the reasonable values of

Maintenance State ⟹		Good			Regular			Bad		
Horizontal Alignment	Profile	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h
Little Sinuous	Level	10.67 (0.11)	4.5 (0.2)	65.6 (3.2)	11.83 (0.16)	4.3 (0.2)	63.1 (2.8)	13.36 (0.23)	4.2 (0.3)	58.4 (2.0)
	Undulated	10.79 (0.11)	4.2 (0.1)	63.6 (1.2)	11.98 (0.15)	4.1 (0.1)	61.3 (1.0)	13.59 (0.21)	4.1 (0.1)	56.8 (1.0)
	Mountainous	10.84 (0.12)	4.2 (0.2)	61.2 (1.3)	12.06 (0.17)	4.1 (0.1)	58.9 (1.3)	13.69 (0.25)	3.9 (0.1)	54.7 (1.1)
Middle Sinuous	Level	11.29 (0.06)	4.5 (0.2)	64.6 (1.9)	12.70 (0.08)	4.4 (0.2)	62.4 (1.6)	14.66 (0.12)	4.3 (0.2)	58.1 (1.5)
	Undulated	11.39 (0.46)	4.3 (0.2)	61.3 (3.4)	12.84 (0.67)	4.1 (0.2)	59.3 (3.1)	14.91 (0.07)	3.9 (0.2)	55.5 (2.6)
	Mountainous	11.62 (0.30)	3.8 (0.2)	53.9 (4.8)	13.17 (0.43)	3.7 (0.3)	52.3 (4.4)	15.42 (0.69)	3.6 (0.3)	49.1 (3.7)
Very Sinuous	Level	11.76 (0.09)	4.5 (0.2)	64.2 (0.9)	13.38 (0.13)	4.4 (0.2)	62.2 (1.0)	15.76 (0.21)	4.3 (0.2)	58.0 (1.3)
	Undulated	13.31 (0.60)	4.2 (0.1)	57.4 (1.5)	15.85 (1.03)	4.1 (0.1)	55.8 (1.7)	20.38 (2.16)	3.9 (0.1)	52.7 (1.8)
	Mountainous	14.16 (1.56)	3.0 (0.4)	41.3 (5.3)	17.48 (2.82)	2.8 (0.3)	40.6 (5.0)	24.61 (6.78)	2.8 (0.3)	39.3 (4.2)

Table 8 Road Cost Factors - Paved Road, Light Truck

Maintenance State ⟹		Good			Regular			Bad		
Horizontal Alignment	Profile	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h
Little Sinuous	Level	17.62 (0.2)	4.2 (0.3)	65.5 (5.5)	19.47 (0.2)	2.8 (5.3)	61.3 (0.2)	21.93 (0.2)	2.8 (0.1)	56.1 (1.8)
	Undulated	17.99 (0.2)	4.1 (0.1)	57.9 (2.3)	19.90 (0.2)	2.6 (0.1)	55.9 (2.2)	22.45 (0.2)	2.6 (0.1)	51.6 (1.8)
	Mountainous	18.64 (0.5)	4.1 (0.2)	53.5 (0.8)	20.66 (0.5)	2.6 (0.1)	51.6 (1.0)	22.33 (0.6)	2.5 (0.0)	48.1 (1.5)
Middle Sinuous	Level	18.14 (0.1)	4.3 (0.2)	62.7 (3.2)	20.10 (0.1)	2.9 (0.2)	60.5 (2.9)	22.73 (0.1)	2.9 (0.2)	56.0 (2.4)
	Undulated	18.47 (0.4)	4.1 (0.1)	54.7 (4.0)	20.50 (0.5)	2.5 (0.2)	53.1 (3.8)	23.21 (0.7)	2.5 (0.2)	49.9 (3.3)
	Mountainous	19.12 (0.4)	3.8 (0.3)	44.6 (5.0)	21.27 (0.4)	2.2 (0.3)	43.5 (1.9)	24.15 (0.6)	2.1 (0.3)	41.0 (4.6)
Very Sinuous	Level	18.48 (0.1)	4.3 (0.1)	62.9 (3.2)	20.53 (0.1)	3.0 (0.1)	60.8 (3.2)	23.28 (0.1)	2.9 (0.1)	56.3 (2.9)
	Undulated	20.14 (0.5)	4.1 (0.1)	52.1 (4.2)	22.65 (0.7)	2.6 (0.1)	50.6 (4.1)	26.09 (0.9))	2.5 (0.2)	47.5 (3.9)
	Mountainous	21.75 (1.3)	3.3 (0.2)	32.1 (4.8)	24.68 (1.8))	1.6 (0.2)	31.7 (4.6)	20.79 (2.2)	1.6 (0.2)	30.8 (4.1)

Table 9 Road Cost Factors - Paved Road, Middle-Size Truck

Maintenance State ⟹		Good			Regular			Bad		
Horizontal Alignment	Profile	Total Opera- Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h	Total Opera- Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h	Total Opera- Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h
Little Sinuous	Level	31.72 (0.21)	1.7 (0.2)	66.7 (8.30	33.69 (0.24)	1.7 (0.20	61.9 (6.3)	36.32 (0.28)	1.7 (0.1)	51.9 (3.2)
	Undulated	32.14 (0.20)	1.6 (0.1)	58.5 (2.6)	34.17 (0.23)	1.5 (0.1)	54.8 (2.2)	36.61 (0.46)	1.5 (0.1)	47.0 (2.0)
	Mountainous	36.12 (0.33)	1.5 (0.1)	53.7 (1.0)	38.20 (0.35)	1.5 (0.1)	50.5 (1.4)	40.98 (0.39)	1.4 (0.0)	43.7 (1.4)
Middle Sinuous	Level	32.42 (0.15)	1.7 (0.1)	63.3 (3.4)	34.53 (0.17)	1.7 (0.1)	60.1 (3.1)	37.35 (0.20)	1.6 (0.1)	51.8 (2.1)
	Undulated	32.78 (0.55)	1.4 (0.1)	55.0 (4.4)	34.95 (0.66)	1.4 (0.1)	52.8 (4.2)	37.85 (0.82)	1.4 (0.1)	46.5 (3.2)
	Mountainous	36.86 (0.39)	1.2 (0.2)	43.4 (5.5)	39.13 (0.47)	1.2 (0.2)	41.8 (5.1)	42.16 (0.57)	1.1 (0.1)	37.5 (4.0)
Very Sinuous	Level	32.87 (0.05)	1.7 (0.0)	64.6 (1.3)	35.08 (0.05)	1.7 (0.0)	61.2 (2.1)	38.83 (1.37)	1.7 (0.1)	52.3 (2.6)
	Undulated	34.79 (0.56)	1.5 (0.1)	50.6 (3.9)	37.43 (0.71)	1.4 (0.1)	48.6 (4.0)	42.18 (1.68)	1.3 (0.1)	43.7 (3.7)
	Mountainous	39.55 (1.30)	0.9 (0.1)	30.4 (4.7)	42.45 (1.65)	0.9 (0.1)	30.0 (4.4)	46.41 (2.18)	0.8 (0.1)	28.7 (3.5)

Table 10 Road Cost Factors - Paved Road, Heavy Truck

Maintenance State ⟹		Good			Regular			Bad		
Horizontal Alignment	Profile	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h	TotaL Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h
Little Sinuous	Level	13.53	4.2	55.4	15.69	4.2	50.3	24.93	4.0	39.8
		(0.23)	(0.2)	(2.1)	(0.36)	(0.1)	(1.5)	(1.53)	(0.2)	(0.6)
	Undulated	13.76	4.0	54.0	16.05	3.9	49.0	26.50	3.8	38.9
		(0.21)	(0.1)	(1.0)	(0.34)	(0.1)	(0.8)	(1.47)	(0.2)	(0.6)
	Mountainous	13.87	3.9	52.2	16.22	3.9	47.6	27.31	3.7	38.1
		(0.25)	(0.1)	(1.1)	(0.41)	(0.1)	(0.8)	(2.03)	(0.2)	(0.4)
Middle Sinuous	Level	14.84	4.2	53.9	17.85	4.1	49.4	33.87	4.0	39.5
		(0.12)	(0.1)	(1.3)	(0.22)	(0.1)	(0.8)	(0.00)	(0.1)	(0.4)
	Undulated	15.08	3.8	52.5	18.35	3.8	48.1	32.34	3.7	38.6
		(1.07)	(0.3)	(2.6)	(1.94)	(0.2)	(1.9)	(2.65)	(0.2)	(0.9)
	Mountainous	15.59	3.6	46.7	19.26	3.6	43.4	33.87	3.3	36.1
		(0.69)	(0.4)	(3.3)	(1.28)	(0.4)	(2.8)	(0.00)	(0.4)	(1.6)
Very Sinuous	Level	15.93	4.3	53.6	19.88	4.2	49.3	33.87	4.1	39.5
		(0.21)	(0.3)	(0.7)	(0.41)	(0.2)	(0.7)	(0.00)	(0.1)	(0.5)
	Undulated	20.51	3.8	48.2	29.35	3.7	45.0	33.87	3.6	37.2
		(2.17)	(0.2)	(0.8)	(3.10)	(0.2)	(1.2)	(0.00)	(0.2)	(0.9)
	Mountainous	24.78	2.8	36.6	29.55	2.7	35.3	33.87	2.6	31.5
		(6.78)	(0.3)	(4.1)	(4.50)	(0.3)	(3.3)	(0.00)	(0.3)	(2.0)

Table 11 Road Cost Factors - Unpaved Road, Light Truck

Maintenance State ⟹		Good			Regular			Bad		
Horizontal Alignment	Profile	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h
Little Sinuous	Level	21.93 (0.07)	2.9 (0.2)	52.3 (3.7)	24.54 (0.29)	2.9 (0.1)	47.0 (2.4)	30.58 (0.05)	2.8 (0.1)	36.7 (1.0)
	Undulated	22.45 (0.240	2.6 (0.1)	48.6 (1.7)	25.17 (0.30)	2.6 (0.1)	44.0 (1.5)	31.61 (0.53)	2.4 (0.1)	34.9 (1.0)
	Mountainous	23.33 (0.64)	2.5 (0.0)	45.5 (1.5)	26.24 (0.77)	2.4 (0.0)	41.5 (1.2)	33.28 (1.19)	2.2 (0.1)	33.6 (0.7)
Middle Sinuous	Level	22.73 (0.18)	2.9 (0.1)	50.6 (1.7)	25.58 (0.23)	2.8 (0.1)	46.1 (1.4)	32.60 (0.41)	2.7 (0.1)	36.5 (0.6)
	Undulated	23.21 (0.69)	2.5 (0.2)	46.8 (3.3)	26.19 (0.92)	2.5 (0.2)	43.1 (2.6)	33.76 (1.99)	2.4 (0.1)	34.6 (0.6)
	Mountainous	24.15 (0.56)	2.1 (0.3)	38.7 (4.1)	27.36 (0.73)	2.0 (0.2)	36.1 (3.4)	35.86 (1.50)	1.9 (0.2)	30.6 (2.1)
Very Sinuous	Level	23.28 (0.07)	2.9 (0.1)	50.7 (1.7)	26.33 (0.07)	2.8 (0.2)	46.3 (1.7)	34.24 (0.05)	2.8 (0.2)	36.6 (1.1)
	Undulated	26.09 (0.93)	2.4 (0.2)	42.7 (2.4)	30.28 (1.42)	2.3 (0.2)	39.8 (2.3)	44.08 (3.22)	2.2 (0.2)	32.9 (1.6)
	Mountainous	28.79 (2.46)	1.5 (0.2)	28.8 (3.7)	34.17 (3.80)	1.5 (0.2)	27.8 (3.1)	47.89 (6.11)	1.5 (0.2)	25.4 (2.2)

Table 12 Road Cost Factors - Unpaved Road, Middle-Size Truck

Maintenance State ⟹		Good			Regular			Bad		
Horizontal Alignment	Profile	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h	Total Opera-Ting Cost (1980)Cr$/km	Fuel Consump Km/l	Speed Km/h
Little Sinuous	Level	36.32 (0.28)	1.6 (0.1)	43.2 (1.9)	38.09 (0.34)	1.6 (0.1)	38.6 (1.2)	41.62 (0.55)	1.5 (0.0)	29.2 (0.4)
	Undulated	36.88 (0.28)	1.4 (0.1)	40.2 (1.5)	38.76 (0.34)	1.4 (0.1)	36.3 (1.2)	42.65 (0.54)	1.3 (0.1)	28.2 (0.6)
	Mountainous	40.98 (0.39)	1.3 (0.0)	38.1 (1.0)	42.95 (0.43)	1.3 (0.0)	34.7 (0.8)	47.12 (0.57)	1.2 (0.1)	27.4 (0.5)
Middle Sinuous	Level	37.35 (0.20)	1.6 (0.1)	41.8 (1.0)	39.40 (0.24)	1.6 (0.1)	37.8 (0.7)	43.91 (0.40)	1.4 (0.1)	28.9 (0.3)
	Undulated	37.85 (0.82)	1.4 (0.1)	39.4 (2.3)	40.00 (1.05)	1.4 (0.1)	35.8 (1.7)	44.93 (1.97)	1.3 (0.1)	27.9 (0.8)
	Mountainous	42.16 (0.57)	1.1 (0.1)	33.3 (3.0)	44.49 (0.72)	1.1 (0.1)	31.1 (2.5)	50.08 (1.32)	1.1 (0.1)	25.8 (1.4)
Very Sinuous	Level	38.04 (0.05)	1.6 (0.1)	41.8 (1.0)	40.29 (0.04)	1.6 (0.1)	37.8 (0.9)	45.60 (0.01)	1.5 (0.1)	29.0 (0.5)
	Undulated	41.01 (0.92)	1.3 (0.1)	36.0 (1.8)	44.19 (1.27)	1.2 (0.1)	33.3 (1.7)	53.76 (3.08)	1.2 (0.1)	26.9 (0.9)
	Mountainous	46.41 (2.18)	0.8 (0.1)	25.6 (2.9)	50.19 (3.05)	0.8 (0.1)	24.8 (2.4)	63.13 (8.05)	0.8 (0.1)	22.2 (1.5)

Table 13 Road Cost Factors - Unpaved Road, Heavy Truck

their averages, make them suitable for utilization in the pilot application of the STAN system.

The speed and fuel consumption estimates were determined by the Model for Time and Fuel Consumption (MTC - 2nd version), developed by PICR (GEIPOT, 1985). The Traffic and Fuel Consumption experiments aimed at constructing a mathematical model capable of simulating the performance of vehicles travelling on road sections having known characteristics and free traffic. The data consisted of fuel consumption observations collected by means of accurate instruments installed in appropriate vehicles as they moved at pre-established speed and gear, on sections representing variations in terms of maintenance, vertical and horizontal geometry. Speed observations, by using radar, were also available on the same sections, in order to translate the psychological attitude of the vehicle driver. Other than the statistical approach to the data, the MTC incorporates relations obtained from classical mechanics. The major vehicle characteristics are: power, breaking capacity, freight load; whereas for the road, detailed data are needed on grade, curvature radius, superelevation, as well as type and level of pavement roughness. It is stressed that road sections were classified into QI, ADC and RF ranges, even though in the calculation of these costs detailed data were used, in order to be coherent with the road network classification.

In the MTC, speed is determined based on the assumption that there is an average speed, inherent to a given combination of vehicle and road homogeneous section. This average speed is calculated based on several restrictions represented by the characteristics of the vehicle, the road and the driver (psychological factors). Fuel consumption is expressed as a function of the power used and of engine speed. The power used is estimated as a function of speed and acceleration, by means of a mechanistic approach based on the equilibrium of forces acting upon the vehicle movement, as well as on basic principles of vehicle mechanics. A logical sequence of gear changes is assumed for determining engine speed, respecting the maximum speed limits legally established. The results of these estimates are also shown in Tables 8 to 13.

In general, the standard deviations presented are relatively low, both for speed and fuel consumption, and are of the order of 5% of the average value, with higher values at the extreme levels of the factors considered, where the deviation reaches about 15% of the average. As to the behavior of the average values, the following observations are relevant:

- Speed and fuel consumption (km/l) vary inversely with the level of severity of the road characteristics and vehicle size;
- Speed and fuel consumption (km/l) values for paved roads are higher than those for unpaved roads;
- Whereas on unpaved roads speed always varies inversely with vehicle size, on paved sections, the same speed level is observed for middle and heavy trucks, when they are classified as bad in terms of maintenance;
- Estimated fuel consuption for light trucks is more suceptible to variations in terms of the state of road maintenance, than the estimated consumption for heavier trucks;
- The road profile influence upon vehicle speed and consumption increases with road sinuosity, principally on mountainous sections.

