PRELIMINARY EVALUATION FOR ROAD NETWORK IMPROVEMENT ALTERNATIVES IN LESS DEVELOPED COUNTRIES

by

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ABSTRACT

An approach is developed to provide the decision makers in a Less
Development Country with a tool for selecting an investment program and
operating policy best suited to its development criteria and the existing
Economic and political conditions. Using the Highway Cost Model, which
provides a detailed, accurate framework for assessing the costs and
benefits associated with the operation and development of links in a low
volume highway network, it generates and presents the consequences of
potential investment alternatives in a concise form, based on the input
of Highway Cost Model link strategies. The choice and relative timing of
these link strategies may vary within bounds, and patterns of network
strategies, which do not satisfy the investment constraints are elimi-
nated. For those remaining, year by year benefits may be determined
considering the users' consumer surplus, maintenance and construction
costs. The net present value is computed for these network strategies,
and used to rank them.

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Finally, I would like to express my deepest appreciation to those, who by their love and devotion helped me to achieve what I have achieved, and to whom I wish to dedicate this thesis, my beloved parents.
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1.1 Objectives for Planning a Transport Network

The planning of a transport network is fundamental, not only for the transport of goods and people, but for the country's economy as well. As stated by the Harvard Transport Research Program (1): "any change in the Country's transportation network has obvious repercussions throughout the entire economy". The goal of transport network planning is to achieve balanced and sustained economic growth. In numerous developing and less developed countries, the expected impact for transportation investment is so significant that the investments on network improvements have accounted for over 25 percent of the total public investments (2).

Planning of transport network improvement is usually undertaken in a hierarchical fashion. Regional economic goals are identified, then transport needs. Projects or sets of projects may be identified to satisfy these needs and then strategies consisting of their implementation sequences in specific years are generated. Project improvements to the network are then made following a chosen strategy, and projects designed in more detail.

The objectives of the transport network planning are the economic growth of the country and the improvement of the existing social conditions (i.e. education, way of life). These are accomplished with the increase of mobility throughout the country, resulting from the improvement of the transport network's level of service. These objectives are:

i. To decrease the transport costs and travel time between the production and consumption centers;
ii. To create access roads to remote areas or potential production centers;

iii. To enable the free movements of men and material resources all over the country.

iv. Finally, since all improvements must be accomplished by allocating resources (material, manpower, capital) to projects, improvements should be undertaken so as to attain the most effective consumption of resources.

In achieving the above objectives, careful planning of links improvement is of great importance including their engineering and design characteristics and the choices among alternatives.

The output of transport planning are: (1) The proposal of the improvements and their consequences, (2) which links it is worth improving, when and by which strategy. (3) What are the resulting benefits and the costs, (4) Appraisal of the proposed alternative in comparison with others.

Lansing (3) has summarized these objectives even more broadly by writing:

"Among these goals (of economic policy) are economic efficiency, economic growth, a high level of employment and freedom from pronounced cyclical fluctuations, and a degree of equity in the distribution of the products of economic activity which avoids the juxtaposition of extreme poverty and extreme wealth. Transportation (network) planning is directly involved in the attainment of these objectives".
1.2. Planning process

The transport network planning process consists of the following phases: (1) Definition of objectives, (2) Generation of alternatives for the accomplishment of the objectives, (3) Feasibility of the alternatives and/or screening, (4) Network analysis, (5) Determination of impacts, (6) Evaluation of alternatives, (7) Choice and (8) Implementation (The whole process is represented in figure 1.1).

The definition of objectives is undertaken by the government as part of a proposed Development Plan for the country. They must contribute to the attainment of the broad objective "economic and social development".

The generation of alternatives is done by a transportation planner. He considers all the possible alternatives, that might accomplish the objectives. During the generation, two broad classes of variables are recognized:

(i) options related to transportation itself, and (ii) activity system options.

Transportation options are those items that can be controlled directly by the analyst or the agency for which he works. They are the decision variables, which range from such broad items as alternative technologies and modes to specific items such as vehicle types, links (to be improved), type of improvement (at this point either detailed engineering studies about each improvement strategy or models that simulate the activities of construction and maintenance as needed).

Activity system variables are the social, political and economic variables
Figure 1.1.
Transport Network Planning Process
which determine the demand for the transportation options. They include variables such as spatial patterns of population, economic activity, agricultural and industrial policy and the like, all of which can influence in one way or another the demand for transport services. In most instances these options are taken as major exogenously specified factors, non-maniputable in the direct sense.

The feasibility of each alternative will be examined in the next phase: To be feasible, all the constraints introduced by the analyst must be verified. (Only the feasible alternatives will be considered in the next phases). For each feasible alternative, the analysis of the resulting transport network is done. The analysis may be performed by simulation of all network activities or using direct mathematical procedures. With the analysis, the impacts of each alternative to different groups (users of transport network, producers, consumers, government) will be found. Then, the evaluation of the alternatives will be done.

The next phase is the choice: The alternative that contributes more to the accomplishment of the set objectives is chosen as the one to be implemented. In some cases, the analyst through the screening process may eliminate some alternatives without a detailed evaluation. This will make the task of evaluation easier and faster. The screening is based on criteria set by the analyst and derived from the objectives.

The final phase is the implementation of the best alternative on a proposed time schedule.

1.3. Role of an evaluation model

The role of an evaluation model is to develop the impacts of alternative plans and compare and rank them with each other and the do-nothing
alternative. Most of the evaluation models introduce formulae which enable the analyst to compare the different and often irregular, series of benefits and costs that are associated with alternative plans.

The evaluation model can be compared with other types of network programming tools (e.g. screening): It can rank plans by productivity, by returns, and the like, it enables the analyst to consider numerous alternatives, it gives him a more accurate picture of the impact of each alternative and it takes into consideration the goals and objectives directly and realistically in the evaluation.

Thus, the evaluation model broadens the horizons of the transportation planner during the process of planning transport network improvements.
BACKGROUND

2.1 Evaluation measures and objectives

Several measures for evaluating the consequences of the implementation of an alternative may be identify. The consequences may be measurable in monetary terms (costs, users savings) or non-monetary terms (level of service, environmental impacts). Most studies are concerned only with monetary impacts, using economic or financial cost-benefit analysis exclusively.

The benefits of transport network improvements (or planning in other sectors of the country's economy), will result from a reduction in the consumption of resources. It will impact the economy by altering the interactions between resources, production and transport in such a way as to improve (or deteriorate) the welfare of inhabitants. If an evaluation measure is based on economic analysis, it seeks that alternative which consumes the minimum resources while providing significant economic growth. A number of planning models have been developed which employ the economic analysis in the evaluation of alternative plans. Among them are the Harvard-Brookings Macroeconomic model for evaluation of network alternatives in Colombia (4) and Taborga's work with the Chilean Transport Network (5). (Explained in § 2.2.2). If financial analysis is employed, this would imply that the value of a plan is specified independent of any detailed study about how it may alter the economy, and focuses instead in the investments' consumption of resources; its purpose is to determine the best way to allocate resources to
projects of presumed known value. That is, it is primarily concerned with budget constraints, and not with the economic relationships, which determine an investment's impacts.

The evaluation measures may be classified into four types of analysis according to their objectives. (Based on a classification system introduced by R. de Neufuille and D. Marks (6)).

i. **Type I: Standard Benefits Cost Analysis**

This is the simplest case. The future costs and benefits are discounted to a common point in time (usually the present) and compared. Several criteria exist to the comparison: (1) Benefit-cost criterion, computing the ratio of the present value of all benefits to the present value of all costs, (2) the internal rate of return criterion, that is the discount rate at which the net present value of the benefits equals to the net present value of the costs, (2) net present value criterion, that is the difference between the present value of all benefits and present value of all costs. The underlying assumptions are:

(i) the value of a benefit or cost, increases linearly with the amount of benefits or costs at any time.

(ii) As long as values are linear in the amount of benefits, uncertainty can be introduced with the use of expected values.

(iii) Money is taken to be the measure of all things. If it is not feasible or practical to qualify a benefit or cost, such as an aesthetic one, it does not get considered.

(iv) All parties interested in the investment must agree upon a single criterion of evaluation. This assumption is reasonable so long as groups accept that it is meaningful to measure all benefits and costs,
Figure 2.1: Consumer's Surplus
such as loss of life on a common basis and with the same weight on each kind of benefit and cost.

The objective of this type of measure is to maximize the monetary profits (benefits minus costs) over the time horizon.

ii. Type II: Consumer's Surplus

It recognizes the non-linearity of the values in terms of benefits and costs. The real value of any benefit is known as its utility, and the utility function describes the real value of the benefits. The non-linearity of the utility function, which contradicts the first assumption on which the standard benefit-cost is based, is a pervasive phenomenon. As a general rule, both individuals and the public have a diminishing marginal utility for benefits. As it appears in figure 2.1, someone would be likely to demand more of a good until, at the margin, was equal to its costs. This would occur at $Q^*$ in the figure. It follows that someone's utility or value for less than $Q^*$ of a good is greater than its price. The sum of the utilities over all quantities used will result in the willingness to pay for the good. The difference between the willingness to pay and what actually has been paid to a certain price is the consumer's surplus. This type of analysis attempts to incorporate consumer's surplus into the measurement of benefits. It employs the benefit-cost analysis to accomplish its objective, the maximization of profits. Basically, it recognizes that benefits often have a real value much greater than their price.

iii. Type III: Decision Analysis

This approach includes procedures to quantify any individual's own
utility over risk, usually nonlinear functions. Unlike the utility functions over quantity, however, the utility functions over risk are not expressed in terms of common units, such as money, which different groups might be willing to pay for any specified number of goods.

The process of decision analysis consists of the following steps: (i) all possible sequences of decisions and their consequences are laid out. This is represented as a decision tree, since there can be several choices at any stage and since each choice may branch into several consequences. (ii) All possible outcomes are indicated together with the a priori probability of occurrence. (iii) The utility function of the decision maker is assessed and the utility or real value of each outcome is calculated. Finally, (iv) the optimal choice at each choice at each stage, and thus the optimal sequence of choices, is calculated on the basis of maximizing the expected value of utility.

The objective of the Decision Analysis is to find the optimal sequence of choices of alternatives over time aimed at maximizing the expected value of utility, since uncertainty is incorporated.

Pecknold (7) employ Decision analysis measuring all consequences in monetary terms, as profits or losses.

iv. Type IV. Multiattribute Analysis

This approach attempts to account for the non-linear, nonadditive nature of any individual or group's utility function over several attributes. Once the multiattribute utility function is encoded, it can be used in the evaluation just like a utility function of type I.
Therefore the objectives are the same as of type I.

v. Type V: Multiobjective Evaluation Analysis

So far we have had only one objective. This analysis attempts to lay out explicitly the preferences of the different groups concerned with a project for the set of possible consequences. In this way, it intends to allow the analyst to estimate those choices which are preferable to the several groups, according to their objectives and how these differences might be resolved. It does not define the best alternative, but rather leaves the selection to judgement.

It is important to note that the existing procedures of multiobjective evaluation do not propose clear, analytic methods for determining the preferences of any group. The most cogent descriptions of the theory and proposed practice have been presented under the auspices of the United States Water Resource Council. It has not yet been applied to transport network planning. However, it would be interesting, if it could be applied, since transport network planning implementation affects several groups: the users of the network, the producers and consumers of goods, industry and the government itself.

2.2. State of the art

2.2.1. Link evaluation models

These models deal with the evaluation of the several alternatives for link improvements. It is assumed that (1) the alternatives are mutually exclusive, (2) any improvement of one or more links in the network does not affect the others and (3) the budget allocated to each
link—for its improvement—is fixed; thus, links to be improved are not competing for the same funds.

Wohl and Martin (8) deal with the evaluation of link improvements taking into account present and future impacts of the improvement. Tarplay and Drake (9), Thygeson (10) and Marglin (11), all develop fairly simple evaluation models, incorporating the timing (the improvements to be done in stages, and may be postponed for one or more years). They showed that substantial benefits can be achieved with the appropriate timing. Winfrey (12) is concerned with the optimal staging of an improvement (namely an expansion of a 2-lane highway to a 4-lane one, given that some increased capacity is needed now), and not when the improvement should start. Thus, he ignores the impacts of delaying the starting time and the supply-demand dependencies. Cole (13) develops a model with a probabilistic demand structure but, once the sequences of improvements is decided it would remain unchanged over the economic life of the link, no matter what changes in demand might occur. Howard and Nemhauser (14) introduce dynamic programming for the evaluation of alternative link improvements considering supply-demand dependencies in a fairly theoretical work. Other models simulate the activities which take place on the link during a development and operating time horizon, considering construction, maintenance and vehicle operation. The Highway Cost Model (15) and, the Project Analyzer of the Harvard Brookings Transport Model (16) are such models, calculating economic consequences with a sequential simulation of events over time for the evaluation.
The main characteristics of the above mentioned models are the following:

(1) demand is exogenously given and independent of the alternative selected,
(2) link capacity is merely additive; to meet increasing demands, we need only to widen the link to carry the new volume,
(3) costs are very simple in structure: fixed and variable ones, with the only exception the ones simulated by the HCM,
(4) the problem is one of minimizing total costs only, and simple techniques are used to produce the optimal sequence of the improvements.

2.2.2. Network Evaluation Models

The network evaluation models can be divided into four categories (expanding Pecknold's (7) classification) which become progressively more complex:

(1) capital budgeting models
(2) Network flow models
(3) Stochastic Models
(4) Activity growth models.

The latter are the most complex, introducing the constraints of long-run supply-demand dependencies in addition to normally using a complicated network flow simulation procedure. Surprisingly enough, little work has been done on the use of such models. The reason is their complexity. The most significant studies which employ macroeconomic model in conjunction with a transport model are Taborga (5) work.
with the optimal transportation policy in Chile, the Northeast Corridor Study (NEC) (17) and the Harvard Brookings study on Colombia (4).

2.2.2.1. Capital budgeting models

Capital budgeting models generally assume all benefits are exogenously specified, single valued and independent of the sequence chosen. They incorporate the combinatorial mathematics to select the best sequence of improvement activities subject to capital (budget) constraints. Marglin (11) deals with the network problem in finding the optimal strategy of network improvement, although, he deals with dependencies caused by budget constraints only. The optimal strategy is one that allocates the budget among the links in such way as to maximize the sum of the net present values of the alternative and the net present value of slack, subject to the condition that the sum of alternative outlays in each period not exceed the period's budget. Weingartner (18) uses mathematical programming to solve the capital budgeting problem. Consad (19) proposes several models to find the optimal sequence of improvements of a transport network, still in terms of abstract projects (i.e. projects, although intended to be transport projects, are represented solely by a set of costs and benefits). One of the proposed models for the Northeast corridor project was a quadratic programming model, which can handle project dependent costs and benefits quite easily.

Mori (20) uses dynamic programming for the selection of these link improvement strategies to produce the optimal network improvement alternative subject to capital budget constraints. The optimal alternative
is the one that maximizes the benefits \( B_i \) from all link improvements in each period, for \( P \) periods.

\[
\text{maximize } \quad Z = \sum_{i=1}^{P} \sum_{j=L}^{N} g_{ij}(x_{ij}) = \sum_{i=1}^{P} B_i
\]

s.t.

\[
x_i > \sum_j (x_{ij})
\]

where:

- \( x_{ij} \): the amount allocated for each link \( j \) in period \( i \)
- \( X_i \): the budget available in period \( i \)
- \( g_{ij}(x_{ij}) \): the benefits of each link \( (j) \) improvement
- \( N \): number of improved links.

The technique permits: (i) Examination of many stages for each link alternative proposed as an addition to the road network, however, this technique can handle only two or three stages; (ii) analysis over multiple time periods; (iii) inclusion of budget limitations; and (iv) consideration of situations where system costs and benefits change over time.

Meyer and Straszheim (21) present a fairly concise and clear treatment of the dual problem of the capital budgeting primal problem, the shadow prices and internal (vs. external) opportunity costs of the alternatives.
The network flow models are an extension of the capital budgeting models. The cost and benefits are not exogenously specified, fixed quantities, but depend on some prediction mechanism. In some cases, it can be internal (as in linear flow models) and in others, it is a completely separate model. They all deal with a deterministic and fixed demand structure. They have been generally limited to linear flow models, however. Additionally, they usually ignore the dependency of supply-demand. Recently, developments in branch and bound techniques have placed fewer constraints on the form of the flow model. Herschedorfer (22) applied a branch and bound algorithm—developed by Land and Doig—to the single period, link addition problem developing a linear programming flow model to determine the measure of effectiveness of network changes. He sets up a general network with nodes i=1,2,...,N and directed arcs. Demands are specified between groups of origin-destination pairs. Each "commodity" may be the flow from a single origin to several destinations or from several origins to one destination. There are the flow constraints and capacity constraints for existing links and additional ones. The objective function searches for the minimum additional construction necessary to reduce travel costs.

Roberts (23), at the same time, although independently, was using the same branch and bound algorithm coupled with heuristic backward stepping, time-sequencing algorithm for the multiperiod problem.

Bergendahl (24), in a similar approach to Roberts, used a linear programming flow pattern of any improvement plan at each period, but
employed dynamic programming to search for the optimal sequence of improvements in time. Roberts in Meyer and Straszheim (21) developed a model which minimize the sum of costs for both constructing link additions and operating vehicles over the entire system, subject to the following constraints: (i) all supplies and demands of each commodity type must be met by flow over the network, in which the sum of flows into each node must equal to flows out; (2) if a link is not built, then there can be no flow over it; (3) the amount of funds committed to building new links must not exceed the available budget; and (4) the partial construction or improvement of a link is not permitted. He comes up with the optimal improvements and their timing. It is assumed that the network in any given stage n is a subset of the network which will exist at the next stage n+1. Therefore a dynamic programming approach was introduced. However, there is a shortcoming in the approach: traffic patterns in the last planning period are the only ones that affect the selection of the highly important final or Nth-stage plan. Today's volumes merely determine which links of this final plan to build early. There is, therefore, an element of commitment to the Nth-stage plan, once it is determined. Morlok (25) has proposed a dynamic programming procedure to define the optimal timing and strategies in the Northeast corridor context, ignoring the network effects of multiple and overlapping paths.

Another interesting approach to find the optimal time-staged sequence of improvements is to solve the combinatorial problem using the
discrete optimization technique of branch and bound programming. Ochoa and Silva (26) apply a branch and bound algorithm and a branch backtrack algorithm to the network improvement (single period) problem, using a traditional assignment model as a flow prediction mechanism.

Also, there are a number of heuristic approaches for the network improvements, which concentrate mainly on the link addition or capacity expansion, only in one period, using a simulation model. Barbier (27), Stairs (28), Spenser (29) and Bhatt (30), all propose ways to select improvement plans for testing in a simulation model, which corresponds to a form of direct search procedure. Allman (31), Fisco (32) and others have developed simulation models mainly serving the needs of the railroad in North America.

Carter and Stowers (33) develop a model to find the optimal allocation of funds for network improvements. A general transportation network is specified with n nodes and m arcs with arbitrarily chosen directions. Associated with each arc is a capacity $b_{ij} > 0$ and a travel cost $c_{ij} > 0$. Each distinct flow or "commodity" is defined as the flow from a single source with supply $r_k$ to various destinations. The non-linear relation between link volumes and construction costs is handled by means of a piecewise approximation— one constant user cost is associated with relatively free flow conditions and another constant user cost is charged to all vehicles volumes above a critical "practical capacity". This is easily incorporated into the model by representing each link by two "artificial links", with respectively low and high user costs.
The low cost link will have a capacity equal to the "practical capacity" of the link. The other higher cost link will have a capacity equal to the difference between the possible and practical capacity of the actual link. The optimization algorithm will load the low cost branch first and if its capacity is exceeded the high cost branch will then be loaded. In this way an actual link with nonlinear travel costs will be simulated.

The introduced objective function aims at minimizing the sum of transport costs and cost of improvements, keeping them within the budget limits. The program developed can use a standard linear programming procedure for its solution, but for a relatively large network this might overcome the computer capacity.

Quandt (34) has developed a model having as objective the minimization of user costs. This model is based upon the classic Hitchcock-Koopmans transportation network problem: There are N sources and M destinations and all sources are initially connected to all destinations. Each source has a fixed supply $k_i$ and each destination a fixed requirement $R_j$. He equals the total supplies with the total requirements. Also, he introduces as constraints, the total outflow from source i to be less or equal to its supply $k_i$ and the total inflow to destination j to be greater or equal to its requirement $R_j$. The objective function aims to minimize the total transport costs, provided that the cost of improvements does not exceed the available budget. He associates with each link $ij$ the decision variable $k_{ij}$, the amount of capacity to be added. This variable is continuous and a small positive increase in its value may
well correspond to the widening of a road or the installation of a better signal system; a large value of $k_{ij}$ may well be indicative of the need for provision of an additional link. Though $k_{ij}$ will be restricted to values greater than or equal to zero, links may be taken entirely out of the network or added if their initial capacities $b_{ij}$ are set to zero. Therefore, the total traffic flow on the link must be less or equal to the sum of the initial capacity and the capacity to be added.

2.2.2.3 Stochastic Models

Pecknold's (7) work is the most important in this area. He recognizes that improvements are usually implemented as a series of staged sequential improvements to a fairly extensive existing system and that there is substantial uncertainty over the future demands. He has developed a basic stochastic time-staying model, which is capable of handling supply-demand interdependencies, network connectedness, budget constraints and system dependencies on the type of improvements. The use of a descriptive non-analytic simulation model for transport flows, which recognizes both uncertainty and the multi-stage nature of investment alternatives results in an extensive multi-stage decision tree of extreme dimensions. He introduces approximating procedures, called pruning rules and terminal evaluation functions to heuristically reduce the computations and make application of his sequential decision model feasible for large networks.

2.2.3. Traffic assignment approaches

Numerous approaches have been developed for the assignment of the
traffic on the links of the network. Here we will mention the ones more relevant to our work.

Beckman (35) considers a transport network consisting of N nodes and directed arcs, with a single type of homogenous traffic flowing on it. He solves the problem using an algorithm which:

1. starts with an initial demand $D_{l,k}$ on each origin-destination pair $l,k$ and the flows $x_{ij}$ over the links $ij$;
2. computes the travel costs or time $c_{ij}$ associated with using the link and the flow $x_{ij}$:
   \[ c_{ij} = a + b \cdot x_{ij} \] where: $a, b$ constants.
3. finds out the minimum path for each origin-destination pair $l,k$ with the help of the expression:
   \[ c_{l,k}^* = \min \text{-path} \sum_{ij} c_{ij} \]
   which gives the minimum travel time between $l,k$,
4. now, a new demand is generated:
   \[ D'_{l,k} = f \cdot gc_{l,k}^* \]
   where: $f, g$ are constants
5. a weight sum of the new and the old demand is generated:
   \[ a \cdot D'_{l,k} + (1-a)D_{l,k} \]
   where $0 \leq a \leq 1$
6. the assignment of the flows on the links is done through the imposed conservation conditions:
   \[ \sum_{j=1}^{N} x_{ij} = \begin{cases} D_{l,k} : \text{(at origin)} \\ -D_{l,k} : \text{(at destination)} \\ 0 : \text{(elsewhere)} \end{cases} \]
(7) the same calculations are repeated,
(8) the flows between each O-D pair will oscillate within a. $D^j_{o,k}$ and if a is progressively decreased during the iterations, convergence will be satisfactory.

Manheim and Martin (36) propose an algorithm, which requires as inputs: interzonal transfers, network description, volume-delay characteristics and a specification giving a volume increment and a generation rate characteristic. The algorithm works in five basic phases:

(i) The random selection of a zone pair,
(ii) The determination of the minimum time path between the zone pair,
(iii) The use of a generation rate characteristic to determine the potential volume to be assigned between the zone pair,
(iv) The addition of a small increment of the potential volume to the minimum path,
(v) The use of volume-delay characteristic to update the travel times of the links in the minimum path due to the increase in volume.

The produced output consist of link volumes out travel times, interzonal potential volumes. Isard (37) develops a model handling aggregatively the shipment of commodities between regions; shipments are considered to be direct between origins and destinations; rerouting and transshipment possibilities as well as capacity constraints on the links are not considered. The model defines the shipment of commodities
is such a way as to maximize the regional income subject to the conservation rule of supply and demand.

Tomlin (38) develops a model defining the flows over the links according to the minimum costs of transport. A network is specified with nodes 1,2,...,N and directed arcs 1,2,...,M. Associated with each arc is a capacity $b_{ij} > 0$ and an average user cost $c_{ij}$. The objective function is the one minimizing the overall user costs:

$$\text{minimize} \quad Z = \sum_{k=1}^{q} c_k \cdot x_k,$$

where:

- $c_k$: the vector of the transport costs of the $k^{th}$ commodity over each link.
- $x_k$: the flow vector for the $k^{th}$ commodity over each link.

The introduced constraint is the one of flow conservation at node $i$:

$$\sum_{j=1}^{N} x_{ij} - x_{ji} = \begin{cases} r_k \text{ (origin)} \\ -r_k \text{ (destination)} \\ 0 \text{ (elsewhere)} \end{cases}$$

The arc-node formulation leads to a basis of large size. The program can be handled by means of the decomposition principle developed by Dantzig (39).

2.3. Conclusions

After reviewing a number of models, we can conclude the following:

- The evaluation of alternative network improvements and the choice of the optimal one is a problem which is complex in theory and depends largely on whose point of view we are concerned with;
the problem has been approached from a variety of different perspectives, each emphasizing a certain commitment to a profession, to a mode, or a philosophy which emphasizes some aspects and largely ignores others;

- a number of computational techniques have been used to solve the problem, not recognizing the non-linear status of the problem, or introducing assumptions to transform the non-linearity to linearity;
- none of these techniques or algorithms can be used satisfactorially in all of these basic problems of transport investment planning.

Furthermore, reviewing the models with the perspective of being applied in a less developed country we may find some that are inappropriate for couple of reasons:

- They are too sophisticated, thus they need large computer facilities (usually unavailable in a less developed country) to be implemented,
- the data requirements are such that it is impossible to meet them with the available resources and facilities in a LDC. (most of the data does not even exist, thus making those models which are highly sensitive to accurate data obsolete).

Summing up our conclusions for the type of evaluation model needed for the improvements of the transport network in a LDC we may recommend: a model which is easily applied, straightforward, with few data requirements. Finally, it must be able to serve in the best possible way the needs of a LDC for better transport.
3.1. The approach

3.1.1. Definitions

Before describing the approach itself, the definition of the words, expressions and concepts employed should be done. A transport network is composed of links and nodes. It is assumed that all economic activity takes place within nodes, cities or villages, rather than being continuously distributed over space and that transport is confined to links, routes between these nodes. A point where two or more links join must also be a node, even if not a point of economic activity. Each commodity is produced at one or more supply nodes. Demands for these commodities exist at other nodes within the network. Commodities are shipped from supply nodes (origin) to demand nodes (destination) over the links of the network. Similarly, people are moving from the origin node for the destination node over the links. A transport network is composed by links of several modal types: highway, rail, waterway and air. In this study only the case of the highway mode is considered.

Network improvements denote the construction of new links, the upgrading or widening of parts of others, or better maintenance for the road surface, aimed at lowering the vehicle operating costs. Network improvements are executed according to a proposed plan called a network improvement strategy. Network improvement strategy, or network strategy (N.S), is composed of one improvement strategy for one or more links—the link improvement strategy, which is a time sequence of projects or
changes on the link, is chosen from among alternatives. It is obvious that the number of network strategies possibly considered depends on the number of links to be improved and the number of tentative link improvement strategies. With the timing of a link strategy left as a variable, one network strategy may be identical to another except for the time when one link strategy is implemented.

A link improvement strategy, or link strategy (L.S.), may denote one or more of the following: (i) the timing of the construction projects for a new link, staged or not; (ii) the maintenance of policy to be followed overtime; (iii) the time-sequence of the upgrading (e.g. the year that an earth road will be improved to a gravel one, and, possibly, to a paved road) to part or all of the link; (iv) the time-sequence of widening the road or adding a new lane; or (v) no improvement at all. It should be pointed out a link strategy is a sequence of activities with a fixed relative timing. The entire sequence may be shifted in time.

3.1.2. Overview of the logic

The approach, advanced here, generates alternatives network strategies from proposed link strategies, simulates the network performance over the time horizon for each feasible network strategy, and finally, evaluates it.

The consequences of a network strategy are evaluated as follows: First, the alternative is checked to see whether it satisfies the imposed constraints on budget, foreign exchange and skilled labor. Then, during the simulation of the network, the annual costs and benefits are computed.
The cost are those associated with construction and maintenance activities. The benefits are defined as the difference between the price a user is willing to pay or was paying before the implementation of an incremental cost change due to a change in transport cost and the price actually paid. To estimate the transport cost for each trip from its origin to its destination, the routes of the vehicles must be determined and the cost of time and congestion added to the operating costs. The evaluation of the alternative is based on the net present values of these incremental costs and benefits produced by the simulation for each alternative when compared to a base network solution. The approach proposes as the optimal network strategy for implementation the one with the highest net present value. The figure 3.1 shows the several steps of the approach.