Again the small variance in speed and fuel consumption values, together with the coherent behavior of their averages, did not restrict their utilization in applications of the STAN system.

The analysis of the variations in average impedances with road characteristics showed the possibility of considering the joint effect of vertical and horizontal geometry, for a given road maintenance state. Such a correlation was also observed in the road classification, in where the ADC was estimated based on the number of curves with a radius below 100 m, and a significant coefficient was obtained for the RF. However, the initial idea was maintained for the distinction of road types, in order to be coherent with the models and equations used to estimate the variables and with the data in the DNER inventory.

It is also necessary to establish how to determine the three types of cost functions (operating, time, and energy costs) used in the STAN system, based on these estimates of road section impedances. The unit energy cost was determined by the ratio between the price of a liter of fuel and the consumption of each vehicle moving on each road type. Despite the alternative of obtaining consumption through the equations from the User Survey, which included fuel as an operating cost item, the option was to consider MTC estimates , since they were closer to the vehicle mechanical characteristics and to the disaggregate road information. The price of a liter of fuel was estimated through the average of the prices for year 1980, weighted by the period they were in force, thus obtaining a value of Cr$ 14.61 per liter of diesel oil. On the other hand, the total operating cost is obtained directly from the estimates of operating costs as impedances, thus differentiating both vehicle class and road type.

Time cost, in the context of a cost approach using the transportation production measures, refers to those items of operating cost not directly associated to the distance travelled. Initially, the items corresponding to vehicle depreciation and insurance/licensing were selected. Later on, driver wages were also included, assuming that they are not paid according to production. The conversion from a kilometer base, obtained from PICR equations, into an hour base was done by applying the ratio between the vehicle monthly utilization (in km) and the monthly number of hours. The monthly utilization was also estimated by PICR equations, whereas the monthly number of hours is total (720h) for the depreciation and insurance/licensing items, and partial (250h) for driver wage. Table 14 shows time cost estimates (Cr$/h) by vehicle, independent of road characteristics. It is stressed that this cost does not refer to the road transport operator, and does not reflect considerations on stock and in-transit capital of the client, which determine the modal split.

Vehicle Class	Cr$ de 1980/h
Light Truck (Diesel)	89,79
Middle - Size Truck	99,89
Heavy Truck	135,98

Table 14 Time Cost Estimates - Road

Finally, the development of a generalized-cost function identifies two important aspects. In order to consider a linear combination of time, operating and energy costs, it is necessary to previously convert the former into Cr$/km as a function of the average speed for each road section, or to consider the total operating cost estimates as sufficient. It is important to note that, in the first case, the summation of the three cost types would include a double counting of fuel consumption and of the items considered in the time cost, which makes it necessary to previously determine a residual operating cost. In the application of the STAN system, the cost functions are in Cr$ per ton-km of each product, and it was necessary to make aggregations according to fleet utilization and capacity coefficients (only one class of light truck was considered, independent of fuel type).

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CHAPTER FOUR

PORTS AND NAVIGATION

4.1 PORT DATA

The final port network representation, described in Chapter 5, Part II, was used to model all the ports, included in the study area, which are relevant for the movement of the selected products. Despite the individualization of the different port administrations in the Southeast region, the ports included in the application were aggregated into three main port systems around the major ports of Vitória (Espirito Santo), Rio de Janeiro (Rio de Janeiro) and Santos (São Paulo). This aggregation do not significantly alter the results of transportation analyses in the Southeast region since, administratively, state port companies with normative and strategic responsabilities already exist, distances between ports in the same state are very small and small terminals are usually specialized for specific products. For ports outside the study area, the representation of transshipment operations was modeled by the port access arcs linking the land transportation network to the coastal navigation network.

The first, and one of the most important, attribute that we attempted to estimate for port networks is the total port handling capacity for each product. Port capacity was computed by multiplying the average (for the different moorages) hourly productivity by the number of working hours in the analysis period (in this case, year 1980). For the latter, the occupation of moorages was evaluated, thus including into the resulting figure the effect of the waiting time and the ship arrival frequency. Consequently, port capacity consisted of the tonnage handled in 1980 at the various moorages, whose estimation was determined by the projection of the average productivity and occupation rates for those locations.

The determination of the productivity indices used data available in the PORTOBRÁS statistical yearbook and, in a more disaggregate form, in ship operation bulletins. Table 1 shows average productivity rates for the 17 ports selected for the pilot study. Productivity rates have been assigned to each product by considering the cargo types defined in the PORTOBRÁS statistical yearbook (PORTOBRÁS, 1980b) according to the following rules:

- soya bean and soya meal: the largest productivity rate for solid bulk products;
- soya oil: the average productivity rate for liquid bulk products (vegetal oils) or for general cargo (boxes with soya oil cans for domestic consumption) when the former are not found in the port's operations;
- metallurgical products: the average productivity rate associated to metallurgical products themselves (depending on equipment used) or to heavy general cargo;
- cement: the highest productivity rate for solid bulk (cement) and sacks-pallets;
- other products: the productivity rate for the type of cargo with the same reference.

Better productivity rates were generally observed for ports in the Southeast region, except for the movement of bulk agricultural products (soya bean and meal), for which the southern ports of Paranaguá and Rio Grande are more efficient. On the other hand, movements of coal and iron ore are basically limited to ports in the Southeast and South regions, whereas metallurgical products and cement are handled by all the selected ports. Soya bean and its by-products use the same ports as fertilizers but move generally in opposite directions for loading/unloading purposes.

PORTS	SOYA BEAN	SOYA MEAL	SOYA OIL	FERTILI-ZERS	IRON ORE	METAL. PRODUCTS	COAL	CEMENT
SOUTHEAST REGION								
Vitória (ES)	83.3	83.3	21.0	64.0	77.7	54.7	86.3	20.3
Rio de Janeiro/Angra dos Reis (RJ)	61.4	61.4	58.6 (LB)	138.7	181.7	38.7	273.2	20.9
Santos/São Sebastião (SP)	30.8	30.8	49.0 (LB)	* 126.5	45.0	43.6	70.8	47.8
OTHER REGIONS								
Santarém/Manaus (AM)	24.2	24.2	24.7	-	-	24.4	-	18.9
Belém (PA)	7.5	7.5	12.6	20.8	-	38.0	-	19.8
Itaqui (MA)	53.3	53.3	18.9	23.0	-	27.8	-	17.2
Fortaleza (CE)	14.9	14.9	31.0	41.6	-	68.5	-	19.5
Natal (RN)	-	-	15.6	-	-	18.1	-	24.0
Cabedelo (PB)	37.7	37.7	13.5	-	53.4	58.1	-	19.8
Recife (PE)	20.2	20.2	35.4 (LB)	25.0	35.3	28.5	-	30.5
Maceió (AL)	-	-	10.7	38.6	-	21.1	-	11.6
Aracaju (SE)	-	-	30.3	-	-	23.4	-	49.4 (SB)
Ilhéus/Salvador/Aratu (BA)	119.6	119.6	23.3	23.0	169.0	33.4	93.9	23.0
Paranaguá/Antonina (PR)	68.3	68.3	161.8 (LB)	68.9	98.7	33.1	39.7	17.4
São Francisco do Sul/Imbituba (SC)	78.5	78.5	20.0	* 129.3	92.2	33.5	* 245.3	27.1
Porto Alegre (RS)	-	-	73.7	57.1	-	22.8	99.9	26.7
Rio Grande (RS)	221.3	221.3	143.5 (LB)	90.4	184.4	43.2	164.2	60.2 (SB)

Note: * The total movement is not significant

The values within parentheses correspond to packaging type, when different for different ports (LB-LIQUID BULK, SB - SOLID BULK, GC - GENERAL CARGO)

Table 1 Actual Productivity Rates (tons/hour)

Particularly for the ports in the Southeast region, the information contained in the ship operation bulletins was analyzed, which permitted to determine productivity rates by product at each port, according to the navigation type and cargo volumes (in tons). In addition, the effect of ship waiting at ports was observed and productivity rates were determined for total times and times in operation. A correlation was found between the tonnage handled and the productivity rates: improvements were identified for large volumes, while some problems were observed in the ranges below 10,000 tons. As to the navigation type, productivity was relatively lower for coastal navigation, since the larger cargo lots moved by ocean navigation are handled by better equipment (in terms of quantity and productivity), including the ship's own. The final productivity rates compared advantageously to the information in PORTOBRÁS statistical yearbooks and did not show significant distortions.

The second major step in obtaining data for the port mode consisted in the determination of port unit operating costs. The PORTOBRÁS tariff system, which depends upon transshipment operations was adopted for the pilot application. This emphasizes the difficulty of computing unit costs by ton and was deemed satisfactory because it deals homogeneously with all ports and because its overestimation of cost may represent adverse factors (losses, damages and time loss) resulting from cargo handling.

Figure 1 illustrates port operations with the tariffs charged at domestic ports. In general, a distinction is made between direct and indirect loading/unloading and when special equipment and warehouses are used for the movement of solid and liquid bulk products. The shipowner is responsible of the tasks concerning the ship operations, such as moorage, towing and piloting, etc., while the cargo owner is responsible for cargo handling, including storage. On the other hand, two types

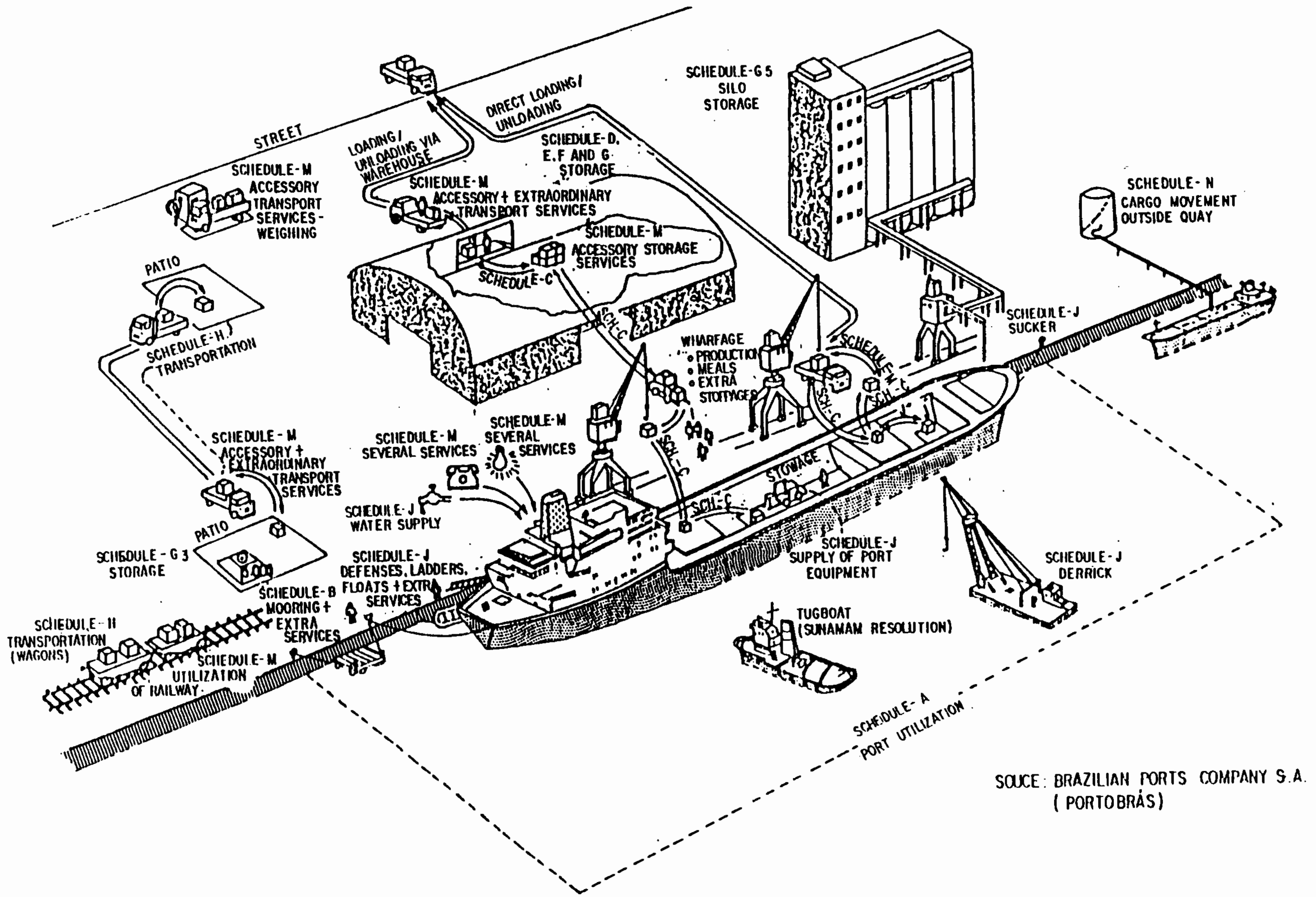

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Figure 1 Port Operations and Tariffs

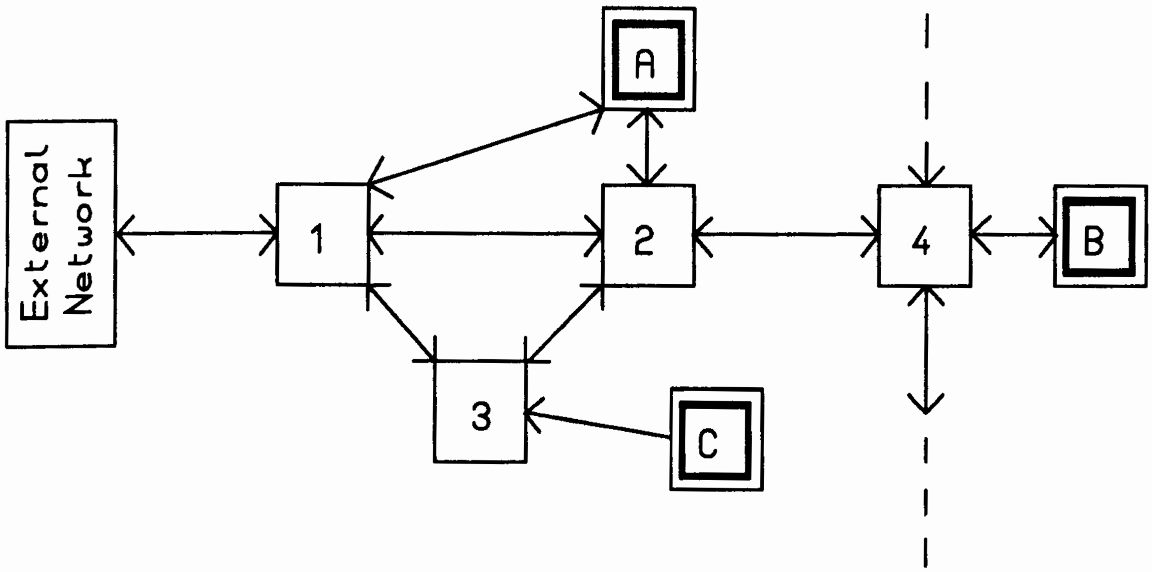


Figure 2 Port Network Representation

of port workers were identified in transshipment operations: for wharfage and for stowage at ship holds, the cost of the latter being determined by the contract union. Tariff values depend directly on the gross weight of the cargo handled, except for ship tariffs (e.g. moorage) whose average characteristics by product (net capacity, length, etc.) permitted a conversion to a ton basis, and for storage tariffs for which a period of 15 days was adopted (minimum in schedules D, E, F or G) independent of any period of exemption at the port.

The interpretation of the port network model (see Chapter 5, Part II and Figure 2) allowed PORTOBRÁS tariff schedules to be associated to links and transfers, as shown in Tables 2 and 3. In order to illustrate the utilization of the PORTOBRÁS tariffs, Tables 4 and 5 show the tariffs charged at the port of Vitória. These tariffs consist of average values for the year 1980, weighted for the period by the prices published by the Diário Oficial (PORTOBRÁS, 1980a) (figures are in 1980 Cr$/ton).