3.2. Constraints on the feasibility of an alternative

The constraints imposed to each network strategy are of three types: 1) those related to the costs of improvements, 2) those related to the timing of each strategy and 3) those economic weightings associated with each strategy which determine its importance in the economic improvement of the country. The feasibility of a network improvement strategy is based on whether it satisfies constraints introduced to prune the generated network strategies. An annual budget is allocated for highway construction and maintenance, and distributed among the regions of the country. Each network strategy may not have costs of construction and maintenance activities for each region higher than the
Input Network Configuration

For a link

Repeat for each link

For a link strategy

Repeat for each link strategy

LINK SIMULATION
HCM performs the simulation of the construction and maintenance activities and vehicle operation

Input links characteristics

Network Strategies Generation

Generate a N.S. from one or more L.S.

Check the feasibility
If it satisfies the set criteria store it for the evaluation

Figure 3.1.: Flow Diagram of the Approach
Input base network strategy. It includes only the strategy of each link denoting no change or pre-determined improvement.

Input demand characteristics

For a network strategy do the evaluation

Repeat for each N.S.

For each year

Repeat for each year

Define the routing of traffic, assuming that a vehicle will follow the route with the minimum transport costs for each O-D

Assign the traffic on links. Traffic is computed in vehicle numbers and in passenger car units

Figure 3.1.: (continued) Flow Diagram of the Approach
For an O-D pair
Compute the total transport costs
Compute the benefits (Consumer surplus measures the benefits. It is calculated comparing the N.S. with the base network strategy, computing the savings and the resulting increased demand)
Calculate the total benefits and then the discounted benefits
Evaluation of N.S. terminated. The NPV has been computed
Do the ranking the N.S. according to their NPV

Figure 3.1 (continued) Flow Diagram of the Approach
annual regional budget.

Two other constraints are closely related to the economic conditions: Most of the money available for initial construction comes from abroad either as direct aid in foreign exchange or low interest, long term loans. The balance of payments usually constraints the growth of the country; therefore the available money for purchases of machinery, materials, etc. is limited to the aid or loan money or to specific allocations to the transport sector as a whole. Therefore the model allows foreign exchange allocations in each region to be constraint. Similarly, there is often a scarcity in skilled labor. This may be a deterrent to development or imply the use of labor instead of capital intensive techniques, the latter using mostly skilled labor. It may be specified as a regional constraint.

3.3 The Costs

3.3.1. The cost of construction and maintenance activities

An improvement may be any continuation of upgrading or construction of part or all of a link. The costs are those resulting from the construction or upgrading that occur during the improvement phase as well as those associated with the maintenance of the link.

The cost may be specified exogenously or computed by the Highway Cost Model (HCM) after simulation of the activities of improvement. Construction costs may be computed directly and accurately by the HCM; maintenance costs can only be approximated because they vary with the traffic on the link, which is not known until the entire network is simulated. Maintenance costs are computed for an approximate expected
volume. Although fairly insensitive to volume, these costs could be adjusted if the volume turns to be significantly different.

The cost of construction and maintenance activities may be distinguished as financial and economic costs, the economic costs being those obtained by deducting from the financial costs the percentage resulting from indirect taxes and import duties. This is an estimate of the "cost of the improvement" to the country's economy net of the payments of taxes. It is this cost that is used to measure national objectives. The financial costs, perceived by the user, as the costs that influence his behavior. Budgets are stated in these terms. Similarly, budget constraints may also be stated in terms of other critical resources, such as foreign exchange and skilled labor, since their allocation to other sectors of the economy than in the transport sector, could influence the country's economic growth.

3.3.2. Vehicle operating costs

Since the model will be integrated with the HCM, it adopts some of its characteristics and constraints. One of these is that, seven vehicles types may be handled. They are usually designated as: passenger car, bus, pick-up truck, 5-ton truck, 10-ton truck and two types of tractor-trailers.

Vehicle operating costs are dependent on the design and the surface as well as on the traffic volume on the road. The operating costs resulting from the road conditions can be exogenously specified or computed by the HCM through the simulation process. The costs due to the introduced monetary value of the travel time are computed by the
evaluation model. The vehicle operating costs are computed as both financial and economic costs. Economic costs are these derived from fuel and lubricants consumption, tires usage, vehicle depreciation and interest on capital, maintenance and repairs and wages (in the case of trucks and busses). The financial costs are the economic costs plus the costs of insurance and taxes. The financial costs are used to determine the routing of the traffic between Origin and Destination (O-D) and changes in demand due to operating costs, and the economic costs used to compute the benefits resulting from the improvement.

3.4. Definition of demand and the generated traffic

The traffic on the network originates from the supply nodes, its destination being the demand nodes. The demand is given by O-D pairs (origin-destination nodes). A supply (origin) node represents a production region where one or many crops are produced, a mine, a place where animals are raised, or a city or industrial area where manufactured goods are produced, ready to be consumed locally or shipped to other places. A demand (destination) node represents a city, a town or a village where the goods are consumed.

The annual based demand is a function of the population and its growth rate, the average income and its increase, the price of the commodity etc. The changes in transport costs will shift the demand up or down due to price elasticity. The number of vehicles moving on the links of the network is based on such demand of the commodities between each O-D pair.
The model handles seven different vehicles types, each with different capacities. It is assumed that for one O-D pair, one vehicle type carries one commodity type or at least ones with similar handling and transporting characteristics. Thus, the model limits the number of substantially different commodities which can be transport between each O-D pair to five, not including passengers. Demand can be measured in two ways: in number of vehicles per day (according to vehicle type) for each O-D pair; or in tons per day. (From the volume of commodities in the vehicle capacities and the load factors, the number of vehicles for each O-D pair is easily computed). Each vehicle type will follow that sequence of links which connect the O-D pair and minimize its total operating costs. As the network characteristics change, so may be the routing.

3.5. Impacts of the Improvement on Demands and Traffic

Any change in the operating characteristics of a link in the network will affect the distribution of traffic on the links. Changes may induce greater demands, divert traffic from other links, or create congestion on the link due to the traffic increase.

The demand of commodities and passengers between origin and destination pairs is influenced by changes in the transport costs. This sensitivity to demand is denoted as the price elasticity. Price elasticity is the percentage change in demand that results when the transport costs have changed by one percent. Elasticity may vary from O-D (inelastic demand, i.e. no change in demand) to values as high as 0.1 to
Figure 3.2.: Schematic model for forecasting passenger and freight transportation demand
Several approaches have been developed to estimate the demands of the O-D pairs. Their general scheme is portrayed in the flow chart in figure 3.2. It begins with land use or spatial location characteristics, derive trip demands and trip destinations and then follow this with an assignment or allocation of these trips to a network. When the demand is elastic any change in the transport costs, resulting from the route assignment, will change the demand.

Route assignment provides specific estimates of demand placed on various links in a network summed from the individual O-D demands. Since there may be a number of alternatives paths that can be used for connecting the O-D pairs, the assignment selects the least costly route. These costs vary with travel time, which varies with link (not O-D) volume. If links capacities were infinite, and the travel time therefore did not vary, the assignment would be relatively simple. However, as flows on a transportation network change, the cost-performance characteristics on the network also change. Real world users adapt their behavior to local capacity shortages. If a shorter, faster route becomes congested (and thereby slower), users will shift to a less congested and formerly slower alternative route. The result is a complex equilibrating process of travel demands, travel speeds and link volumes. There are numerous solution approaches and assumptions introduced to solve such problem. For LDC's, where alternatives are fewer, we will assume away this problem by assuming that congestion costs do not alter the routing, determined ignoring congestion.
3.6 The Assignment of Traffic on the Links

The assignment of traffic follows the assumption that each vehicle will travel the sequence of links that connect the O-D pair and minimize its total operating costs. No reassignment of the traffic on the links is considered for changes in transport costs due to the increased travel times caused by congestion. This limitation is not considered to be significant since most links in LDC's are uncongested and usually there is only one reasonably feasible route connecting most O-D pairs, which the vehicles must follow regardless of congestion. Congestion, however, if it exists, is considered by computing the costs resulting from the time value of the commodities and the passengers.

Initially the assignment is done for the first year of the simulation. It is then repeated during the time horizon if any change occurs in the network (identified by changes in user costs in any link) or if specified by the analyst.

3.6.1. The Routing Algorithm

Numerous algorithms have been developed which search a sequence of links to find minimum cost routes.

The Algorithm developed by Floyd (40), which can treat efficiently a general network and multiple O-D pairs, has been applied.

The Floyd procedure builds optional paths (routes) by inserting nodes, when appropriate into more direct paths. The algorithm starts with a NXN matrix C of transport costs, and N matrices are constructed sequentially, where N is the number of nodes. The Kth such matrix can be interpreted as giving the minimum transport costs of all possible routes between all node pairs (i j), where only routes with intermediate nodes
belonging to the set of nodes 1 through k are allowed. The (k + 1)st matrix is constructed from the kth using the formula:

\[
C_{ij}^{(k+1)} = \min \left( C_{ij}^{(k)}, \ C_{i,k+1}^{(k)} + C_{k+1,j}^{(k)} \right), \ C_{ij}^{(0)} = c_{ij} \quad (3-1)
\]

Here, K, which is initially zero, is incremented by 1 after i and j have ranged over the values 1,...,n; and K=N-1 at termination. If two nodes are not connected directly by a link, the assigned transport costs for this link is a large number. Also a time matrix T is introduced being the same as, C, but with travel times on the links as its elements.

The label matrix has as elements in the initial stage the nodes denoting the beginning of each link; i.e. the element aij is i, if i is the beginning node of link ij. Note that all matrices have elements defined by node pairs, not by O-D pairs.

The algorithm proceeds as follows: It pivots on every node of the network, i.e. it obliges all traffic between O-D pairs to pass through this pivot node for each O-D pair, it compares the resulting transport costs with the previous ones and saves the leasts ones as the transport costs of the O-D pair under consideration.

If the traffic has to pass through the pivot node, the algorithm updates the label matrix and the time matrix as well. The pivoting had ended, for each O-D pair the cost matrix C would come up with the minimum transport costs the time matrix T with the resulting travel time and the label matrix L with the previous node of any node, both nodes defining a link of the minimum costs route.

Finally, the set of links of which the route is made up may be found.
Initialize Matrices

\( C, T, L \)

Repeat for all nodes

Pivot on a node: \( p \)

Repeat for all node pairs

For a node pair \( ij \)

Compute costs on direct link \( ij: C_{ij} \)

Compute costs on route composed of link: \( ip \) and \( pj \):

\( C'_{ij} = C_{ip} + C_{pj} \)

\( C'_{ij} < C_{ij} \) ?

UPDATE MATRICES

\( C_{ij} = C'_{ij} \) (C)

\( t_{ij} = t'_{ij} \) (T)

\( l_{ij} = p \) (L)

Find the links of which each route composed

Figure 3.3.: Minimum Cost Route Algorithm
The steps of the algorithm are shown in figure 3.3. An example of the algorithm application is presented in Appendix 1 of this chapter.

Using the routing so determined, the transport costs by O-D pair may be computed. To the total operating costs found by the algorithm, we add the costs associated with the time lost in travelling, determined without taking in to consideration any costs resulting from possible congestion.

3.6.2. Congestion

If congestion occurs during anytime period, it will cause vehicles to lower their speeds, thus increase the travel times and transport cost. If the average traffic volumes on a link are given on a daily basis, which is usually the case, we must translate them to a distribution of volume levels, but on an hourly basis to determine whether congestion will occur or not. If one sampled the hourly volumes at many points in time, the result would be a distribution of hourly volume levels for the whole day. If speeds are determined at each volume level and the resultant ravel times weighted by the number of vehicles traveling at that volume level, the estimate of "average" conditions is much improved. The distribution of hourly volumes varies for different types of roads. In general, heavily traveled roads tend to have distributions in which the "peak volume" is skewed towards the higher volume levels, while the distributions of volumes on less traveled roads are heavily skewed toward very low volume levels. Roberts (16), introduced a probability mass function, which is analogous to the one resulting from the "binomial distribution". There are 4 Bernouilli trials, the
success $Y_k$ being whether the hourly volume will fall in the $k^{th}$ volume level. Therefore, he measures the probability of each hourly volume level to be the same as the hourly volume on the link—which is unknown, the volume given on a daily basis. Thus without knowing the hourly volumes on a link, he comes up with an approximation of them, sufficient to help solving the congestion problem. His approach has been applied, as described belows.

3.6.2.1. Measuring the Traffic in Passenger Car units (PCU)

The traffic on the links is given in numbers of vehicles by vehicle type (cars, busses, trucks). A common unit of measure for traffic is needed in order to represent it. This is taken as one passenger car, all other vehicles are represented by passenger car units (CU). Factors are introduced for each vehicle type for this transformation.

The Highway Capacity Manual (41) considers a truck or a bus displacing several passenger cars in the flow on the road. The number of passenger cars that each truck or bus represents under specific conditions is termed the "passenger car equivalent" (PCE) for those conditions. Note that the passenger car units (PCU) for a truck is equal to its PCE. (Passenger Car Equivalents) In level terrain where trucks can maintain speeds that equal or approach the speed of passenger cars, it has been found that the average truck is equivalent, in a capacity sense, to between 2 and 3 passengers cars on 2-lane highways depending on the level of service. These values are appropriate for most downgrades as well. On upgrades, the passenger car equivalent of trucks may vary widely, depending on steepness and length of grade and number
of lanes. For approximate analyses of operations on a given road, section it may be sufficient to apply an overall approximate equivalency factor to the road as a whole.

According to Highway Capacity Manual, for the case of two-lane roads, the difference, between truck speeds and passenger car speeds on grades, is what causes trucks to reduce the traffic volume carried by a road at any given level of service. The greater the speed difference, the greater is the reduction in any given volume, with corresponding increase in the passenger car units. Roberts (26) developed a formula to compute the PCE, for each vehicle type.

\[
PCE(IV) = \frac{ROC \times \text{SPEED}(1) - \text{SPEED}(IV)}{10} + 2, \quad (3-2)
\]

Where:

- IV: the vehicle type
- SPEED(1), SPEED(IV): the speeds of passenger car and vehicle type IV respectively (in km/hr)
- ROC: is the increase in PCE for each kilometer per hour difference in speed

Roberts computes ROC taking into account factors such as the number of lanes (LANES), the type of surface (SURF), and the sight distance, using the rise and fall, in m/100m, (RFF) as a surrogate: Thus:

\[
ROC = \frac{SURF \times RFF}{LANES-1} \quad (3-3)
\]

and for the case of a two-lane road, it turns out to be:

\[
ROC = SURF \times RFF \quad (3-4)
\]

For the surface types, Roberts uses indices from 1 to 3; 1 being paved or surface treated road, 2 being gravel and 3 being earth road.
Considering only the surface type and the rise and fall of the road, this does not take into account the impact of the design standards of the road. Since, the other important factors in the road design standards are, besides the surface type and the sight distance, the horizontal alignment and the width of the road, it would be appropriate to introduce these as factors to determine the ROC. This is done with a road design index, RDI, taking values from 1 to 3, combining the roads surface type, the road width and the horizontal alignment. Since all these factors may be reflected in the design speed of the road, the RDI may be calculated if the design speed of the road is known. In our approach a formula is developed according to which RDI equals to 1, when the design speed is 100km/hr and to 3 if it is 25km/hr. Other values may be found through interpolation or applying the developed formula:

\[
RDI = 3.67 - 0.027 \times V \quad (3-5)
\]

where:

V: the design speed of the road.

and, thus:

\[
ROD = RDI \times RFF = (3.67 - 0.027 \times V) \times RFF \quad (3-6)
\]

Thus the RFF and the design speed of the road or the RDI must be inputs. In case that RDI is given, the design speed may be computed applying the equation:

\[
V = 137.5 - 37.5 \times RDI \quad (3-7)
\]
Thus, using the above approach the traffic (ADT) is measured in PCU/day. Given is also the capacity of the road (CAP) in PCU/hr both directions. Assuming the movement will take place only 16 hours per day the daily capacity of the road is computed:

\[ DCAP = 16 \times CAP \quad (3-8) \]

### 3.6.2.2. Determining the Congestion Speeds

The ratio of the daily traffic volume and the road daily capacity

\[ \frac{VOL}{DCAP} \]

may be used as a measure of congestion. According to Roberts (16), if VOLCAP turns out to be less than 0.1, no congestion is likely to occur in any hour of the day. Otherwise the variable RVOL is computed as a function of VOLCAP:

\[ RVOL = 1.25 \times (VOL - 0.10) \quad (3-10) \]

Where, RVOL represents the probability in the Bernoulli trials of and hourly volume level to be equal to the hourly volume on the link. It is assumed that the probability is the same for all volume levels. The proposed probability mass function will be applied for 4 Bernoulli trials. The levels of hourly volumes are 5, represented by VOL (IP) (IP taking values from 1 to 5).

Each volume level is defined as a percentage of the hourly capacity of the road (CAP). Thus:
\[
\text{VOL (1)} = 0.10 \times \text{CAP} \\
\text{VOL (2)} = 0.30 \times \text{CAP} \\
\text{VOL (3)} = 0.50 \times \text{CAP} \\
\text{VOL (4)} = 0.70 \times \text{CAP} \\
\text{VOL (5)} = 0.90 \times \text{CAP}
\] 

The proposed probability mass function of the hourly volume level IP to be equal to the actual hourly volume on the link is given by:

\[
\text{VOL(IP)} = \left( \frac{4}{X} \right) \text{RVOL}^X \times (1-\text{RVOL})^{4-x}
\]

where:

\(X = \text{IP-1}, \) the index numbers for the hourly volume levels, as used in the probability mass function.

\(f(IP)\) is represented in figure (3-4).

The resulting frequency distribution \(f(IP)\), is used to determine the equivalent number of vehicles \(\text{VEHNO (IP)}\), travelling at each volume level, \(\text{(IP)}\), according to the following equation:

\[
\text{VEHNO (IP)} = 2 \times \frac{\text{IP-1}}{10} \times f(IP) \times \text{DCAP}
\]

The speeds of vehicles traveling in each volume level can now be determined by the relationship (a simplified linear version of the volume-speed curves so frequent in the literature):

\[
\text{VEL} = V \times \left( 1 - \frac{\text{VOL (IP)}}{\text{CAP}} \right)
\]

where: \(V\) is design speed of the road.

3.6.2.3. Costs of Congestion

Having defined the VEL for each vehicle type IV, the weighted additional travel time is computed by the equation for each type IV:
Figure 3.4: Comparison of Artificial Traffic Distribution and Binomial Distribution
AAT(IV) = \sum_{IP=1}^{\infty} \frac{(AT(IP) \cdot VEHNO(IP))}{ADT} \quad (3-15)

where:

- **AAT(IV)** = weighted additional travel time of vehicle type IV
- **AT(IP)** = the additional travel time of vehicle type IV, if it was in volume level IP, given by the equation: (T being the travel time on the link without congestion):
  \[ AT(IP) = \frac{V - VEL(IP)}{V} \cdot T \quad (3-16) \]
- **TRAF(IV)** = number of vehicles of type IV
- **ADT** = average daily traffic in PCU/day
- **VEHNO(IP)**: equivalent daily volume of level IP, in PCU/day

The additional travel time is multiplied by the value of the time, to give the costs of congestion for each vehicle type.

An example of the approach is presented in Appendix 2 of this chapter.

### 3.7. Benefits resulting from the Improvement

Using total transport costs for the vehicle movement form origin to destination, the benefits attributable to changes in the network can be defined. They are computed by comparing the transport costs of each O-D pair after the improvement and before. The benefits are the savings, in transports costs, accruing to the network users underneath the demand curve. If the demand curve is unavailable an approximation that can be made is given by the equation:

\[ BEN = \Delta \Theta \cdot T^0 + 0.5 \cdot \Delta \Theta \cdot \Delta T \quad (3-17) \]
where:

\[ \Delta\Theta \cdot T^0 : \] benefits to normal traffic \((T^0)\), after unit transport cost reduction,

\[ 0.5 \cdot \Delta\Theta \cdot \Delta T : \] benefits from the induced traffic \((\Delta T)\); after the unit transport cost reduction, \(\Delta\Theta\)

This equation is another expression of the "consumer surplus" resulting from the improvement. The induced traffic, \(\Delta T\), is the difference between the traffic before the improvement \((T^0)\) and the traffic after \((T')\).

\[ \Delta T = T' - T^0 \]  \(3-18\)

and thus equation 3-17 will be transformed to:

\[ \text{BEN} = 0.5 \cdot (T' + T^0) \cdot \Delta\Theta \] \(3-17a\)

the familiar form of the "consumer surplus". The increase in O-D traffic will result if the demand is elastic with respect to transport costs. Thus, if \(\text{ELA}\) is the elasticity of demand with respect to costs and \(\Theta^0, \Theta'\), the transport costs before and after the improvement:

\[ T' = T^0 \cdot (\frac{\Theta'}{\Theta^0})^{-\text{ELA}} \] \(3-19\)

This is resulting from the definition of the demand function:

\[ T_i = A \cdot \Theta_1^{-\text{ELA}} \] \(3-20\)

where:

\(T_i\) : the traffic (demand) at unit transport cost

\(\Theta_i\) : the unit transport costs

\(\text{ELA}\) : elasticity of demand with respect to costs (positive)

\(A\) : a constant
Figure 3.5: Transport Demand Function
Figure 3.6: The Market for a Transported Commodity in node A (consumption)
Figure 3.7: The Market for a Transport Commodity in node B (production)
Figure 3.5 represents the benefits by the shaded area.

It will be proved that these benefits are equal to the benefits accruing to the consumers and producers of the transported commodities, considering an one commodity transport between two regions (represented by the O-D pair), with no other transport made to share the transport. Another assumption is the indifference with respect to benefit distributions between the two regions and between producers and consumers. Furthermore, it is assumed that the commodity is produced in region B and consumed in region A.

The two regions are connected by a single road and due to the assumed absence of competitive transport, all the volume of the commodity has to use the road—therefore the transport costs are common for each alternative improvement strategy of the road. The equilibrium between supply and demand (see figures 3.6, 3.7) before any improvement sets the per unit price of commodity in A equal to the per unit cost of production in B plus the unit transport costs (which in this case is assumed to be invariant with respect to the volume of transport measured in units of commodity). Similarly, the equilibrium between A and B equal the difference between the per unit price of the commodity in region A and the per unit cost of production of the commodity in region B. (Again the transport costs are assumed to be invariant).

Thus,

$$\mathcal{E} = P_A - P_B$$

(3-21)
Where:

- $\theta$: the unit transport costs between A and B
- $P_A$: unit price of commodity in A
- $P_B$: unit cost of production of commodity in B

Denoting by $^{(0)}$ the case before the improvement, and by $^{(')}$ the case after the improvement, we have:

$$\theta^{(0)} = P_A - P_A^{(0)}$$
$$\theta^{(')} = P_A - P_B$$

(3-22)

The change in unit price of commodity is $A$ due to the improvement is:

$$\Delta P_A = P_A - P_A^{(0)}$$

(3-23a)

since $P_A^{(0)}$ is greater than $P_A^{(')}$ (price reduction after the improvement), $\Delta P_A$ is negative.

The change of the unit costs of commodity in $B$ is:

$$\Delta P_B = P_B - P_B^{(0)}$$

(3-23b)

Since $P_B^{(')}$ is greater than $P_B^{(0)}$ (cost increase), $\Delta P_B$ is positive.

Then change in unit costs of transport are:

$$\Delta \theta = \theta^{(0)} - \theta^{(')}$$

(3-24)

since $\theta^{(')}$ is less than $\theta^{(0)}$ (transport cost reduction), $\Delta \theta$ is positive.

Substituting the $\theta^{(')}$ and $\theta^{(0)}$ in the equation 3-24 from equations 3-22 the outcome is:

$$\Delta \theta = \Delta P_B - \Delta P_A$$

(3-25)

To prove that equation 3-17 gives the benefits to the consumers and producers of the two regions, figures 3.6 and 3.7 are required as reference. The price of commodity in an A falls but the cost in B
risec when the transport costs fall. At the same time the volume of traffic increases from \( T_0 \) to \( T' \). The increase equals the excess demand in A plus the excess supply in B. In region A, the consumers surplus \( \left[ \frac{T_0 + T'}{2} \cdot \Delta P_a \right] \) is offset by the producers losses \( \left[ -\Delta P_a \cdot (T_0 + T') \right] \)

Therefore the benefits of region A (shown in the shaded area of Figure 3.6) are:

\[
\text{BEN}_A = -\Delta P_a \cdot \frac{T_0 + T'}{2}
\]  

(3-26)

Similarly, in region B, a part of the producers surplus \( \left[ \Delta P_b \cdot (T_0 + T') \right] \) is offset by the consumers losses \( \left[ -\Delta P_b \cdot \frac{T_0 + T'}{2} \right] \) Therefore the benefits of region B (shown in the shaded area of Fig. 3.7) are:

\[
\text{BEN}_B = \Delta P_b \cdot \frac{T_0 + T'}{2}
\]  

(3-27)

The total benefits for both regions are:

\[
\text{BEN} = 0.5 \cdot \Delta \theta \cdot (T_0 + T')
\]  

(3-28)

which is the same expression as in the one in 3-17.

These are the benefits observed when we improve a route connecting two regions. What about constructing a new road that will connect two regions, previously unconnected? It is obvious that before the construction no demand of the commodity was existed. However, a potential demand would be up to a maximum of \( T^0 \) units of commodity; where

\[
\theta^0 = \Delta \theta \cdot (T^0)^{-\text{ELA}}
\]

being the difference between the price of commodity in region A (consuming region) and the cost of production in region B (producing region). That is:

\[
\theta^0 = P_a - P_b
\]  

(3-21a)

The new road will reduce the transport costs to \( \Delta P_a' \) and the new prices will be \( P_a' \) and \( P_b' \) as a result the new volume would be

\[
T' = A \cdot (\theta')^{-\text{ELA}}
\]

and the benefits will be measured as previously.
3.8 Evaluation Criterion

Using the costs and benefits computed for every alternative improvement strategy, they must be ranked as the next step is the evaluation process. There are four principal economic evaluation criteria: annual costs, benefit cost ratio, rate of return, and net present value. It must be stressed that each of these techniques has associated with it, in one way or another, an interest rate and a period of analysis, or time horizon. The net present value criterion has been introduced to the model as the evaluation criterion. With this method, present and future costs and benefits are discounted to the present and summed and the difference between the two sums in computed. Strategies having a net present value less than zero is unacceptable and that strategy with the highest net present value will be most desirable, when choosing among mutually exclusive alternatives. The reasons why the net present value is chosen as criterion instead of another, due: (i) the NPV method will always give single valued results; (ii) allows inflation costs to be considered as a component of the discount rate; (iii) provides good relative ranking among alternatives with similar cash flows. It requires, however, a reasonable choice of a discount rate, being the critical issue of the evaluation.
APPENDIX 1: Example about Assignment

The following example will illustrate the effectiveness and the simplicity of the minimum cost route algorithm (3.6.1). In the figure 3.8 a network is represented with the associated vehicle operating costs on the links (it is assumed vehicle type \( \mathbf{1} \)) and travel times. We construct the matrices \( C, T, L \), as follows for the different iterations.