Link (Not Directed)	Meaning	Portobrás Schedule
(1, external network)	Modal access to port	Transportation cost
(1,2)	Direct loading/unloading	C and J
(1,3)	Normal storage	D,E,F or G
(1,A)	Storage between periods	-
(2,3)	Indirect loading/unloading	C and J
(2,C)	Maritime access to port	A
(C,3)	Cargo in warehouses between Periods	-

Table 2 Correspondance Between Tariffs and Link Costs

In general, higher costs were found for the products handled as general cargo (cement and metallurgical products) due to the low productivity of port operations. The tasks associated to transshipment operations were more numerous than those associated to storage. The value of storage in port was many times lower than the costs found outside the port, which led to the utilization of these facilities for the formation of stocks in ports. The high values of stowage represented an operating disfunction, mainly for agricultural bulk products, since the handling of iron ore and coal is exempt from stowage charges. Normally, iron ore and coal are not subject to tariff schedules like the other products, because of an aggreement among

Node	Origins	Destinations	Meaning	Portobrás Schedule
1	External Network	2,3	Vehicle loading/unloading	M and H
1	External Network	A	Storage between periods due to lack of transshipment capacity	-
2	1,3	A,2	Ship loading/unloading	B and Additional C
3	1,C	2	Cargo transportation from warehouse to ship broadside	C (H and M)

Table 3 Correspondance Between Tariffs and Transfer Costs

the major ports in the Southeast region that determine a single tariff by handled ton. An "infinite" (or large enough) cost was associated to the storage of products requiring specialized facilities inexistent in the port, while mooring costs (schedule B), based on linear meters of occupied dock, were multiplied by the ratio between the length of typical ships and their cargo tonnage. When tariffs were subject to discounts, depending on navigation or import/export type, the lowest value was considered and the surplus was applied to the transfers handling these flows (e.g. the "additional" in schedule C).

Schedules	Ocean Navigation	Coastal Navigation
A	19.50	9.50
B	17.00	7.00 (By Linear Meter of Dock)

Table 4 Tariffs for the Port of Vitória - Ships

Product	C	Additional C	D,E,F or G	H	J	M	Stowage
Soya Bean	140.00	-	33.81	-	45.00	44.63	10.57
Soya Meal	72.00	-	33.81	-	45.00	44.63	10.57
Soya Oil	15.00	7.00 (ocean)	inexis-tent	24.00	-	-	137.27
Cement	57.50	28.75 (export) 57.50 (import)	11.00	7.00	10.00	81.00	100.10
Metallurgical Products	77.00	53.00 (ocean)	11.00	19.00	10.00	11.00	97.67
Coal	72.00	-	11.83	8.00	6.00	-	exempt
Iron Ore	72.00	-	11.83	8.00	6.00	-	exempt
Fertilizers	54.60	-	11.83	10.40	6.00	7.00	14.74

Table 5 Tariffs for the Port of Vitória - Products

The separation of flows between storage and direct ship loading was not done by functions that include capacities (see Chapter 8, Part II, for example of functions that may be used to that effect). It was rather estimated by the ratio between direct loading/unloading volumes and the total movement by product in the port, available in the PORTOBRÁS statistics. The projection of this ratio constitutes a parameter for calibrating cost functions for the transfer at node 1 and allows the land mode involved to be differentiated.

As time and energy costs are included in the different port tariffs, delay and energy consumption functions were not individualy defined for the port network. Assignment by time alone was however possible by specifying port possible-through functions based on the inverse of the productivity rates by product.

Finally, it should be noted that, due to lock of appropriate data sources, the other intermodal transshipment facilities of the region, modelled by node transfers, were less extensively analysed.

The evaluation of impedances (cost and times) was limited to the updating of data contained in the Transportation Operating Plans (GEIPOT, 1980b). So, transshipment costs varied from Cr$ 17.75 to Cr$ 59.30/ton according to the product, while capacity and productivity conditions were not identified.

4.2 NAVIGATION DATA

The navigation network includes three transportation subsystems: inland, coastal and ocean navigation. The navigation network was defined so as to connect the major ports of the study area, taking into consideration the flow of the relevant products in terms of transportation demand.

Data for the navigation system, especially between domestic ports, was available from the SUNAMAM line table (SUNAMAM, 1973), which listed the services operated by navigation companies, not only in terms of ports of call and distances travelled, but also in terms of vessel size restrictions and round travel time evaluations. Table 6 illustrates the SUNAMAM coastal navigation line table, together with the respective ports of call classified as major, secondary and alternative/optional ports (according to their relative importance in terms of cargo handling, as well as their physical- operating characteristics).

Coherently with the strategic level of planning adopted for the study, the simplified representation of the navigation network presented in Chapter 5, Part II, was, however, adopted. Service lines were not represented. Instead, all ports were connected through coastal navigation links which run parallel to the shore. In order to facilitate the graphical presentation of links parallel to the Brazilian coast, fictitious links were created, perpendicular to the coast, between each port network and its "navigation" node. The coastal navigation links connected then these port "navigation" nodes. Ocean navigation links, on the other hand, connected the "navigation" node of each port network to a fictitious centroid located in the ocean off the Brazilian coast.

Before proceeding with the representation of the inland navigation subsystem (river and lake), its relevance for transportation in the pilot study area was analyzed. The Plata basin includes, among others, all the navigable rivers in the Southeast region (Tietê, Paraná and Grande), which accounted for only 12% of inland waterway transportation in 1979. Among the selected products, only soya bean and cement marginally participated (6%) in the Plata basin navigation in that year. Thus, inland navigation was not considered in the Southeast region pilot application.

The definition of the navigation network for the study area considers only the relevant ports for the transportation of the selected products. In the case of the Southeast region, seven ports were selected: Praia Mole/Tubarão (Espirito Santo-ES), Vitória (ES), Rio de Janeiro (Rio de Janeiro-RJ), Sepetiba (RJ), Angra dos Reis (RJ), São Sebatião (São Paulo-SP) and Santos (SP). Some of these specialize in handling certain products only. Major ports outside the Southeast region were also selected, in order to permit the interregional exchanges identified by the transportation demand.

Besides length and graphical attributes (nodes coordinates, link types, etc), the only important link attribute in the navigation network is the link *capacity*. All other attributes and cost figures are vehicle (ship) specific and are examined in the following sections.

The navigation transportation capacity is essentially limited by the service capacity of the available ship fleet, which is line specific and therefore difficult to determine as a link attribute. Using SUNAMAM information, a global fleet capacity was however estimated, based on the net tonnage of domestic ships and the number of round trips per year they perform. This capacity may then be assigned to the coastal navigation links. It may also be used in a post-optimization analysis

PORTS	BRAZILIAN TRAFFIC										
	LC-5	LC-6	LC-7	LC-8	LC-9	LC-10	LC-11	LC-12	LC-13	LC-14	LC-15
	FAST TO MANAUS	FAST TO BELEM	GENERAL	GENERAL	GENERAL FOR SUGAR	GENERAL	GENERAL	SUDAM SUDENE-A	SUDAM SUDENE-B		
MANAUS	●				●	●		●	●	● (OP)	● (OP)
AMAZON PORTS						○(1)					
MACAPA											
BELEM	●	●		●	●	●		●	●		
ITAQUI			○				○	○ (OP)	○ (OP)		
MUCURIPE (FORTALEZA)	○ (OP)		●	●			● (OP)		●		
SALTWORKS PORTS											
NATAL									○		
CABEDELO								○ (OP)			
RECIFE					○—(OP)		○ (OP)	●			
MACEIO					○—┘			○			
ARACAJU											
SALVADOR	○ (OP)										
MALHADO (ILHEUS)											
VITORIA											
CABO FRIO											
RIO	○⌐	○⌐		●		○⌐	●				
AIRES	OP	OP		○		A					
SANTOS	○┘	○┘		●		●┘	●				
PARANAGUA				●	●		●				
TEFPE (EX. ANTONIA)				○	○		○				
S. FRANCISCO					○		○				
ITAJAI					○		○				
FLORIANOPOLIS											
RIO GRANDE	●	●									
PELOTAS											
PORTO ALEGRE	●	○	●							● (OP)	● (OP)
ARGENTINE PORTS											
SHIP SIZE	PRIVATE LINES FOR SHIPS ABOVE 3,000 DWT						SPECIAL LINES FOR ANY DWT SHIP			ANY TYPE AND DWT SHIP	OFFSHORE
ROUND TRIP TIME	70	60	50	60	80	55	45	55	45		

Table 6 SUNAMAM Data

of the assignment results by comparing it to the total traffic transiting through the ports of the area. The estimation of link capacity for ocean navigation is even more difficult since many foreign ships are involved. No capacity was assigned to ocean navigation links in our applications.

It should also be noted that, for inland navigation, additional considerations are required when evaluating the link capacity, due to the classification of links into ranges of depth, minimum curve radius and width in straight lines and curves.

4.2.1 Identification of Typical Vehicles

In STAN, the vehicle relates the transportation of the products to the modal networks, and is specific for each product-mode combination. Through its characteristics, net capacity and gross weight, the transportation costs on each link are determined by ton of product, based on estimations of their values by vehicle.

Average characteristics of a typical vehicle for a product is generally based on fleet and capacity utilizations. Fleet utilization defines the participation of each vehicle type, or class, in the transportation of the product. Capacity utilization reflects the average loadings and characteristics of round trips.

For navigation, one generally identifies the navigability index, representing the percentage of time spent navigating, and the occupancy index, representing the occupation of the ships' net capacity. Yet, since we had the observed ton-mile by product and the ships used in fleet calculations, we aggregated the navigability and occupancy indices into the ratio between the observed ton-miles and the supplied capacity (measured in ton/miles). The latter was determined as a function of the average speed, net capacity and days in operation (except docking time), reflecting the conditions of maximum ship occupation with no time in ports. So, the fleet utilization was based on the ratio between the observed ton-miles for the product and the total for the ship, and the ship capacity utilization was based on the ratio between the observed and supplied ship ton-miles, supposing that the later is not specific for each product. The stowage factor (in tons/m^3) for each product was considered when determining the net capacity of typical ships (see Table 7).

Product	Bulk	General Cargo/Sacks
Soya Bean	0.83	0.71
Soya Meal	0.77	0.67
Soya Oil	0.91	0.56
Fertilizers	1.11	0.91
Iron Ore	2.50	—
Coal	0.71	0.83
Metallurgical Products	1.11 (pig iron)	0.91 (finished)
Cement	1.43	0.91

Table 7 Stowage Factors for Selected Products (t/m^3)

The data used for identifying typical ships was SUNAMAM information (SUNAMAM, 1979a, 1979b) available in GEIPOT. Due to processing difficulties, data for 1980 was not available, but it was believed that the general behavior of coastal navigation in Brazil did not change significantly after 1979.

The merchant marine fleet in Brazil had in 1979 about 100 cargo and bulk ships, whose gross weight varied from 800 to 25,000 DWT (dead-weight tons). Due to the high dispersion of the ship gross weights, one of the parameters characterizing typical vehicles in STAN, a preliminary analysis of the frequency distribution was made (in ranges of 500 DWT), in order to identify a number of typical ships used in coastal navigation (see Figure 3 where the values within parentheses correspond to the number of ships in DWT class). This number should be relatively small to insure an efficient computation of their average characteristics and cost functions. More numerous ship types should be retained for cargo than for bulk ships, since the former are more varied and more frequently used in the transportation of the selected products (see Table 8 - SUNAMAM, 1979b).

Product	Cargo Ship	Bulk Ship
Soya Bean [1]	80.0	20.0
Soya Meal	100.0	-
Soya Oil	100.0	-
Fertilizers	100.0	-
Iron Ore	-	100.0
Mineral Coal	25.5	74.5
Metallurgical Products	100.0	-
Cement	100.0	-

[1]Refers to wheat and corn transportation.

Table 8 Utilization of Cargo and Bulk Ships in 1979
(% of ton-miles)

All DWT ranges with at least five ships were selected, the "typical" ship in each class being the one with the highest frequency. For ranges between 500 and 5500 DWT and between 7000 and 7500 DWT, two typical ships were identified since both have similar frequencies and these frequencies were superior to five. In addition,

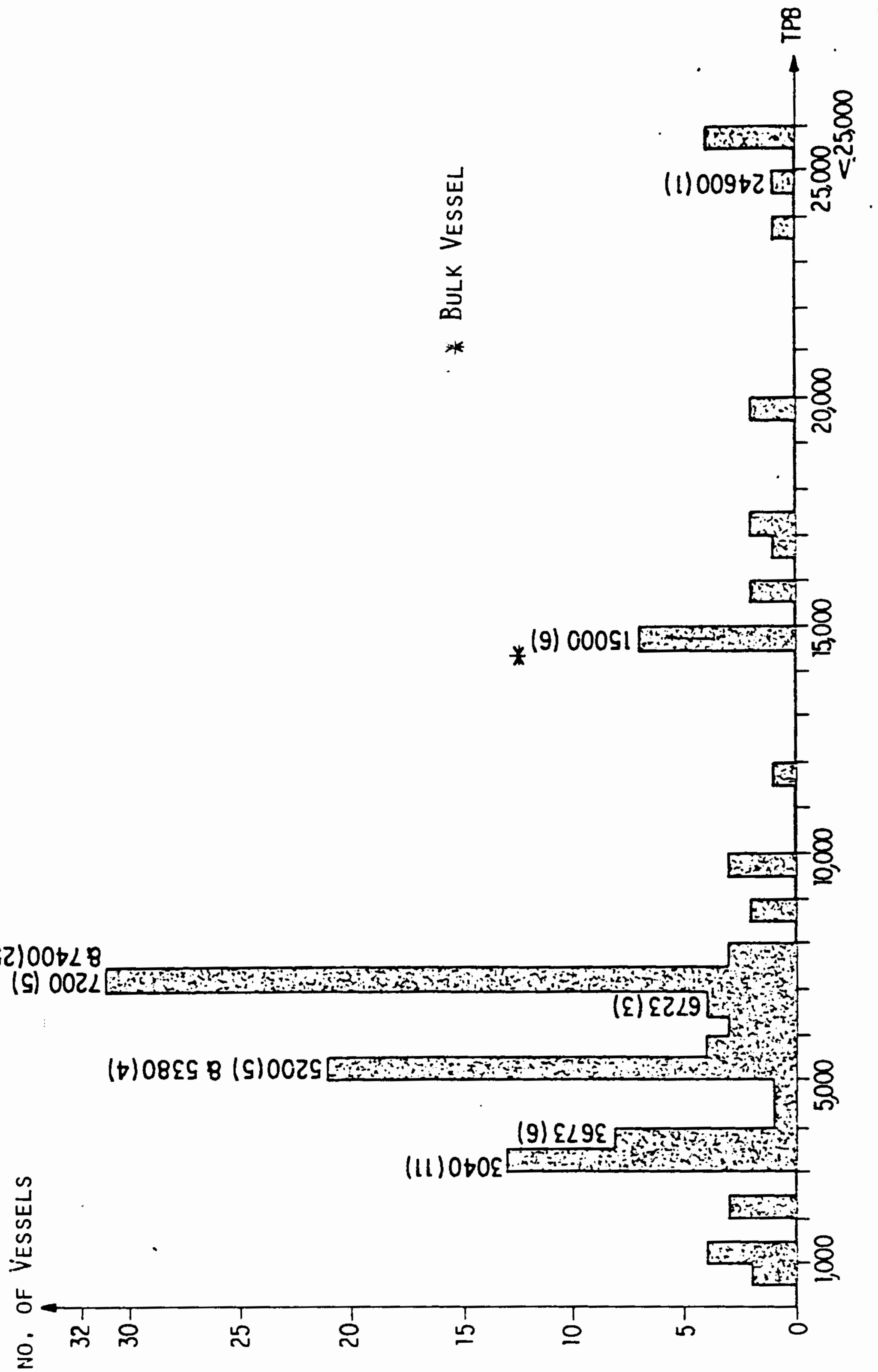


Figure 3 Frequency Distribution for Freight Ships According to Gross Weight (GWT)

one typical ship was selected for the range 6500 to 7000, due to the accumulation of eleven ships ranging from 5500 to 7000 DWT and another of 24600 DWT, representing the largest cargo ship.

The coastal navigation fleet was then reduced to eight typical cargo ships and one bulk ship, representing about 70% of the total number. Table 9 shows the average characteristics for each typical ship, including speed, power and crew size, since these are important factors in the determination of unit costs for the navigation mode. It is important to note that the selection of typical ships according to their gross weight was also validated in terms of these technical characteristics, so as to reflect the different types of operations of coastal navigation. If the net capacity and power distinguished between ships with 3040 and 3673 DWT and between those with 7200 and 7400 DWT, the need was not so evident for individualizing between ships with 5200 DWT and 5380 DWT, excepting the large standard deviation observed for the latter. However, since the definition of these DWT classes is only an intermediate process in the identification of typical vehicles by product, the option to keep it more disaggregate, as originally conceived, was selected.