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$C = \text{Vehicle operating costs (in$)}$

$T = \text{Travel time (in min.)}$

Figure 3.9: The Network of Roads
1st iteration: Pivot on node 1

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<td>8.0</td>
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<td>5</td>
<td>7.0</td>
<td>11.5</td>
<td>10^7</td>
<td>5.0</td>
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2nd iteration: Pivot on node 2

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<td>16.5</td>
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(Cont. 2\textsuperscript{nd} iteration)

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4 & 4 & 1 & 4 & 4 & 4 \\
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\textbf{3\textsuperscript{rd} iteration:} Pivot on node 3

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2 & 4.5 & - & 8.0 & 13.0 & 11.5 \\
3 & 12.5 & 8.0 & - & 5.0 & 10^7 \\
4 & 12 & 13.0 & 5.0 & - & 5.0 \\
5 & 7.0 & 11.5 & 10^7 & 5.0 & - \\
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\end{tabular}
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2 & 20 & - & 40 & 65 & 50 \\
3 & 60 & 40 & - & 25 & 10^7 \\
4 & 60 & 65 & 25 & - & 25 \\
5 & 30 & 50 & 10^7 & 25 & - \\
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\end{tabular}
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\begin{tabular}{c|ccccc}
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2 & 2 & 2 & 2 & 3 & 1 \\
3 & 2 & 2 & 3 & 3 & 2 \\
4 & 4 & 3 & 4 & 4 & 4 \\
5 & 5 & 1 & 2 & 5 & 5 \\
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\end{tabular}
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4th iteration: Pivot on node 4

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<td>11.5</td>
<td>10.0</td>
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5th iteration: Pivot on node 5

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<td>7.0</td>
<td>11.5</td>
<td>10.0</td>
<td>5.0</td>
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</tbody>
</table>
Therefore the minimum cost route for each O-D pair has been found.

e.g. For the (2-5) pair, the vehicle operating costs are $11.5, the travel time 50 minutes, and the route is (2-1), (1-5).
APPENDIX 2: Example about Congestion

This is an example to show how the approach of computing congestion costs can be applied. The following data is assumed for the example:

CAP (road capacity): 2000 PCU/hr and DIS (Length): 100kms;

Road Design speed: 95 km/hr; rise and fall: 3.0m/100m;

The number of vehicles per vehicle type and their speeds are:

<table>
<thead>
<tr>
<th>VEHICLE TYPES</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium volume road traffic</td>
<td>800</td>
<td>400</td>
<td>500</td>
<td>400</td>
</tr>
<tr>
<td>Low volume road traffic</td>
<td>100</td>
<td>100</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>Speed (in km/hr)</td>
<td>70</td>
<td>60</td>
<td>55</td>
<td>50</td>
</tr>
</tbody>
</table>

a. Road design index (RDI) and road condition factor (ROC)

RDI = 3.67 - 0.027 * 95 = 1.1

ROC = 3 * 1.10 = 3.3

b. Vehicles Equivalent factors is given by (3-2) So:

PCE (1) = 1., PCE (2) = 5.3, PCE (3) = 6.95, PCE (4) = 8.6

c.1 Average daily traffic: (low volume road)

ADT = 1565 PCU/day

d. Daily link capacity: DCAP = 16 * CAP = 32000 PCU/day

e.1 Volume to capacity Vatio:

\[
\text{VOLCAP} = \frac{1565}{32000} = 0.05 \text{ less than } 0.10. \text{ Therefore no congestion will occur.}
\]

c.2 Average daily traffic (Medium volume road)

ADT = 9250 PCU/day
Figure 3.9: The Traffic Distribution
e.2 Volume to capacity ratio:

$$\text{VOLCAP} = \frac{9280}{32000} = 0.29$$

f. Probability mass function (represented in figure 3.9)

$$\text{RVOL} = 1.25 \times (\text{VOLCAP} - 0.10) = 0.2375$$

$$f(1) = 1 \times (1 - \text{RVOL})^4 = 0.338$$

$$f(2) = 4 \times \text{RVOL} \times (1 - \text{RVOL})^3 = 0.421$$

$$f(3) = 6 \times \text{RVOL}^2 \times (1 - \text{RVOL})^2 = 0.197$$

$$f(4) = 4 \times \text{RVOL} \times (1 - \text{RVOL})^3 = 0.041$$

$$f(5) = 1 \times \text{RVOL}^4 = 0.003$$

g. Equivalent number of vehicles

$$\text{VEHNO (1)} = 0.338 \times 3,200 = 1,081.6$$

$$\text{VEHNO (2)} = 0.421 \times 9,600 = 4,041.6$$

$$\text{VEHNO (3)} = 0.197 \times 16,000 = 3,152.$$ 

$$\text{VEHNO (4)} = 0.041 \times 22,400 = 918.4$$

$$\text{VEHNO (5)} = 0.003 \times 28,800 = 86.4$$

h. Vehicle speeds on each volume level

Road design speed: \( V = 95 \)

$$\text{VEL (1)} = 95 \times (1 - \frac{200}{2000}) = 84.6$$

$$\text{VEL (2)} = 95 \times 0.7 = 65.8$$

$$\text{VEL (3)} = 95 \times 0.5 = 47.$$ 

$$\text{VEL (4)} = 95 \times 0.3 = 28.2$$

$$\text{VEL (5)} = 95 \times 0.1 = 9.5$$
j. Additional travel time for the vehicles of type I

Additional travel times if it was at volume levels 1, ..., 5

AT (1) = 0.  \quad (\text{VEL} (L) \text{ speed of vehicle type I})

\[
\text{AT (2)} = \frac{100}{65.8} - \frac{100}{70} = 1.52 - 1.43 = 0.09 \text{ hrs.}
\]

\[
\text{AT (3)} = 2.13 - 1.43 = 0.70 \text{ hrs.}
\]
THE NETWORK SIMULATION MODEL

4.1 Overview

The developed model generates, screens and evaluates network development strategies for a rural road networks. Given actual road network demand on an origin-destination basis, and potential demand, if road service were provided, and data on the cost and value of potential investments on network links, the model generates sequences of link investments, screens them for overall value and satisfaction of economic constraints, and allows cost-benefit analysis of the most interesting strategies. The model is integrated with the Highway Cost Model which carries out a simulation and evaluation of the investment strategies for a single link. It may deal with the individual link with the accuracy of the HCM or use more aggregate costs. Its final output may be a ranked list of network strategies, with their evaluation, and the timing of each of the link investments.

The model consists of four computer packages and their data files. The data files store network configuration and strategy data, link strategy data, and origin-destination demand data. The packages are an input data processor, the Highway Cost Model (HCM), a network strategy generator, and an evaluator which simulates the operation of the network over the analysis time span. The model simulates the construction and maintenance activities of each link by using government costs, segregated by local and foreign currency etc., developed by the
Figure 4.1.: Network simulation system flow
HCM or elsewhere. Simulation of the network operation includes the routing of traffic, based on vehicle operating costs, using a minimum cost path criterion. The flow of information in the model is shown on figure 4.1.

The generation of network strategies, to be evaluated and ranked later, is based upon two types of constraints and a single criterion. The first constraints are limits on the timing of link strategies, the amount by which such a strategy can slip in time from its initial sequencing with the HCM. The second are constraints on the capacity for constructing and maintaining the network. Initially we included financial and skilled manpower constraints by regions of the road network. To limit and choose among the large number of remaining potential combinations of link strategies, the model, allows the analyst to assign a social criticality index for each link strategy. The criteria for choice of strategies is to maximize the cumulative criticality indices for included strategies. Only a small number of strategies are kept and evaluated at the analyst's request.

The evaluation of the network strategies follows the simulation of network performance over the time horizon during which: it finds the route of the vehicles from an origin to a destination, computes the total transport costs, compares them with those of the base strategy—i.e., the network to be changed or remain the same according to a present plan—, performs the demand adjustments and computes the benefits, i.e. the savings in transport costs.
4.2 Link simulation (HCM)

The link is simulated by the HCM over the time horizon of interest. All the activities of construction and maintenance are simulated and therefore the financial and economic costs are computed, giving the total expenditures for the road link in each year over the time horizon. Also, the HCM simulates the vehicle operation of a link according to the road conditions but not considering the presence of other vehicles on the link. The network simulation model takes the information about the vehicle operation costs and simulates the vehicle operation according to the traffic calculated to be on the link. Any delays due to possible congestion are computed and the total transport costs on the link for each vehicle type are calculated as the operation costs plus the time loss costs.

It is useful to point out that a link is composed of different segments. Each one may have different surface type, alignment etc. Each project is related to one segment and consists of upgrading or changing the surface type, applying a certain maintenance policy. The HCM simulates the different projects on the link over time, simulates the vehicles operations on the link, then computes the resulting financial and economic costs. Note that a link strategy to be used as a term later is a series of projects over time on the link.

4.3 Network strategies generation

The purpose of each network strategy is to specify a feasible program to improve the existing network over the time horizon. The
existing network, or base network, consists of the links, in the condition they are in the beginning of the time horizon plus any link improvements or additions, which are fully fixed and have been decided in advance by the decision makers, and not to be changed or delayed. To be feasible, it must satisfy regional budget, foreign exchange and skilled labor constraints in each year. The network strategies are generated from the link strategies introduced by the decision maker.

Two types of link strategies are considered; mandatory strategies, with no restriction of when they will be implemented and optional strategies. In using these terms, we are naming the link upgrading strategies as link strategies. For a link multiple strategies may be proposed for implementation and it is up to the model to choose the one to be part of the network strategy.

The generation is coordinated with a branch and bound technique. Because of large calculation requirements, it is not looking for the best feasible solution but for a reasonable set of feasible solutions.

A network strategy is generated as follows: All obligatory links are to have one of their strategies included in the network strategy. The sum of the critical indices of the obligatory link strategies is compared with the network minimal index. If the sum is less, links from the optional set are included until either the minimum critical index is reached or there is no link left to be included. A link strategy critical index is an arbitrary number set by the decision maker. It may reflect the priorities for the link strategies set by the
decision makers. The higher it is, the more likely for the link strategy to be included in a feasible network strategy. It may merely reflect the importance of a link according to decision maker's intuition, it may be set high to include a specific link and its importance of connecting remote areas, or it may reflect the importance of a link to the economic activities of an area. The network strategies minimal critical index is very important, since it prunes all network strategies with lower critical indices than it.

When the preliminary network strategy has been generated, it is tested to see that it verifies the constraints (regional budget, skilled labor and foreign exchange) for each year. If it does, then the generated preliminary network strategy is feasible, and one the strategies of the optional links will be included, but the link will be different than the ones, the network strategy consists of. If one of the constraints is not verified then the model tries to slip the last included link strategy by a number of years (not exceeding the specified maximum slippage for each link strategy) to have the constraints verified. If this can be accomplished the generated network strategy is feasible and it proceeds to generate another one. If the verification of constraints is impossible, it tries to include another link strategy, if available, of the same link, and it tests if the constraints are verified. If they are not, it slips it by a number of years (less than the allowable slippage). If the constraints are verified, it proceeds to generate another one, otherwise it tries to include
another link strategy of the same link. If there is one, the same pro-
cedure will be repeated, otherwise it drops the link from the network
strategy and tries to fit another one, repeating the same. If none of
the remaining links can be fitted in the network strategy, it generates
the network strategy as it is. If a link strategy is included, it
searches for one from another link to be added. It repeats the same
procedure until either no more links are available or no more link
strategies can be included in the network strategy. Had the number of
feasible network strategies equaled the number of strategies to be gene-
rated, as specified by the decision maker, the algorithm keeps the ones
with the highest critical indices. However, it keeps only a specified
percentage of the generated ones. These are the ones to be evaluated
by the network strategies evaluator and be ranked according to their
computed NPV's.

4.4. Network strategies evaluation

4.4.1 Base network strategy

The base network strategy establishes the basis for evaluation,
since it is to if that strategy against which other network strategies
are compared. The base network is the existing network in the beginning
of the time horizon; plus link improvements or additions, which are fully
fixed, decided in advance by the decision makers, not to be changed or
delayed.

The base network is simulated to the same detail as other network
strategies. The demand for each O-D pair may change over the years of
the time horizon, as specified by input. This input is based on first year transport costs; thus, the input demand for other than the first year is computed from the first year applying the annual growth factors, not taking into account any change in transport costs.

### 4.4.2 Demand adjustments

For the base network transport demand may change over the years, if the transport costs have changed. This is the result of the demand function: (equation 3.20).

$$T = A \cdot \theta^{-ELA}$$  \hspace{1cm} (4-1)

if \( \theta \) changes, so will \( T \); (since the demand is sensitive to transport price changes if the price elasticity is not zero). Therefore the new demand will be:

$$T' = A \cdot (\theta')^{-ELA}$$  \hspace{1cm} (4-2)

Since the initial demand is known, as well as the transport costs, dividing the two expressions:

$$T' = T \cdot (\frac{\theta'}{\theta})^{ELA}$$  \hspace{1cm} (4-3)

Where:

- \( ELA \): elasticity of demand with respect to price
- \( T,T' \): traffic demands before and after the improvement
- \( \theta,\theta' \): unit transport costs before and after the improvement.

Demand adjustment will happen also when a network strategy is considered. However, this will be the outcome of change in transport costs those of base network as opposed to those of the network under
consideration. In this case \( \theta \) is the transport cost of the base network and \( \theta' \) the transport costs of the new network. The transport costs may increase if congestion occurs. Thus, the model checks if congestion exists at any link and if it does the transport cost are updated properly and the demands are adjusted.

4.4.3 Network simulation

For every network strategy the network is simulated through the time horizon having the specified characteristics and road conditions by the network strategy under evaluation. The simulation is done for these years of the time horizon, during which an improvement has been terminated or the demand at least for one O-D pair has changed. At the analyst's request the simulation may be done for any year specified by him. The benefits and the costs from one year to the other will remain the same, if no improvement has been undertaken or any change in demand structure has been noticed:

The simulation is done as follows:

a. For each link the passenger car equivalents, PCE, for every vehicle type are computed according to the road conditions, applying equations 3-2 and 3-3.

b.1 For an Origin-Destination pair the minimum transport cost route is found for every vehicle type, and the corresponding economic and financial transport costs are computed. (The process is described in § 3.6.1).
b.2 If the economic transport costs are greater than the price, the user is willing or could afford to pay for the transport, no traffic will be generated from the origin.

b.3 Otherwise, the traffic generated is assigned to the links that belong to the O-D pair minimum cost route. The traffic is computed in number of vehicles per vehicle type and in passenger car units, PCU, applying the computed PCE.

c. The steps (b.1), (b.2) and (b.3) are repeated for all O-D pairs for which demand exists.

d.1 For each link the possibility of congestion is checked. If it is not congested, no change in the already computed transport cost will be made. In case it is congested, the congestion costs, due to the additional travel time are computed, and added to the already calculated transport costs. (The process is described in § 3.6.2).

d.2 The step d.1 is done for all links of the network, thus the total transport costs for all vehicle types are calculated.

e. For each O-D pair the demands are adjusted for the new transport costs applying the equation:4-3:

\[ T' = T \cdot \left( \frac{\theta'}{\theta} \right) - ELA \]

where:

- \( T' \) : the new demand
- \( T \) : the demand as it would be, if the base network strategy was applied
- \( \theta' \) : the new transport costs
- \( \theta \) : the transport costs, if the base network strategy was applied.
ELA: the elasticity of demand with respect to transport costs.

The demand is measured in number of vehicles (in case that it is given in tons for the commodities, dividing the tons by the vehicle capacity times the load factor, we come out with the number of vehicles). If no route existed before the improvement connecting the two nodes, \((O-D)\), \(\theta\) is set to be the maximum transport costs the user is willing to pay for the transport. In the case of a commodity this maximum cost is the difference of the selling price at destination and the production costs at the origin. Having the simulation done, we may proceed to evaluate the network strategy comparing it with the base network strategy.

4.4.4 Network strategies evaluation

To do the evaluation the benefits and the cost of the network strategy must be calculated. The network strategy costs, are the economic costs associated with the activities of construction and maintenance proposed by the strategy, less those costs of the base network strategy. They are calculated for each year of simulation, remaining the same until the next simulation.

The benefits are computed for each year of the simulation, and for each O-D pair generally applying the equation 3-17:

\[
BEN = \frac{1}{2} (T+T') \cdot \Delta \theta
\]  

(4-4)

for every vehicle type. (The variables are as specified in page. The total benefits of the year are the sum of the benefits at all O-D pairs. They remain the same until the next simulation. There are some
special cases to be considered in calculating the benefits:

i. If no traffic exists between an origin-destination pair, although there is potential demand, the benefits are zero.

ii. If no route existed before the improvement connecting an origin to destination, although there is potential demand, the benefits are computed applying equation (4-3). However, instead of $\theta$ being the transport costs of the base network strategy—which in this case would be infinity since no route exists—, $\theta$ equals to the maximum price the user could afford to pay for the transport between origin to destination.

Having computed both costs and benefits the calculation of the net benefits is done:

$$\text{NETBEN} = \text{BEN} - \text{COSTS} \quad (4-5)$$

Finally, the net present value of benefits and costs is calculated discounting the net benefits to the present and adding them for all years:

$$\text{NPV} = \sum_{I=1}^{N} \text{NETBEN} \times (1+r)^{-I}$$

where:

$r$: the discount rate and $I$: the year number.

Thus, the network strategy has been evaluated. It will be compared with the others and finally a ranking of the generated network strategies will be undertaken, the first being the one with the greater net present value. This will be the strategy recommended by our approach for implementation.
The following application of the model in Ethiopia's regional network of Asela-Dodola will show its capabilities and possible limitations from the introduced assumptions.
CHAPTER FIVE

APPLICATION OF THE MODEL IN ETHIOPIA

5.1 Ethiopia

Ethiopia lies in the Horn of Africa, the north-east of the continent bordered by the Indian Ocean and the Gulf of Aden. The country is situated just north of the Equator, and is bounded to the east by Somalia and the French Territory of Afars and Issas, so that its own coastline of about 1,000 kms lies on the Red Sea. Ethiopia's other neighbors are Kenya, to the south, and Sudan, to the west. (A map is provided in the next pages).

Its area is 1,220,000 square kilometres, mainly high plateaux and mountains. The official population is 26,000,000 people, and the annual growth rate ranges 2.0% to 2.6%. In terms of urban areas, there are only two cities of significant size: They are Addis Ababa, the capital with a population of 1,000,000 and Asmara with a population approaching 300,000. All other towns, including the provincial capitals, have a population of less than 50,000. With 90% of its population living in the countryside, Ethiopia is basically an agricultural country. Ethiopia's economy is to a large extent dependent on farming and cattle raising. At present, Ethiopia's main crops are teff (staple food of the Central Highlands), maize, sorghum, wheat, barley, soybeans, coffee, oil, seeds, pulses, cotton and sugar cane.

Ethiopia's major industry is construction followed by textile, food and beverage processing and marketing. Most of the industries are located in or near the three largest cities, Addis Ababa, Smora and
Map 1 - Ethiopia
Diredawa. The handful of major industries not located in these cities are widely scattered and include a refinery, a cement factory, a textile mill and two sugar factories. The country's only sea ports are at Assab and Massawa.

Ethiopia's main imports are machinery, vehicles, spare parts, crude oil, rubber, electrical supplies and building materials.

5.2. Ethiopia's transport network

Ethiopia's development has been hindered by the slow improvement and growth of its transportation network. In a country that covers 1,300,000 square kilometers, the total length of its transport network of roads and railroads is limited to 30,000 kms. The country has two lines of railroad, one from Massawa to Asmara and from Djibouti to Addis Ababa. The Ethiopian Highway Authority (EHA) is responsible for the maintenance of 7,000-8,000 kms of existing all weather roads and some 16,000-20,000 kms of dry weather roads including trails made "servicable" by the provincial authorities. The EHA is responsible for the planning, supervision and maintenance of the most additions to the road system. Domestic air transportation is minimal although about 50 towns over the country are serviced. Freight movement by air is limited to coffee shipments from a few regions that lack adequate surface transportation. The bulk of air traffic is passenger.

In regard to road transportation, the majority of roads have been built to connect the provincial capitals to Addis Ababa. The country has a severe lack of penetration and farm to market roads. This is
the result of inadequate budget and the difficult terrain as well the weather conditions prevailing in the central, west and Southwestern regions.

The Fourth Highway Program, with a planned level of investment in road construction during the second Five Year Plan of E$140,100, 000, had actual expenditures of E$130,100, 000, or 93% of the target. This tends, however, to mask the fact that the mileage of new roads actually constructed was under implemented by 40%. The Third Five Year Plan proposes an investment in road construction amounting to E$250,000,000. According to the Plan provisions, the constructions of the Asela-Dodola road was to be undertaken. Our analysis and evaluation is concerned with this construction and its effect on the regions transport network.

5.3 Asela-Dodola road and the surrounding region

The Asela-Dodola project was envisioned primarily as a service road to be used by farmers in the area to deliver their products to large population center. The region the road is currently engaged in an agricultural development program which is expected to produce (or increase) surpluses in several crops. The region is now served by dirt tracks, which make it both difficult and expensive to deliver products to the markets. The EHA planned to make these markets accessible and thus spur development of the region.

For the purpose of describing the regions traffic characteristics, the area primarily affected by the road can be divided into two zones.
Map 2 - Existing Network of Asela-Dodola Region
The first zone is about 20 kms. wide and 70 kms long stretching from Asela to Meraro. The second zone is 20 kms wide and 51 kms long, beginning at Meraro and ending at Dodola. (see Map 2).

The region which encompasses the two zones is served by a network of five roads. They are: Mojo-Shashemane, Shashemane-Dodola, Dodola-Asela, Asela-Nazreth, and Nazreth-Mojo. The Shashemane-Dodola road (76 kms) is a gravel road in good condition. The Mojo-Nazreth road (24.7 kms) and the first 16 kms of the Nazreth-Asela road are highly designed, bituminous in good condition. The other 62 kms of the Nazreth-Asela road is gravel and in good condition. The Mojo-Shashemane road (182 kms) is bituminous surfaced and in fair condition. The road we are primarily concerned with, Asela-Dodola, is an earth track, most of which is washed out during the rainy season. While the section from Asela to Meraro is in fair shape, the section from Meraro to Dodola is passable only with 4-wheel drive vehicles even during the dry season. It is almost impossible to travel the length of the road during the wet season; as such there is no through traffic during that part of the year.

On the network, the majority of the vehicles using the link is through traffic having neither its origin nor destination within the region served. The purpose of the planned road is to provide a shorter, faster route for through traffic and provide an access to markets for the agricultural surpluses of zones one and two. The agricultural development program now in progress is expected to increase the freight traffic originating in the two zones. Also, an increase in personal income is likely to encourage more passenger traffic. The road improvement is also
seen as part of Ethiopia's continuing effort to upgrade its transportation network.

5.4 Feasibility analysis of the road by Sauti consultants

The feasibility analysis of the Asela-Dodola road's potential for upgrading was conducted by Sauti (42) in 1969 and 1970. The road had earlier been investigated by the Ethiopian Highway Authority (EHA) to determine the feasibility of upgrading the road to a gravel, secondary road (see EHA road standards, table #5.). The information from this investigation was combined with information from the General Road Study (43) and their own investigation served as a data base for the study. The options that were to be investigated were: optimal size (feeder, secondary or primary standard), gravel vs. surface treated, optimal timing of the project and labor intensive vs. capital intensive construction. Several assumptions were made to facilitate the study. Among the assumptions were: complete information for traffic forecasts are certain, inelastic transport demand, and inclusion of only direct benefits (user savings and maintenance savings). The investigation was to cover a twenty year life of the project.

5.4.1 Construction and maintenance

As previously noted the EHA had evaluated the feasibility of upgrading the Asela-Dodola road to a gravel, secondary road. The Sauti team had this information available when their study began. After reviewing the EHA's calculation for accuracy, it was determined that these calculations could be used as a basis for estimation of earthwork. The EHA's calculations were based on a secondary road so it was necessary
<table>
<thead>
<tr>
<th>Topography</th>
<th>Flat</th>
<th></th>
<th>Rolling</th>
<th></th>
<th>Mountainous</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
<td>Secondary</td>
<td>Feeder</td>
<td>Primary</td>
<td>Secondary</td>
<td>Feeder</td>
</tr>
<tr>
<td>Design speed (km/h)</td>
<td>100</td>
<td>90</td>
<td>80</td>
<td>80</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>Width of pavement (m)</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Total width (m)</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Radius: minimum (m)</td>
<td>500</td>
<td>300</td>
<td>250</td>
<td>300</td>
<td>175</td>
<td>125</td>
</tr>
<tr>
<td>Radius: minimum exceptional (m)</td>
<td>300</td>
<td>175</td>
<td>125</td>
<td>175</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>Maximum gradient (%)</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Maximum exceptional gradient (%)</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>
to determine the variance in earthwork quantities between primary, secondary and feeder standards roads. The variance in earthwork quantities could then be applied to determine quantities for feeder and primary roads. Investigations were made by the Sauti team to determine the unit cost of different construction operations (for gravel and for surface treatment), was also determined. These costs with that of the clearing effort gave the costs for the entire operation.

In terms of road maintenance, the Sauti team used an estimation technique to determine the costs. The technique is an application of the conclusions of the Highway Research Board Bulletin 155, January 1956. The procedure takes into account the type of pavement, traffic intensity and the road width in determining the annual average maintenance costs on a per kilometer basis. The "basic maintenance costs" (minimum maintenance costs for a certain type surface encountered up to a certain traffic level) was determined through investigations with the EHA; this basic maintenance cost with adjustment factors for road width and traffic above a certain level produces an annual cost per kilometer for routine and periodic maintenance.

5.4.2 Traffic and vehicle operating costs

The Sauti team estimated traffic based on the traffic data of the General Road Study and the expected traffic due to an agricultural development program in the area. The increased level of production expected in the area was determined from yield/hectare estimates. The surplus was determined by subtracting from this figure, the local consumption and the loss due to spoilage and re-utilization. The surplus
was then allocated to deficit zones in ten ton trucks to determine the increased traffic from agricultural activity. The investigating team also considered diversion of traffic from other roads in the network in their estimation of traffic. The traffic growth was presented in the form of projected average daily traffic (according to three vehicle types) for 1970, 1980, and 1990. The calculation of vehicle operating cost was through the use of "virtual lengths" of road. Information was already available for the costs of operating each vehicle type.

5.4.3 Conclusions

The Sauti team investigators concluded that the best alternative was a primary road with bituminous surface treatment for the first seventy kilometers, Asela to Meraro, and a secondary road with bituminous surface treatment for the last fifty kilometers, Meraro and Dodola. The optional opening year would be 1981 if the road was constructed with capital intensive technique and 1977 if constructed with labor intensive technique. The investigators concluded that staged construction does not improve the solution because of the slow growth of traffic and the major benefits accruing after the second stage of construction. In determining the net benefits, the benefit/cost ratio, the cost of construction and savings in user cost and maintenance were discounted to the opening year of the road. The results of the calculations using a 10% discount rate are shown below.
<table>
<thead>
<tr>
<th>Link</th>
<th>Length (kms)</th>
<th>Capacity (PCU/hr)</th>
<th>Design speed (Kms/hr)</th>
<th>Rise and fall (m/100m)</th>
<th>Costs (in billions $)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Financial</td>
</tr>
<tr>
<td>1: Moijo-Nazreth</td>
<td>25.0</td>
<td>2000</td>
<td>95</td>
<td>1.7</td>
<td>50,000</td>
</tr>
<tr>
<td>2: Nazreth-Asela</td>
<td>73</td>
<td>1550</td>
<td>75</td>
<td>4.8</td>
<td>58,000</td>
</tr>
<tr>
<td>3: Asela-Meraro</td>
<td>71</td>
<td>900</td>
<td>45</td>
<td>6.9</td>
<td>46,000</td>
</tr>
<tr>
<td>4: Meraro-Dodola</td>
<td>49</td>
<td>900</td>
<td>45</td>
<td>6.9</td>
<td>32,000</td>
</tr>
<tr>
<td>5: Dodola-Shashmene</td>
<td>73</td>
<td>1370</td>
<td>80</td>
<td>4.0</td>
<td>58,000</td>
</tr>
<tr>
<td>6: Shashmene-Moijo</td>
<td>182</td>
<td>1750</td>
<td>95</td>
<td>1.7</td>
<td>364,000</td>
</tr>
<tr>
<td>No.</td>
<td>Link</td>
<td>CAR</td>
<td>BUS</td>
<td>TRUCK</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>--------------------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Travel Time (in hrs)</td>
<td>Financial cost (in $E$)</td>
<td>Economic costs (in $E$)</td>
<td>Travel Time (in hrs)</td>
</tr>
<tr>
<td>1</td>
<td>Moijo-Nazareth</td>
<td>0.40</td>
<td>4.30</td>
<td>2.20</td>
<td>0.45</td>
</tr>
<tr>
<td>2</td>
<td>Nazareth-Asela</td>
<td>1.20</td>
<td>15.0</td>
<td>7.60</td>
<td>1.40</td>
</tr>
<tr>
<td>3</td>
<td>Asela-Meraro</td>
<td>1.80</td>
<td>23.30</td>
<td>14.40</td>
<td>2.0</td>
</tr>
<tr>
<td>4</td>
<td>Meraro-Dodola</td>
<td>1.6</td>
<td>16.0</td>
<td>9.0</td>
<td>1.9</td>
</tr>
<tr>
<td>5</td>
<td>Dodola-Shashmene</td>
<td>1.40</td>
<td>19.50</td>
<td>11.20</td>
<td>1.80</td>
</tr>
<tr>
<td>6</td>
<td>Shashmene-Moijo</td>
<td>3.10</td>
<td>35</td>
<td>22</td>
<td>3.50</td>
</tr>
</tbody>
</table>
### 5.5 Applications of the Model

#### 5.5.1 Inputs

**5.5.1.1 Network configuration**

The network considered is the one consisting of the links Mojo-Shashemane, Shashemane-Dodola, Dodola-Meraro, Meraro-Asela, Asela-Nazreth and Nazreth-Mojo. Only links Dodola-Meraro and Meraro-Asela are to improved. The figure 5.1 represents the network with its links and nodes numbers. The network configuration inputs are handled by the Input Data Processor.

**5.5.1.2 Links characteristics and strategies**

Also, the link characteristics and the link strategies are handled by the Input Data Processor; however, some of the data will be provided by the HCM performing the link simulation, when its modification will be done.

Table 5.2 presents the link characteristics if the base network strategy will be applied. The characteristics, being the same for all years of the time horizon, are being presented only for year 1.