The determination of the utilization coefficients did not include all the Brazilian merchant fleet, but only the vessels included in the above-mentioned DWT classes or close to them. The analysis of the available information indicated two types of parameters that are of importance: the ton-miles transported and the number of ships on the line. Despite that these parameters have the same relative behavior for the intermediate DWT classes, distortions were observed when the number of ships was small and the ship gross weight was high, as a result of the non-proportional increase in the number of ton-miles. This last index was adopted as a calculation basis for the fleet utilization coefficients (measured in % of the total ton-miles observed) shown in Table 10, since it is more representative of the transportation

Gross Weight (DWT)	Number	Capacity (t)	Power (BHP)	Speed (Knots)	Crew Size (Units)
Cargo Ships					
3040	11	2,670	1,770	11.4	21
		(470)	(90.1)	(0.95)	(0.4)
3673	6	3,560	1,080	10.0	18
		(52)	(0)	(0)	(0)
5200	5	4,900	3,000	11.5	22
		(149)	(0)	(1.50)	(1.1)
5380	4	4,400	2,775	11.5	24
		(1340)	(50)	(1.0)	(2.5)
6723	3	5,900	5,400	14.0	30
		(0)	(0)	(3.45)	(0)
7200	5	5,700	3,000	11.2	25
		(722)	(0)	(0.15)	(1.5)
7400	25	7,100	4,200	12.0	28
		(0)	(227)	(1.35)	(0)
24600	1	22,400	10,000	14.5	24
		(0)	(0)	(0)	(0)
Bulk Ships					
15000	6	14,050	6,400	14.5	29
		(778)	(1666)	(0.12)	(3)

Table 9 Average (Standard Deviation) Characteristics for Typical Ships

service rendered. Statistics on the ton-miles and ships/line are also presented, aggregated for the products and for the DWT classes, for year 1979.

The analysis of the two largest coefficients for each product demonstrated the general participation of all the DWT classes (with the possible exception of the 5380 DWT typical ship, confirming the previous observation that it is not necessary to consider it when including the 5200 DWT typical ship). For the products considered, three groups were observed:

- soya meal and fertilizers: small ships (more than 70% moved in ships below 5380 DWT);
- iron ore and coal: larger ships (more than 85% in ships above 7400 DWT);
- the other products: generally use all the DWT classes.

These groups reflect the cargo lots and, in some measure, the fleet availability. Thus the typical bulk ship (15000 DWT) was the most utilized in terms of ton-miles, followed by the DWT classes of 7200, 7400 and 5200. This does not correspond to an ordering of the DWT classes according to the number of ships/line.

The capacity utilization coefficients were determined by the ratio between the product ton-miles observed and supplied, for the coastal navigation ships in the DWT classes. This ratio reflects the effects from the net capacity occupation and from the percentage of time spent navigating, the latter being also shown in Table 11. It was noted that, in general, the utilization of the capacity of coastal navigation ships was about 50%, except for the 7200 and 5200 DWT classes, which reached 75%, and for the heaviest classes, with 25%. The navigability coefficients varied from 35% to 45%, which is approximately equal to the ratio between the ton-miles observed and supplied for the 15000 and 24600 DWT ships. So it was observed that the occupation of the ship's capacity normally contributed to increase the utilization

Gross Weight / Product	Soya Bean[1]	Soya Meal	Soya Oil	Ferti-lizers	Iron Ore	Coal[2]	Metal. Products	Cement	10^6 Ton[3] Miles	Ships[3] Line
Packaging	Solid Bulk	Solid Bulk	General Cargo	Solid Bulk	Solid Bulk	Solid Bulk	General Cargo	General Cargo		
Cargo Ships										
3040	0.5	0.3	-	33.6	-	2.3	6.6	8.0	68.5	16
3673	2.7	30.1	2.1	11.7	-	2.1	29.4	7.1	149.9	24
5200	20.0	29.5	50.0	54.7	-	3.1	8.7	11.3	290.6	33
5380	11.7	17.3	-	-	-	2.0	14.1	0.3	147.7	12
6723	0.4	1.1	31.2	-	-	2.1	9.3	27.1	126.6	22
7200	31.5	9.4	4.2	-	-	3.5	12.9	13.8	353.0	15
7400	13.2	12.3	12.5	-	-	-	19.0	32.4	290.9	53
24600	-	-	-	-	38.0	10.4	-	-	263.1	2
Bulk Ships										
15000	20.0	-	-	-	62.0	74.5	-	-	778.5	13
10^6 Ton-Miles	796.1	92.3	4.3	46.1	649.3	390.9	310.4	194.4	-	-
Ships/Line	27	14	8	8	8	19	33	29	-	-

(1) Information for wheat/corn was adopted.

(2) Information only for mineral coal.

(3) Includes other packaging types for the selected products.

Table 10 Fleet Utilization Factors for Coastal Navigation Ships (% of ton-miles)

Gross Weitht (DWT)	Capacity Utilization (% Ton.-Miles)	Navigability (% Days Navigating)
Cargo Ships		
3040	53.45	42.88
	(18.98)	(8.66)
3673	56.31	37.10
	(20.23)	(8.13)
5200	75.84	38.34
	(37.36)	(7.23)
5380	52.79	37.84
	(27.30)	(16.73)
6723	46.64	35.33
	(11.47)	(2.57)
7200	78.64	39.87
	(12.69)	(5.44)
7400	46.74	41.54
	(13.44)	(9.57)
24600	23.40	24.19
	(0)	(0)
Bulk Ships		
15000	26.25	29.33
	(1.16)	(2.38)

Table 11 Capacity Utilization Factors for Coastal Navigation Ships

of the supplied capacity (in terms of ton-miles), making the problem of the time spent in ports, critical for 1979. These coefficients did not discriminate between the products, since it was observed that the same ship is used for transporting different cargoes and types of packaging.

The determination of the typical ships for coastal navigation by product corresponds to the averages of the DWT classes, weighted by the fleet utilization factors. Particularly for the net capacity factor, the utilization rate associated to each ship and the product stowage factor were considered, and thus values around 90% of the gross weight were obtained.

For ocean navigation, the identification of typical ships was simplified due to the hypotheses adopted in the definition of its network. Ship characterization consisted of an evaluation of needs in terms of fleet, with no influence upon the costs and characteritics that determined the flow routes. An analysis was carried out examining the ocean-going ships calling in Brazilian maritime ports, according to PORTOBRÁS statistics. Based on the ships' average gross weight and on the major goods included in the ocean navigation flows at each port, a typical DWT by product was determined, which is shown in Table 12. The statistics for metallurgical products and cement were not satisfactory, because those for metallurgical products were aggregated to petroleum flows, and cement was not a relevant product in the national export/import records of 1980. The cargo tonnage of the ship was considered as being 90% of the DWT by product, according to coastal navigation estimates. If these average characteristics were to be associated to the links of the ocean navigation network, they should be better evaluated, although still in the context of the same major maritime ports participating in the import/export activities.

Although inland navigation was not included in the study area, some aspects

Port	No. of Ships	DWT	Main Products in Ocean Navigation
Southeast Region			
Tubarão (ES)	589	82,700	Iron ore
Vitória (ES)	488	18,500	Coal and wheat
Rio de Janeiro (RJ)	2,787	14,300	Petroleum, coal and iron ore
Angra dos Reis (RJ)	93	61,300	Petroleum, wheat and metallurgical products
São Sebastião (SP)	203	57,500	Petroleum
Santos (SP)	4,938	9,600	Wheat and coal
Outside the Southeast Region			
Belém (PA)/Manaus (AM)	409	8,100	Petroleum and wheat
Itaqui (MA)	39	21,400	Wheat and coal
Fortaleza (CE)	199	16,500	Wheat and petroleum
Natal/Areia Branca (RN)	27	11,200	Salt
Cabedelo (PB)	61	10,500	Bentonite and sisal
Recife(PE)	408	11,900	Wheat and fertilizers
Maceió (AL)	170	20,400	Wheat and fertilizers
Aracaju (SE)	11	72,300	Petroleum
Salvador/Aratu/Ilhéus (BA)	951	11,900	Wheat and fertilizers
Paranaguá (PR)	1,151	12,400	Soya bean
São Francisco do Sul/Imbituba (SC)	391	21,800	Soya bean, sugar and ores
Porto Alegre/Rio Grande (RS)	979	19,800	Soya bean and fertilizers

Selected products	DWT Ship Class	Determinant Ports
Soya (Bean, meal and oil)	19,800	Porto Alegre/Rio Grande
Fertilizers	12,900	Recife, Maceió, Salvador/Aratu/Ilhéus
Iron ore	82,700	Tubarão
Coal	18,500	Vitória
Metal. Products	61,300	Angra dos Reis
Cement (General Cargo)[1]	11,300	Rio de Janeiro and Santos

[1]Product not included in the national import/export flows average

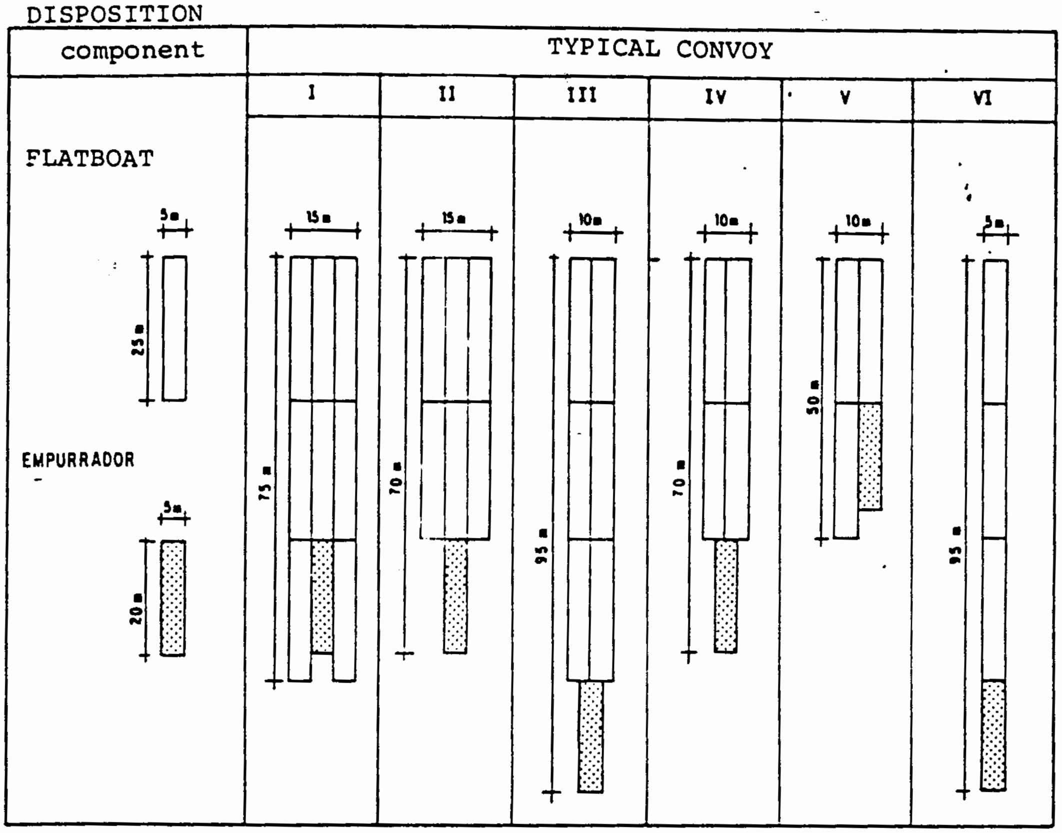
Table 12 Typical Ships for Ocean Navigation were observed for the identification of the representative vehicles for this transportation mode. Both self-proppelled vehicles and the formation of flatboat convoys with one propeller were observed. As an illustration, Figure 4 shows the types of convoys adopted in the Transportation Operating Plan (GEIPOT, 1980b) according to their technical characteristics (power and loading capacity). The convoy types depend also upon the characteristics of the waterways, such as straight-line and curve width, curve depth and minimum radius, thus making it difficult to define them based only on product and transportation modes. It is noteworthy, however, that in the STAN system it is possible to identify vehicle convoys by means of their total capacity, which may be used to estimate propeller fleet.

4.2.2 Definition of Unit Costs

The STAN assignment algorithm seeks the minimization of the total generalized transportation cost, which is composed by the operation, delay and energy consumption costs for each product, on each link and transfer of the modal subsystems.

In STAN, non-linear cost functions may be used to represent congestion effects due to limited capacities of the facilities modeled through the links and transfers of the network. For the coastal and ocean navigation subsystems, however, congestion effects were not observed, due to the practical unlimited capacity of the waterways (this is not valid for inland navigation). Furthermore, the effect of cargo lots is minimized when specifying typical ships, while the aggregation process generating typical vehicles makes it difficult to identify advantages relating to the ship size or to the various types of flatboat convoys. Therefore, linear cost functions were used for the navigation network in the pilot application.

DISPOSITION



MINIMUM DRAFT AND POWER

DRAFT m	POWER (HP) BY TYPICAL CONVOY					
	I	II	III	IV	V	VI
1.50	450	350	350	250	200	200
2.50	750	550	550	450	350	350
3.50	1,050	750	750	550	450	450

CONVOY LOAD CAPACITY FOR A LOAD FACTOR = 0.7 (in net tons)

MINIMUM DRAFT m	TYPICAL CONVOY					
	I	II	III	IV	V	VI
1.50	2,016	1,512	1,512	1,008	756	756
2.50	3,360	2,520	2,520	1,680	1,260	1,260
3.50	4,704	3,528	3,528	2,352	1,764	1,764

MINIMUM WATERWAY CHARACTERISTICS (in m)

characteristics	CONVOY TYPE					
	I	II	III	IV	V	VI
straight-line width	60	60	40	40	40	20
minimum curve radius	300	280	380	280	200	380
curve width	66	67	43	43	44	21

Figure 4 Navigation Convoys Characteristics

For these functions, unit costs were determined on a ton-mile basis, for operating and energy consumption costs and on a ton-hour basis for delay costs. As for the other modes, unit costs include only those items varying with the transported tonnage, that is, ship operating cost items, in the case of navigation. Theoretically, one should also consider the cost for maintaining the waterways (channels, floodgates, etc.) that vary with traffic, particularly for inland navigation. In practice, however, this cost does not affect the route selection, both because it is considered as pre-established in the determination of the waterway characteristics relevant to navigation and because the operator is exempt from responsibility. It is important to stress again the need of evaluating these fixed costs when determining the modal split prior to the assignment.

For the navigation mode, the unit costs did not vary for the various links and transfers of the network, which is a very realistic hypothesis for the coastal and ocean navigation environment. However, during the modeling of the inland navigation system, the need was identified to differentiate according to the direction of the river flow. The other restrictions (minimum straight-line width, depth and minimum curve radius) were taken into account when defining the formation of convoys. On the other hand, ship cargo tonnage was considered when computing unit costs by assuming that 40 cubic feet of cargo weight 1 ton in average. The results were then adjusted by the stowage factor for each product.

Coastal navigation data was taken from statistics provided by the SUNAMAM Navigation Costing Division (SUNAMAM, 1979b). It covers fuel and lubricant consumption, travel times, revenues and expenses for each ship, by round trip, and is aggregated yearly for the 1973-1979 period. The same DWT classes as those adopted for the identification of typical ships and their technical characteristics (speed, power and crew size) were considered when computing unit costs. Finally, regression equations, developed by the project "Waterway Transportation Cost Study" (GEIPOT, 1982), were used to associate these ship characteristics to the cost items.

In the specific case of fuels and lubricants, estimating consumption and costs using data provided by SUNAMAM proved difficult, since this data do not make any distinction between the fuel used in the main and in the auxiliary engines (the latter generating power for the ship's equipment and electrical installations). While the auxiliary engines use only diesel oil, the main ones use a mixture of diesel and fuel oil, the latter proportion increasing with ship size. It was then decided to use the fuel consumption information from the National Petroleum Council (CNP), collected by CNP for taxation purposes, which besides separating the consumption of diesel oil, is also more reliable, since it accompany the shipowner's purchase invoice.

The sample contained 18 ships covering all DWT classes, principally sizes 3040, 5200, 7400 and 15000, which account for 203 round trips. Speed, power and DWT for each ship were taken as parameters (obtained from the Lloyd's Register of Shipping - LLOYD'S 1981, 1982) in the regression analyses, determining four basic functions: fuel consumption while navigating, percentage of fuel oil in the mixture used in the main engines, diesel oil consumption in auxiliary engines and lubricant consumption.

The fuel consumption estimates for each DWT class, shown in Table 13, are the means of the above-mentioned regression equations for each DWT ship class. Besides differentiating the fuel type, the results, in liters/day, also discriminate between the ship being in port or navigating. The results for ships in port should be used in the port access links. The conversion of these results into weight units should use the factors 0.828 kg/l of diesel oil and 0.964/l of fuel oil.