<table>
<thead>
<tr>
<th></th>
<th>Capital Intensive</th>
<th>Labor Intensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Benefit (E$)</td>
<td>4,817,000</td>
<td>5,784,000</td>
</tr>
<tr>
<td>Benefit/Cost Ratio</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Cost of Construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(financial)</td>
<td>6,020,000</td>
<td>7,139,000</td>
</tr>
<tr>
<td>(economic)</td>
<td>4,174,000</td>
<td>5,015,000</td>
</tr>
</tbody>
</table>
Figure 5.1: Representation of the Asela-Dodola Region's Network
Table 5.3.a. Link #3 Characteristics, according to strategy followed

<table>
<thead>
<tr>
<th>Strategy Followed</th>
<th>Year(s)</th>
<th>Capacity (PCU/hr)</th>
<th>Design speed (kms/hr)</th>
<th>Length (kms)</th>
<th>Rise and Fall (m/100m)</th>
<th>Financial Cost (inE $)</th>
<th>Economic Cost (inE $)</th>
<th>Foreign Exchange Cost (inE $)</th>
<th>Skilled Labor Cost (inE $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: No change</td>
<td>1.20</td>
<td>900</td>
<td>45</td>
<td>72</td>
<td>6.9</td>
<td>46,000</td>
<td>35,500</td>
<td>1,000</td>
<td>500</td>
</tr>
<tr>
<td>2: Capital intensive tech., Primary Road Standards</td>
<td>1</td>
<td>2000</td>
<td>85</td>
<td>72</td>
<td>4.5</td>
<td>9,640,000</td>
<td>6,560,000</td>
<td>6,508,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td></td>
<td>2-20</td>
<td>2000</td>
<td>85</td>
<td>72</td>
<td>4.5</td>
<td>142,000</td>
<td>113,600</td>
<td>40,000</td>
<td>3,500</td>
</tr>
<tr>
<td>3: Capital Intensive tech., sec. road stand.</td>
<td>1</td>
<td>1750</td>
<td>75</td>
<td>71</td>
<td>4.5</td>
<td>8,000,000</td>
<td>5,400,000</td>
<td>6,110,000</td>
<td>900,000</td>
</tr>
<tr>
<td></td>
<td>2.20</td>
<td>1750</td>
<td>75</td>
<td>71</td>
<td>4.5</td>
<td>122,000</td>
<td>103,000</td>
<td>35,000</td>
<td>3,000</td>
</tr>
<tr>
<td>4: Capital intensive tech., feeder road stand.</td>
<td>1</td>
<td>1550</td>
<td>60</td>
<td>71</td>
<td>4.5</td>
<td>6,600,000</td>
<td>4,400,000</td>
<td>4,600,000</td>
<td>800,000</td>
</tr>
<tr>
<td></td>
<td>2-20</td>
<td>1550</td>
<td>60</td>
<td>71</td>
<td>4.5</td>
<td>100,000</td>
<td>195,000</td>
<td>28,000</td>
<td>2,500</td>
</tr>
<tr>
<td>5: Labor intensive tech., primary road stand.</td>
<td>1</td>
<td>2000</td>
<td>85</td>
<td>71</td>
<td>4.5</td>
<td>7,630,000</td>
<td>5,300,000</td>
<td>3,800,000</td>
<td>500,000</td>
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<td></td>
<td>2-20</td>
<td>2000</td>
<td>85</td>
<td>71</td>
<td>4.5</td>
<td>130,000</td>
<td>105,000</td>
<td>30,000</td>
<td>1,000</td>
</tr>
</tbody>
</table>
Continuation of Table 5.3.a

<table>
<thead>
<tr>
<th>Strategy Followed</th>
<th>Years(s)</th>
<th>Capacity (PUC/hr)</th>
<th>Design Speed (kms/hr)</th>
<th>Length (kms)</th>
<th>Rise and Fall (m/100m)</th>
<th>Cost (inE$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Financial</td>
</tr>
<tr>
<td>6: Labor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensive</td>
<td>1</td>
<td>1,750</td>
<td>75</td>
<td>71</td>
<td>4.5</td>
<td>6,400,000</td>
</tr>
<tr>
<td>technique:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary Road</td>
<td>2-20</td>
<td>1,750</td>
<td>75</td>
<td>71</td>
<td>4.5</td>
<td>113,000</td>
</tr>
<tr>
<td>Standards</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7: Labor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensive</td>
<td>1</td>
<td>1,550</td>
<td>60</td>
<td>71</td>
<td>4.5</td>
<td>5,300,000</td>
</tr>
<tr>
<td>technique:</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Feeder Road</td>
<td>2-20</td>
<td>1,550</td>
<td>60</td>
<td>71</td>
<td>4.5</td>
<td>100,000</td>
</tr>
<tr>
<td>Standards</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5.3.b Vehicles operation on link #3 according to strategy followed

<table>
<thead>
<tr>
<th>Link Strategies</th>
<th>CAR</th>
<th></th>
<th></th>
<th>BUS</th>
<th></th>
<th></th>
<th>TRUCK</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Travel</td>
<td>Financial</td>
<td>Economic</td>
<td>Travel</td>
<td>Financial</td>
<td>Economic</td>
<td>Travel</td>
<td>Financial</td>
<td>Economic</td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td>cost</td>
<td>costs</td>
<td>Time</td>
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<td>Time</td>
<td>cost</td>
<td>costs</td>
</tr>
<tr>
<td></td>
<td>(in hrs.)</td>
<td>(inE$)</td>
<td>(inE$)</td>
<td>(in hrs)</td>
<td>(inE$)</td>
<td>(inE$)</td>
<td>(in hrs)</td>
<td>(inE$)</td>
<td>(inE$)</td>
</tr>
<tr>
<td>1</td>
<td>1.80</td>
<td>23.30</td>
<td>14.40</td>
<td>2.0</td>
<td>104.40</td>
<td>79.50</td>
<td>2.0</td>
<td>68.30</td>
<td>56.70</td>
</tr>
<tr>
<td>2,5</td>
<td>0.95</td>
<td>13.50</td>
<td>7.00</td>
<td>1.10</td>
<td>57.0</td>
<td>40.0</td>
<td>1.10</td>
<td>39.0</td>
<td>29.0</td>
</tr>
<tr>
<td>3,6</td>
<td>1.01</td>
<td>14.40</td>
<td>7.50</td>
<td>1.16</td>
<td>60.0</td>
<td>47.50</td>
<td>1.16</td>
<td>41.0</td>
<td>30.0</td>
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<td>4,7</td>
<td>1.30</td>
<td>19.0</td>
<td>10.15</td>
<td>1.50</td>
<td>80.0</td>
<td>55.7</td>
<td>1.50</td>
<td>54.0</td>
<td>40.0</td>
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</table>
Table 5.4.a Link #4 Characteristics according to strategy followed

<table>
<thead>
<tr>
<th>Strategy Followed</th>
<th>Years(s)</th>
<th>Capacity (PCU/hr)</th>
<th>Design Speed (kms/hr)</th>
<th>Length (kms)</th>
<th>Rise and Fall (m/100m)</th>
<th>Cost (inE$)</th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<td>Financial</td>
<td>Economic</td>
<td>Foreign Exchange</td>
<td>Skilled Labor</td>
</tr>
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<td>49</td>
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<td>500</td>
</tr>
<tr>
<td>2: Capital intensive</td>
<td>1</td>
<td>2000</td>
<td>85</td>
<td>49</td>
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<td>4,500,000</td>
<td>4,850,000</td>
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<tr>
<td>technique: Primary Rd.</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>Standards</td>
<td>2-20</td>
<td>2000</td>
<td>85</td>
<td>49</td>
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<td>78,000</td>
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<tr>
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<td>75</td>
<td>49</td>
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<tr>
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<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
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<td>60</td>
<td>49</td>
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<td>60</td>
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<td>83,000</td>
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</tr>
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<td>85</td>
<td>49</td>
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<tr>
<td>, Primary Rd. Standards</td>
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<td>73,000</td>
<td>20,000</td>
<td>600</td>
</tr>
<tr>
<td>Strategy Followed</td>
<td>Years(s)</td>
<td>Capacity (PCU/hr)</td>
<td>Design Speed (kms/hr)</td>
<td>Length (kms)</td>
<td>Rise and Fall (m/100m)</td>
<td>Cost (inE$)</td>
<td>Financial</td>
<td>Economic</td>
<td>Foreign Exchange</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------</td>
<td>-------------------</td>
<td>-----------------------</td>
<td>--------------</td>
<td>------------------------</td>
<td>------------</td>
<td>----------</td>
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<td>-----------------</td>
</tr>
<tr>
<td>6: Labor Intensive Tech., Secondary Road Standards</td>
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<td>1,750</td>
<td>75</td>
<td>49</td>
<td>4.5</td>
<td>4,400,000</td>
<td>3,000,000</td>
<td>2,200,000</td>
<td>200,000</td>
</tr>
<tr>
<td></td>
<td>2-20</td>
<td>1,750</td>
<td>75</td>
<td>49</td>
<td>4.5</td>
<td>82,000</td>
<td>67,000</td>
<td>17,000</td>
<td>500</td>
</tr>
<tr>
<td>7: Labor Intensive Technique Feeder Rd Standards</td>
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<td>1,550</td>
<td>60</td>
<td>49</td>
<td>4.5</td>
<td>3,600,000</td>
<td>2,500,000</td>
<td>1,800,000</td>
<td>100,000</td>
</tr>
<tr>
<td></td>
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<td>1,550</td>
<td>60</td>
<td>49</td>
<td>4.5</td>
<td>75,000</td>
<td>61,000</td>
<td>14,000</td>
<td>400</td>
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### Table 5.4.b Vehicles operation on Link #4 according to strategy followed

<table>
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<th>Link Strategies</th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Travel Time (in hrs)</td>
<td>Financial costs (inE$)</td>
<td>Economic costs (inE$)</td>
<td>Travel Time (in hrs)</td>
<td>Financial costs (inE$)</td>
<td>Economic costs (inE$)</td>
<td>Travel Time (in hrs)</td>
<td>Financial costs (inE$)</td>
</tr>
<tr>
<td>1</td>
<td>1.6</td>
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<td>1.9</td>
<td>69.0</td>
<td>56.0</td>
<td>1.9</td>
<td>47.0</td>
</tr>
<tr>
<td>2,5</td>
<td>0.65</td>
<td>9.0</td>
<td>4.70</td>
<td>0.75</td>
<td>38.0</td>
<td>27.0</td>
<td>0.75</td>
<td>25.50</td>
</tr>
<tr>
<td>3,6</td>
<td>0.70</td>
<td>10.0</td>
<td>5.10</td>
<td>0.80</td>
<td>41.0</td>
<td>28.70</td>
<td>0.80</td>
<td>28.0</td>
</tr>
<tr>
<td>4,7</td>
<td>0.90</td>
<td>13.0</td>
<td>7.0</td>
<td>1.02</td>
<td>55.0</td>
<td>38.50</td>
<td>1.02</td>
<td>38.0</td>
</tr>
</tbody>
</table>
Tables 5.3 and 5.4 present the characteristics of links 3 (Asela-Meraro) and 4 (Meraro-Dodola) respectively, according to the proposed link strategies. The data used in the application of the model is the same with what the Sauti consultants used, with some differences in vehicle operating costs.

5.5.1.3 Demand

The demand is given on a O-D pair basis in number of vehicles. Three types of vehicles have been considered: a 5-passengers car, a 45-50 passengers bus and a 7.0 ton-truck. The load factors, common for all O-D pairs demands, are 50% for passenger cars and 75% for bus and trucks. Also, common are: the elasticity of demand, being 1% for all vehicles types and the value of travel time being: E$0.24/pass-hr for cars and bus and E$.001/ton-hr for the trucks. Table 5.5 presents the demand in vehicle numbers for each O-D pair and the maximum price the user is willing to pay for transport in E$/vehicle.

It should be noticed that the demand although shown as originating from Moijo, it is actually originating from Addis Ababa, the link Addis-Ababa-Moijo being omitted for simplicity. Furthermore, it is assumed that the traffic, having destinations at intermediate points on the links, it is not considered. The data about the data has been derived from the information provided by the Sauti report. It is given for the opening year 1977 and it is updated every 5 years. The assumptions that the demand will remain constant over the 5 year period,
Table 55. Demand Between O-D Pairs

<table>
<thead>
<tr>
<th>O-D Pair</th>
<th>Number of cars</th>
<th>Number of Busses</th>
<th>Number of Trucks</th>
<th>Maximum price to be paid for transport (in £/veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-4 10-14 15-20</td>
<td>1-4 10-14 15-20</td>
<td>1-4 10-14 15-20</td>
<td>Cars  Busses  Trucks</td>
</tr>
<tr>
<td>1-2</td>
<td>8 11 15 20</td>
<td>4 6 9 11</td>
<td>7 9 13 15</td>
<td>8. 35. 25.</td>
</tr>
<tr>
<td>1-3</td>
<td>42 60 75 90</td>
<td>20 30 45 60</td>
<td>30 45 60 80</td>
<td>30. 110. 70.</td>
</tr>
<tr>
<td>1-4</td>
<td>9 12 17 22</td>
<td>4 6 8 10</td>
<td>4 6 8 10</td>
<td>50. 230. 135.</td>
</tr>
<tr>
<td>1-5</td>
<td>7 10 15 20</td>
<td>15 20 30 40</td>
<td>28 35 50 65</td>
<td>60. 250. 150.</td>
</tr>
<tr>
<td>1-6</td>
<td>12 20 30 40</td>
<td>7 10 15 20</td>
<td>4 5 7 10</td>
<td>40. 160. 100.</td>
</tr>
<tr>
<td>2-3</td>
<td>25 30 40 50</td>
<td>15 20 30 40</td>
<td>15 20 30 40</td>
<td>20. 80. 50.</td>
</tr>
<tr>
<td>3-4</td>
<td>8 12 15 18</td>
<td>6 8 10 14</td>
<td>7 10 13 18</td>
<td>25. 125. 70.</td>
</tr>
<tr>
<td>3-5</td>
<td>11 15 20 26</td>
<td>5 6 8 10</td>
<td>20 28 32 40</td>
<td>24. 166. 95.</td>
</tr>
<tr>
<td>4-5</td>
<td>11 15 20 28</td>
<td>3 4 6 8</td>
<td>15 20 28 35</td>
<td>9. 70. 39.</td>
</tr>
<tr>
<td>5-6</td>
<td>3 4 6 8</td>
<td>6 8 10 12</td>
<td>6 7 9 11</td>
<td>25. 90. 55.</td>
</tr>
</tbody>
</table>
made by the Sauti study will prevail in our study too. All inputs are handled by the Input Data Processor, i.e., they are provided exogeneously, since the interface of the system with the HCM has not yet been accomplished.

5.5.2. Network strategies generation

From the provided 7 strategies for the two links: Asela-Meraro and Meraro-Dodola and the 5 years allowable delay in implementing a strategy, the network strategies generator, comes out with 29 feasible network strategies. Each network strategy is composed of link strategies and the corresponding opening year. They are presented in Table 5.6.

5.5.3. The network strategies evaluation

Table 5.6 presents the results of the evaluation of the 29 network strategies. They are ranked according to their net present value of their costs and benefits. The NPV is given for discount rate 10% and considering as present the opening year 1977.

5.5.4. Conclusions

Our approach proposes as the best alternative, the network strategy applying labor intensive techniques for the construction of both links. When the discount rates are 10% and 12% the optimal is the one that proposes the two roads to be constructed to a secondary road design standards. However, when the discount rate is 8% the optimal alternative turns out to be the one that proposes the Asela-Meraro road to
Table 5.6. Network Strategies

<table>
<thead>
<tr>
<th>Rank</th>
<th>N.S.# (as Generated)</th>
<th>NPV (in $) (Discount rate 10%)</th>
<th>Description of N.S.</th>
<th>Link 3 L.S. # Opening year</th>
<th>Link 4 L.S. # Opening year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29</td>
<td>14,438,980.</td>
<td>6</td>
<td>1977</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>14,358,145.</td>
<td>6</td>
<td>1977</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
<td>14,117,486.</td>
<td>5</td>
<td>1977</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
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<td>14,036,645.</td>
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<td>5</td>
</tr>
<tr>
<td>5</td>
<td>28</td>
<td>13,667,174.</td>
<td>6</td>
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<td>3</td>
</tr>
<tr>
<td>6</td>
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<td>13,283,984.</td>
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<td>7</td>
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<td>13,223,532.</td>
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<td>1977</td>
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<tr>
<td>8</td>
<td>19</td>
<td>13,143,983.</td>
<td>3</td>
<td>1977</td>
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<td>9</td>
<td>21</td>
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<td>5</td>
<td>1977</td>
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<td>10</td>
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<td>2</td>
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<tr>
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<tr>
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<td>13</td>
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<td>1977</td>
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<tr>
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<td>2</td>
<td>11,802,898.</td>
<td>2</td>
<td>1977</td>
<td>2</td>
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<td>15</td>
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<td>1977</td>
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<td>1977</td>
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</table>

Explanation of symbols in page 116.
Continuation of Table 5.6:

Explanations of symbols:

L.S. = Link Strategy; N.S. = Network Strategy

L.S. #1: No improvement

L.S. #2: Construction to primary road with capital intensive techniques

L.S. #3: Construction to secondary road with capital intensive techniques

L.S. #4: Construction to feeder road with capital intensive techniques

L.S. #5: Construction to primary road with labor intensive techniques

L.S. #6: Construction to secondary road with labor intensive techniques

L.S. #7: Construction to feeder road with labor intensive techniques.
be constructed according to secondary road design standards and the Meraro-Dodola road according to primary road design standards. In all cases the opening year turns out to be 1977, i.e., no delay in initial construction.

Since the first 4 best alternative network strategies have resulted close NPV's all four are included in Tables 5.7, 5.8, and 5.9, where the NPV's are computed for 3 discount rates 8%, 10% and 12% and possible delays in initial construction are considered as new alternatives network strategies. Tables 5.7, 5.8 and 5.9 give the total discounted costs, total discounted benefits and the NPV for each network strategy.

We conclude that the optimal network strategy will propose opening year 1977 and the roads to be constructed according to secondary road design standards, since the 10% discount rate is the one more frequently applied in the evaluation of transport investment. Table 5.10 presents the traffic on the links of the network if the above network strategy is implemented.

The conclusions derived from the analysis are:

(1) The low demand for almost all O-D pairs, suggests that any change in the elasticity of demand will not increase the demand significantly. e.g. From Table 5.5, between Mojo and Asela the average daily traffic consists of 7 cars, 15 buses and 28 trucks. Considering the demand for trucks, the transport costs before the improvement were 129 E$/vehicle. If the optimal network strategy is implemented the new transport costs will be 93.60 E$/vehicle.
### TABLE 5.7 The 4 Best Network Strategies = 1, 24, 25, 29

*Discount rate: 8%*

<table>
<thead>
<tr>
<th>N.S. # Generated Gas</th>
<th>Opening Year</th>
<th>Total Discounted costs (in E$)</th>
<th>Total Discounted benefits (in E$)</th>
<th>Net Present Value (in E$)</th>
<th>Rank</th>
</tr>
</thead>
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<tr>
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</tr>
<tr>
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<td>1977</td>
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<td>26,927,463</td>
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<tr>
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<tr>
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<td>1982</td>
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<tr>
<td>29</td>
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<td>5,910,844</td>
<td>20,363,115</td>
<td>14,452,271</td>
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</tbody>
</table>
## Table 5.8 The 4 Best Network Strategies: 1, 24, 25, 29

Discount rate 10%

<table>
<thead>
<tr>
<th>N.S. # (as Generated)</th>
<th>Opening year</th>
<th>Total Discounted costs (in $)</th>
<th>Total Discounted costs (in $)</th>
<th>Net Present value (in $)</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1977</td>
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</tr>
<tr>
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<td>14,117,486</td>
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<tr>
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<td>23,074,265</td>
<td>14,358,145</td>
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<td>22,464,910</td>
<td>14,438,980</td>
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</tr>
<tr>
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<td>17,195,010</td>
<td>11,287,510</td>
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<tr>
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<td>1982</td>
<td>5,439,210</td>
<td>16,743,396</td>
<td>11,304,186</td>
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<tr>
<td>N.S. # (as Generated)</td>
<td>Opening year</td>
<td>Total discounted costs (in $)</td>
<td>Total discounted benefits (in $)</td>
<td>Net present value (in $)</td>
<td>Rank</td>
</tr>
<tr>
<td>-----------------------</td>
<td>--------------</td>
<td>-------------------------------</td>
<td>--------------------------------</td>
<td>-------------------------</td>
<td>------</td>
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<tr>
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<td>1977</td>
<td>9,616,600</td>
<td>20,619,080</td>
<td>11,002,480</td>
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<td>20,090,481</td>
<td>11,158,077</td>
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<td>20,029,991</td>
<td>11,401,783</td>
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<td>11,690,118</td>
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<td>6,080,580</td>
<td>14,696,591</td>
<td>8,616,011</td>
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<tr>
<td>24</td>
<td>1982</td>
<td>5,647,566</td>
<td>14,321,924</td>
<td>8,674,358</td>
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<tr>
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<td>1982</td>
<td>5,456,232</td>
<td>14,278,199</td>
<td>8,821,967</td>
<td></td>
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<tr>
<td>29</td>
<td>1982</td>
<td>5,023,218</td>
<td>13,903,539</td>
<td>8,880,321</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.10 Average daily traffic on links
(Simulated by the model for the optimal network strategy 29)

<table>
<thead>
<tr>
<th>Links</th>
<th>Vehicle Type</th>
<th>Years</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moijo-Nazreth</td>
<td>cars</td>
<td>66</td>
<td>93</td>
<td>122</td>
<td>152</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>bus</td>
<td>43</td>
<td>62</td>
<td>92</td>
<td>121</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>trucks</td>
<td>69</td>
<td>95</td>
<td>131</td>
<td>170</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>in PCU's</td>
<td>431</td>
<td>612</td>
<td>849</td>
<td>1100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nazreth-Asela</td>
<td>cars</td>
<td>83</td>
<td>112</td>
<td>147</td>
<td>182</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>bus</td>
<td>54</td>
<td>76</td>
<td>113</td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>trucks</td>
<td>77</td>
<td>106</td>
<td>148</td>
<td>195</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>in PCU's</td>
<td>1183</td>
<td>1725</td>
<td>2339</td>
<td>3079</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asela-Meraro</td>
<td>cars</td>
<td>35</td>
<td>49</td>
<td>67</td>
<td>86</td>
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<td></td>
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<tr>
<td></td>
<td>bus</td>
<td>30</td>
<td>40</td>
<td>56</td>
<td>74</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>trucks</td>
<td>59</td>
<td>79</td>
<td>103</td>
<td>133</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>in P.C.U.'s</td>
<td>658</td>
<td>1037</td>
<td>1180</td>
<td>1535</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meraro-Dodola</td>
<td>cars</td>
<td>29</td>
<td>40</td>
<td>55</td>
<td>74</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>bus</td>
<td>23</td>
<td>30</td>
<td>44</td>
<td>58</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>trucks</td>
<td>63</td>
<td>83</td>
<td>110</td>
<td>140</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>in P.C.U.'s</td>
<td>631</td>
<td>969</td>
<td>1133</td>
<td>1460</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dodola-Shashemane</td>
<td>cars</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>bus</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>trucks</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>in P.C.U.'s</td>
<td>113</td>
<td>139</td>
<td>181</td>
<td>219</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shashemane-Moijo</td>
<td>cars</td>
<td>12</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>bus</td>
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<td>10</td>
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<td>20</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>trucks</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>in P.C.U.'s</td>
<td>46</td>
<td>69</td>
<td>98</td>
<td>132</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Applying the equation 3.19 about the new demand due to decrease in transport costs, we have:

\[ T' = 28 \times \left( \frac{93.6}{129} \right) - ELA. \]

The new demand is changing as the elasticity changes:

- **ELA = 0.** (inelastic demand): \( T = 28 \) (no change)
- **ELA = 0.1** (elastic demand) \( T = 28.9 \) (3.2% increase)
- **ELA = 0.01** (approaching inelastic demand) \( T = 28.09 \) (0.32% increase)

(2) Any postponement of the initial construction is not worth it, since the traffic is at such high level that it pays to improve the road immediately.

(3) The case of constructing the road according to feeder road design standards does not have to be considered in any further analysis, since it comes up with low NPV.

(4) Congestion did not occur at any link. (It may be seen also in Table 5.10 how low the traffic is on the links).

5.6 Comparison with the Sauti study

The Sauti investigators concluded that the best alternative was a primary road for Asela to Meraro and a secondary road from Meraro to Dodola. They set opening year 1977 if the road is constructed using labor intensive techniques and 1981, if capital intensive techniques are used. Our approach concluded that the best alternative was a secondary road for both Asela-Meraro and Meraro-Dodola. This results
from: (i) not considering any maintenance costs over the years in the Sauti study for the improved road; however ours takes them into account,

(ii) Our approach considers the demand on a O-D pair basis and computes the benefits attributed to each O-D pair; they consider demand on a link-basis and they compute the benefits resulting from the travel on the each link,

(iii) As an evaluation criterion the Sauti Consultants have used the Benefit/cost ratio; our approach uses the net present value criterion.

According to our model the alternative that the Sauti study proposes as the optimal has a NPV by E$321,500 less than the one of the best alternative proposed by our approach. Therefore, we may conclude that both alternatives are acceptable for implementation, and it is up to the decision maker, to choose the one proposed by the approach he thinks best.
CONCLUSIONS, RECOMMENDATIONS

The development model has found to be a very useful tool for the network strategies evaluation. It is capable of generating the 29 most interesting network strategies, to simulate the network activities to evaluate them and to rank them. Work that may require in a consultant firm months of computation and analysis by engineers, it may be done in few minutes and with minimal expenses applying the developed model.

The presented case study showed the model's capabilities efficiency. The comparison with the Sauti study found it in a better position.

Although the model, as it has been developed, is appropriate for less developed countries, some additions would be useful. The issue of demand generation is an important one. A model may be developed to generate the demand not only according to transport costs flunctuations, but according to population growth, the per capital income changes, etc. The issue of other modes competing for the same O-D pair may be considered. As a result the demand for the O-D pair will be distributed to different modes according to the offered transport prices.

The issue of multi-regional distribution of the same commodity will complicate the model, but it would be very useful. The nature of this is that a truck may not follow the minimum cost route for each O-D pair having to distribute a payload of a commodity to more than one distribution points. It will follow the route that will maximize the revenues of the shipper (how much he is going to get selling the commodity minus the costs of transport).

Another issue to be addressed in the possible redistribution of traffic after the first assignment if congestion occurs to some links.
However, if all these are included in a model, it will become very complicated, sophisticated and hard to be applied in a less developed country, since it would require disaggregate data, sophisticated computer facilities and a lot of planning.
APPENDIX A

The Network Evaluation Model consists of four computer packages: the Highway Cost Model, the Input Data Processor, the Network Strategies Generator and the Network Strategies Evaluator. A description of each and its subroutines appear in Chapter 4 and Appendix B of this document. A listing of the computer programs is presented in Appendix C.

The Network Evaluation Model (NEM) allows a user to investigate, in a searching, probing manner, the behavior of a rural highway network to the consequences of investment criteria and constraints. It is a data base system, thus allowing the user to reuse prior information and results, to change small amounts of information for sensitivity analysis, and to direct the evaluation process himself. Each processor may be applied numerous times. Constraints on this probing can be minimal, and logical. Network strategies must be generated prior to evaluation, the base network against which alternative strategies are compared must be evaluated first. Demand and user cost data must be input prior to evaluation and link strategy data provided for generation. Whenever a process is executed the most recent and existing data and intermediate results are used.

1. Language Conventions for the Model's Input

The language used for the Input to NEM is a flexible problem oriented language. It allows great freedom in the ordering and presentation of input. Each communication to the computer program is given through a statement called a command. Each of these commands either supplies some data to the program or instructs it to perform some calculations on the
There are three basic elements that are used to make up the various commands. They are:

(a) Integers: These are numbers that do not contain a decimal point.
Examples: 1, 38, +999, -108. Possible errors (non-integers): 6.0 - This contains a decimal point 10,000 - This contains a comma. If a sign is omitted, it is assumed to be plus (+). The notation used for the integers is: \( i_1, i_2, \ldots \), or \( n_1, n_2, \ldots \) in the language description.

(b) Real numbers: These must contain a decimal point. Only normal decimals are accepted in the commands. They consist of digits only, a decimal point, and optionally a sign.
Example: 6.0 3.14 -2. .003
If a sign is omitted, it is assumed to be plus (+). The notation used for the real numbers for the language description is \( x_1, x_2, \ldots \) or \( y_1, y_2, \ldots \) or \( z_1, z_2, \ldots \).

(c) Words: Various words and single letters have specific meaning as input to the models. These words may be used in commands and are not chosen by the user. They are symbols that are recognized by the processors. Words are shown in the language description in capital letters. If a word in the language description is in parenthesis, this means that the word may be omitted or included. Unless its inclusion is
merely cosmetic, the consequences of including or omitting a word is explained in the description of the command. A word may be consisted of letters and numbers. Since the processors read only the three first character of each word, any additional characters may be omitted. Words are also used in special ways as data labels, identifying the meaning of the data value immediately following the label. For convenience, data labels may be omitted if the standard order (given in the command description) is used. If only selected data values are given or the data is given in a different sequences, labels are needed. The one exception is that labels are not needed, if the standard order is used, but proceeds through only part of the potential input. Note: non-inputted data in a command remains unchanged from its prior value, unless otherwise stated in the command description. Labels are identified with brackets, [ ] , in the command descriptions.

The input commands for the processors must be punched onto cards and submitted as program data. In doing so, all 80 columns of the card may be utilized, in free format. A blank and/or comma must separate each field in a command. If more than 80 columns are needed for any command, the user will use the continuation symbol $ at the 80th column of the card and continue on the next. If the user desires to insert comments into the input data, he may punch in the column 1 of any card the $. This card is taken as a comment card, echo printed on the output listing,
2. Language Description for the Model's Input. Instructions for its Application

2.1 Data Input Processor

The commands are divided into six categories:

(1) System commands, (2) Network configuration, (3) Link Characteristics, (4) Demand Input, (5) Budget input and (6) Additional minor data input commands.

2.1.1 System commands

At the beginning of a run, the user must indicate whether he wants to start accumulating data, or supplement or modifying prior data. He does so using one of the following two commands:

INITIALIZE: performs initialization of the files and the zeroing of any previously stored data. The data input node is then assumed to be ADD.

UPDATE: initializes without zeroing data, in preparation for new input which will add to, change or delete prior data. The ADD mode is also assumed initially. Data may be input not only to add new information to the data base, but also to change or delete prior input. An input mode is therefore identified with one of the following commands, and all subsequent input so treated until the mode is changed.

CHANGE: part or all of some existing data is to be changed. If data to be changed does not exist, a warning message is given and the data added as new.
DELETE; used when the stored data is to be deleted.
PRINT: used to print all the data stored on the files.
FINISHED: used to terminate execution.
STORE: used to store the basic data on the files.

These commands are one-word commands; each must appear on a separate card.

2.12 Network Information

The network configuration is input with the NETWORK and LINK DATA commands:

NETWORK [LINKS] i_1 [NODES] i_2 [REGIONS] i_3

where:

i_1: the number of links in the network
i_2: the number of nodes in the network
i_3: the number of regions.

Note that the words and their corresponding numbers may change order.

LINK DATA

[LINK] i_1 [BEGINS] i_2 [CONCLUDES] i_3 [REGION] i_4 [FEASIBLE STRATEGIES]

END

where:

i_1 = link number
i_2 = node, where link begins
i_3 = node, where link concludes
i_4 = region, where link belongs
i_5 = total number of link strategies.
The data for the link characteristics must begin with the word LINK or its number. If the user wants to change the order of the other numbers or omit one of them, he must use, in front of all numbers, the corresponding word. Otherwise, he may omit the words, but keep the numbers in the specified order.

END denotes the end of the command, i.e. the data about links connectivity.

2.1.3 Link Characteristics

Following is the way to input the data about: the travel time, the financial and economic costs of the vehicles travelling on the links, the costs resulting from any construction and maintenance activities on the links and the link characteristics, such as capacity, design speed and rise and fall.

\[
\text{LINK } i_1 \text{ [STRATEGY] } i_2 \text{ [INDEX] } i_3 \text{ [SLIPPAGE] } i_4
\]

\[
\]

\[
\]

\[
\]

\[
(\eta_i) \text{ [ETC] } y_1 \text{ [FTC] } y_2 \text{ [FOR] } y_3 \text{ [SKL] } y_4
\]

\[
(\eta_i) \text{ [LEN] } z_1 \text{ [CAP] } z_2 \text{ [RAP] } z_3 \text{ [DSP] } z_4
\]

END

where:

\[
i_1 = \text{ link number}
\]

\[
i_2 = \text{ link strategy number}
\]

\[
i_3 = \text{ critical index of the link strategy}
\]

\[
i_4 = \text{ maximum allowable delay indicative of the strategy}
\]

If not given, \(i_2\) is assumed equal to 1, \(i_3\) and \(i_4\) equal to zero.
\( n_i \) = the year number. Data need be given in the ADD mode only for years when values change. Intermediate years up to the time horizon are automatically inserted with prior year values.

ATT = average travel time over the link in hours, for each vehicle type.

\([V\text{N}]x_n\) = denotes the average travel time \( x_n \) in hours of vehicle type vn. Up to 7 vehicle types may be used.

EOC = economic costs of vehicle operation over the link, with \( x_n \) in \$/vehicle.

FOC = financial costs of vehicle operation over the link, with \( x_n \) in \$/vehicle.

\( y_1 \) = economic costs of construction and maintenance activities on the link in given year (in $).

\( y_2 \) = financial costs for the same.

\( y_3 \) = foreign exchange costs for the same.

\( y_4 \) = skilled labor costs for the same.

\( z_1 \) = link's length (in kms).

\( z_2 \) = link's capacity (in PCU/hr)

\( z_3 \) = link's rise and fall (in m/100m)

\( z_4 \) = link's design speed (in kms/hr).
It should be pointed out that only the first data card for a year must contain the year. The order of the cards for a year may be altered, and not all cards given for a year. Labels must be used on the construction and maintenance cost and link characteristics cards. In the ADD mode, years must be given in ascending order. Except for the header data and the years, both integer and real numbers are acceptable for the data.

2.1.4 Demand

The data about demand is given by O-D pair using the multi-statement DEMAND command.

```
DEMAND (0) i_1 (D) i_2


END
```

where:

- $i_1$ = origin node
- $i_2$ = destination node
- $n_1$ = the year number for the volume data.
Volume data may be given for each vehicle type either in vehicles per day or, for truck types, in tons per day. This latter form is designated by the user by issuing a command to this effect prior to demand input. This is currently an OPTION 1 command. In the ADD node, demand volumes must be given for ascending years, and after the first only for those years when values change from the previous year.

The remaining data is considered to be year independent. The elasticity is given in terms of the percentage change in demand due to a percentage change is user costs over the links. The commodity price is the maximum transportation cost that would result in any shipment between O-D pair, given in demand units. These values are used to determine whether or not a demand is likely to be fulfilled, and the consumers surplus for newly generated demands. Similarly, the time value of the transported goods, given in $/passenger-hour and for V1 and V2, and $/ton-hour for trucks is used for benefit calculation. Load factor are given as decimal fractions of load.

2.1.5 Budget constraints

The following command used input of budget constraints:

\[ \text{BEDGET CONSTRAINTS} \]

\[ \text{REGION } i_1 \]

\[ \eta_i [TB] \times_1 [FE] \times_2 [SL] \times_3 \]

END

where:

\[ i_1 = \text{region number. All budget constraints are input separately for every region, and therefore must proceed regional budget data.} \]
\[ n_i = \text{year number} \]
\[ x_1 = \text{Total budget available in \$}, \text{for year} \]
\[ x_2 = \text{Foreign exchange available in \$}, \text{for year} \]
\[ x_3 = \text{Skilled labor available is \$}, \text{for year}. \]

In the ADD mode, years, after the first, unchanged from the prior year for a region need not be repeated in input.

2.1.6 Additional minor data

The user must input the following data:

i. The vehicle capacities, their input to be handled by the command:

\[
\text{VEHICLE CAPACITIES } [V1] x_1 [V2] x_2 [V3] x_3 [V4] x_4 \]
\[
[V5] x_5 [V6] x_6 [V7] x_7
\]

where \[x_i\] will be given in pass./vehicle for vehicle types 1 and 2 and in tons/vehicle for the rest vehicle types.

ii. The interest rate, to be given by the command:

\[
\text{INTEREST RATE } x_1
\]

where \[x_1\] is a percentage number (e.g. 10, for 10\%)

and

iii. The time horizon, which is stated with the command:

\[
\text{TIME HORIZON } i_1
\]

where \[i_1\] the total number of years.

2.2 Network Strategies Generator

The network strategy generator takes link strategy and budget constraint data and generates interesting and feasible alternatives.
It considers three types of links, unchanged links in the base network, for which a single defined strategy is taken, obligatory links, for which one among alternate strategies must be taken (the difference might merely represent slippage), and optional links, for which one alternative strategy may be taken, or the link left unaltered. The later two links are specified with the commands

\[
\text{OBLIGATORY (LINKS) } n_1, n_2, \ldots
\]

\[
\text{OPTIONAL (LINKS) } n_1, n_2, \ldots
\]

where \( n_i \) are link numbers. For all links, the strategy 1 is assumed to be the base network.

Four data input commands are given to allow more efficient generation of alternatives. The command

\[
\text{SLIPPAGE (INCREMENT) } i
\]

provides an alternative to considering year by year slippage combinations. The command

\[
\text{MINIMUM CRITICALITY INDEX } i
\]

provides an additional pruning rule. Until the sum of the link CI's for all included links exceeds the value \( i \), other constraints need not be checked. If, when it does exceed \( i \), it also, exceed busget cons- traints, the branch in the search, may be terminated.

For efficiency, this processor generated a block of feasible network strategies at one time, rank orders these, and discards the worst. These are then replaced with more and the process repeated. The size of the block is specified with the command

\[
\text{NETWORK (STRATEGIES) } n
\]
taken usually to be about 100. The percentage retained after ranking is specified with

\[ \text{PERCENTAGE (OR) (NETWORK) (STRATEGIES)} \times \]

\[ x \] being a decimal number.

Generation is performed with a command GENERATE at the \( n^x \) best strategies identified in the data use for evaluation.

2.3 Network Strategies Evaluator

With the network strategies generated, the user looks at the output, chooses those he wants to evaluate further. He does so with a series of simple, directive commands. These commands are of two types, those which cause an operation, such as the evaluation of a strategy to take place, and those which provide data for the operations.

2.3.1 Data Input Commands

The simulate command, in the form:

\[ \text{SIMULATE } n_1, n_2, \ldots \text{ (YEARS)} \]

is used to define to the evaluation operations the year for which, at a minimum, the network must be analyzed. Results from one year will be used in subsequent years up to the next analysis year or the end of the time horizon. Intermediate analysis years will be inserted by the processor. In any year user or government costs change on any link.

The PRINT command, similarly, in the form

\[ \text{PRINT } n_1, n_2, \ldots \text{ (YEARS)} \]

is used to state years for which detailed output is to be provided. This output consists of:

1. The routing of the traffic
2. The traffic volumes or the links.
3. The economic and financial transport costs for O-D pair.

2.3.2 Operational commands

For a particular network configuration, the user compares alternatives against a base network strategy. He may do so by selectively requesting the evaluation of specific generated strategies, and even going back to the generator and, by changing some input, generating new strategies for evaluation. Prior to such evaluations, the base network must be analyzed and, if any of its conditions changed, reanalyzed.

To analyze the base network the user uses the command:

    ANALYZE (BASE) (NETWORK)

He may then evaluate alternatives using the command:

    EVALUATE (N.S.) n_i

or

    EVALUATE ALL (n_j) (N.S.)

where n_i is a strategy number and

    n_j is the number of strategies, 1 to n_j, evaluated.

Any number of EVALUATE commands may be given, and the results stred in the data base. If n_j is omitted, all saved generated strategies are evaluated. Evaluation go to the point of determining the net present value of the total costs and benefits of the alternative relative to the base network.

The RANK command, with no arguments, provides a ranked list of network strategies ordered on decreasing NPV. It considers all alter-
alternatives for which evaluation results have been stored in the database.

3. Job Control Language Cards

The Network Evaluation Model needs the following Job Control Cards to be operational in the IPC Computer facility of MIT.

In the beginning of each one of the computer programs the JCL cards are:

```plaintext
//' name of the user', REGION=200K
/* MITID (problem no, programmers no, password)
/* MAIN LINES=15
   // EXEC FORCGO
   // SYSIN DD.*, DCB=BLKSIZE=2000
```

At the end of the main program and before the data cards the JCL cards are:

```plaintext
//G.FT10F001 DD DSN=U.M11943.12404. BASIC DATA
//DISP=(OLD,KEEP)
//UNIT=STORAGE, SPACE=(3600,(6))

//G.FT11F001 DD DSN=U.M11943.12404. LINK. DATA,
//DISP=(OLD-KEEP),
//UNIT=STORAGE, SPACE=(2332,(300))

//G.FT12F001 DD DSN=U.M11943.12404. DEMAND DATA,
//DISP=(OLD,KEEP),
//UNIT=STORAGE, SPACE=(1792,(30))
/*
//G.SYSIN DD*, DCB=BLKSIZE=2000
```
1. System structure and file usage

The system consists of four computer packages: the HCM, the Input Data Processor, the Network Strategies Generator, and the Network Strategies Evaluator. It allows flow of input-output from one computer package to the other with the use of files, independent runs of each computer package, changes in the inputs. The system is presented in the figure B.1. All the computer packages are written in FORTRAN language and with the DEFINE FILE command, and the READ - WRITE statements for the access to the files.

There are three files with the identification numbers 10, 11 and 12, as they have been initialized in the IPC Computer facility of MIT.

1.1 File 10

File 10 stores data provided by the Input Data Processor and the Network Strategies Generator. It consists of 6 records each of 900 words length.

a. Record 1

The following variables are stored with the WRITE statement from the Input Data Processor (with the only exception of NRANK which is stored from the Network Strategies Evaluator):
Figure B.1: Network simulation system flow
<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>WORDS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NLINK</td>
<td>1</td>
<td>Number of links in the network</td>
</tr>
<tr>
<td>NODE</td>
<td>1</td>
<td>Number of nodes in the network</td>
</tr>
<tr>
<td>NREG</td>
<td>1</td>
<td>Number of regions</td>
</tr>
<tr>
<td>IHORIZ</td>
<td>1</td>
<td>Time Horizon</td>
</tr>
<tr>
<td>JIM</td>
<td>1</td>
<td>Number of O-D pairs</td>
</tr>
<tr>
<td>RATE</td>
<td>1</td>
<td>Interest rate</td>
</tr>
<tr>
<td>VCAP</td>
<td>7</td>
<td>Vehicle capacities for the 7 types (in pass. for 1,2 and tons for the rest)</td>
</tr>
<tr>
<td>LBEG</td>
<td>30</td>
<td>Node where a link (x) begins</td>
</tr>
<tr>
<td>LEND</td>
<td>30</td>
<td>Node where a link (x) ends</td>
</tr>
<tr>
<td>LST</td>
<td>30</td>
<td>Number of strategies per link</td>
</tr>
<tr>
<td>MDIS</td>
<td>30</td>
<td>Region where a link (x) belongs</td>
</tr>
<tr>
<td>IOPT</td>
<td>1</td>
<td>Index number for option of demand data units (tons or vehicles)</td>
</tr>
<tr>
<td>COSTMA</td>
<td>200</td>
<td>A (10,20) array about annual regional budget constraints</td>
</tr>
<tr>
<td>FOCAMA</td>
<td>200</td>
<td>A (10,20) array about annual regional foreign exchange constraints</td>
</tr>
<tr>
<td>SKLAMA</td>
<td>200</td>
<td>A (10,20) array about annual regional skilled labor constraints</td>
</tr>
<tr>
<td>NRANK</td>
<td>30</td>
<td>Rank of the N.S. according to their NPV.</td>
</tr>
</tbody>
</table>

Total length of the record (actual): 794 words.
b. Record 2

It stores only one array LLA(30,30) provided by the Input Data Processor. LLA is the link incidence matrix, giving for each node pair the corresponding link number, if it exists.

Total length of the record (actual): 900 words.

c. Record 3

It stores the array LOD(30,30) provided by the Input Data Processor. Since the Input Data Processor arbitrarily assigns a number to each O-D pair, LOD facilitates to found the O-D pair given this number.

Total length of the record (actual): 900 words.

d. Record 4

It stores NWSTR(30,30) provided by the Network Strategies Generator. NWSTR stores the link strategy to be implemented given the specified network strategy and the link number.

Total length of the record (actual): 900 words.

e. Record 5

It stores NWSL(30,30) provided by the Network Strategies Generator. NWSL stores the link strategy slippage to be implemented given the specified network strategy and the link number.

Total length of the record (actual): 900 words.

f. Record 6

It stores TCOST(30,20), BCOST(20), IAA(30) provided by the Network Strategies Generator.
TCOST  Stores the annual total costs for each network strategy.
BCOST  Stores the annual total costs for the base network strategy.
IAA    Stores the correspondence between the actual link number, as specified in Record 1 and the number given to each link by the Network Strategies Generator.

Total length of the record (actual): 650 words.

1.2 File 11

File 11 includes identical records of total length of 583 words. Each record stores information for each link strategy. Only ten strategies per link are permitted. The number is given to each record as follow: Assuming a link has the number: x. (Note that x should be at the most 30), and the specified link strategy is y (1 ≤ y ≤ 10). The record number is then: 10 \cdot (x-1)+y. Therefore no matter how the data of the links is provided, the record number is specified. The total number of records are 300 (30 links times 10 strategies). The data is provided partially by the HCM and by the Input Data Processor. The variables stored are:

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>WORDS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATT</td>
<td>140</td>
<td>A (20,7) array about average travel time on the link (assumed uncongested) per vehicle type, per year.</td>
</tr>
<tr>
<td>EOC</td>
<td>140</td>
<td>A (20,7) array about vehicle economic costs of operation on the link per vehicle type, per year.</td>
</tr>
<tr>
<td>VARIABLES</td>
<td>WORDS</td>
<td>COMMENTS</td>
</tr>
<tr>
<td>-----------</td>
<td>-------</td>
<td>----------</td>
</tr>
<tr>
<td>FOC</td>
<td>140</td>
<td>A (20,7) array about vehicle financial costs of operation on the link per vehicle type, per year.</td>
</tr>
<tr>
<td>ETC</td>
<td>20</td>
<td>Array about annual economic costs of link construction and maintenance according to the specific link strategy.</td>
</tr>
<tr>
<td>FTC</td>
<td>20</td>
<td>Array about annual financial costs of link construction and maintenance according to the specified link strategy.</td>
</tr>
<tr>
<td>SKL</td>
<td>20</td>
<td>Array about annual skilled labor costs of link construction and maintenance according to the specified link strategy.</td>
</tr>
<tr>
<td>FOR</td>
<td>20</td>
<td>Array about annual foreign exchange of link construction and maintenance according to the specified link strategy for every year.</td>
</tr>
<tr>
<td>DIS</td>
<td>20</td>
<td>Array about link length according to the specified link strategy.</td>
</tr>
<tr>
<td>CP</td>
<td>20</td>
<td>Array about link capacity according to the specified link strategy for every year.</td>
</tr>
</tbody>
</table>
VARIABLES          WORDS          COMMENTS

RAF              20          Array about rise and fall of the road surface according to the specified link strategy for every year.

DSP              20          Array about the design speed of the road surface according to the specified link strategy for every year.

ISTR             1           Link strategy number

NCRIT            1           Critical Index for the link strategy.

NSLIM            1           Max slippage for the link strategy.

The variables CP, ISTR, NCRIT and NSLIM are provided only by the Input Data Processor. The others may be provided by the HCM.

**1.3 File 12**

It includes identical records of total length of 448. The data is provided by the Input Data Processor, except of the BVEC, BVFC variables provided by the Network Strategies Evaluator. The record number is assigned arbitrary to each O-D pair, however once it is set, it remains the same. The variables are:

VARIABLES          WORDS          COMMENTS

DEMAND            140          A (20,7) array about the daily demand per commodity type for the O-D pair. For types 1, and 2 it gives in vehicles, for the rest it depends on the options (either tons or vehicles).
VARIABLES | WORDS | COMMENTS
--- | --- | ---
ELA | 7 | Elasticity of demand with respect to transport costs for each commodity type.
PRICE | 7 | maximum transport cost per unit of commodity, per commodity type, to be worth the production. ($/unit of comm.).
VALT | 7 | Value of loss of time for each commodity type ($/hr.unit).
FLOAD | 7 | Load factor of each vehicle type.
BVEC | 140 | A (20,7) array about the transport economic costs of each commodity type.
BVFC | 140 | A (20,7) array about the transport financial costs of each commodity type, if the base network strategy was to be implemented.

2. HCM modification and interface with the system

The HCM is designed to simulate the costs of various investments strategies on a road link. It simulates: (i) the construction and maintenance activities over the time horizon of each alternative link strategy and (ii) the vehicles operation on the link.

The HCM simulates one link at a time. However, it may simulate alternative link strategies in each run. The role of the HCM in the system is the following: For each link, that either no data about costs (for construction or maintenance activities or vehicle operation)
exists; or the link will be improved; or the link was not existed before and it will be constructed, the HCM will simulate the activities and provide (1) the financial and economic costs of the construction and maintenance activities over the time horizon, as well the skilled labor costs and the foreign exchange; (2) the vehicle operation costs (financial and economic) and the average travel time for the whole link over the time horizon according to the link strategy followed. Note that it always simulates the link for the 'base strategy', i.e., no activity different than the existing one up to date would take place. This data is stored on disk according to the number the link has in the network and the strategy followed. This data complemented by the data provided by the Data Processor will be input data to the Network Strategies Generator and Evaluator.

3. The Input Data Processor

The purpose of this computer package is to read the data required for the function of the system and to store it into disks for further use.

It has the capability to read from the same card words and numbers. This simplified the input of the data, minimize possible errors and allows the change of any part of the data stored. This is accomplished with the use of the SUBROUTINE MATCH, developed originally by R.D. Logcher et.al.
3.1 MATCH subroutine

MATCH is designed to be usable with FORTRAN for operations on logical input fields. The translation of a field identifies its form and meaning. MATCH reads a card into a alphanumeric array, converts each column to an integer code in a numeric array and decodes each logical field on the card. Each code number represents a character and is formed into list words by combining the code times some power of 100. Therefore each words need to be read has to be included in an integer array (to be called dictionary) with its corresponding integer numbers. Although MATCH provides a general input capability, versatile translation requires extensive logical programming. Branching on translated words is accomplished with the "computed GO TO" statement, with the control variable determined from the position of the translated word in the dictionary. The subroutine MATCH is used by the Data Processor program, the card to be read and the dictionary to be utilized have been specified. The MATCH gives back the word read, for the branching, or the number read.

Virtually any type of input can be performed. Even if a word is read from the card but not found in the dictionary, and it is not necessary to be translated, it is possible with the appropriate logic in programming for this case to make MATCH to skip it.

3.2 Input data

Input to the Data Processor can be separated into the following types:

(i) Systems commands: The processor may handle the cases of updating
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Figure B.2: Input Data Processor - Flow Chart (Partial)
Figure B.2: (Continued) Input Data Processor - Flow Chart
Figure B.2: (Continued) Input Data Processor - Flow Chart
Figure B.2: (Continued) Input Data Processor - Flow Chart
already existed data; changing parts of it; delete portions or add others. The format is simple. One-word commands, i.e., INITIATE, UPDATE, DELETE, CHANGE, ADD.

(ii) Network Information: This data type describes the network, assigning numbers on the nodes and links; specifies the regions to be examined and the links they belong to each of them.

(iii) Budget Information: For each year the available budget, the skilled labor and the foreign exchange for each region is provided.

(iv) Demand Information: Two options of demands are provided. Option 1 gives the demand in vehicle numbers. Seven types of vehicles are possible. Option 2 gives the demand in vehicle numbers for the passenger cars and buses but in tons for the rest 5 types, assuming a commodity will be transported by its corresponding vehicle (i.e. commodity, its demand given by type 3, will be transported by vehicle type 3). Demand for both options is given on an average daily basis, for each year, for each supply-demand nodes pair. (to be called origin destination pair). Also for each O-D pair the following data is provided: the elasticity of demand with respect to transport costs; the maximum transport price the operator is willing to pay (where costs equal to revenues for the vehicle's operator); the value of travel time (in $/hr./passenger for the passenger cars and buses and in $/hr./ton for the trucks); the load factor of the vehicles. Also the capacities of the vehicles used are specified: In passengers for cars and buses and in tons for trucks.
(v) Link Information: Portion of this data may be provided from the HCM. This portion includes: the average travel time on the link, the link length, the design speed of the link, the rise and fall, the vehicle operating costs (financial and economic), costs of construction and/or maintenance (financial and economic). If a link have not been stimulated by the HCM this data should be provided here. The portion that has to be inputed here includes the link capacity in PCU/hour, the critical index for each link strategy (to be specified in the Network Strategies Generator) and the maximum allowable slippage in years of a link strategy.

This is the data required as input to the Network Strategies Generator and Network Strategies Evaluator. The presented flow chart of the part of the Data Processor handling the instructions about the System gives a feeling of how the computer package works: It is a branching mechanism. (Branch on each key-word). The Data Processor has the option of printing the data stored on files.

4. **Network Strategies Generator.** (Developed originally by Y. Lasage)

The objective of this computer package is the generation of feasible network strategies for the improvement of a given network of roads over the time horizon. A network strategy will be feasible if it verifies the following regional constraints per year:

(i) budget  
(ii) skilled labor  
(iii) foreign exchange.

It is assumed that four kinds of links exist:

(i) link with maintenance activities (maybe no maintenance at all)
(ii) link with activities of either initial construction or improvement; however according to a fixed strategy. (they belong to the so-called "base network").

(iii) link with mandatory activities of either initial construction or improvement; however the timing of the strategy may change (obligatory link).

(iv) link with optional activities of initial construction or improvement (optional link).

The Generator deals with (iii) and (iv) kinds of links. Base network is the original network as it is up to date to which the links of kinds (i) and (ii) are added.

The inputs to the Generator are (1) the data stored on files by the HCM and the Data Processor and (2) the desired feasible network strategies to be generated; the optional and obligatory links; a minimal network strategy critical index. The inputs (2) are read with the use of SUBROUTINE MATCH, the input formats being words and numbers.

The output is stored on files for further use by the Network Strategies Evaluator. The output consists of two matrices: matrix NWSTR will give the links and their corresponding link strategies included in each generated feasible network strategy. Matrix NWSL will give the links, and the corresponding slippage in years of their defined link strategy in matrix NWSTR, for each generated feasible network strategy.
4.1 The approach

In order to clarify the approach we describe the treatment of link (iv). (Note that the treatment of link type (iii) is quite similar)

Definitions:

i: number of the link I considered

\( \bar{i} \): maximum number of links

\( \lambda \): number of strategy L considered

\( \bar{\lambda} \): maximum number of strategies

j: number of N.S.

The algorithm is the following:

STEP 1: Initialization: \( i=1, j=1, \lambda=1, \bar{\lambda}=1 \)

STEP 2: Consider the N.S. \( j \)

STEP 3: Add the L.S. (link strategy) \( (i, \lambda) \) to \( NS_j \)

- If \( NS_j \) verifies the constraints set \( k=i \) Go To 4
  - If \( NS_j \) does not verify the constraints Go To 6

STEP 4: Set: \( i=i+2 \)

  If \( i \) is greater than \( \bar{i} \) Go To 5
  If \( i \) is not greater than \( \bar{i} \), make \( \lambda=1 \) and Go To 2

STEP 5: Set \( j=j+i \) and \( i=k \)

  Include in \( NS_j \) all LS of \( NS(j-1) \) [\( LS(i,\lambda) \)] Go To 6

STEP 6: Subtract LS \( (i, \lambda) \) from \( NS_j \).

  Slippage of LS \( (i, \lambda) \) possible?

  Yes: slip it and Go To 3
  No: Go To 7
STEP 7: Is there another strategy available for link i?
   Yes: \$=k+1 \quad \text{Go To 3}
   No: \quad \text{Go To 8}

STEP 8: Is \( k' = k \)?
   No: Set \( k' = k \) \quad \text{Go To 4}
   Yes: \quad \text{Go To 9}

STEP 9: Is \( k' = 1 \)?
   No: \( k = k - 1, k' = k \) and \( i = k \) \quad \text{Go To 4}
   Yes: \quad \text{END}

4.2 Description of SUBROUTINES

4.2.1 SUBROUTINE ADDCOM \((N, VBAR, V1, V2, V)\)

Objectives: This subroutine computes the sum of two vectors \( V2 \) and \( V \), taking in account a slippage of \( N \) components between the two vectors. Then it compares the sum to a vector \( VBAR \).

\[
\begin{align*}
\text{If } V1 & > VBAR & \text{INDEX} = 1 \\
V1 & \leq VBAR & \text{INDEX} = 0
\end{align*}
\]

N.B. \( V1 > VBAR \) if one of the components of \( V1 \) at least is greater than its corresponding component of \( VBAR \).

4.2.2 SUBROUTINE ADDCOL \((N, ABAR, A1, A2, V)\)

Objectives: This subroutine is similar to ADDCOM for the arrays.

4.2.3 SUBROUTINE CALCOL

Objectives: This subroutine uses ADDCOM and ADDCOL to verify that a N.S. verifies all the constraints.
Computation of the number of L.S. for each N.S.

Prune the N.S. with a Low number of L.S.

Computation of Critical index of each N.S.

Is the last call of critic

N

Y

Rank the N.S. by critical indices

END

Figure B.3: Network Strategies Generator
Flow Chart of Subroutine CRITIC
Figure B.4. Network Strategies Generator. Flow chart of subroutine VERCAL.
Figure B.5: Network strategies generator
Flow chart of MAIN.
4.2.4 SUBROUTINE REMEMB

Objective: This subroutine reinitializes matrices when a N.S. does not verify the constraints.

4.2.5 SUBROUTINE REINIT

Objective: This subroutine reinitializes matrices when a N.S. verifies the constraints.

4.2.6 SUBROUTINE RECAL

Objective: This subroutine, as REMEMB, reinitializes matrices but when the reinitialization does not concern the same number of L.S. in a N.S.

4.2.7 SUBROUTINE CRITIC

Objective: This subroutine computes

a. the number of L.S. in each N.S.

b. the N.S. critical index from L.S. critical indices

Then it prunes the feasible N.S. with a low number of L.S. and with a low critical index.