Ship Gross-Weight Classes	Number of Ships	Speed (knots)	Energy Consumption: Fuel (liters/day) Navigating	Energy Consumption: Fuel (liters/day) Port	Energy Consumption: Diesel Oil (liters/day) Navigating	Energy Consumption: Lubricants Total
Cargo Ship						
3040	11	11.4	3,235.3	388.8	602.1	25.5
		(0.95)	(14.3)	(0.0)	(159.3)	(1.3)
3673	06	10.0	2,656.8	447.6	-	15.4
		(0.0)	(0.0)	(0.0)	-	(0.0)
5200	05	11.5	3,769.6	578.8	2,899.3	43.7
		(1.50)	(0.0)	(0.0)	(0.0)	(0.0)
5380	04	11.5	3,775.9	594.5	2,463.3	40.7
		(1.00)	(5.3)	(0.0)	(96.4)	(0.7)
6723	03	14.0	4,191.4	701.6	7,828.3	79.7
		(3.45)	(0.0)	(0.0)	(0.0)	(0.0)
7200	05	11.2	4,086.6	738.3	2,899.3	43.7
		(0.15)	(0.0)	(0.0)	(0.0)	(0.0)
7400	25	12.0	4,218.7	761.0	5,825.9	65.4
		(1.35)	(0.0)	(0.0)	(0.0)	(0.0)
24600	01	14.5	6,849.0	1,840.7	17,949.7	149.7
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Bulk Ship						
15000	06	14.5	5,377.5	1,274.2	10,059.0	94.9
		(0.12)	(107.4)	(0.0)	(3,510.1)	(25.1)

Table 13 Average Energy Consumption for each DWT Ship Class

Two procedures were used for determining unit operating costs for coastal navigation ships: (i) based on expenditure information for each ship in 1979 (SUNAMAM), or (ii) on equations developed by the project "Waterway Transportation Costs Study" (GEIPOT, 1982). It is important to note that these equations were obtained from regression analyses of SUNAMAM data. They do not therefore constitute a different information source, but only the possibility to consider other explanatory variables which had not been included in the expenditure averages by DWT class.

Unit costs were estimated as an average for all vessels in each DWT ship class, by selecting a typical ship with average characteristics (see section 4.2.1). In general, cost estimates were provided on a yearly basis and their conversion into ton-miles used the transportation acomplished by each ship in 1979. The cost items considered were: fuels and lubricants, crew expenses, capital expenses and other expenses (operations and administration).

For fuel cost, the consumption quantities shown in Table 13 were used, while the average 1980 energy prices were: diesel oil = Cr$ 14.50/l, fuel oil = Cr$ 6.45/l and lubricants = Cr$ 27.24/kg. We emphasize the need for associating the navigation time and the ton-miles transported, since fuel costs in port are associated to the access links, together with other port expenses (piloting and towing).

Crew expenses cover not only wages and social charges but also alimentation costs within the ship. SUNAMAM information for the 1973-1979 period was used in the regression analyses, corrected by the General Price Index for year 1980. The equations were determined as a function of ship crew size. When this information was not available, it was estimated based on the DWT for bulk and cargo vessels. Average wages for all crew members were computed, since data do not discriminate between officials and sailors. The validation of these equations using 1980 information from navigation companies demonstrated significant variations in actual (wages and alimentation) costs, making them difficult to adjust.

Besides ship depreciation, capital expenses included maintenance and in-travel repairs, docking and hull insurance. Docking costs were estimated using limited data provided by shipowners and ship repair companies. For maintenance, in-travel repairs and hull insurance values we had a sample of data in round-trip bulletins, which are the basis for SUNAMAM information, consolidated by ship for 1980. These three items were estimated as a percent of ship purchase price, provided by the Lloyd's Shipping Economist publications by ship type (general cargo, solid bulk, oil tanker, chemical and roll-on/roll-off) and updated for 1980 according to the average exchange rate in force. For depreciation, the linear method, adopted for the Amortization Fund, was retained with an interest rate of 12% and a useful life of 20 years for the ships, independent of any capital remuneration.

Maintenance, in-travel repair and docking expenses varied from 2.86% to 3.39% of ship purchase price per year which, compared to the international figure of 4%, showed lower expenses in Brazil. Likewise, the values internationally accepted for hull insurance are 2% of the ship purchase price, against figures from 1.10% to 1.44% found by the equations. It is important to note that, despite some shipowners including docking cost in the in-travel maintenance item, this cost was estimated individually according to the validated hypothesis of biannual docking with an average value 1.2% of ship purchase price, distributed along a useful life of 20 years.

Expenses related to cargo, such as commission and insurance, were not considered in the composition of the operating cost, in order to be coherent with the other modes. Nor were included other operating expenses (such as communications, ship inspection, etc.) that were observed but were of small relevance, nor the administrative expenses of the coastal navigation companies, estimated between 25% and 34% of the sum of costs for fuel/lubricants, crew and maintenance/repairs.

Tables 14a and 14b show unit costs for each DWT class (in thousands of 1980 Cruzeiros), indicating the average characteristics of the ships in each class and the characteristics of the corresponding standard ship. The time cost includes wages and social charges, depreciation and hull insurance, converted into hourly basis through coefficient of 250 h/month for the first two and 720 h/month for the others. Operating and fuel costs were computed on a distance basis, with operating costs excluding time and fuel cost items.

Although large distortions were not observed between the two calculation parameters, the decision was to adopt, for pilot applications, the average characteristics of ships in each DWT class, since it reflected better the actual performance of existing coastal navigation ships. In general, transportation production costs decreased with ship size, thus indicating the presence of economies of scale, depending upon the size of cargo lots. For fuel, the DWT gains were not relevant, and even a conter performance was observed for large ships (over 7200 DWT) due to the requested ship power. On the other hand, time and operating costs were typically decrescent with the DWT, since the latter cost was considered as a dependent variable in the regression and because it is directly related to the other variables, such as crew size. As to DWT classes, an increased relative efficiency was found for the 7200-ton ships, even where compared to larger ones, thus justifying their increased utilization for all selected products. It is noteworthy that it was necessary to adjust these costs by ton in accordance with the stowage factor for the products.

Ship Gross Weight (DWT)	Average Cost for Ships in the Class			
	No.	Fuel $/ton. mile	Time $/th	Operating $/ton. mile
Cargo Ships				
3040	09	61.90	370.0	78.20
3673	06	48.85	400.0	54.69
5200	05	44.90	380.0	41.24
5380	04	56.09	410.0	56.81
6723	03	53.83	460.0	40.31
7200	04	33.70	380.0	43.61
7400	19	51.85	260.0	61.31
24600	01	41.30	190.0	54.47
Bulk Ship				
15000	02	39.96	170.0	33.48

Table 14a Coastal Navigation Costs by DWT Class

Ship Gross Weight (DWT)	Standard-Ship Cost			
	No.	Fuel $/ton. mile	Time $/th	Operating $/ton. mile
Cargo Ships				
3040	09	63.66	345.30	72.85
3673	06	42.33	395.70	44.07
5200	05	36.02	374.00	29.35
5380	04	46.59	304.10	53.68
6723	03	45.11	457.70	33.74
7200	04	33.72	424.70	34.77
7400	19	54.01	258.00	63.62
24600	01	41.30	194.90	54.46
Bulk Ship				
15000	02	48.16	158.20	52.73

Table 14b Coastal Navigation Costs by DWT Class

4.2.3 Conclusions

The direct information on expenses for each ship, available from SUNAMAM, was used to validate regression equation estimates. Table 15 shows a comparison between the actual transportation costs and the estimated costs, separated into operating and fuel costs, both being based on the average of ships in each DWT class. The estimates are more acceptable for fuel, while presenting significant distortions (above 50%) for operating costs. However, the incoherent variations in the values for transport services rendered, showed a certain risk in using SUNAMAM statistics directly, a problem that was minimized with the identification of other dependent variables in the regression analysis.

For ocean navigation, unit costs were not estimated, due to the unavailability of information. However, the application of STAN was not impaired by the simplifying hypotheses concerning the definition of the ocean-navigation network. When typical ships are to be considered on the ocean navigation links, estimates may be adopted for large ships (15000-ton bulk ships and 24600-ton cargo ships), since they correspond to the fleets observed in maritime ports (see Table 12).

Finally, only some modeling aspects were examined for inland navigation, according to the concepts presented in the Transportation Operating Plans (GEIPOT, 1980b). As in the case of coastal navigation, fixed costs must be identified (depreciation and wages), as well as variable costs (fuel and maintenance), but separated in terms of propeller and flatboats. In these studies, the operating costs varied from Cr$ 0.0681 to Cr$ 0.1675 by ton in the year 1977, depending upon type of convoy (see Figure 4) and ship draft. It is important to point out the need for considering floodgate crossing costs for inland navigation links.

Ship Gross Weight (DWT)	Operating Cost ($/t mile)		Fuel Cost ($/t mile)	
	Actual	Estimated	Actual	Estimated
Cargo Ship				
3040	67.56	78.20	66.34	61.90
3673	75.43	54.69	68.81	48.85
5200	29.48	41.24	43.54	44.90
5380	14.95	56.81	44.15	56.09
6723	9.74	40.31	38.52	53.83
7200	17.06	43.61	42.14	33.70
7400	31.64	61.31	25.36	51.85
24600	17.57	54.47	31.52	41.30
Bulk Ship				
15000	5.78	33.48	31.11	39.96

Table 15 Comparison Between Actual and Estimated Coastal Navigation Costs

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CHAPTER FIVE

TRANSPORTATION DEMAND

Transportation demand is assumed to be constant over the planning period in the STAN system. The effects of the transportation level of service are considered exogenously in the quantification of the production and consumption levels of the products.

The origin/destination (O/D) matrices, or the desire lines presented in matrix form, are identified by considering the zoning system and the product aggregation. A zonal subdivision of the study area is carried out according to criteria well specified, such as the homogeneity of regions and the aggregation of production/consumption units according to their demand for transportation. The zoning criteria are determined by the objectives of the study. Then, the products are selected considering their relevant operating characteristics, such as vehicle-type, storage/handling and packaging, and their significance in terms of magnitude of transportation demand. It is worth noting that when identifying the production and consumption in the various regions, different demand and supply possibilities may be represented by introducing artificial origins and destinations. For instance, for export flows one may place a destination centroid somewhere in the ocean and connect it with the different ports of the network, in which case the definition of these ports as destinations as well depends upon the local demand of the cities near them.

The definition of transportation modes used to satisfy the demand specified by the O/D matrices is based on the costs perceived by the user and the tariffs offered by operators. One may use a modal split model to subdivide the O/D matrices by mode, but such a model normally requires a considerable volume of information for calibration. Alternatively, it is possible to determine the modal subdivision of the O/D matrices while performing a multimodal assignment, in which case the identification of the minimum-impedance path also determines the modes that will be selected to transport the product. The STAN system permits the specification of an exogeneous modal split or allows the mode choice to be determined by the assignment.

The way in which the O/D matrices were determined and validated for the pilot application of STAN, as well as procedures for forecasting O/D matrices for future scenarios are presented in this chapter. The traditional methods of *matrix balancing* and *input-output* analysis will be used. We also present how were obtained the observed O/D matrices by mode, and how were considered export and import flows.

5.1 ESTIMATED DEMAND

5.1.1 Characterization of the Study Area

In the STAN system, the study area is defined temporally and spatially. Initially, the base year is selected and then the planning horizon is determined according to the objectives of the study and by considering the availability of required data. The information sources used to determine the demand were available from other studies or analyses and were not complemented by field surveys. The year 1980 was selected as the base year for the pilot application of STAN, principally because it is compatible with the availability of information in the Transportation Operating Plans and in the Freight Transportation Demand Studies carried out by GEIPOT (1980a, 1980b, 1983). Therefore, the statistical hypotheses of representativeness and consistency were taken as verified in the studies that generated the data, unless new information became available during the analysis process.

Although the preliminary proposal of the project included all the Brazilian territory as a study area, only data for the Southeast region was analyzed in detail during the development phase of the STAN system. This decision was made because of the economic differences between the regions of the Brazilian territory, and because this region is very important in the structural and strategic context of the economy of the country. The remaining regions were considered only in terms of interchange of freight with the Southeast, either for the Brazilian market, or for export and import, with a simplification of the corresponding transportation network. It is worth noting that in the delimitation of the study area, the interactions between the Southeast and the other regions were not ignored since, in a systems approach to transportation, such consideration is required when a region is inserted into a wider context of freight flow analysis.

In order to quantify the transportation demand, the ideal method would have been the analysis of each production source (industry, mine, etc.) and the determination of product destinations, as well as routes and transportation modes to the different consumption locations. Due to the large size of the Brazilian territory (even of the Southeast region itself), it was not possible to locate and analyse individual production and consumption sources; not only their number is high, but also the required statistical data for most of the products is inexistent (except for specific goods with well defined marketing patterns such as iron ore, coal and petroleum byproducts). A first practical aggregation is obtained by the adoption of the municipality as a production and consumption unit; but, due to the small economic relevance of some of the municipalities and to their high number (4,123 in Brazil and 1,413 in the Southeast region), this approach is still too detailed for the need to determine only the significant transportation flows.

The solution that we adopted was to aggregate municipalities into traffic zones of sufficient economic importance. Each traffic zone is then characterized by the selection of an internal node, the centroid, which is considered, with an acceptable margin of error, as the origin and destination of the products of the zone. In the quantification of transportation demand, one considers that all the production and consumption of any part of a zone is concentrated in its centroid. The movement within the zone is not analyzed explicitly (except for some data about the typical transportation route, such as average interzonal distances). The following are the basic criteria adopted for zoning in this transportation study:

- The zones are to be organized so as to include only one connection with the basic transportation system. Whenever possible the zones are to be selected so as the trips initiating or terminating in a given zone use the same point of connection with the transportation system.
- The zones are chosen as not to subdivide local areas of commerce and are to be homogeneous concerning production, consumption and development prospects.
- The limits of the zones are not to cross state boundaries and are to follow the municipal limits in order to allow the use of historical time series data (in principle, cities with 200,000 to 300,000 inhabitants or more are to be considered as a zone).
- The selection of zones must allow an adequate definition of the important transport corridors; successive adjacent zones along the transportation network make it possible to identify the alternative routes between relevant zones.
- The zones must identify the large poles of generation and attraction of relevant transportation flows, being selective in terms of "long distance".

Thus, a set of centroid-cities is selected in accordance with the principal transportation axes by using maps that localize economic activities and population distribution. Neighboring municipalities are then aggregated according to the above-mentioned criteria.

The zoning system adopted is basically the same as that of the GEIPOT Transportation Operating Plan, also used by DNER in its Highway Master Plan (SAPSA, 1976). There are a total of 455 traffic zones in Brazil, of which 165 are in the Southeast region. These were geo-coded for the data base used in the pilot application of STAN.

The selection of relevant products for the interzonal freight transportation demand was done from the consolidation of a list of 102 products contained in the Brazilian Nomenclature of Commodities. In general, the following factors were taken into account:

- magnitude and concentration of the flows;
- economic importance of the products;
- prospective expansion of the sector.

In the Transportation Operating Plan (GEIPOT, 1980b), a major information source, 76 products were initially studied and presented in 20 reports according to the criteria of similarity or production dependence. When these studies were updated, 29 products were selected and presented in 15 reports according to the re-evaluation of the above-mentioned factors. It is worth mentioning that the selection of products took into consideration transportation flows, including those of export and import, so as to cover at least 80% of production and consumption in each region.

In the initial pilot study with the STAN system, only the most important products in the study area were selected, that is, those with concentrated production areas and transportation flows, and with present and future significance in specific decisions in the planning of the transportation system. These eight major products were: iron ore, metallurgical products, mineral coal and charcoal, cement, fertilizers and soya bean, soya meal, and soya oil. The latter four products were considered because of the prospective expansion of the "cerrado" agricultural frontier and the demands they impose upon the freight transportation system in the Southeast. Petroleum byproducts were not considered because of their uniformity and complete definition of their transportation flows; thus they do not need further analysis in terms of sectorial strategic planning.

It is worth noting that the selection of products with high demand causes the railway and waterway modes to be intensively used which may introduce a bias in the sector analysis. However, while investment decisions concerning the network of these modes result generally from needs concerning middle and long-distance freight transportation, the investments in the roadway sector are justified by several factors, among which passenger transportation and short-distance freight transport are also major considerations.

As to the selection of products, it is interesting to present some ideas about classification and grouping, principally in view of the restrictions imposed by the computer system. Specifically for the STAN system it is possible to define a maximum of 16 *product classes*, with a maximum of 6 for a simultaneous assignment. The transportation demand is specified as O/D matrices by product, while the transportation supply is specified by the characteristics of the typical vehicle used for each product in each mode. Despite the fact that there are no clear rules for classifying the products for a given application, three basic aspects, included in other studies and analysis carried out by GEIPOT, were considered:

- transportation mode usage;
- cargo handling;
- storage handling.