4.2.8 SUBROUTINE VERCAL

Objective: This subroutine generates N.S. from the L.S. It operates on links.

A link may be either a link the inclusion of which is obligatory: L1, or a link the inclusion of which is facultative: L2.

L1 have only one strategy which may be slipped by a variable number of years, L2 have as many strategies as the Decision Maker asks.

4.2.9 MAIN

Objective: The main program defines the set of obligatory and links for VERCAL. In order to do this selection, it uses a minimal critical index, and a minimal number of strategies.
4.2.10 SUBROUTINE BUDGET

Objective: This subroutine computes the economic costs of base network strategy construction and maintenance activities. It subtracts the financial costs from the available budget and if the resulting budget turns out to be less or equal to zero the task of generation is abandoned. It updates also the available foreign exchange and the skilled labor.

4.2.11 SUBROUTINE INITIA

Objective: Reads the data from the files and from the input cards.

4.2.12 SUBROUTINE ECRIRE

Objective: Writes the NWSTR and NWSL arrays to the records 5 and 6 of file 10 and prints out the results.

5. Network strategies evaluator

This computer package evaluate each network strategy applying the NPV criterion for the economic costs of the construction and maintenance activities proposed by the strategy and the resulting benefits.

It needs only as input data the desired network strategies to be evaluated, chosen from the generated ones the years to be simulated and the years for which the detail results will be printed. The rest of the data is read from the files. In the event the base network has been analysed previously, it is not necessary to be analysed again, if no change has been occurred to it. The results of the analysis may be read from the file and used directly for the evaluation. Also, there is the option of keeping the ranking of previously evaluated N.S.

The provided output for each network strategy consists of:
The net present value, the annual benefits and costs, the average daily traffic on links every year of the time horizon, for each origin-destination pair the minimum cost route. Finally, a ranking of all network strategies according to their NPV is provided.

5.1 Description of SUBROUTINES

5.1.1 SUBROUTINE BASENE

Objective: It simulates each year of the base network. If no change occurs the same data of the previous year is saved for this year. If changes occur, then it computes the new transport costs between the O-D pairs and updates the demand according to the elasticity of demand with respect to price, as follows:

\[
DEMAND' = DEMAND \times \left( \frac{BVFV(I)}{BVFV(I-1)} \right)^{-ELA}, \text{ where:}
\]

DEMAND: old demand
DEMAND': new demand
BVFV(I): transport costs of year I
BVFV(I-1): transport costs of previous year (I-1).

Finally it saves the results into file 12 according to the O-D pair number.

5.1.2 SUBROUTINE ROUTE

Objective: It finds the minimum cost route of each vehicle type, computes the transport costs (both economic and financial) as a sum of the vehicle operation costs and the loss of time costs. Then it assigns the traffic on the links. The algorithm that computes the minimum cost route is described in Chapter 3.
Figure B.6: Network strategies evaluator - Flow Chart of Subroutine BASENE
Set data for this year the same as of previous for each O-D pair

Do loop on O-D pairs
k=1, JIM

Update demand of each type if vehicle operating costs have been changed

\[
\text{DEMAND} = \text{DEMAND} \times \left( \frac{BVFV(I)}{BVFV(I-1)} \right)^\text{ELA}
\]

Save new demand and BVFC, BVEC on file

Figure B.6: (Continued) Network strategies evaluator
Flow Chart of Subroutine BASENE
Construc initial cost matrix $C_{ij}$

$C_{ij} =$ vehicle operation costs

where $i, j$ nodes if link does exist

set $C_{ij} = 10$

Construct label matrix $\lambda_{ij} = i$. if link $\lambda_{ij}$ starts at $i$ and ends at $j$

Start pivoting

Do loop on all other nodes except $I$

$K0 = 1, NODE (K0 \neq I)$

Do loop on all other nodes except $I$ and $K0, KD = 1, NODE (KD \neq I, K0)$

Compute new $C'$ (the traffic has to pass through $I$)

$C' = C_{K0, I} + C_{I, KD}$

$C' < C_{K0, KD}$

Figure B.7: Network strategies evaluator. Flow Chart of Subroutine ROUTE
Figure B.7: Network strategies evaluator. Flow Chart of Subroutine ROUTE.
Figure B.3: Network strategies evaluator. Flow Chart of Subroutine ROUTE
Figure B.8 Network Strategies Evaluator. Flow chart of subroutine COST.
Figure B.8 (Continued) Network Strategies Evaluator. Flow chart of subroutine COST.

Do loop on vehicle types
IV = 1, 7

Do loop on volume levels
IP = 1, 5

PCVEH(IP) = \( \frac{VEHNO(IP)}{TRAFF(I)} \)

\( VEL = V - \frac{V \cdot VOL(IP)}{CAP(I)} \)

Yes

VEL > SPD

Yes

VEL < 0.10*V

No

VEL = 0.10*V

AT(IP) = \( \frac{RLEN(I)}{VEL} - \frac{RLEN(I)}{VEL} \)

VEHNO(IP) = VEHTRA(I, IV) \cdot PCVEH(IP) + VEHNO(IP) \cdot AT(IP)

Loop terminated

Loop terminated

RVOL = 1.25 = (VOLCAP -.10)
A = .10 * TOTCAP
VEHNO(1) = A * (1 - RVOL)
VEHNO(2) = 12. * A * RVOL * (1 - RVOL)
VEHNO(3) = 30 * A * RVOL^2 * (1 - RVOL)
VEHNO(4) = 28 * A * RVOL^3 * (1 - RVOL)
VEHNO(5) = A * RVOL^4
Figure B.8 (Continued) Network Strategies Evaluator. Flow chart of subroutine COST
Start

Initialize

Read N.S. to be evaluated

Read basic data from files

Analysis of Base Network

Call BASENE

Start analysis of each specified strategy
N.S.: I=1,LASTNS

L

Last N.S.

Yes

Ranking desired

No

EXIT

Print out

Yes

Do Ranking of N.S.

M

Figure B.9: Network strategies evaluator.
Flow chart of MAIN
Read strategy 1 of link, ISTR=1

Figure B.9. Network strategies evaluator. Flow chart of MAIN
Figure B.9. Network strategies evaluator. Flow chart of MAIN
Figure B.9. Network strategies evaluator. Flow chart of MAIN

\[ CS = \frac{1}{2} (\text{DEMAND} + \text{DEMAND}')(\text{BVEC} - \text{VEC}) + CS \]

\[ \text{BENEF} = \text{CS} - \text{T} \text{COST(I, IYR)} - \text{BCOST(IYR)} \]

\[ \text{ACBEN} = \text{ACBEN} + (\text{BENEF}) \cdot \left( \frac{1}{1 + \text{RATE}} \right) - (\text{IYR} - 1) \]
Figure B.9. Network strategies evaluator. Flow chart of MAIN
5.1.3. SUBROUTINE COST

Objective: It checks if congestion occurs. If it does, it computes the congestion costs. (The method is described in Chapter 3). Finally, it computes the total transport costs for each O-D pair.

5.1.4. MAIN

Objective: It reads the data from the cards and the files. For each network strategy it does the evaluation. It computes for each O-D pair the minimum cost routes calling ROUTE, it computes the vehicle equivalent factors and it calls COST to do the congestion computations. It computes the benefits, applying the formula (in general form):

\[ CS = \frac{1}{2}(T+T')(C-C') \]

where:

- \( T, C \): the demand and the costs of the base network
- \( T' = T \cdot \left( \frac{C'}{C} \right)^{-ELA} \): the new demand and, \( C' \) = the new costs.

Next it computes the net benefits of the year

\[ \text{NETBENEFITS} = \text{TOTAL BENEFITS} - \text{TOTAL COSTS}. \]

It discounts them to the present and it computes the NPV for all years of the time horizon.

If desired, it ranks the alternative network strategies according to their computed NPV.
APPENDIX C:

COMPUTER LISTINGS
INPUT DATA PROCESSOR
C MAIN PROGRAM TO READ INPUT DATA FOR NETWORK EVALUATION

DEFINE FILE 10 (6,900, U, INF)
DEFINE FILE 11 (300, 583, U, LAM)
DEFINE FILE 12 (30, 448, U, JMC)

DIMENSION F10 (900), F11 (583), F12 (168), VCAP (7), LBEG (30), LEND (30),
INST (30), LREG (30), RAF (20), TB (10, 20), FX (10, 20), SL (10, 20), LLA (30, 30)
2, LOR (30, 30), ATT (20, 7), EOC (20, 7), FOC (20, 7), ETC (20), FTC (20), SKL (20)
3, POR (20), CAP (20), DEMAND (20, 7), FLA (7), VALT (7), FLOAD (7),
5IDICT1 (19), IDICT2 (5), IDICT3 (9), IDICT4 (7), IDICT5 (14), IDICT6 (8),
6IDICT7 (11), IW (10), L (10), RI (11), IDICT8 (8), DSP (20)

INTEGER UED, RG
REAL LEN (20)

C WORDS IN IDICT1: INITIALIZE, UPDATE, ADD, DELETE, CHANGE, STOP, NETWORK, TIME, LINK,
C BUDGET, DEMAND, INTEREST, VEHICLE, END, PRINT, FINISHED, OPTION
C WORDS IN IDICT2: LINKS, NODES, REGIONS
C WORDS IN IDICT3: STRATEGY, DATA, D, END, INDEX, SLIPAGE
C WORDS IN IDICT4: TB, FE, SI, END, REGION
C WORDS IN IDICT5: ATT, EOC, FOC, FTC, FTC, SKL, POR, LEN, CAP, RAF, DSP, END
C WORDS IN IDICT6: VOLUME, ELASTICITY, COMMODITY, TIME, LOAD, END
C WORDS IN IDICT7: V1, V2, V3, V4, V5, V6, V7, VOLUME, CAPACITIES
C WORDS IN IDICT8: LINK, REGIONS, CONCLUDES, REGION, FEASIBLE, STRATEGIES

DATA IDICT1/3,17,283328,403523,202323,232431,222720,
1383934,332439,392832,312833,214023,232432,283339,412427,243323,353
2728,252833,343539/
DATA IDICT2/3,3,312833,333423,372426/
DATA IDICT3/3,7,383937,232039,341414,231414,243323,283323,383128/
DATA IDICT4/3,5,392114,252414,383114,243323,372426/
DATA IDICT5/3,12,203939,243422,253422,243922,253922,383031,253437,
131243,222035,372025,233835,243323/
DATA IDICT6/3,6,413431,243120,223432,392832,313420,243323/
DATA IDICT7/3,9,410114,410214,410314,410414,410514,410614,410714,
143431,222035/
DATA IDICT8/3,6,312833,212426,223433,372426,252420,383937/
JIME=1
JOPT=0
DATA F1C/900.0/.
DATA F11/583*0.
DATA F12/168*0.
DATA VCAP/7*0.
DATA LDFG/30*0.
DATA LEND/30*0.
DATA LST/30*0.
DATA LREF/30*0.
DATA LIA/900*0.
DATA IC0/900*0.
DATA TP/200*0.
DATA FF/200*0.
DATA ST/200*0.
C EXECUTION BEGINS.
C FIND THE FIRST WORD OF THE CARD
   10 LARG=1
      CALL MATCH (ITYPE,IDICT1,K,PK,LARG)
      GO TO (10,11,11,11,12,45),ITYPE
   11 GO TO 2001
   12 IK1=K
      GO TO (15,50,100,105,110,3000,150,200,250,400,500,800,850,10,40,45
      1,900),IK1
C INITIATE COMMAND. ZERO ALL RECORDS.
   15 UPPZ=2
      DO 20 INF=1,3
         WRITE (10'INF) F10
      CONTINUE
   20 CONTINUE
      DO 30 JIMC=1,30
         WRITE (12'JIMC) F12
      CONTINUE
   30 CONTINUE
      GO TO 104
   40 CALL GRAFHE
      GO TO 10
   900 LARG=2
      CALL MATCH (ITYPE,IDICT2,K,RK,LARG)
      GO TO (10,911,910,900,900),ITYPE
   910 K=RK
911 ICFT=K
    GO TO 10
C IF UPDATE OCCURS: PUT IN CORE ALL BASE DATA
  50 UPD=1
  INF=1
  READ (10*1) NLINK, NODE, NREG, THORIZ, JIM, RATE, VCAP, LREG, LEND, LST, LREG,
  TB, FF, SL, IOPT
  READ (10*2) LLA
  READ (10*3) LOD
  GO TO 10
CCC CHECK FOR TYPE OF UPDATE
  10 MOD=0
    GO TO 10
  105 MOD=2
    GO TO 10
    DO 25 IAU=1,300
    WRITE (11,LAU) F11
    25 CONTINUE
    GO TO 10
  110 MOD=1
    GO TO 10
C EXECUTION TERMINATED
  3000 WRITE (10*1) NLINK, NODE, NREG, THORIZ, JIM, RATE, VCAP, LREG, LEND, LST, LREG,
  1, TB, FF, SL, IOPT
  WRITE (10*2) LLA
  WRITE (10*3) LOD
  GO TO 10
  45 CONTINUE
  CALL EXIT
C INFORMATION ABOUT THE NETWORK
  153 KK=0
    L (1) = 0
    L (2) = 0
    L (3) = 0
    IW(1) = 1
    IW(2) = 2
I kWh(3) = 3
160 CALL MATCH(ITYPE, IDICT2, K, RK, 0)
GO TO (165, 185, 2005, 2005, 190), ITYPE
165 IF (KK .EQ. 0) GO TO 2005
166 IF (UPD .EQ. 0) GO TO 180
167 CONTINUE
GO TO 10
170 NLINK = L(1)
NODE = L(2)
NREG = L(3)
GO TO 10
180 L(1) = L(KK + 1)
GO TO 160
190 ITW(KK + 1) = K
GO TO 160
C INFORMATION ABOUT THE TIME
200 CALL MATCH(ITYPE, IDICT3, K, RK, 0)
GO TO (10, 205, 2010, 200, 200), ITYPE
205 IHORTZ = K
GO TO 10
C INFORMATION ABOUT THE LINKS. CONSTRUCTION OF MATRICES INDICATING OF
C WHICH NODES A LINK IS BOUNDED.
250 CALL MATCH(ITYPE, IDICT3, K, RK, 0)
GO TO (260, 1000, 2015, 2015, 255), ITYPE
255 IF (K .NE. 2) GO TO 2015
260 LAFG = 1
KK = 0
L(1) = 0
L(2) = 0
L(3) = 0
L(4) = 0
L(5) = 1

265 CALL MATCH(ITYPE, IDICT3, K, RK, LNP)
GO TO (300, 270, 2020, 275, 205, 5, 282, I TYPE)

270 KK = KK + 1
L(KK) = K
L(KK) = K
LAPG = 0
GO TO 265

280 IF(K .NE. 5) GO TO 275
GO TO 10

300 IF(KK .EQ. 0) GO TO 2020
IF(UPD .NE. C) GO TO 340

301 IF(L(I) .EQ. 0 .OR. L(2) .EQ. 0 .OR. L(3) .EQ. 0) GO TO 2020

305 LINK = L(1)
KO = L(2)
KD = L(3)
LLA(KO, KD) = LINK
LLA(KD, KO) = LINK
LNP(LINK) = KO
LEND(LINK) = KD
LREG(LINK) = L(4)
LST(LINK) = L(5)
GO TO 265

340 IF(MOD .EQ. 0) GO TO 301
IF(L(I) .EQ. 0 .OR. L(2) .EQ. 0 .OR. L(3) .EQ. 0) GO TO 2020
LINK = L(1)
KO = L(2)
KD = L(3)
KLINK = LLA(KO, KD)
MLINK = LLA(KD, KO)
IF(KLINK .EQ. LINK .OR. MLINK .EQ. LINK) GO TO 350

C LINK IS A DIFFERENT THAN WHICH ought to BE. ERASE RECORDS OF KLINK
I = 10 * (KLINK - 1) + 1
DO 342 J = 1, 583
P11(J) = 0.
342 CONTINUE
II = II + 9
DC 345 IAU = I, II
WRITE(11, LAU) P11
345 CONTINUE
350 IF (L(4).NE.0) GO TO 355
L(4) = LREG (LINK)
355 IF (L(5).NE.0) GO TO 355
L(5) = LST (LINK)
GO TO 305
C INFORMATION ABOUT BUDGET CONSTRAINTS (TOTAL BUDGET, FOREIGN C EXCHANGE, SKILLED LABOR)
400 KK = 0
RL(1) = 3.
RL(2) = 0.
RL(3) = 0.
IW(1) = 1
IW(2) = 2
IW(3) = 3
CALL MATCH (ITYPE, IDICT4, K, RK, 1)
GO TO (2025, 410, 2025, 2025, 405), ITYPE
415 IF (K.EQ.4) GO TO 10
IF (K.NE.5) GO TO 2027
CALL MATCH (ITYPE, IDICT4, K, RK, 0)
GO TO (2027, 406, 2027, 2027, 2027), ITYPE
420 RG = K
GO TO 400
410 IYR = K
415 CALL MATCH (ITYPE, IDICT4, K, RK, 0)
GO TO (420, 450, 452, 2025, 460), ITYPE
420 IF (KK.EQ.0) GO TO 2025
DO 440 KKK = 1, KK
T = TH (KKK)
GO TO (425, 430, 435), T
425 TP (RG, IYR) = RL(1)
GO TO 440
430 FE(RG, IYR) = RL(2)
GO TO 440
435 SL(RG, IYR) = RL(3)
440 CONTINUE
IF (UPD. EQ. 0.0) GO TO 470
IF (MOD. NE. 0.0) GO TO 400
470 CONTINUE
II = IYR + 1
DO 480 I = II, 20
TB(RG, I) = TB(RG, IYR)
FE(RG, I) = FE(RG, IYR)
SL(RG, I) = SL(RG, IYR)
480 CONTINUE
GO TO 400
450 KK = K
455 KK = KK + 1
RL(IW(KK)) = PK
GO TO 415
460 IW(KK + 1) = K
GO TO 415
C INFORMATION ABOUT THE DEMAND
500 KK = 0
C ZERO THE ARRAYS IN CORE
DO 700 I = 1, 20
DO 690 J = 1, 7
DEMAND(I, J) = 0.
690 CONTINUE
700 CONTINUE
DO 710 I = 1, 7
ELA(I) = 0.
PRICE(I) = 0.
VALT(I) = 0.
PLAD(I) = 0.
710 CONTINUE
505 CALL MATCH(ITYPE, IDICT3, K, RK, C)
0C 1D (220, 620, 662, 704, 746, 788)!

1C CALL MATCH (1104, 1146, 1188)

2C MOV DATA SET OF VOLUMES BETWEEN C-D PATH.

3C GO TO (234, 634, 676, 718, 760, 800, 842)

4C CALL MATCH (1128, 1170, 1212)

5C CONNECT

6C C = 0

7C C = 0

8C MOV DATA FROM FICHE, C - D

9C GO TO (510, 552, 594, 636, 678, 720, 762)
620 IF (KK.EQ.0) GO TO 2040
   DO 625 KKK=1,KK
   IFM(KK) = IFM(KK)
   DEMAND(IYR,IK)=PL(IK)
625 CONTINUE
628 IF (IPD.EQ.0) GO TO 630
   IF (MOD.EQ.1) GO TO 600
630 II=IYR+1
   DO 640 J=II,20
      DO 635 KK=1,7
         IF (PL(KK).NE.0.) GO TO 635
         DEMAND(I,KK)=DEMAND(IYR,KK)
635 CONTINUE
640 CONTINUE
   GC TO 600
650 RK=K
652 KK=KK+1
   DO 655 I=1,7
      IF (IK(KK).NE.0) GO TO 655
      TW(KK)=KK
655 RL(IW(KK))=RK
   GC TO 610
660 IF (K.EQ.0) GO TO 610
   IK(KK+1)=K
665 RK=K
680 CONTINUE
C BRANCH ON WORD TYPE IN DATA SET.
C END OF DATA FOR C-D PAIR.
670 TK1=K
   GC TO (2040,720,750,780,760,675),IK1
C UPDATE THE RECORD NUMBER. STORE IN THE RECORD THE DATA
675 IF (UPD.EQ.0) GO TO 680
   JIMC=JIMC+1
   JIMC=JIM
   LCD(KO,KE)=JIMC
   GC TO 685
680 JIMC=JIMC
685 WRITE(12,JIMC) DEMAND,FLA,PRICE,VAIT,PLOAD
C DATA ABOUT ELASTICITY OF DEMAND
720 CALL MATCH(ITYPE, IDICT7, K, PK, ?)
    GO TO (725, 740, 742, 2045, 748), ITYPE
725 IF(KK.EQ.0) GO TO 2045
    DO 730 KKK=1, KK
    IK=IW(KK)
    ELA(IK)=RI(IK)
730 CONTINUE
    GO TO 600
740 PK=K
742 KK=KK+1
    IF(IW(KK).NE.0) GO TO 745
    IW(KK)=KK
745 RL(IW(KK))=PK
    GO TO 720
748 IW(KK+1)=K
    GO TO 720
C DATA ABOUT COMMODITY PRICE
750 CALL MATCH(ITYPP, IDICT7, K, PK, ?)
    GO TO (755, 770, 772, 750, 778), ITYPE
755 IF(KK.EQ.0) GO TO 2050
    DO 758 KKK=1, KK
    IK=IW(KKK)
    PRICP(IK)=RL(IK)
758 CONTINUE
    GO TO 600
770 PK=K
772 KK=KK+1
    IF(IW(KK).NE.0) GO TO 775
    IW(KK)=KK
775 RL(IW(KK))=PK
    GO TO 750
778 IW(KK+1)=K
    GO TO 750
C DATA ABOUT VALUE OF TIME
C VEHICLE CAPACITIES
850 KK=0
   DC 860 I=1,7
   RI(I)=0.
   IW(I)=0
860 CONTINUE
865 CALL MATCH(I'TYPE,1DICT7,K,RK,0)
   GO TO (970,880,885,2060,890),ITYPE
870 IF(KK.EQ.0) GO TO 2060
   DO 875 KKK=1,KK
      TK=IW(KK)
      VC A(TK) =EL(TK)
   CONTINUE
880 RK=K
895 KK=KK+1
   IF(IW(KK).NE.0) GO TO 888
   IW(KK)=KK
888 EL(IW(KK))=PK
   GO TO 865
890 IF(K.EQ.9) GO TO 865
   IW(KK+1)=K
   GO TO 865
C DATA ABOUT LINK CHARACTERISTICS.
C FIND LINK NUMBER AND STRATEGY NUMBER.
1000 LINK=K
   DC 1088 I=1,20
   DC 1095 J=1,7
   ATT(I,J)=0.
   ECC(I,J)=0.
   POC(I,J)=0.
1095 CONTINUE
1088 CONTINUE
DC 1093 I=1, 7.57
1P) MOD 932 (GO TO 1404
1P) MOD 932 (GO TO 1441
IR=IV

1025 LAV=1+(LINK-1)+158

C FIND THE RECORD NUMBER, READ DATA FROM FILE IF NECESSARY
   L=1
   1021 ISEL=1
   1024 TO 1025
   (L=1)
   1020 LSR=1
   GO TO 1025
   1016 IM(K)+1=K
   GO TO 1025
   1017 (K)=(K)+1
   TO CALL MATCHES (IM=0, IM馔, IM馔, K)
   TO CONTINUE
   IM=0 (I)=1
   TO CONTINUE
   DC 1061 I=1, 7
   K=0
   ISRI=0
   XSS=0
   KSR=0
   TO CONTINUE
   DS=1
   AV=1
   CDP=1
   SIF=1
   TO CONTINUE
   DO 1098 I=1, 20
   DO
I1(I)=0.
1030 CONTINUE
   WRITE(11,'IAU')11
   GO TO 10
1040 READ(11,'LAU')ATT,FOC,FOC,EFC,FTC,SKL,FOC,LEN,CAP,RAF,DSP,ISTR,NCPIT
1,NSLIM
   IF(L(6).NE.0) GO TO 1042
   L(6)=NCRIT
1042 IF(L(7).NE.0) GO TO 1043
   L(7)=NSLIM
1043 CONTINUE
1044 NCRIT=L(6)
   NSLIM=L(7)
   ISTR=L(1)
C READ DATA ABOUT THE LINK
1045 LARG=1
1050 CALL MATCH(IYF,FIDCT5,K,PK,LAPG)
   GO TO (1045,1060,2070,2070,1080),IYF
1060 IYF=K
   KK=0
   DC 1665 I=1,7
   RL(I)=0.
   IW(I)=0
1065 CONTINUE
1070 CALL MATCH(IYF,FIDCT5,K,PK,0)
   GO TO (2070,2070,2070,2070,1100),IYF
1080 IF(K,NE.12) GO TO 1095
   LAU=LAU2
   WRITE(11,'IAU')ATT,FOC,FOC,EFC,FTC,FTC,SKL,FOC,LEN,CAP,RAF,DSP,ISTR,NCPIT
1,NSLIM
   GO TO 10
1095 KK=0
   DO 1098 I=1,7
      RL(I)=0.
      IW(I)=0
1098 CONTINUE
C DATA ABOUT AVERAGE TRAVEL TIME.
1105 CALL MATCH(ITYPE, IDICT7, K, RK, )
GO TO (1150, 1110, 1112, 2075, 1120), ITYPE
1110 RK=K
1112 KK=KK+1
IF (IW(KK).NE.0) GO TO 1115
IW(KK)=KK
1115 RL(IW(KK))=RK
GO TO 1115
1120 IW(KK+1)=K
GO TO 1105
1150 IF (KK.EQ.0) GO TO 2075
DO 1155 KKK=1, KK
IK=IW(KKK)
ATT(IYR,IK)=RL(IK)
1155 CONTINUE
1160 IF (UPD.EQ.0) GO TO 1165
IF (MOD.EQ.1) GO TO 1045
1165 II=IYR+1
DO 1170 II=II, 20
DO 1160 KK=1, 7
IF (RL(KK).EQ.0) GO TO 1168
ATT(I, KK)=ATT(IYR, KK)
1168 CONTINUE
1170 CONTINUE
GO TO 1045
C DATA ABOUT ECONOMIC COSTS OF VEHICLE OPERATION
1200 CALL MATCH(ITYPE, IDICT7, K, RK, )
GO TO (1250, 1210, 1212, 2080, 1220), ITYPE
1210 RK=K
1212 KK=KK+1
IF (IW(KK).NE.0) GO TO 1215
IW(KK)=RK
IF(MOD.TQ. 1) GO TO 1045
1365 IT=IYR+1
DO 1370 I=II,20
DO 1368 KK=1,7
IF(RL(KK) . EQ.0.) GO TO 1368
FOC(I,KK)=FOC(IYR,KK)
1368 CONTINUE
1370 CONTINUE
GO TO 1045
C DATA ABOUT COSTS ASSOCIATED WITH LINK IMPROVEMENT, IF ANY.
1400 IW(KK+1)=IK1
1405 CALL MATCH(ITYPE,IDLCT5,K,RK,0)
GO TO (1430,1410,1412,2090,1420),ITYPE
1410 RK=K
1412 KK=KK+1
PL(IW(KK))=9K
GO TO 1405
1420 IW(KK+1)=K
GO TO 1405
1430 CONTINUE
DC 1445 KKK=1,KK
IK=IW(KK)
KKK=IK-3
GO TO (1431,1435,1440,1444),KKK
1421 FTC(IYR)=FL(4)
GO TO 1445
1435 FTC(IYR)=FL(5)
GO TO 1445
1440 SKL(IYR)=FL(6)
GO TO 1445
1444 FOC(IYR)=FL(7)
1445 CONTINUE
1450 IF(UPD.EQ.0) GO TO 1455
IF(MOD.FC.1) GO TO 1045
1455 CONTINUE
II=IYR+1
DC 1490 I=IT,20
1490 IF(PL(4),F0.0,) GO TO 1460
1490 FTC(I)=FTC(IYR)
1460 IF(PL(5),F0.0,) GO TO 1465
1465 FTC(I)=FTC(IYR)
1465 IF(PL(6),F0.0,) GO TO 1470
1470 SKL(I)=SKL(IYR)
1470 IF(PL(7),F0.0,) GO TO 1490
1490 CONTINUE
1490 LARG=0
1490 GO TO 1050

C DATA ABOUT LINK LENGTH, CAPACITY, RISE AND FALL, DESIGN SPEED
1500 IR(KK+1)=IK
1505 CALL MATCH(IYAMK(1),KK,KK,0)
1510 RK=K
1512 KK=KK+1
1520 IN(KK+1)=K
1530 CONTINUE
1535 LFM(IYK)=RI(8)
1540 CAP(IYK)=PL(9)
1570 SAF(IYK)=PL(10)
1590 DSP(IYK)=PL(11)
1545 CONTINUE
1550 IF(UPD,BO.0) GO TO 1555
IF (MOD. EQ. 1) GO TO 1045
1555 CONTINUE
   II=II+1
   DO 1590 I=II,26
   IF (RL(I),EQ.0.) GO TO 1560
   LEN(I)=LEN(IYR)
1560 IF (RL(I),EQ.0.) GO TO 1575
   CAP(I)=CAP(IYR)
1575 IF (RL(I),EQ.0.) GO TO 1585
   PAF(I)=PAF(IYR)
1585 IF (RL(I),EQ.0.) GO TO 1590
   DSF(I)=DSF(IYR)
1590 CONTINUE
   LARG=0
   GO TO 1050
C ERRORS FORMATS
2001 WRITE (6,2002)
2002 FORMAT (/,'FORMAT ERROR IN FIRST COMMAND CARD')
   GO TO 10
2005 WRITE (6,2006)
2006 FORMAT (/,'FORMAT ERROR IN NETWORK COMMAND OR DATA CARDS')
   GO TO 10
2010 WRITE (6,2011)
2011 FORMAT (/,'FORMAT ERROR IN TIME HORIZON COMMAND CARD')
   GO TO 10
2015 WRITE (6,2016)
2016 FORMAT (/,'FORMAT ERROR IN LINK DATA OR STRATEGY COMMAND CARD')
   GO TO 10
2020 WRITE (6,2021)
2021 FORMAT (/,'FORMAT ERROR IN LINK DATA CARDS')
   GO TO 10
2025 WRITE (6,2026)
2026 FORMAT (/,'FORMAT ERROR IN BUDGET DATA CARDS')
   GO TO 400
2027 WRITE (6,2028)
2028 FORMAT (/,'FORMAT ERROR IN BUDGET CARDS')
GO TO 10
2030 WRITE(6,2031)
2031 FORMAT(/'FORMAT ERROR IN DEMAND O-D CARD'
   GO TO 10
2035 WRITE(6,2036)
2036 FORMAT(/'FORMAT ERROR IN DATA CARDS OF O-D DEMAND'
   GO TO 10
2040 WRITE(6,2041)
2041 FORMAT(/'FORMAT ERROR IN DATA CARD OF VOLUME'
   GO TO 600
2045 WRITE(6,2046)
2046 FORMAT(/'FORMAT ERROR IN DATA CARD OF ELASTICITY'
   GO TO 600
2050 WRITE(6,2051)
2051 FORMAT(/'FORMAT ERROR IN DATA CARD OF COMMODITY PRICE'
   GO TO 600
2055 WRITE(6,2056)
2056 FORMAT(/'FORMAT ERROR IN DATA CARD OF VALUE OF TIME'
   GO TO 600
2057 WRITE(6,2058)
2058 FORMAT(/'FORMAT ERROR IN DATA CARD OF LOAD FACTOR'
   GO TO 600
2060 WRITE(6,2061)
2061 FORMAT(/'FORMAT ERROR IN DATA OF VEHICLE CAPACITIES'
   GO TO 10
2065 WRITE(6,2066)
2066 FORMAT(/'FORMAT ERROR IN LINK-STRATEGY CARD'
   GO TO 10
2070 WRITE(6,2071)
2071 FORMAT(/'FORMAT ERROR IN LINK CHARACTERISTICS DATA CARD'
   GO TO 1045
2075 WRITE(6,2076)
2076 FORMAT(/'FORMAT ERROR IN AVERAGE TRAVEL TIME DATA CARD'
   GO TO 1045
2080 WRITE(6,2081)
2081 FORMAT(/'FORMAT ERROR IN ECONOMIC COSTS OF VEHICLE OPERATION DATA
1 CARD
GC TO 1045
2085 WRITE(6, 2086)
2086 FORMAT(/,'FORMAT ERROR IN FINANCIAL COSTS OF VEHICLE OPERATION DATA'
             1A CARD')
GC TO 1045
2090 WRITE(6, 2091)
2091 FORMAT(/,'FORMAT ERROR IN COST DATA ABOUT THE LINK'
             )
GC TO 1045
2095 WRITE(6, 2096)
2096 FORMAT(/,'FORMAT ERROR IN LINK LENGTH AND CAPACITY DATA'
             )
GC TO 1045
9999 STOP
END
SUBROUTINE GRAPH
C PROGRAM TO TEST IF DATA IS WRITTEN ACCURATELY IN THE DISK
C
DIMENSION VCAP(7), LBFG(30), LEND(30), LST(30), LREG(30), TB(10, 20),
       FR(110, 20), SL(10, 20), LLA(30, 30), LOD(30, 30), ATT(20, 7), FOC(20, 7),
       2POC(20, 7), ETC(20), FTC(20), SKL(20), POF(20), CAP(20),
       3DEMAND(20, 7), FIA(7), PRICE(7), VALT(7), PLOAD(7), RPF(20), DSP(20),
       RIAL LFN(20),
C READ THE BASIC DATA
C
READ(10,1) NLINK, NODE, NREG, IHORIZ, JIM, RATE, VCAP, LBEG, LEND, LST, LREG,
       1TE, FF, SL, IOPT
READ(10,2) LLA
READ(10,3) LOD
C PRINT THE BASIC DATA
C
WRITE(6,10) NLINK, NODE, IHORIZ, RATE, NREG
DC 90, I=1, NREG
WRITE(6,85) I
85 FORMAT(/,25X,' FOR REGION',I3)
WRITE(6,70)
70 FORMAT(/,3X,'YEAR',5X,'TOTAL BUDGET',10X, 'FOREIGN EXCHANGE',7X, 'SKILLED LABOR')
DO 75 J=1, IHORIZ
WRITE(6,60) J, TR(I,J), PR(I,J), SL(I,J)
60 FORMAT(3X, I3, 7X, F15.5, 9X, F15.5, 3X, F15.5)
75 CONTINUE
80 CONTINUE
WRITE(6,12) (I, I=1, 7)
12 FORMAT(/, 25X,' VEHICLE CAPACITIES', /, 5X, ' TYPES', 13X, 7(I2, 12X))
WRITE(6,14) (VCAP(I), I=1, 7)
15 CONTINUE
LAU=I
DC 330  I=1,NLINK
LAUC=10*(I-1)
KK=LST(I)
DO 292  J=1, KK
LAU=LAUC+J
READ (11'LAU) ATT, FOC, ETC, FTC, SKL, POF, LEN, CAP, RAP, DSP, ISTR, NCPIT, NSLIM
WRITE (6, 195) I
195 FORMAT ('//', ' LINK', I5, '/', '13X', 'STARTS', 2X, 'ENDS', 2X, 'REGION', 2X, 'STR
IAGETY #', 2X, 'CRITICAL INDEX', 2X, 'MAX SLIPPAGE')
WRITE (6, 20) LREG(I), LEND(I), LREG(I), ISTR, NCPIT, NSLIM
20 FORMAT (15X, I2, 5X, I2, 5X, I2, 11X, I2, 11X, I2, 12X, I2)
WRITE (6, 215)
215 FORMAT ('//', 'VEHICLE INFORMATION')
WRITE (6, 217)
217 FORMAT ('//', 'TRAVEL TIME ON THE LINK IN HOURS')
WRITE (6, 219)
1, 'V5', 10X, 'V6', 10X, 'V7', '/', 10X, 'YEAR')
DO 220  IK=1, IHORIZ
WRITE (6, 225) IK, (ATT(IK, IV), IV=1,7)
225 FORMAT (11X, I2, 22X, 7 (2X, F8.3, 2X))
220 CONTINUE
WRITE (6, 227)
227 FORMAT ('//', 'VEHICLE ECONOMIC COSTS IN $ FOR THE WHOLE LINK')
WRITE (6, 228)
1, 'V5', 10X, 'V6', 10X, 'V7', '/', 10X, 'YEAR')
DC 230  IK=1, IHORIZ
WRITE (6, 235) IK, (FOC(IK, IV), IV=1,7)
235 FORMAT (11X, I2, 22X, 7 (2X, F8.3, 2X))
230 CONTINUE
WRITE (6, 237)
237 FORMAT ('//', 'VEHICLE FINANCIAL COSTS IN $ FOR THE WHOLE LINK')
WRITE (6, 228)
1, 'V5', 10X, 'V6', 10X, 'V7', '/', 10X, 'YEAR')
DC 240  IK=1,ITHORIZ
WRITE (6,245) IK, (FOC(IK,IV), IV=1,7)
245 FORMAT (11X,I2,22X,7(2X,FR.3,2X))
240 CONTINUE
WRITE (6,250)
250 FORMAT (/40X,'LINK INFORMATION')
WRITE (6,301)
301 FORMAT (/1X,'YEAR',2X,'FINANCIAL COST',2X,'ECONOMIC COST',2X,'FOREIGN EXCHANGE',2X,'SKILLED LABOR',2X,'LINK LENGTH',2X,'LINK CAPACITY',2X,'DESIGN SPEED',2X,'(KMS)',2X,'(PCU/HR)',2X,'(M/100M)',2X,'(KMS/HR)')
DO 310 IK=1,ITHORIZ
WRITE (6,315) IK,FTC (IK),ETC (IK),FOR (IK),SCL (IK),LEN (IK),CAP (IK),RA
1,1X,F9.4,2X,F12.4)
310 CONTINUE
DO 260 IK=1,ITHORIZ
FTC (IK) = 0.
ETC (IK) = 0.
FOR (IK) = 0.
LEN (IK) = 0.
CAP (IK) = 0.
RA (IK) = 0.
DSP (IK) = 0.
DO 255 IV=1,7
ATT (IK,IV) = 0.
ECC (IK,IV) = 0.
FOC (IK,IV) = 0.
255 CONTINUE
260 CONTINUE
290 CONTINUE
300 CONTINUE
DO 230 ICE=1,NO
DC 19C KD=1, NODE
IF (IOP (K, KD), 30, 3) GO TO 19C
WRITE (6, 100) KG, KD, IOD (KG, KD)
100 FORMAT ('///', 'DATA FOR O-D PAIR: ', I2, ',', -I2, ', (STORED IN
1 RECORD, I2, '))
JMIC=IOD (KG, KD)
READ (12, JIMC) DEMAND, ELA, PRICE, VALT, FLOAD
WRITE (6, 102)
102 FORMAT ('///', 'DEMAND')
WRITE (6, 105)
1X, 'V5', '10X, 'V6', '10X, 'V7')
IF (IOP (E0, I)) GO TO 500
WRITE (6, 106)
106 FORMAT ('///', 'VEHICLES', '4X, 'VEHICLES', '2X, '5 (4X, 'TONS', '4X))
GO TO 550
500 WRITE (6, 510)
510 FORMAT ('///', 'VEHICLES', '2X))
550 DC 14D I=1, IHRIZ
WRITE (6, 115) I, (DEMAND (I, J), J=1, 7)
115 FORMAT ('///', 'DEMAND (I, J), J=1, 7)
140 CONTINUE
DC 143 I=1, IHRIZ
DO 142 J=1, 7
DEMAND (I, J) = 0.
142 CONTINUE
143 CONTINUE
WRITE (6, 145)
145 FORMAT ('///', 'TYPE', '33X, 'V1', '10X, 'V2', '10X, 'V3', '10X, 'V4', '10X, 'V5', '1
10X, 'V6', '10X, 'V7')
WRITE (6, 150) (ELA (I), I=1, 7)
150 FORMAT ('///', 'ELASTICITY WITH RESPECT TO TRANSPORT COSTS', '7 (2X, P8.4,
12X)
WRITE (6, 152) (PRICE (I), I=1, 7)
152 FORMAT ('///', 'COST OF TRANSPORT ($/VH), '7 (2X, P8.3, 2X)
WRITE (6, 153) (VALT (I), I=1, 7)
153  FORMAT(1 'VALUE OF TIME-PASSENGERS ($/PASS-HR)', 5X, 2(2X, F8.3, 2X))
      1, 16X, 'COMMODITIES ($/TON-HR)', 31X, 5(2X, F8.5, 2X))
      WRITE (6, 154) (FLOAD (I), I = 1, 7)
154  FORMAT(1 'LOAD FACTOR', 31X, 7(2X, F8.4, 2X))
      DC 151 IV = 1, 7
      ELA (IV) = 0.
      FLOAD (IV) = 0.
      PRICE (IV) = 0.
      VALT (IV) = 0.
151  CONTINUE
193  CONTINUE
200  CONTINUE
      RETURN
      END
SUBROUTINE MATCH (NATCH, LIST, K, RK, LARG)

MATCH READS A CARD IN 80A1 FORMAT INTO JBUP, CONVERTS EACH COLUMN TO AN INTEGER CODE IN IBUP, AND DECODES EACH LOGICAL FIELD ON THE CARD. THE LAST USABLE COLUMN IS INDICATED BY THE DATA SPECIFICATION FOR 'LASTCC'.

EACH CODE NUMBER REPRESENTS A CHARACTER AND IS FORMED INTO LIST WORDS BY COMBINING THE CODE TIMES SOME POWER OF 100. THUS IF A WORD MAY CONTAIN 4 CHARACTERS, (LIST(1)=4), AND THE WORD 'THE' IS TO BE REPRESENTED, THE CODED WORD IS 39272414, BLANK PADDED (14) ON THE RIGHT.

LIST=DICTIONARY ADDRESS (INTEGER ARRAY)

LIST(1)=NUMBER OF CHARACTERS/WORD
LIST(2)=NUMBER OF LIST WORDS IN DICTIONARY
LIST(3)=... TO LIST(N) ARE CODED WORDS
TOTAL LENGTH=LIST (2)+2 INTEGER WORDS

NATCH=

1, END OF STATEMENT
2, INTEGER NUMBER
3, REAL NUMBER
4, WORD NOT IN DICTIONARY
5, WORD IN DICTIONARY

CODE IS INTEGER DECIMAL, 00 TO 45, AS INDICATED BELOW.
THE CODES ARE AS FOLLOWS...

<table>
<thead>
<tr>
<th>CODE</th>
<th>CHARACTER REPRESENTED</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
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<tr>
<td>1</td>
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<td>9</td>
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</tr>
</tbody>
</table>
K = POSITION OF WORD IN DICTIONARY (EXCLUSIVE OF FIRST 2 CONTROL
WORDS) IF MATCH = 5
= NUMBER IF MATCH = 2
= SUBSCRIPT IN JBUF OF FIRST CHARACTER OF UNRECOGNIZED WORD
IF MATCH = 4
RK = REAL NUMBER IF MATCH = 3

LARG = 0, READ NEXT FIELD ON CARD
= 1, READ NEW CARD-FIRST FIELD

' $' IS CONTINUATION CARD MARK
$ IN CC1 IS A COMMENT CARD

THE MAXIMUM NUMBER OF CHARACTERS PER WORD DEPENDS ON THE
ALLOWABLE NUMBER OF DECIMAL DIGITS PFP INTEGER WORD.

IN SUBROUTINE CODES
THE ABOVE CODES ARE SET BY A DATA SPECIFICATION FOR LET (1-46)
LET(I) HAS THE CHARACTER REPRESENTATION (1H) OF THE CHARACTER
WITH CODE I-1.  THUS LET(21) = 'HA.

INTEGER BLANK, COMMA, PLUS, MINUS, DP
INTEGER LIST(2)
DIMENSION LET(46), TBUF (80)
DATA LET/ '0', '1', '2', '3', '4', '5', '6', '7', '8', '9', '+', '-', '1'
'2', '3', '4', '5', '6', '7', '8', '9', '0', '1', '2', '3', '4', '5', '6', '7', '8', '9', '+', '-', '1'
'2', '3', '4', '5', '6', '7', '8', '9', '0', '1', '2', '3', '4', '5', '6', '7', '8', '9', '+', '-', '1'

DATA LASTC, IREAD, IPRNT, BLANK, COMMA, PLUS, MINUS, DP/80, 5, 6, 14, 13, 10,
$11, 12/

ENTRY POINT-CHECK OP CODE
ANUMB = 0.0
L = IARG
IF (L. = 20.0) GO TO 110

L = 1, READ NEXT CARD, CONVERT TO DECIMAL CODE, SET BUFFER POINTER IC
TO FIRST NON-BLANK CHAR.
DO 800 ISS=1,80
     IFUP(TSS)=LET (15)
800 CONTINUE
     READ(TBASE,1000,ERR=801,END=802)TFUP
1000 FORMAT (30A1)
     GO TO 801
802 MATCH=6
     GO TO 290
801 DO 101 I=1,90
     DO 102 J=1,46
     IF(TBUF(I)-LET(J))102,103,102
102 CONTINUE
     NC MATCH-ILLEGAL CHARACTER,SET=50 IN TFUP
     TBUF(I)=50
     GO TO 101
103 MATCHED
     TBUF(I)=J-1
101 CONTINUE
     SET TC AS FIRST NON-BLANK COLUMN
     DO 104 I=1,LASTC
     TF(TBUF(I)-BLANK)105,104,105
104 CONTINUE
105 IC=I
C
C POINTED IS ALWAYS SET TO FIRST CHARACTER OF NEW FIELD ON LEAVING
C MATCH OR BY READING A NEW CARD-IT MAY BE LEFT PAST THE LAST
C RECOGNIZEABLE COLUMN,LASTCC
110 ICAP=TFUP(TC)
     IF(IC-LASTC)115,115,120
115 END OF STATEMENT
C
C NATCH=1
280 RETURN
C
C OK-CHECK IF NEW FIELD IS A NUMBER,-9,+,-,OR.
115 IF(ITAR-12)125,125,300
C    NUMBER FOUND-SET INITIAL PARAMETERS
C    DECIMAL POINT=NO
    125 IDP=0
C    NEGATIVE=NO
C    NO SIGNIFICANT DIGIT YET
    ISGN=1
C    NUMERICAL VALUE OF NUMBER (REAL OR INTGREF)
    NUMR=1
C    SAVE START OF NUMBER
    ICSTR =IC
C    IS FIRST CHAR A PLUS SIGN-IGNORE IF YES
    IF(ICAP=PLUS) 126, 130, 126
C    CHECK IF MINUS SIGN-SET ISIGN=1 IF YES
    126 IF(ICAP=MINUS) 135, 127, 135
    127 ISGN=1
R    LEADING PLUS OR MINUS SIGN-BUMP CARD COLUMN POINTER-CHECK
C    IF END OF FIELD
C    THIS IS GENERAL CC BUFFER SECTION OF CODE
    130 IC=IC+1
C    IC=IC+1
    IF(IC=LASTC ) 135, 135, 140
C    CHECK IF CC IS BLANK OR COMMA
    135 IF(ICAP=BLANK) 145, 140, 145
    145 IF(ICAP=COMMA) 150, 140, 150
C    NOT END OF FIELD-IS IT A DIGIT...
    150 IF(ICAP=9) 155, 155, 160
C    DIGIT (-9, DECIMAL POINT YET...
    155 IF(IDP=1) 165, 170, 165
C    ALREADY HAVE DP,N IS THUS NEGATIVE,NUMBER IN A NUMB
    170 ANUMB=ANUMB+FLOAT(ICAP)*10.**N
    N=N-1
G    GO TO 130
C    NO DP YET,IS DIGIT A ZER0...
    165 IF(ICAP) 175, 180, 175
C NOT ZERO, THUS IT IS SIGNIFICANT
175 ISIG=1
     GO TO 185
C ZER0-CHECK IF SIGNIFICANT, IF NOT SKIP
185 IF(ISIG-1) 130, 185, 130
     NUMB=10*NUMB+ICAF
     GO TO 130
C
C CHARACTER NOT DIGIT IS IT DP...
160 IF(ICAP-DP) 195, 190, 195
C YES, WAS ONE GIVEN PREVIOUSLY...
190 IF(TDP-1) 200, 99, 200
200 N=-1
     IDP=1
     A NUMB=NUMB
     GO TO 130
C
C NOT DIGIT OR DP, IS IT E..., IF NOT, ERROR(99)
195 IF(ICAP-24) 99, 205, 99
C E FOM-E(PLUS OR MINUS) N1, (N2)
205 IF(IDP-1) 210, 214, 210
C NO DP YET, FLOAT NUMBER
210 A NUMB=NUMB
     TEP=1
     I=1
214 C SIGN OF EXPONENT=PLUS
     TEP=+1
C VALUE OF EXPONENT=0
     TEP=0
C NEXT COLUMN
215 TC=IC+1
     ICAP=ICUP(TC)
     IF(IC-LASTC) 216, 216, 99
216 IF(ICAR-BLANK) 217, 99, 217
217 IF(ICAR-COMMA) 218, 99, 218
218 GO TO (222, 225), I
CHARACTER AFTER E IS IT PLUS, MINUS, OR DIGIT...

225 IF (ICAR - PLUS) 226, 230, 235
235 IF (ICAR - MINUS) 99, 240, 99

MINUS SIGN

240 IEP = -1
C HELP FOR PLUS SIGN ALSO
C RESET SWITCH AND GET NEXT COLUMN
230 I = 2
GO TO 215
C FIRST OF ONE OR TWO EXPONENT DIGITS
225 IF (ICAR - 9) 226, 226, 99
226 IFX = ICAR
T = 1

223 IC = IC + 1
ICAR = IBUF (IC)
IF (IC - IASTC) 231, 231, 250
231 IF (ICAR - BLANK) 227, 250, 227
227 IF (ICAR - COMMA) 228, 250, 228
228 GO TO (224, 99), I
224 IF (ICAR - 9) 229, 229, 99
229 T = 2
IFX = IC - IFX + ICAR
GO TO 223
C END OF F PGM - MULTIPLY NUMBER BY EXPONENT
250 AM = AM * (10 ** (IEP * IFX))
C
C END OF NUMBER, POINTER AT BLANK, COMMA, OR DEC
C IEP = 0, INTEGER IN NUMB-IPD = 1, FIXED IN AM

140 IF (ISCN - 1) 144, 144, 144
C NEGATE CHECK IF INTEGER OR REAL
141 IF (ITD) 142, 142, 142
C REAL
142 AM = - AM
GO TO 144
C INTEGER
143 AM = - AM

00002150 PGM30217
00002160 PGM30218
00002170 PGM30219
00002180 PGM30220
00002190 PGM30221
00002200 PGM30222
00002210 PGM30223
00002220 PGM30224
00002230 PGM30225
00002240 PGM30226
00002250 PGM30227
00002260 PGM30228
00002270 PGM30229
00002280 PGM30230
00002290 PGM30231
00002300 PGM30232
00002310 PGM30233
00002320 PGM30234
00002330 PGM30235
00002340 PGM30236
00002350 PGM30237
00002360 PGM30238
00002370 PGM30239
00002380 PGM30240
00002390 PGM30241
00002400 PGM30242
00002410 PGM30243
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C CHECK IF FIELDS IS SHORTER THAN DICT. WORDS
IF (NCW-NC) 440, 455, 455
C SHORTER=BLANK PAD
440 DC 445 I=1,NCW
IJK=ICSTR +I-1
445 IWD=100*IWD+1481(IJK)
DC 450 J=NCW1,NC
450 IWD=100*IWD+BLANK
GC TO 465
C NCW,NP,NC
455 DC 460 I=1,NC
IJK=ICSTR +I-1
460 IWD=100*IWD+1481(IJK)
C NOW IWD CONTAINS NC CHARACTERS TO COMPARE
C TO DICTIONARY WORDS
465 NWDS=LIST (2)
DC 475 I=1,NWDS
IF (IWD-LIST (I+2)) 475,485,475
475 CONTINUE
C WORD NOT FOUND IN DICTIONARY
NATCH=4
K=ICSTR
GO TO 270
C WORD FOUND IN DICTIONARY
480 K=T
NATCH=5
GO TO 270
C C ERROR IN NUMBER FIELD
93 WRITE(10987, 999)
K=ICSTR
NATCH =4
GO TO 270
999 FFORMAT(25H ERROR IN NUMBER FIELD.)
NETWORK STRATEGIES GENERATOR
DEFINE FILE 10(6,900,U,INF)
DEFINE FILE 11(300,583,U,LAU)

C THIS PROGRAM GENERATES NETWORK STRATEGIES FROM LINK-STRATEGIES

COMMON /AME/ IDICA(32), NGENE(32), IDILIM
COMMON /CRI/ PERCE, NCRITI(100)
COMMON /MIN/ MINCRI, MINSTR
COMMON /NUM/ NUMCRI(32), NUMM
COMMON /PER/ IMP, LEC
COMMON /SLI/ NSLIP, MC, NUMST, IDIC, NSR
COMMON /LYS/ NSLIMA(100), NUMBER(30), MEIS(30)
COMMON /FILE/ NLINK, NFEG, LST(30), IAA(30)
COMMON /SIR/ ILIM, JMAX, NUMLIM, NADD

INTEGER*2 IAA
DIMENSION NGECRI(32)

CALL INITIA
IDICA(JMAX+1)=JMAX+1
NUMSTR=1
ILIMFO=ILIM
MINSTR=ILIMFO
NUMM=1
DC 1 I=1,JMAX
IDICA(I)=I
NGENE(I)=0
CONTINUE
IDIR=1
NGIL=1
NGENE(1)=1
NGCRIC(1)=0
NGECRI(2)=NGERIC
4 ILDIL=ILDIL+1
IF(ILDIL.GT.JMAX) GO TO 2
11 IF(NGENE(IDIL).LT.NUMBER(IDII)) GC TC 3
    NGENE(IDII)=0
    IF(IDIL.LE.ILIMPO) GO TC 8
    GC TO 4
8 IF(IDIL.EQ.1) GO TO 9
    IDIL=IDIL-2
    IDIR=IDIR-1
    GO TO 7
9 IF(NUMSTR.NE.1) GO TO 16
    WRITE(IMP,502)
502 FORMAT(*1",' IT IS IMPOSSIBLE TO FIND A NETWORK-STRATEGY WHICH INC
1LUDES ALL OBLIGATORY LINK-STRATEGIES*/1")
    STOP
16 NUMMM=0
    CALL CRITIC
    CALL ECRIF
    STOP
3 ILIM=IDIR+1
    IDICA(IDIR)=IDIL
    NGENE(IDII)=NGENE(IDII)+1
    MC=NUMCUM(IDIL)+NGENE(IDII)-1
    NCRIGE=NCRIGE+NCRITI(MC)
    NCRIGE(IDII+1)=NCRIGE
    IF(NCRIGE.LT.MINCR) GC TO 4
    IF(IDIR.LE.MINSTR) GO TC 4
3 ILIM=IDIR
    IDIRC=IDIL
    CALL VERCAL
    IDIR=IDIR-1
    IDIL=ILIM
    I1=IDIL+1
    IF(I1.GT.JMAX) GO TO 19
    DC 12 I=I1,JMAX
19 CONTINUE
    CONTINUE
19 CONTINUE
MC = NUMCUM (IDIL) + NGENE (IDIL) - NC
NCRIGE = NGENE (IDIL+1) - NCRITI (MC)
IC TO 11
7 ILIM = IDIL + 1
MC = NUMCUM (ILIM) + NGENE (ILIM) - 1
NCRIGE = NGENE (ILIM+1) - NCRITI (MC)
I1 = ILIM + 1
DO 10 I = I1, JMAX
NGENE (I) = 0
10 CONTINUE
GC TO 4
2 DO 5 I = 1, JMAX
I1 = JMAX - I + 1
IF (NGENE (I1). EQ. 0) GC TO 5
IIDIL = I1 - 1
IDIR = 0
DO 6 J = 1, IDIL
IF (NGENE (J). NE. 0) IDIR = IDIR + 1
6 CONTINUE
GC TO 7
5 CONTINUE
NUMMM = 0
CALL CRITIC
CALL ECFIFF
STOP
END
SUPROUTINE VERCAL

COMMON /AME/ IDICA(32),NGENE(32),IDIIIM
COMMON /CCM/ KOMPTE,KCMIIIM
COMMON /IND/ INDEX
COMMON /IDR/ IDIR
COMMON /LYS/NSLIMA(100),NUMBER(30),MDIS(30)
COMMON /NUM/ NUMCUM(32),NUMMM
COMMON /FES/ NWSTRA(102,20),NWSLIP(102,20)
COMMON /PER/ IMP,LEC
COMMON /SLI/ NSLIP,MC,NUMSTR,IDIC,NSTR
COMMON /STR/ ILIM,JMAX,NUMLIN,NADD
COMMON /YEA/ NY,NUMDIS
COMMON /FILE/ NLINK,NREG,LST(30),IAC(30)
COMMON /VR//LL

INTEGER*2 IAA
DIMENSION IONVEP(31)

FIRST PART OF THE PROGRAM SEARCH OF A NETWORK STRATEGY WHICH INCLUDE

OBLIGATORY LINK-STRATEGIES

LL=1
CALL ZEC
DC 27 I=1,JMAX
IONVER(I)=0
27 CONTINUE
NUMST2=NUMSTR
IDIR=1
NSTR=0
INDEX=0
IDIC=IDICA(1)
IF(ILIM.EQ.0) GO TO 1
2 NSLIP=-NADD
NUMDIS=MDIS(IDIC)
3 NSIP=NGENE(IDIC)