To determine the transportation mode usage, the peculiarities of each product that influence its transportation mode were analyzed; among these, most important are: the concentration of the transportation demand by O/D pair; the mean transportation distance; the sale unit value; the relevance of losses and damages in transportation when deciding the mode to be selected; the influence of travel time. For example, the product group that use the rail mode contain those products having a high mass concentration, middle transportation distance and low sale value per unit; in addition, losses, damages and travel time are not so relevant for selecting the transportation mode. When, in addition to such characteristics, the mean transportation distance of the product is above those found in the railway mode (in Brazil, above 1500 km), such products are transported by a waterway mode. On the other hand, products for which those factors do not apply, are mostly transported by the road mode. Finally, products that do not clearly meet the above characteristics are classified in a group where modal competition applies.

Within a product group that has a clear mode choice, there may be products requiring different handling in loading and unloading operations; there may be as well differences in terms of the appropriate vehicle for their transportation. For cargo handling, the products may be classified into solid bulk, liquid bulk and general cargo, which is an already widely accepted classification.

Another fundamental aspect to be considered in the identification of homogeneous characteristics of the products, for the purpose of assigning them to the transportation network, is the way they are to be stored. In this respect the products may be classified in the following groups: silo or covered warehouses, liquid storage tanks, open air storage and storage into special warehouses.

By using the previously mentioned considerations, groups of products with homogeneous characteristics are defined. In the Transportation Operating Plans (GEIPOT, 1980b), the eight selected products were classified into four groups:

- railway mode, solid bulk, open air storage: iron ore and mineral coal;
- multiple modes, solid bulk, open air storage, covered warehouse or silo: charcoal, pig iron (metallurgical products), cement, fertilizers and soya bean (grain and meal);
- multiple modes, liquid bulk, tank storage: soya bean and soya oil;
- multiple modes, general cargo (light or heavy), storage into covered warehouses: (finished) metallurgical products.

The characterization of the study area in the pilot application of the STAN system leads to the information to be used in the construction of the data-base and in the modelling choices made for the application of the multi-product, multi-modal allocation algorithm. The considerations presented above must be generally considered in the definition of any application of the STAN system and are more general than the particular use described in this document.

5.1.2 O/D Matrices by Product - Sources and Characteristics

The transportation demand by product was obtained by using the O/D matrices found in the Freight Transportation Demand Study (GEIPOT, 1983), for the year 1980. These O/D matrices were determined by a variety of methods: direct surveys were carried out in companies, patronal entities and public organisations involved in the transportation sector, in order to obtain the most accurate data about the supply and demand for the products, as well as their origin/destination distribution at several levels of spatial aggregation (states, traffic zones, municipalities and production/consumption units).

For most of the products, these surveys were carried out all over the country, by means of questionnaires and direct interviews that were addressed to a large portion of the companies producing them. In some cases, the patronal entities or the public organisation (for instance, ANFAVEA, ABRACAVE, CNP and DNPM) possessed the information required about companies of the sector. For agricultural products, the survey was carried out by sampling about 70% of the total cargo movement. The survey was carried out in the major production, distribution and processing centers.

Despite the fact that economic growth rates were above 10% per year in previous years, in 1980 a period of economic restriction policies began, in order to reduce domestic demand and inflation and to improve the balance of payments by reducing imports and increasing exports. For the 29 products surveyed in the study, the national production in 1980 was approximately 355 million tons, versus a consumption of 245 million tons. In 1980, 70% of this production was concentrated in the Southeast region, with predominance of the mineral, industrial and energy sectors. The Southeast region in 1980 also was predominant in terms of consumption, with 63% of the total consumption in the country, with mineral and industrial products again being the most important. It is noteworthy that the eight products selected in the pilot application of the STAN system represent more than 50 per cent of the production and consumption both of Brazil and of the Southeast region. Tables 1 and 2 (GEIPOT, 1983) show the participation of the Southeast region and of the selected products in the national production and consumption. As to import and export, the ports of the Southeast region participated in 72% and 89% of the national movements, respectively.

	Production			Consumption		
Sector[1]	Southeast Region	Brazil	%	Southeast Region	Brazil	%
Agriculture	8,594	48,001	17.9	13,980	44,903	31.3
Cattle Raising	2,893	6,392	45.3	2,798	6,453	43.4
Industry	53,955	85,601	63.0	46,862	68,164	68.8
Energy	35,391	54,999	64.3	36,945	59,936	61.7
Mineral	145,324	159,781	91.0	53,637	68,082	78.8
Total	246,157	354,774	69.4	154,222	247,538	62.3

1 Selected products: soya bean (agriculture), cement (industry), fertilizers (industry), metallurgical products (industry), soya meal and oil (industry), vegetal and mineral coal (energy), and iron ore (mineral).

Table 1 Participation of the Southeast Region in the Production and Consumption of National Economic Sectors (Year 1980) in 10^3 Tons

The desire lines were basically determined from the same direct surveys carried out in the Freight Transportation Demand Study (GEIPOT, 1983). Specifically for the eight selected products, the information about the companies surveyed and their typical distribution of sales is presented in Table 3 (GEIPOT, 1983).

In general, 92% of all transportation in 1980 was intra-regional, 54% intra-state and 27% intrazonal, according to Table 4 (GEIPOT, 1980b), which includes a disaggregation by product groups. The Southeast region participated in 72% of the total freight generated and attracted, and 94% of the freight with origin in this region

	Brazil			
Product	Production	%	Consumption	%
Soya Bean	15,156	4.3	14,068	5.8
Soya Meal	9,714	2.7	2,447	1.0
Soya Oil	2,399	0.7	1,505	0.6
Finished Metal. Prod.	13,308	3.8	12,126	5.0
Pig Iron	12,685	3.6	11,844	4.8
Charcoal	4,624	1.3	4,624	1.9
Mineral Coal	4,985	1.4	8,963	3.7
Iron Ore	113,024	31.9	68,082	27.9
Other Products	178,879	50.3	120,879	49.3
Total	354,774	100	244,538	100

	Southeast Region			
Product	Production	%	Consumption	%
Soya Bean	1,389	0.6	2,166	1.4
Soya Meal	1,525	0.6	1,337	0.9
Soya Oil	185	0.1	1,005	0.7
Finished Metal. Prod.	12,336	5.0	9,714	6.2
Pig Iron	12,667	5.2	11,565	7.5
Charcoal	2,894	1.2	4,514	2.9
Mineral Coal	-	-	6,271	4.1
Iron Ore	112,806	45.8	20,464	13.3
Other Products	102,355	41.5	97,186	63.0
Total	246,157	100	154,222	100

Table 2 Participation of the Selected Products in the Production of Brazil and the Southeast Region (Year 1980), in 10^3 tons

Product	Organization Surveyed	Typical Scheme
Soya Bean	Producer cooperatives, processing and live stock food industries	Production zone-milling industry or embarkation port
Soya Meal and Oil	Producer cooperatives, industries, statistics from ports and other controlling organs	Plant-refineries or ration factories or embarkation port
Fertilizers	Manufacturing companies	Importing port - production centers, Importing port - mixing plants - production centers
Cement	CDI, SNIC and industries when necessary	Plant-dealer, plant-final consummer
Metallurgical Products	SIDERBRAS AND CONSIDER (for flat and non-flat rolled products, ACESITA, BELGO MINEIRA and MANNESMANN)	Plant-final consummer (finished product) Plant-exporting ports (pig iron)
Charcoal	Sector companies and plants	Mine-final consummer
Mineral Coal	CAEEB	Mine-final consummer
Iron Ore	DNPM	Mine-plant or embarkation port

Table 3 Demand Survey For the Eight Selected Products

was attracted to other points within the same region. In a preliminary analysis, a larger concentration of intra-regional transportation was observed as compared to inter-regional transportation, with a strong predominance of the Southeast region (Table 5 - GEIPOT, 1980b). The state of Minas Gerais was the largest cargo generator in the country, with 44% of the total, whereas the state of Espirito Santo was the one attracting most cargo, with 26% of the total, basically due to export of iron ore. In terms of traffic zones, 34 origin/destination pairs represent 52% of the total movement in 1980, and approximately 48% of the movement between these principal O/D pairs took place within the Southeast region.

Product Group	Intra-Regional	Intra-State	Intrazonal
Solid Bulk	94	41	17
Liquid Bulk	90	83	48
General Cargo	81	47	18
Total	92	54	27

Table 4 Cargo Movement in Brazil (Year 1980), in %

	North	Northeast	Southeast	South	Middle West	Total
North	0.9	0.1	-	-	-	1.0
Northeast	0.2	5.5	0.8	0.1	-	6.6
Southeast	0.2	1.1	70.1	1.1	0.9	73.4
South	-	0.3	2.3	13.8	-	16.4
Middle West	-	-	1.2	-	1.4	2.6
Total	1.3	7.7	73.1	15.6	2.3	100.0

Table 5 Intra and Interregional Movement of Products in the Base Year (in %)

The production and consumption statistics prove the importance of the Southeast region in the regional economic context, and this was one of the principal reasons for this region being selected as study area in the pilot application of the STAN system. In addition, the Southeast region has a complex transportation system, with prospects of structural changes in the middle and long term, as well as interesting scenarios for strategic planning.

5.1.3 Validation of O/D Matrices by Product

The method proposed for validating O/D matrices by product permits one to evaluate the generation/attraction consistency in each zone in relation to the production/consumption structure in the associated region. By using restrictions of the input/output type, the matrices will be changed the minimum possible in order to assure the balancing between the flows of a given product and the quantities of production and consumption in each region. It should be stressed that the validation procedures included the interrelations of production sectors associated to the O/D matrices.

The major purpose of input/output (I/O) analyses is to evaluate direct and indirect impacts on the production of a given country or region in different scenarios, as for example those resulting from variations in final demand or in production of sectors or industries. The analyses of these impacts are based on technical and market utilization coefficients, requiring a large volume of information, as shown in Table 6.

The association of different regions is determined, for example, according to the Moses-Chenery hypothesis, under which each sector of the economy in region i has

Input Data			Unit
V_i^{nk}	=	production of product k by sector n in region i	in tons and in monetary values for all i, j, k, n.
U_j^{nk}	=	quantity of product k used in sector n in region j	
X_i^k	=	quantity of product k exported by region i	
M_{ij}^k	=	flow of product k between region i and j	

COEFFICIENTS:

$$b_i^{nk} = \frac{U_i^{nk}}{\sum_{h=1}^{H} V_i^{nh}}$$

Utilization coefficient for region i, representing the quantity of product k used in each unit produced by industry (or sector) n.

$$d_i^{nk} = \frac{V_i^{nk}}{\sum_{n=1}^{N-1} V_i^{nh}}$$

Market coefficient for region i, representing the split of production with origin in sector n.

$$a_i^{nk} = \sum_{n=1}^{N-1} b_i^{nk} d_i^{nk}$$

Technical coefficient for region i, indicating the quantity k used in each unit produced of product h.

Note: With sector N representing the final consumption of the product.

Table 6 Input Data and Utilization Coefficients in Input/Output Analyses the same commercial relations with the other regions. Therefore, the coefficient a_{ij}^{kh}, representing the utilization of product k from region i in each unit of product h from region j, is determined by the following relation:

$$a_{ij}^{kh} = a_j^{kh} * t_{ij}^k$$

where:

$$t_{ij}^k = z_{ij}^k / z_j^k$$

and

$$z_j^k = \sum_i^k z_{ij}^k$$

with z_{ij}^k being the flow of product k between region i and j (in tons).

However, the general input/output methodology is not adequate for O/D matrix validation since, in order to calculate this latter coefficient, the value of the z_{ij}^k provided by those matrices is needed. In fact, one would be using the information one whishes to validate, in the process of the validation itself, in which case the results would not be significant.

The method proposed for the validation of O/D matrices does not verify each cell of each matrix, but permits one to evaluate if the input/output restrictions are valid. These restrictions ensure the balancing between the flows of a given product and the quantities of production and consumption in each region by the following formula:

$$\sum_j z_{ij}^k = \sum_{h=1}^{H} a_i^{kh} \cdot \sum_j z_{ij}^h + \psi_i^k$$

The term on the left represents the total input of product k in region i, and the term on the right represents the summation of utilization of the product in the industries transforming the products h *(h=1,...,H)* and the export/demand for final consumption of product k in region i.

When these restrictions are not respected, one would adopt for the correction of the O/D matrices the solution of the following problem:

$$\min_{z_{ij}^k} \sum_i \sum_j \tilde{z}_{ij}^k \ln \frac{\tilde{z}_{ij}^k}{z_{ij}^h}$$

$$\textit{Subject to} \quad \sum_j z_{ij}^k = \sum_{h=1}^{H} a_i^{kh} \cdot \sum_j z_{ij}^h + \psi_i^k$$

$$\sum_j z_{ij}^k = P_i^k$$

where P_i^k is the total production of the product in region i

$\tilde{z}_{ij}^k$ are the corrected flows and z_{ij}^k is used as an initial distribution to estimate the new flows.

The solution reached ($\tilde{z}_{ij}^k$) respects the I/O and production restrictions, and is as close as possible to the original O/D matrix (z_{ij}^k).

Through the analytical formulation of the validation method the following balancing equation is identified:

$$\textit{Production}_i^k + \textit{Import}_i^k =$$
$$\textstyle\sum_j(\textit{Quantity to Industry } j)_i^k + \textit{Export}_i^k + \textit{Final Consumption}_i^k$$

The information required to apply this equation can be classified into two groups: supply and demand. In the first, the supply of product k in region i is represented by the summation of its production in that region and of the quantity imported from others. The demand, in the second group, was divided into three parts: the quantity of product k used in industries of the region i; its consumption as final product in that region; its export to others. It is stressed that the other restrictions in the validation method do not impose any additional data requirements, but only use the available data in a different way.

The O/D matrices are directly used in determining imports and exports by the summation of flows of a given product with destination or origin in that region, respectively. It is admitted that these flows include external points overseas, even in aggregate form, that is, without identifying countries, but only the port or embarcation place.

The production and consumption data were collected in the same studies that determined the O/D matrices, which facilitates their aggregation into traffic zones. However, the consumption information refers to apparent consumption, that is, the consumption determined by the difference between supply and export of product k in region i. In an attempt to indentify the part concerning the utilization of products in industries based on apparent consumption data, technical coefficients for these industries were identified, which provided the quantity used of each input by produced unit of the final product, based on the performance of industrial plants and independent of market conditions. Therefore, the total quantity used of each input is determined with the data of production of the final product associated and the technical coefficient.

The interrelation of different O/D matrices was considered only when including at least two of the eight previously selected products. At first, one identified production balances for the inputs that are transformed into the final product, as well as the productivity relations, when the inputs contribute, in an indirect and dispensable manner, to the production process. Thus, the following coefficients were adopted:

- Transformation Industries:
  - soya bean in the production of meal (0.76:1) and oil (0.19:1);
  - iron ore (1.4:1) and metallurgy coal (0.7:1) in the production of metallurgical products;

- Secondary Use: - fertilizers for the production of soya bean;
  - energy coal (1:5 or 3) in cement production.

The consumption of each input as final product is obtained by the difference between apparent consumption and the total quantity used by transformation or secondary utilization industries.

Therefore, the method proposed for the validation of the O/D matrices evaluates the balance between the flows of a given product and its supply and demand quantities in each traffic zone, changing the former as little as possible in order to meet the input/output restrictions. Its application includes two phases: one to verify the supply and demand excesses and another to relate apparent consumption of inputs to the demand generated by the quantities produced of the final product. In the first step, there is a redistribution of flows in order to make the supply match the demand within a traffic zone, with O/D matrices being considered as independent. In the second step, different products are related by using average transformation coefficients or by using secondary utilization in industries or other production processes.

The analysis of the available information for each related product also restricted the application of the matrix validation method. For the product supply, the domestic production and the imports were quantified, as well as the destinations of cargo flows in the O/D matrices. For demand, the apparent consumption was identified together with the exports that must be added to the origin flows. The data aggregation level used was that of the traffic zones in the Southeast region for the base year 1980. On the other hand, the technical coefficients in the second phase represent averages for the domestic industries. We note that estimates or indirect calculations were also used when observed data were not available; however, the latter were given preference, even when the analysis was done at a more aggregate level.

In addition, the established production capacity was determined, whenever possible and pertinent, in order to evaluate utilisation of industrial capacity when compared to the consumption of the final product. It should be noted that one alternative to the correction of the original O/D matrices is the evaluation of production within the limits of capacity to meet input/output restrictions, depending upon the reliability of the available information.

A number of conclusions from the validation analyses of O/D matrices by product are presented below:

- For metallurgical products (pig iron, flat and non-flat rolled products) only excess supply in some traffic zones was identified, probably because of stocks or exported quantities not being considered in the O/D matrices; these are independent, therefore, of flow changes. Metallurgical plants use iron ore and mineral coal as inputs in the production of pig iron and, later on, use pig iron and additional quantities of iron ore to obtain steel, assuming that no significant loss occurs in the lamination process. It was necessary to differentiate pig iron and finished products due to the existence of non-integrated metallurgical plants that supply both the foreign market and other metallurgical plants. So, before redistributing the observed excess supply, it is appropriate to check the consistency of the O/D matrix data;
- The iron ore supply versus demand balances, considering the gross production, also identified only excess supply in production zones, as a result of stocks in mines and export ports, which made it unnecessary to apply the first step of validation of O/D matrices. As to its utilization as an input, only the participation of the metallurgical sector was observed;
- Mineral coal was split up into metallurgical and energy coal, which presented excess supply and null balances, respectively. The application of the first validation stage was restricted to metallurgical coal, but with more accurate

import statistics, since the non-null balances for energy coal are insignifiant. The utilization of mineral coal as an input differentiates the metallurgical sector from the cement industries, which use the energy coal; the energy coal used in the metallurgical sector is not significant at this level of aggregation;

- For charcoal, the determination of supply versus demand balances is of little significance, both because it considers production and consumption estimates, and because it presents insignificant non zero values, obviating the redistribution of flows recomended in the first validation stage. The charcoal is considered an input only in the metallurgical sector, and was differentiated from the mineral energy coal by means of the technical coefficient and the participation of the production processes using it;
- In the case of cement, excess supply was identified in production traffic zones, whereas in consumption zones, which are more numerous, there were demand excesses or null balances. The redistribution of flows in the O/D matrices presented difficulties regarding the verification of stock information consistency, due to the complexity of its marketing structure. The utilization of mineral energy coal does not represent significant quantities in 1980;
- The quantification of production and consumption of soya bean and byproducts also presented problems of unavailability of information, with the supply versus demand balance being considered as a lower limit of the non-quantified variables, that only in extreme situations could change the flows in the O/D matrices. For soya bean (grain) this balance represents the lower limit of its industrial processing. The application of the first validation stage identified the following types of traffic zones: production zones without industries, intermediary in transportation, requiring redistribution of flows to eliminate supply and demand excesses; production zones with industries, and non- production zones with industry (whose comparison with the established capacity showed idleness levels in industries above 40%), the flows being redistributed

only when supply excesses were identified after the industrial consumption was taken into consideration (60% of the capacity), since the demand excesses could be included in the utilization level of industries;

- It was not possible to identify the production of soya oil because of the difficulties in quantifying grain consumption in milling industries, thus reflecting the lower limit in the supply versus demand balance. It is important to observe that consumption in traffic zones was estimated by means of per capita consumption patterns, estimated only at a state level, making it difficult to justify any redistribution of flows in O/D matrices, especially when the demand for grains by the industries was not met;
- For soya meal, other then the fact that production was not quantified for the same reasons as for soya oil, the domestic consumption data in food industries were restricted to a fraction of this production at national level. Therefore, information was insufficient to apply the first stage of the O/D matrix validation procedure for soya meal;
- Concerning the interrelation of soya bean with its byproducts, the average transformation coefficients were determined but unavailability of observed data, both for production and consumption of these products, makes it impossible to check the supplying of the industries that associate them. It may be interesting to consider only one stage of the O/D matrix validation, in which the production of meal and oil would be determined by the availability of grain, independently of the established capacity of the industrial park. Under this hypothesis, the consumption estimates would be ignored, the balancing restrictions becoming inequalities in order to match at least the flows of their O/D matrices. It should be stressed that despite the fact that soya bean cultivation is associated with the highest utilization of fertilizers, their utilization is under the 10% technically recomended rate; to check whether demand was met or not is not advisable, especially because the coefficients of

secondary utilization were not identified;

- The information on fertilizers presented was difficult to analyze since the rate of response of direct surveys was not satisfactory. If available data are to be accepted, the values of the supply versus demand balances were small, with redistribution of flows being unnecessary.

Therefore, by using the two-stage validation process it was possible to check the consistency of the information before modifying the O/D matrices, principally by means of the stocks and the inclusion of import/export flows. Although the data may be analysed by computer, it is interesting to note that the analysis of each product is not systematized due to the different distribution structures found in practice. In the hypothesis of the data being aggregated at the level of apparent consumption, the interrelation of different production sectors should not be made explicit in the balancing equation; rather one should verify if the required input quantity, determined through the production of final product and through the technical coefficients, is met by the produced quantity and the quantity attracted by the traffic zone.

5.1.4 Projection of O/D Matrices by Product

The projection of economic growth, at a global and sectorial level, is very complex in developing countries, not only because of the instability of domestic factors (such as inflation and interest rates) but also because of the interdependence with the international economy. For the projection of the O/D matrices in the secondary sources, the evalution of sectorial statistics was considered (production, import, export and consumption), as well as governmental plans and programs aimed at influencing economic growth. Other then determining criteria for projecting supply, demand and desire lines, the secondary sources showed different hypotheses by sector/product, as presented in Table 7.

Generally, the estimates used are those of sectorial coordinating organisations (CDI, CONSIDER, SIDERBRAS, DNPM and others) and of major producers/consumers of the selected products. However, in some cases, the projection of production/consumption of a given product was determined by the demand of other sectors that use it exhaustively as an input, or by the established or programmed capacity of the industrial park, principally when idleness was observed in the base year. Although projection horizons were not selected previously in the development of the STAN system, the secondary information sources (GEIPOT, 1983) for years 1985 and 1990 were used for the transportation demand projections.

In the period from 1980 to 1990 the projections of supply and consumption by product varied, on the average, around a growth rate from 4% to 6% per year. The Southeastern region will continue to have the largest participation in the total supply and consumption, in both cases above 60% in 1985/90. The state of Minas Gerais will remain the largest producer, with an outstanding participation for mineral products, followed by São Paulo, which will have its largest production in the industrial and energy products. On the other hand, in terms of consumption there is an inversion in the order of prominence of the above states, São Paulo being the largest consumer (around 25% of the total in 1985/90). So, there were no structural changes during the year-base 1980, except for the utilization of domestic production of some products (for example, fertilizers) instead of imports, as well as changes in export flows.

The future O/D matrices were predicted, in the secondary information sources, based on the distribution existent in 1980. However, the expansion of agricultural

Sector/Product	Production	Demand
AGRICULTURE	Tendency analysis of time series 1971/80 for cultivated areas and yield	Per capita consumption and population growth
Soya Bean	Considered as basic export product	f(demand for soya oil and meal)
INDUSTRY	Estimates by coordinating organization	Estimates by coordinating organization
Cement	CDI (production and capacity of each industry)	CDI
Fertilizer	CDI and ANDA (capacity of each industry[1])	CEFER
Metallurgical Products	SIDERBRAS AND CONSIDER (production and capacity of each industry and, for pig iron, f(steel demand))	CONSIDER
Soya Meal	f(milling and refining capacity[2])	Per capita consumption and demand by ration industries
ENERGY	To meet demand	Sectorial analyses
Charcoal	To meet demand	GEIPOT and DNPM
MINERAL		
Iron Ore	DNPM (production by each mine)	Depend on the demand by metallurgical sector

(1) It was assumed that the domestic demand will not be met, even considering projections of capacity expansion, thus making importations necessary.

(2) It was assumed that milling and refining industries were idle, thus the current capacity would be sufficient to absorb the predicted production of soy bean.

Table 7 Criteria and Hypotheses Adopted in Production/Consumption Projections by Sector and Product in Secondary Sources and cattle raising frontiers was examined, as well as the installation of new industrial units, and their influence on the demand as new production/consumption centers. In addition, supply versus demand balances were prepared based on production and consumption projections, thus determining regions with surpluses and deficits. It is stressed that the evaluation of governmental policies also produced information relevant for demand prediction.

At a regional level, the Southeast will continue to predominate the movement of freight in the country, generating and attracting more than 60% of it in 1985/90, with 90% of it occurring within the region itself. As to the states, the most prominent participations are those of Minas Gerais and São Paulo. The port of Espirito Santo is noteworthy, and more recently, the port of Rio de Janeiro, attracting ore flows for export. Again, a small number of traffic zones was observed (52 pairs of O/D responsible for more than 57% of the cargo movement in the projection horizons), as well as a few O/D pairs (620) with flows above 100,000 tons. Six major transportation corridors were thus identified in the Southeastern region, according to the characteristic products:

- Belo Horizonte/Vitória and Belo Horizonte/Rio de Janeiro, with iron ores flows;
- Belo Horizonte/São Paulo and Rio de Janeiro/São Paulo, with flows of metallurgical products;
- Ribeirão Preto/São Paulo, with major flows of petroleum byproducts and fertilizers;
- Ourinhos/São Paulo, principally for cement flows.

Two balancing procedures are included in the STAN system: two dimensional and tridimensional. The balancing methods are used to estimate the projected matrices from estimates of totals generated in or attracted from each traffic zone, in a form proportional to the base year matrices, in the bidimensional case, and also considering a third distribution of values, in the tridimensional case. Both procedures are interactive, and one tries to reproduce the aggregate values for supply and consumption by product. It is worth stressing that the projection of O/D matrices in the secondary sources does not mention the utilization of balancing procedures, despite its suitability for the final results.

5.1.5 Modal Split of O/D Matrices By Product

In the STAN system the algorithm assigning freight to the transportation network is as multi-modal. The multi-modality is represented both in the transportation supply, through the definition of modal networks and impedances associated to the links, and in the transportation demand, by the definition of O/D matrices for various combination of modes.

Transportation modes are defined as specific attributes of the links of the network and are also differentiated by the cost and delay functions and by the vehicles used. The concept of modal exclusivity of the links does not make impossible the existence of alternative modes in the network since parallel links are permitted, connecting the same pair of nodes. The vehicles define the transportation capacity by product, independent of fleet restrictions The impedance functions associate a "transportation cost" to the freight transported by these vehicles, which is necessary in the optimization of cargo assignment. Therefore, the transportation modes integrate the elements that define sector supply, characterizing them as exclusive, that is, the vehicles defined for the transportation of each product in each mode only travel on the links of the network associated to it.

The O/D matrices are identified by product and by the combination of permitted modes in transportation. However, the definition of permitted modes does not specify the relative participation of each mode, unless sub-matrices are defined that are exclusive to a mode.

The identification of more than one mode by O/D matrix assumes the accomplishment of modal split simultaneously with the assignment of freight flows to the network, that is, that the same impedances are to be used in both processes. In fact, the algorithm used in STAN selects a sub-network based on the combination of modes specified and determines the assignment by means of the impedance functions associated to its links and transfers. The multi-modality may result in either a splitting of flows between modes at the origin, or in modal integration, depending upon the lowest impedance routes on the selected network, including the inter-modal transfer "costs".

Usually, however, the influence of tariffs on modal split, cannot be easily individualized by link, since it is often associated to the route used between the O/D pair. Thus, the flexibility in the definition of mode combination by O/D matrix must be contrasted to this limitation in the result of the consequent modal split. It is stressed that the formulation of the general assignment model is based on the optimization of the transportation system, whereas tariffs are is a responsibility of the user and may not be associated to the impedances of the transportation system (operating cost, mean speed, fuel consumption), even if they usually reflect the values of these impedances.

The sources of information on modal split are secondary, available principally in the Transportation Operation Plan (GEIPOT, 1980), which represents an alternative to the direct surveys developed in modal organisation responsible for freight transportation in Brazil. It is important to observe that this information was obtained from the users of the transportation system, that is, the owners of the cargo, and no indirect calculations were identified for determining the participation of a mode, due, for example, to the diversity of operators, as in the road mode. However, there are difficulties concerning the age of the existing studies, the majority of which were produced in the beginning of the 70's, and difficulties due to the small sample of flows for a number of products in the selected region.

The basic information on transportation demand was collected in the 1974-78 period by means of questionnaires, specific for each product, from cargo owners or users of the system. These questionnaires contained information about the product and its marketing structure, as well as a definition and evaluation of the transportation system it used.

With the objective of identifying critical points in the transportation of the selected products, the Transportation Operating Plan made pragmatic assignments of flows to the transportation network. Through information about the quantity of each product by O/D pair and the indication of the modes transportating these products, as well as the routes followed for each product and O/D pair, the observed loading of the transportation network was obtained. However, due to the fact that the collection of information covered different base years, according to the time when specific analyses of the products were carried out (1974-78), an allocation of the total transportation demand was also determined for the base year 1977, considering first, the same preferences of the user and products obtained at the time of the studies and, later on, the route modifications due to invesments or transportation operating improvements that took place in this period. It is stressed that in order to take into consideration the peculiarities of each product in extrapolations of the network loading based on the 1974 data, these products were classified into homogeneous groups in terms of modal vocation, cargo handling and storage type, these criteria also being considered in the evaluation of the route selection.

Therefore, the modal split information contained in the mentioned secondary sources refers to the preferences of the users obtained in direct surveys carried out in the 1974-78 period, which were updated according to transportation supply changes until 1977, principally concerning the execution of proposals for capacitation of the sector. If, on the one hand, the first network loading identified the routes by product, on the other hand, in the second loading, the assignment was proportional to the flows in the same routes, considering the updating of transportation supply without individualizing the products. The available information on modal split by product refers, therefore, to O/D pairs, independent of routes used, and is contained in users questionaires as identified modal preferences.

The statistical analyses of this information were developed in terms of modal split by products selected in the Southeast region, or in Brazil when the flow sample was not sufficient. Frequency distributions and their position and dispertion measure were determined relating the number of O/D pairs to the tonnage transported by mode.

In the survey, the questionaires covered the supply of inputs and the expedition of the final product in terms of desire lines (quantity transported) and associated modes. In addition, in the case of expeditions, informations were requested concerning the sizes of typical lots and the routes used in transportation, together with the respective times on transit in terminals and freight charges. In qualitative terms, the appreciation of the transportation system by mode concentrated in five items: insufficiency of vehicles, access deficiency, delay in transportation, losses and damages, and tariffs, other than general considerations.

Initially, the modal split of the selected products in Brazil (Table 8 - GEIPOT, 1980b) and in the Southeast (Table 9 - GEIPOT, 1980b) was determined in terms of transported tonnage by mode. In general, it was observed that the selection of products with concentrated flows provided greater utilization of the railway mode as compared to the products analyzed in the Operating Transportation Plan, that is, from a roadway/railway ratio of 60/40 to 30/70 in Brazil. It is important to observe that the principal product responsible for this change is iron ore, not only for the almost exclusive utilization of the railway (96%), but also for the high tonnage transported (83% of the flows), whereas for the remaining products the roadway transported more than 50%. The participation of the waterway mode is irrelevant for the majority of the products, except for mineral coal, with 17%.

Product	Highway		Railway		Waterway		Total
	t	%	t	%	t	%	t
Iron Ore	3848.8	3.7	99046.0	95.7	557.4	0.5	103452.2
Mineral Coal	170.5	2.5	5580.6	80.9	1151.2	16.7	6902.3
Charcoal	4033.5	81.5	912.9	18.5	—	—	4902.3
Finished Metal Prod.	6824.4	74.1	2369.4	25.7	18.7	0.2	9212.5
Pig Iron	2361.2	68.1	1104.2	31.9	—	—	3465.4
Cement	16045.6	78.8	4308.1	21.2	—	—	20353.7
Soya Bean	6217.4	76.2	1942.2	23.8	—	—	8159.6
Soya Meal	2708.3	55.0	2216.7	45.0	—	—	4925.0
Soya Oil	685.0	69.8	296.0	30.2	—	—	981.0
Fertilizers	8696.0	83.6	1711.5	16.4	—	—	10407.5
Total Sel. Product	51590.7	29.9	119487.6	69.1	1727.3	1.0	172805.6
Total	174514.1	50.3	137156.0	39.5	9042.1	2.6	347106.2[1]

(1) Including the pipeline mode.

Table 8 Modal Split of the Selected Products in Brazil

Product	Highway		Railway		Waterway		Total
	t	%	t	%	t	%	t
Iron Ore	2665.8	3.6	70192.0	95.6	557.4	0.8	73415.2
Mineral Coal	170.5	4.7	2317.2	63.7	1151.2	31.6	3638.9
Charcoal	490.1	34.9	912.9	65.1	—	—	1403.0
Finished Metal Prod.	4388.9	65.1	2345.6	34.8	10.2	0.1	6744.7
Pig Iron	1747.2	61.3	1104.2	38.7	—	—	2851.4
Cement	6260.6	62.2	3175.4	33.6	14.7	0.2	9450.7
Soya Bean	—	—	5.0	100.0	—	—	5.0
Soya Meal	90.5	66.5	45.5	33.5	—	—	136.0
Soya Oil	42.0	91.3	4.0	8.7	—	—	981.0
Fertilizers	3547.7	73.1	1308.8	26.9	—	—	4856.5
Total	19403.3	18.9	81410.6	79.4	1733.5	1.7	102547.4

Table 9 Modal Split of the Selected Products in the Southeast Region

In the Southeast, the predominance of the railway mode in the transportation of the selected products is more evident (80%), again with the predominance of iron ore, which is responsible for more than 70% of the production. The indentification of the flows in this region included not only internal O/D pairs, but also interchanges with the other regions. However, representativeness was not obtained (above 50% of the flows) for some of the products (cement, soya bean and fertilizers), either due to production dispersion in Brazil, or because they constitute potential flows, as for example those resulting from expanding the agricultural frontier. It is noteworthy that the roadway transportation was significant for most of the products, and the waterway participation, on the contrary, was only perceived for mineral coal (coastal navigation).

Based on this aggregate analysis of the selected product flows, studies were conducted at the O/D pair level in order to identify the combination of possible modes to meet transportation demand. Before going on with this level of information disaggregation, the representativeness of the flows in the Southeast region was verified through the distribution of the number of O/D pairs for the selected products (Table 10 - GEIPOT, 1980b). In this distribution, the O/D pairs within the Southeast region were identified, as well as those that export (in-out) and those that import (out-in) freight from the Southeast, and those in other regions. For iron ore, coal and metallurgical products, almost all the O/D pairs (more than 95%) are within the Southeast region or represent interchanges with it, whereas for soya bean, fertilizers and cement this concentration is no longer so evident. These latter products were included because they represented potential flows. So reference areas (noted with an $*$) were defined in order to determine the modal split at the level of O/D pairs, that is, the Southeast region and Brazil when the flows observed in the former were not significant.

The information on combinations of possible modes in the transportation of each O/D matrix is determined at a level of modal participation by O/D pair, that is, sub-matrices are defined which are homogeneous in terms of modal utilization by product. However, because the available information is from the 1974-77 period, it was preferable to define the number of O/D pairs and the tonnage transported with exclusiveness or modal competitiveness by product in the above-mentioned reference area (Table 11 - GEIPOT, 1980b). Modal exclusivity is identified when transportation is totally done by one mode (railway, roadway or waterway); otherwise, competitiveness among participating modes was admitted. For finished metallurgical products and fertilizers, there was a predominance of competition between the roadway and railway modes, both in terms of O/D pairs and transported tonnage. The exclusivity of the railway mode was patent for iron ore and mineral

Product	Southeast Regions					
	Brazil	Internal	In-Out	Out-In	Total	Other Region
Iron Ore	41	38	03	—	41*	—
Mineral Coal	12	02	01	06	09*	03
Charcoal	17	17	—	—	17*	—
Finished Metal						
Product	239	167	58	01	266*	13
Pig Iron	11	10	01	—	11*	—
Cement	253	253	38	07	298	277
Fertilizers	224*	80	24	—	104	120
Soya Bean	83*	—	—	01	01	82
Soya Meal	40*	—	01	11	12	28
Soya Oil	17*	—	—	10	10	07

Table 10 Distribution of the Number of O/D Pairs for the Selected Products (Year 1977)

coal, whereas exclusivity was observed in the case of the roadway mode for products such as cement, charcoal, metallurgical products and fertilizers. For pig iron and soya bean there was exclusivity and competition between modes to the same degre of importance. The participation of the waterway mode as exclusive transportation mode was noted only for non-important products, while no splitting of flows between this mode and roadways or railway was observed. This information resulted from an analysis of each O/D pair by product, the routes being identified with the quantities transported.

Product	Total	Modal Exclusiveness			Modal
		Highway (H)	Railway (R)	Waterway	Competition H/R
Iron Ore	73415.2	2925.0	67551.0	323.2	2616.0
	(41)	(13)	(23)	(4)	(1)
Mineral Coal	3638.9	316.0	2375.0	974.9	—
	(9)	(3)	(2)	(4)	(-)
Charcoal	1403.0	644.0	180.0	—	579.0
	(17)	(13)	(3)	(-)	(1)
Finished Metal Prod.	6744.7	1558.7	—	10.8	5175.2
	(226)	(128)	(-)	(2)	(96)
Pig Iron	496.0	211.0	114.0	—	171.0
	(11)	(7)	(2)	(-)	(1)
Cement	14166.7	7099.1	1066.5	220.5	5780.6
	(575)	(380)	(63)	(19)	(113)
Fertilizers	6712.0	2188.0	—	—	4524.0
	(224)	(119)	(2)	(-)	(105)
Soya Bean	3661.7	1919.9	500.2	210.3	1031.3
	(83)	(44)	(25)	(3)	(11)
Soya Meal	1980.0	765.0	916.0	67.0	232.0
	(40)	(22)	(15)	(1)	(2)
Soya Oil	67.0	67.0	—	—	—
	(17)	(17)	(-)	(-)	(-)

Table 11 Modal Exclusiveness/Competition for Each Selected Product in the Reference Area (Year 1977) - Tons (No. of O/D pairs)

Finally, Table 12 (GEIPOT, 1980b) presents the average and the standard deviation of modal split by product, considering the O/D pairs in the reference areas. These average and dispersion measures were determined to be the basis of the calculation of modal split (%) for each O/D pair, for each product, and not the aggregated information. These figures reflect the relevance of the modal exclusivity for most of the products, since their O/D pairs present values polarized in the extremes 0%

Product	Reference Area[1]	Modes					
		Roadway		Railway		Waterway	
Iron Ore	Southeast	31.9	(47.0)	58.3	(49.7)	9.8	(30.0)
Mineral Coal	Southeast	33.3	(50.0)	22.2	(44.1)	44.5	(52.7)
Charcoal	Southeast	81.2	(39.0)	18.8	(39.0)	—	
Finished Metal Products	Southeast	82.5	(23.5)	16.8	(22.1)	0.9	(9.4)
Pig Iron	Southeast	75.7	(39.8)	24.3	(39.8)	—	
Cement	Brazil	76.2	(39.0)	20.5	(36.6)	3.3	(17.9)
Soya Bean	Brazil	59.8	(46.7)	36.6	(45.8)	3.6	(18.8)
Soya Meal	Brazil	59.5	(47.9)	40.5	(47.9)	—	
Soya Oil	Brazil	100.0	(0.0)	—		—	
Fertilizers	Southeast	88.3	(20.6)	11.7	(20.6)	—	

1 The selection of the reference area depends upon the representativeness of the flows in the Southeast region.

Table 12 Average (Standard Deviation) Modal Split of Selected Products by O/D Pairs in Reference Area

and 100% in each mode. Therefore, it is preferable not to consider specific values of modal split for the O/D matrices, not only because the information is out of date, but also because of the small significance of the above mentioned statistical measures. It is important also to observe the discrepancy between the modal split determined in an aggregate form and that determined by O/D pair, which introduces additional uncertainties as to its utilization.

So, the final information presented consisted in the identification of possible modes in the transportation of each product, based on the exclusivity or competition observed. For iron ore and mineral coal there would not be any important risk of error in considering only the railway mode if the O/D pairs were connected by this mode, with the participation of the waterway mode being noted in the transportation of mineral coal, either because of the individualization of flows, or the identification of modal competition (R/W). For the remaining products it is more prudent to consider the railway and roadway modes as competitive, the participation of the waterway mode being unnecessary, especially due to the definition of the study area in the Southeast. One also comes to the conclusion that the modal split information provided by the user should be specified in terms of factors that determined it, so that it become valid both for spatial (study area) and temporal (projection horizons) extrapolations.

5.2 OBSERVED DEMAND

The knowledge of observed flows by mode and the corresponding origin-destination (O/D) demand matrices are of primary importance in the context of strategic planning. This type of information may be used, among other things, for model validation purposes (by validating a base year assignment, for example), scenario definition (e.g. specification of external network) and in deciding how to carry out assignments (e.g. modal split), among others.

Reliable observed data is usually not easy to obtain, as can will be described in the following pages. Moreover, it is almost impossible to obtain data for determining reliable pure modal origin-destination demand matrices since carriers do not generally record the transportation mode which carries the freight before and after it is carried on their own mode.

Yet, as the overall benefit of using observed demand data when preparing and analysing a scenario is so important, it warrants the effort of collecting as much observed data as possible. This section briefly presents the activities carried out during the project to this end.

5.2.1 Rail Observed O/D Demand

The objective was to obtain the rail origin-destination demand matrices for the year 1980, in a format compatible with the specifications of the rail system representation included in the analyses performed by using STAN.

The characteristics of the available data varied for each of the rail companies that carry freight in Brazil. In general, railways use very detailed product definitions, which are usually different for each company, and traffic is recorded as station to station movements. Therefore, in order to use such data several sucessive aggregations had to be performed.

FEPASA and CVRD record and provided annual, commodity disaggregated, station to station data for all the network. Similar data was found in the regional administrative offices of RFFSA, but on a monthly basis. Since all this data was not in computer readable form, a first step was dedicated to manually punching it. We also aggregated, when appropriate, the monthly data into yearly figures.

Both FEPASA and CVRD allocate the movements which originate or are destined to points outside their own networks to border points in their networks. RFFSA, on the other hand, records the true origin or destination of such movements. Therefore, in order to avoid double counting, only movements originating inside their own networks have been accounted for in the FEPASA and CVRD O/D matrices.

A first aggregation was performed following the correspondance between the product definition used by the various companies and that specified for our application. The station to station movement matrices were then redefined according to the network representation used in the application. When several stations were aggregated in the model, the corresponding traffic was combined accordingly. On the other hand, the traffic coming into or out of a station not represented in the network model was allocated to a neighbouring station. Finally, the resulting station to station matrices were aggregated into centroid to centroid O/D matrices according to the definition of the zones.

An attempt was also made to identify "pure" modal matrices, according to the mode specification used in the application: by gauge and traction mode. A first separation was performed according to the subnetwork to which the origin and destination of each flow belong to: the proper "pure" modal matrix when both end points belong to the same subnetwork and to a mixed matrix otherwise. A shortest path routine was then used to determine if each flow assigned to a "pure" modal matrix may be transported from its origin to its destination exclusively on the links of the appropriate subnetwork. When this was not possible, the flow was reassigned to the mixed matrix.

This procedure uncovered some connectivity problems associated with the large gauge and the electric traction subnetworks, with the latter representing the majority of such problems.

5.2.2 Road Observed O/D Demand

The task of obtaining reliable O/D demand matrices for the transportation of freight by road in the base year 1980 proved to be a most formidable endeavour. The scarcity, age and general fuzziness of the available data were the major factors affecting this process. Therefore, we did not achieve a reliable estimation of such matrices. The goal of this section is to present the available data and present some ideas about the methodological issues and difficulties involved.

There were no road O/D freight demand matrices available in Brazil for the year 1980. DNER, however, did undertake, between 1973 and 1977, a major survey of the road traffic in all of Brazil. To our knowledge, this is the only data source that at the present may be used to estimate road O/D matrices in Brazil.

The DNER survey, from 1973 to 1977, consists of road countings permanently collected at several survey posts throughout the Brazilian road network. Table 13 displays the number of counting posts for each state in the Southeast region, and also indicates at how many of these the daily average traffic ("DAT") is less then 2500 vehicles.

State	Number of posts	Number of posts with DAT $\leq$ 2500
Minas Gerais	68	2
Espírito Santo	31	2
Rio de Janeiro	37	18
São Paulo	89	14
Total	225	36

Table 13 Distribution of Counting Posts troughout the Southest Region

At all posts where the daily average traffic was expected to be less than 2500 vehicles, all vehicles were stopped and an extensive interview was conducted with the driver. At the other posts, only a sample of the passing vehicles were stopped for further inquiries. Most of the counting posts were operated for a seven days period, while a few were operated for only three days.

A total of 2,055,616 vehicles were counted by all the posts in the Southest region, with 31.8% of these being trucks. Of the data collected during the interview, the most relevant for the present purpose are:

- identification of the counting post;
- direction of traveling;
- description of the vehicle (including, for trucks, a specification as either light, middle or heavy vehicle, or as a trailer or semi-trailer truck);
- origin (state and district; 1410 districts formed the Southeast region);
- destination (state and district);
- product transported;
- weight of the load.

It is relevant to note that, even if this data source appears to be quite rich, it also raises several very serious problems. The consistency of the countings is one of these problems. The counting periods were different among the various posts, the differences being as large as several months between posts in different states.

Multiple countings present the other serious problem, when attempting to use this data to derive O/D demand matrices. For most of the origin-destination pairs, especially within the Southeast region, several paths were possible through the road network. In addition, traffic from most of these origin-destination pairs would pass by several counting posts on any of these paths.

Despite these major difficulties, an estimation procedure has been proposed and some limited tests have been performed. The main steps of the procedure are:

1. Introduction of the DNER counting posts into the representation of the Southest road network used in STAN;
2. Aggregation of the DNER districts in the traffic zones defined in the GEIPOT, and STAN, network;
3. Expansion of the counting data to a yearly basis (to alleviate the period inconsistency problem);
4. Identification of the most probable paths for each origin-destination pair and of the counting posts located on these paths. Selection of a meaningful set of counting posts for each origin-destination pair in order to attempt to eliminate the multiple counting problem;
5. Estimation of the 1973 O/D demand matrix, for each product, by using the selected counting posts;
6. Evaluation of the 1980 O/D demand matices, based on the 1973 estimates.

The method presented by Van Zuylen and Willumsen (1980) was used at step 5. Balancing methods may be used at step 6, if reliable information concerning the zonal production, consumption and mode choice, by product, is available. Step 4 presents a number of significant challenges, both methodological and experimental, due to the lack of control data. Heuristic procedures, based on network modeling approches, have been used (Leal, 1987).

We tested the procedure on data for one product (coal; see Leal, 1987) and the results indicated that this approach may yield satisfactory results. Further methodological developments are however required, as well as additionnal data to experiment with, in order to validate the experimental results.

5.3 ESTIMATION OF IMPORTS AND EXPORTS

GEIPOT deals in its projects mostly with issues related to transportation *inside* Brazil. Consequently, the origin-destination matrices built at GEIPOT do not identify explicitly the import and export flows; these are accounted for at the entry or exit points which may be ports or border nodes. Although this type of O/D matrices is adequate for a large variety of applications, an estimation of the import and export flows is essential for several important classes of scenarios.

The knowledge of import/export type of data was not required during the development of the STAN model and planning system. Yet, given the importance of the subject, we investigated the available data sources and examined a promising methodology that might be used to perform the estimation of imports and exports and to adjust the original O/D demand matrices, available from GEIPOT.

It should be first emphasized that a simple and direct decomposition by an input-output methodlogy of the demand contained in the original matrices is not the most efficient procedure, since it requires large quantities of data that is difficult to obtain, such as local consumption, production and storage activities in each zone, among other relevant socio-economic data.

Several institutions compile data related to Brazilian imports and exports (Keller and Magalhães, 1984):

1) CIEF, the Economic Fiscal Information Center of the Finance Ministry, is responsible for compiling the official statistics concerning the Brazilian imports. The main data source is the import declaration form filled with the customs authorities (Secretaria da Receita Federal - SRF). The product classification is extremely detailed and there may be a significant time lapse between the

actual moment of the import and that of the document filling.

2) CACEX, the External Trade Office of the Banco do Brazil, has similar responsabilities for Brazilian exports.

3) The Statistical Division of SUNAMAM, the Superindendence of Merchant Marine, compiles statistics relative to import/export movements through the Brazilian ports. The ships' manifests form the basic data source for these statistics. This data source seems to be less reliable due to the numerous errors possible when filling out the manifest forms.

4) PORTOBRÁS, the Enterprise of Ports of Brazil, collects data relative to all movements through the various ports of Brazil. Data is collected in each port, directly from the loading/unloading waybill of each ship. Products are classified following internal norms based on the Brazilian freight nomenclature.

Following this analysis, the PORTOBRÁS data was considered as the most adequate for estimating imports and exports. Several reasons justify this choice, among which the product classification which may easily be manipulated and the reliability of the data due to immediate correspondence between its collection and the actual freight movement.

By using the imports and exports values evaluated from the PORTOBRÁS data and, eventually, other data sources (e.g. the rail O/D matrix), some ajustments have been made to the original O/D matrices. When the initial matrix entry shows a surplus when compared to the import/export figures, internal consumption/production is assumed. In the symetric case, the required ajustment is made. Then, new rows and columns are added to the O/D matrices corresponding to the import/export flows, while the other entries are modified accordingly.

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