PAGE 4
MC = NUMCUM(IDIC) + NSTR - 1
4 NSLIP = NSLIP + NADD
   CALL CALCUL
   IF(INDEX.EQ.1) GO TO 5
   IONVER(IDIR) = 1
   CALL REINIT
   IF(IDIC.LE.ILIM) GO TO 2
   IF(JMAX.GT.ILIM) GO TO 1
   GO TO 19
5 CALL REMEMB
6 IF(II.EQ.0) GO TO 26
   IF(NSLIP.LT.NSILMA(MC)) GO TO 4
   IF(IDC.EQ.1) GO TO 7
   NWSTRA(NUMSTR,IDIC) = 0
   ILIR = IDIR - 1
   IDIC = IDICA(IDIR)
   CALL RECAL
   GO TO 6
C SECOND PART OF THE PROGRAM SEARCH OF LINK-STRATEGIES WHICH MIGHT FIT
C THE NETWORK-STRATEGY ALREADY FOUND
1 CONTINUE
3 NSLIP = -NADD
   NUMDIS = MDIS(IDIC)
9 NSTR = NSTR + 1
   MC = NUMCUM(IDIC) + NSTR - 1
10 NSLIP = NSLIP + NADD
   CALL CALCUL
   IF(INDEX.EQ.1) GO TO 11
   CALL REINIT
15 IF(IDC.LE.JMAX) GO TO 8
16 NUMSTR = NUMSTR + 1
   DO 13 I = 1, JMAX
      NWSTRA(NUMSTR, I) = NWSTRA(NUMSTR - 1, I)
      NWSLIP(NUMSTR, I) = NWSLIP(NUMSTR - 1, I)
      13 CONTINUE
13 CONTINUE
CALL CRITIC
IF (NUMSTR.LT.NUMLIM) GO TO 12
NUMST2=0
12 CONTINUE
DO 20 I=1,JMAX
I1=JMAX+1-I
IF (NWSTRA(NUMSTR,I1).EQ.C) GO TO 20
MC=NUMCUM(I1)+NWSTRA(NUMSTR,I1)-1
IF (NWSLIF(NUMSTR,I1).LT.NSLIMA(MC)) GO TO 21
IF (I1.LE.ILIM) GO TO 28
IF (NWSTRA(NUMSTR,I1).LT.NUMBER(I1)) GO TO 21
20 NWSTRA(NUMSTR,I1)=0
CONTINUE
GO TO 26
21 IDIC=I1
CALL RECAL
IF (IDIC.GT.ILIM) GO TO 14
IDIF=0
DO 25 I=1,1DIC
IF (NWSTRA(NUMSTR,I).NE.C) IDIF=IDIF+1
25 CONTINUE
IDIR=IDIF+1
CONTINUE
GO TO 6
11 CALL REMEMB
14 IF (NWSLIF.LT.NSLIMA(MC)) GO TO 10
NSHIP=-NADD
IF (NSTR.LT.NUMBEP(IDIC)) GO TO 9
IDIC=IDIC+1
NSTR=0
GO TO 15
7 IF (NUMSTR.LE.NUMST2) GO TO 16
GO TO 26
16 DO 23 J=1,IDILIM
I=IDILIM+1-J
IF (ICNVER(I).EQ.0) GO TO 23
ILIM=IDICA(I)
ILILIM=I
GO TO 26
23 CONTINUE
RETURN
26 CONTINUE
DC 24 I=1,JMAX
NWSTRA(NUMSTP,I)=0
24 CONTINUE
RETURN
END
SUBROUTINE ADDCOM(CBAF,C1,C2,C)
C THIS SUBROUTINE MAKES C1=C2+C TAKING INTO ACCOUNT A SLIPPAGE OF N YEARS
C, AND COMPARES THE C1 TO CBAR. INDEX=1 IF ONE OF THE ELEMENTS
C OF C1 IS GREATER THAN THE CORRESPONDING ELEMENT IN CBAF. INDEX=2
C OTHERWISE

DIMENSION CBAR(10,20),C1(10,20),C2(10,20),C(20)
COMMON /IND/ INDEX
COMMON /SLI/ NSLIP,MC,NUMSTR,IDIC,NSTR
COMMON /YFA/ NY,NUMDIS
COMMON /FILE/ NLINK,NREG,LST(30),IAA(30)
INTEGER*2 IAA

N1=NSLIP+1
IF(N1.LE.NY) GO TO 3
WRITE(6,501)
501 FORMAT(' I ','SOMETHING STRANGE ONE SLIPPAGE EQUALS NY OR MORE'/
11')
STOP
3 4 I=N1,NY
C1(NUMDIS,I)=C2(NUMDIS,I)+C(I-NSLIP)
IF(C1(NUMDIS,I).LT.CBAR(NUMDIS,I)) GO TO 4
INDEX=1
RETURN
CONTINUE
RETURN
END
SUBROUTINE CALCUL

COMMON/AVE/ GECO1(10,20), GECO2(10,20), GEFO1(10,20), GEFO2(10,20),
GESK1(10,20), GESK2(10,20),
COMMON/AVE/ KOMPTE, KCMIIIM
COMMON/IND/ INDEX
COMMON/LIM/ COSTMA(1C,2C), FOCAMA(1C,2C), SKLAMA(10,20)
COMMON/PAE/ COST(20,100), FOREIG(20,100), SKILLE(20,100)
COMMON/SLI/ NSLIP, MC, NUMSTR, IDIC, NSTR

C FOR REGIONAL BUDGET CONSTRAINTS
CALL ADDCOM(COSTMA, GECO2, GEC01, CCST(1, MC))
IF (INDEX.EQ.1) RETURN
C FOR REGIONAL FOREIGN EXCHANGE
CALL ADDCOM(FOCAMA, GECO2, GEFO1, FOFEIG(1, MC))
IF (INDEX.EQ.1) RETURN
C FOR REGIONAL SKILLED LABOR
CALL ADDCOM(SKLAMA, GESK2, GESK1, SKILLE(1, MC))
RETURN
END
SUBROUTINE PEMEMB

C THIS SUBROUTINE GIVES BACK THE CLD VALUES TO THE VECTORS USED IN PRUNI

COMMON/AVE/ GECO1, GECO2, GEFC1, GEFC2, GESK1, GESK2
COMMON/IND/ INDEX
COMMON/SLI/NSLIP, MC, NVMSTR, IDIC, NSTR
COMMON/YEA/NY, NUMDIS

N1=NSLIP+1
IF(N1.GT.NY) RETURN
DO 1 I=N1,NY
GECO2(NUMDIS,I)=GECO1(NUMDIS,I)
GEFC2(NUMDIS,I)=GEFC1(NUMDIS,I)
GESK2(NUMDIS,I)=GESK1(NUMDIS,I)
1 CONTINUE
INDEX=0
RETURN
END
SUBROUTINE RECAL

THIS SUBROUTINE Initializes some matrices after going back to a link strategy with a lower number of reference.

COMMON /AME/ IDICA(32), NGENE(32), IDILIM
COMMON /AVE/ GECO1(10,20), GECO2(10,20), GEFO1(10,20), GEFO2(10,20),
GESK1(10,20), GESK2(10,20)
COMMON /IP/ IDIP
COMMON /LYS/ NSLIMA(100), NUMBER(30), MDIS(30)
COMMON /NUM/ NUMCUM(32), NUMMM
COMMON /RAP/ RECOST(30,10,20), REFCRE(30,10,20), RESKIL(30,10,20)
COMMON /FES/ NWSTRA(102,20), NWSLIP(102,20)
COMMON /SL/ NSLIP, MC, NUMSTR, IDIC, NSTR
COMMON /STR/ ILIM, JMAX, NUMLIM, NADD
COMMON /YIA/ NY, NUMDIS
COMMON /FILE/ NLINK, NREG, LST(30), IAA(30)

INTEGER*2 IAA

NSTP=NWSIF (NUMSTR, ILIC)
NSLIP=NWSILP (NUMSTR, IDIC)
NUMDIS=MDIS (IDIC)
MC=NUMCUM (IDIC)*NSTP-1
IF(IDIC.EQ.1) GO TO 8
1=IDIC-1
DO 3 I=1,NREG
DO 4 J=1,11
J1=IDIC-J
IF(NWSTRA(NUMSTR, J1).EQ.0) GO TO 4
IF(I.NE.MDIS(J1)) GC TC 4
DC 5 K=1,NY
GECO2(I,K)=RECOST(J1,I,K)
GECO1(I,K)=GECO2(I,K)
GESK2(I,K)=RFSKIL(J1,I,K)
SUBROUTINE PEINIT

C THIS SUBROUTINE INITIALIZES SOME MATRICES AFTER A LINK STRATEGY IS FOUND TO FIT INTO A NETWORK STRATEGY

COMMON /AME/ IDICA(32), NGFNE(32), IDILIM
COMMON /AVE/ GECO1(10, 20), GECO2(10, 20), GEPO1(10, 20), GEPO2(10, 20), GESK1(10, 20), GESK2(10, 20)
COMMON /IDR/ IDIP
COMMON /EAI/ RECOST(30, 10, 20), REPORE(30, 10, 20), RESKIL(30, 10, 20)
COMMON /ESI/ NWSLIP(102, 20), NWSLIP(102, 20)
COMMON /YEA/ NY, NUMDIS

NWSLIP(NUMSTR, IDIC) = NSTR
NWSLIP(NUMSTR, IDIC) = NSTR

1 CONTINUE
NSTR = 0
IF (IDIR .NE. IDILIM) GO TO 2
IDIR = IDIR + 1
IDIC = IDICA(IDIR)
GO TO 3

2 IDTC = IDIC + 1
1 CONTINUE
RETURN
END
GESK1(I,K) = GESK2(I,K)
5 CONTINUE
GO TO 3
4 CONTINUE
3 CONTINUE
GO TO 11
9 CONTINUE
CALL ZRFC
11 CONTINUE
DC 2 I=IC,JMAX
NWSTRA(NUMSTP,I)=0
2 CONTINUE
RETURN
END
SUBROUTINE CRITIC

THIS SUBROUTINE COMPUTES CRITICAL INDICES FOR NETWORK-STRATEGIES AND
FROM STRATEGIES WITH LOW INDEX

COMMON /CRI/ PERCE,NCRIT(100)
COMMON /RES/ NWSTRA (102,20),NWSTIP (102,20)
COMMON /MIN/ MINCRI,MINST1
COMMON /NUM/ NUMSTR (102),NUMMM
COMMON /STI/ NSLIP,MC,NUMST1,IDIC,NST1
COMMON /STR/ ILIM,JMAX,NUMLIM,NALE
COMMON /TRA/ NUMAX
COMMON /FILE/ NLINK,NREG,IST (30),IAA (30)
COMMON /YEA/ NY,NUMDIS
COMMON /LYS/ NSLIMA(100),NUMBER (30),MDIS (30)
COMMON /PAR/ COST (20,100),PORFIG (20,100),SKILLE (20,100)
COMMON /VB/LL
INTEGER*2 IAA
DIMENSION NWCRIT(102)
DIMENSION NBSTRA (102)
NUMST1=NUMSTR-1
IF(NUMST1.GE.NUMAX) GO TO 28
IF (NUMMM.LE.0) RETURN
NUMST1=NUMSTR
NUMAX=NUMST1
28 CONTINUE
DO 21 I=1,NUMST1
J=0
DO 22 K=1,JMAX
IF (NWSTRA(I,K).EQ.0) GC TO 22
J=J+1
22 CONTINUE
NBSTRA(I)=J
21 CONTINUE
DO 23 I=1,NUMAX
J=0
DC 24 K=1,NUMST1
JJ=NBSTRA(K)
IF(JJ.LE.J) GO TO 24
J=JJ
K1=K
24 CONTINUE
NBSTRA(K1)=-J
23 CONTINUE
JJ=-NBSTRA(K1)
J=0
DO 25 I=1,NUMST1
J=0
IF(NBSTRA(I).LT.0) GO TO 26
IF(NBSTRA(I).LT.JJ) GO TO 25
26 J=J+1
IF(I.EQ.J) GO TO 25
DO 27 K=1,JMAX
NWSTRA(J,K)=NWSTRA(I,K)
27 CONTINUE
25 CONTINUE
NUMST1=J
IF(NUMST1.LT.NUMAX) NUMST1=NUMAX
MINSTR=JJ
DO 1 I=1,NUMST1
J=0
DO 2 K=1,JMAX
IF(NWSTRA(I,K).EQ.0) GO TO 2
MC=NUMCUM(K)+NWSTRA(I,K)-1
J=J+NCRIT(MC)
2 CONTINUE
NWCRIT(I)=J
1 CONTINUE
II=0
DC 5 I=1,NUMAX
J=0
DC 6 K=1,NUMST1
JJ=NWCRIT(K)
IF(JJ.LE.J) GO TO 6
J=JJ
K1=K
6 CONTINUE
NWCRIT(K1)=-J
5 CONTINUE
K=1
JJ=-100000
7 DO 7 I=1,NUMST1
IF(NWCRIT(I).GE.0) GO TO 7
IF(NWCRIT(I).GT.JJ) JJ=NWCRIT(I)
DO 8 J=1,JMAX
IF(K.NE.I) IL=1
NWSTRA(K,J)=NWSTRA(I,J)
NWSLIP(K,J)=NWSLIP(I,J)
8 CONTINUE
K=K+1
IF(K.GT.NUMAX) GO TO 9
7 CONTINUE
9 NUMSTR=NUMAX+1
MINCRI=-JJ
IF(NUMMM.NE.1) GO TO 11
DO 10 I=1,JMAX
NWSTRA(NUMSTR,I)=NWSTRA(NUMLIN,I)
NWSLIP(NUMSTR,I)=NWSLIP(NUMLIN,I)
10 CONTINUE
RETURN
11 K=NUMAX-1
DO 12 I=1,K
I1=I
JJ=I+1
K1=NWCRIT(I)
12 DO 13 J=JJ,JMAX
I1=J
IF(K1.LT.NWCRIT(J)) GO TO 13
K1=NWCRIT(J)
13 RETURN
13 CONTINUE
   IF (I1.EQ.I) GO TO 12
   DC 14 J=1,JMAX
   N1=NWSTRA(I1,J)
   N2=NWSLIP(I1,J)
   NWSTRA(I1,J)=NWSTRA(I,J)
   NWSLIP(I1,J)=NWSLIP(I,J)
   NWSTRA(I,J)=N1
   NWSLIP(I,J)=N2
14 CONTINUE
12 CONTINUE
RETURN
END
SUBROUTINE ECRIRE

COMMON/PAR/COST(2C,100),PORFIG(20,100),SKILLE(20,100)
COMMON/PER/IMPLE
COMMON/RES/NWSTRA(102,20),NWSLIP(102,20)
COMMON/STR/ILIM,JMAX,KUMLIM,NADE
COMMON/TRA/NUMAX
COMMON/LYS/NSLIMA(100),NUMBER(30),MDIS(30)
COMMON/NUM/NMCUM(32),NUMM
COMMON/CPI/PERCE,NCRITI(100)
COMMON/EXECOST(30,20),BCOST(20)
COMMON/YFA/NY,NUMEIS
COMMON/FILE/NLINK,NREG,LST(30),IAA(30)

INTEGER IAA
INTEGER LFT(52),NWSTRA(30,30),NWSLIP(30,30),IN(30,30)
DIMENSION NWSTR(30,30),NWSL(30,30),NUM(420),ETC(20),ETCB(20)

DATA LFT/2H 0,2H 1,2H 2,2H 3,2H 4,2H 5,2H 6,2H 7,2H 8,2H 9,2H 10,2
  1H 11,2H 12,2H 13,2H 14,2H 15,2H 16,2H 17,2H 18,2H 19,2H 20,2H 21,2H 22,2H 23,2H
  224,2H 25,2H 26,2H 27,2H 28,2H 29,2H 30,2H 31,2H 32,2H 33,2H 34,2H 35,2H 36,2H 37,
  2H 38,2H 39,2H 40,2H 41,2H 42,2H 43,2H 44,2H 45,2H 46,2H 47,2H 48,2H 49,2H 50
  4,2H /
DATA NWSTR/900*0/
DATA NWSL/900*0/
DO 1 T=1,NUMAX
DC 50 JJ=1,16
NWSTRA(I,JJ)=LFT(52)
NWSLIP(I,JJ)=LFT(52)
IN(T,JJ)=LFT(52)
50 CONTINUE
KKK=JMAX+1
IF(KKK,GT.16)GO TO 53
DO 52 KJ=KKK,16
IAA(KJ)=LFT(52)
52 CONTINUE
DO 2 K=1,JMAX
  IF(NWSTRA(I,K).EQ.0) GO TO 2
  DO 4 L=1,16
  IF(NWSTRA(I,K).EQ.L) GO TO 5
  CONTINUE
  NWSTRA(I,K) = LET(L+1)
  DO 6 L=1,17
    L1=1-L
    IF(NWSLIF(I,K).EQ.L1) GO TO 7
  CONTINUE
  NWSLIF(I,K) = LET(L)
  CONTINUE
  DC 30 I=1,NUMAX
  DO 25 K=1,NLINK
    ETC(IE) = 0.
    GO TO 2
  CONTINUE
  GO TO 51
  LAU=10*(K-1)+1
  GC TC 71
  LAU=10*(K-1)+IK
  GO TO 310
  IF(E1.EQ.1) GO TO 325
  IF(E1.GT.IY) GO TO 330
  IF(E2.EQ.5) GO TO 326
  IF(E2.GT.E3) GO TO 310
  TCOST(I,N) = TCOST(I,N) + ETC(1)
DO 10 K=1,JMAX
   IF (NWSTFA (I,K) .LE.0) GO TO 101
   II=NWSTFA (K)-1+NWSTRA (I,K)
   DO 20 L=1,52
      L1=L-1
      IF (NCRITI (II).EQ.L1) GC TO 27
   20 CONTINUE
   IN(I,K)=IFT (I)
   CONTINUE
   KK=JMAX+1
   IF (KK.GE.15) GC TO 40
   WRITE (6,502) I, (NWSTRA (I,K), K=1,16), (MWSLIP (I,K), K=1,16), (IN(I,K), K=1,16)
   CONTINUE
   10 CONTINUE
   50 2 FORMAT ('* ',13X,'**',16(6X,'**')/* N.S. 'I3,'**',16(2X,'A2',2X,'**')/** 13X,'**',16(6X,'**')/* SLACK7,X,'**',16(2X,'A2',2X,'**')/** 26 I,A,'13X,'**',16(2X,'A2',2X,'**')/** 13X,'**',16(6X,'**')/1X,127(** })
CONTINUE
DO 150 I=1,NUMAX
DC 140 K=1,JMAX
IJ=IAA(K)
NWSTRA(I,K)=NWSTRA(I,K)
NWSL(I,K)=NWSL(I,K)
CONTINUE
DO 190 I=1,NUMAX,5
II=I+4
WRITE(6,85) (K,K=KK,II)
FORMAT('1',20X,'TOTAL EXPENDITURES ($'),/ ,20X,23('*'),/ ,2X,'YEAR'
,,5X,5('6X','N.S.',I3,9X))
DC 200 J=1,NY
WRITE(6,87) J, (TCOST(K,J),K=KK,II)
FORMAT(3X,12,6X,5(F20.0,2X))
CONTINUE
DO 210 J=1,NY
WRITE(6,100) J,BCOST(J)
FORMAT(3X,12,8X,F20.3)
CONTINUE
RETURN
END
SUBROUTINE MATCH (NATCHLIST,K,RK,LAPG)
INTEGER BLANK,COMMA,PLUS,MINUS,DP
INTEGER LIST(8)
DIMENSION LET(46),IBUF(8C)
DATA LASTC,IRFAD,IPRNT, BLANK,COMMA,PLUS,MINUS,DP/80,5,6,14,13,10,60001020 PGM10009
$11,12/
C ENTRY POINT-CHECK CP CODE
ANUMB=0.0
L=LARG
IF(L.EQ.0) GO TO 110
L=1,READ NEW CARD,CONVERT TO DECIMAL CODE,SET BUFFER POINTER IC
TC FIRST NON-BLANK CHAR.
DC 800 ISS=1,80
IBUF(ISS)=LET(15)
800 CONTINUE
READ(IREAD,10C0,ERR=8C1,END=8C2) IBUF
1000 FORMAT(80A1)
GC TO 8C1
8C1 DC 101 I=1,90
DO 102 J=1,46
IF (IBUF(I)-LET(J)) 102,103,102
102 CONTINUE
C MATCH-ILLEGAL CHARACTER,SET=50 IN IBUF
IBUF(I)=50
GC TO 101
C MATCHED
103 IBUF(I)=J-1
101 CONTINUE
C SET IC AS FIRST NON-BLANK COLUMN
DC 104 I=1, LASTC
IF (IBUF (I) - BLANK) 105, 104, 105
104 CONTINUE
105 IC = I
C
C POINTER IS ALWAYS SET TO FIRST CHARACTER OF NEW FIELD ON LEAVING
C MATCH OR BY READING A NEW CARD-IT MAY BE LEFT PAST THE LAST
C RECOGNIZABLE COLUMN, LASTCC
110 ICAR = IBUF (IC)
IF (IC - LASTC) 115, 115, 120
110 END OF STATEMENT
120 MATCH = 1
280 RETURN
C
C OK-CHECK IF NEW FIELD IS A NUMBER, 0-9, +, -, OR.
115 IF (ICAR - 12) 125, 125, 300
C NUMBER FOUND-SET INITIAL PARAMETERS
C DECIMAL POINT = NO
125 IDP = 0
C NEGATIVE = NO
ISGN = 0
C NO SIGNIFICANT DIGIT YET
ISIG = 0
C NUMERICAL VALUE OF NUMBER (REAL OR INTEGER)
NUMB = 0
C SAVE START OF NUMBER
ICSTR = IC
C IS FIRST CHAR A PLUS SIGN-IGNORE IF YES
IF (ICAR - PLUS) 126, 130, 126
C CHECK IF MINUS SIGN-SET ISIGN = 1 IF YES
126 IF (ICAR - MINUS) 135, 127, 135
C LEADING PLUS OR MINUS SIGN-BUMP CARD COLUMN POINTER-CHECK
C IF END OF FIELD
C THIS IS GENERAL CC BUFFER SECTION OF CODE
130 IC=IC+1
  ICAR=IBUF(IC)
  IF (IC-LASTC) 135,135,140
C CHECK IF CC IS BLANK OR COMMA
135 IF (ICAR-ELANK) 145,140,145
145 IF (ICAR-CCMMA) 150,140,150
C NOT END OF FIELD--IS IT A DIGIT...
150 IF (ICAR-9) 155,155,160
C DIGIT 0-9, DECIAML POINT YET...
155 IF (IDP-1) 165,170,165
C ALREADY HAVE DP, N IS THE NEGATIVE, NUMBER IN A NUMB
170 ANUMB=ANUMB+FLOAT (ICAR)* (10.**N)
N=N-1
  GC TO 130
C NOT DP YET, IS DIGIT A ZERO...
165 IF (ICAR) 175,180,175
C NOT ZERO, THUS IT IS SIGNIFICANT
175 ISIG=1
  GO TO 185
C ZERO-CHECK IF SIGNIFICANT, IF NOT SKIP
180 IF (ISIG-1) 130,185,130
185 NUMB=10*NUMB+ICAF
  GO TO 130
C CHARACTER NOT DIGIT IS IT DF...
160 IF (ICAF-DF) 195,190,195
C YES, WAS ONE GIVEN PREVIOUSLY...
190 IF (IDP-1) 200,99,200
200 N=-1
  IDP=1
  ANUMB=NUME
  GO TO 130
C NOT DIGIT OR DP, IS IT F... IF NOT, ERROR(99)
195 IF (ICAR-24) 99,205,99
C & FORM-E (PLUS OR MINUS) M1, (N2)
205 IF(IDP-1) 210, 214, 210
C NO DP YET, PLCAT NUMBER
210 ANUMB=NUMB
IDP=1
214 I=1
C SIGN OF EXPONENT=PLUS
IFP=+1
C VALUE OF EXPONENT=0
IX=0
C NEXT COLUMN
215 IC=IC+1
ICAR=IBUF(IC)
IF(IC-LASTC) 216, 216, 59
216 IF(ICAR-BLANK) 217, 99, 217
217 IF(ICAR-COMMA) 218, 99, 218
218 GO TO (220, 225), T
C CHARACTER AFTER E, IS IT PLUS, MINSUS, OR DIGIT...
220 IF(ICAR-PLUS) 226, 230, 235
235 IF(ICAR-MINUS) 99, 240, 99
C MINSUS SIGN
240 IFP=-1
C HERE FOR PLUS SIGN ALSO
C RESET SWITCH AND GET NEXT COLUMN
230 I=2
GO TO 215
C FIRST OF ONE OR TWO EXPONENT DIGITS
225 IF(ICAR-9) 226, 226, 99
226 IPX=ICAR
I=1
223 IC=IC+1
ICAR=IBUF(IC)
IF(IC-LASTC) 231, 231, 250
231 IF(ICAR-BLANK) 227, 250, 227
227 IF(ICAR-COMMA) 228, 250, 228
228 GO TO (224, 99), T
224 IF(ICAR-9) 229, 229, 99
I=2
IEX=10*IEX+ICAR
GO TO 223

C END OF F FORM-MULTIPLY NUMBER BY EXPONENT
ANUMB=ANUMB*(10.**(IEX*IEX))

C END OF NUMBER, POINTER AT BLANK, COMMA, CR ECC
140 IF (ISGN=1) 144, 141, 144
C IEP=0, INTEGER IN NUMB, IEP=1, REAL IN ANUMB
C NEGATE-CHECK IF INTEGER OR REAL
141 IF (IDP) 142, 143, 144
C REAL
142 ANUMB=-ANUMB
GO TO 144
C INTEGER
143 NUMB=-NUMB
144 NATCH=IDP+2
K=NUMB
RK=ANUMB
C POINTER AT BLANK, COMMA, CR EOC-BUMP TO A NON-BLANK, NON-COMMA
C CHARACTER OR LEAVE AT EOC, THIS SECTION OF CODE IS USED
C BEFORE RETURNING
270 IF (IC-LASTC ) 271, 271, 280
271 IC=IC+1
IF (IC-LASTC ) 272, 272, 280
272 IF (IBUF (IC) =BLANK) 273, 271, 273
273 IF (IBUF (IC) =COMMA) 280, 271, 280
C FIRST CHAR IS NOT EOC, NUMBER-IS IT $...
300 IF (ICAR-17) 330, 120, 330
C BY ELIMINATION, THE FIELD IS A WORD-SAVE IC AND GET END OF WORD.
C FCFM PACKED WORD IN DECIMAL CODE TO COMPARE AGAINST LIST-NEED
C FIRST WORD IN LIST AS NUMBER OF CHARS IN WORD.
C BLANK PAD ON RIGHT.

330 ICSTR =IC
410 IC=IC+1
   ICAR=IBUF(IC)
   IF(IC-LASTC ) 415,415,42C
415 IF(ICAR-COMMA)4 05,420,405
405 IF(ICAR-BLANK)410,420,410
C END OF FIELD
C 42C IIND=IC-1
C USE LIST FIRST
NC=LIST (1)
C GET CHARACTERS IN WORD
NCW=IEND+1-ICSTP
NCW1=NCW+1
IWD=0
C CHECK IF FIELDS IS SHORTER THAN DICT. WORDS
IF(NCW-NC)4409,455,455
C SHORTER-BLANK PAD
440 DO 445  I=1,NCW
   IJK=ICSTR +I-1
445 IWD=100*IWD+IBUF(IJK)
   DO 450  I=NCW1,NC
   GC TO 466
450 IWD=100*IWD+BLANK
C NCW,GE,NC
455 DC 460  I=1,NC
   IJK=ICSTR +I-1
460 IWD=100*IWD+IBUF(IJK)
C NOW IWD CONTAINS NC CHARACTERS TO COMPARE
C TO DICTIONARY WORDS
465 NWDS=LIST(2)
   DC 475  I=1,NWDS
   IF(IWD-LIST(I+2))475,480,475
475 CONTINUE
C WORD NOT FOUND IN DICTIONARY
   MATCH=4
   K=ICSTIR
   GO TO 270
C WORD FOUND IN DICTIONARY
   480 K=I
   MATCH=5
   GO TO 270
C C C C ERROR IN NUMBER FIELD
   99 WRITE(IERNT, 999)
   K=ICSTIR
   MATCH =4
   GO TO 270
   999 FORMAT(25H ERROR IN NUMERIC FIELD.)
C C C RETURN
   END
SUBROUTINE INITIA
COMMON /AVI/ GECO1(10,20),GECO2(10,20),GEPO1(10,20),GEFC2(10,20),
1GESK1(10,20),GESK2(10,20)
COMMON /CCM/ KOMPTE,KOMIM
COMMON /CRT/ PERCE,NCRITI(100)
COMMON /LIM/ COSTMA(10,20),FOCAMA(10,20),SKLAMA(10,20)
COMMON /LYS/NSSLIMA(100),NUMBER(30),MDIS(30)
COMMON /MIN/ MINCRE,MINTF
COMMON /NUM/ NUMCUM(32),NUMM
COMMON /PAR/ COST(20,100),FOREIG(20,100),SKILLE(20,100)
COMMON /PER/ IMP,LEC
COMMON /EXF/TCOST(30,20),BCOST(20)
COMMON /FAE/ RECOST(30,10,20),REFGRE(30,10,20),RESKIL(30,10,20)
COMMON /RES/ NWSTRA(102,20),NWSLIP(102,20)
COMMON /STR/ ILIM,JMAX,NUMLIM,NADD
COMMON /TRA/ NUMAX
COMMON /YEA/ NY,NUMDIS
COMMON /FILE/ NLINK,NREG,IST(30),IAA(30)
INTEGER*2 IAA
DIMENSION VCAP(7),LDUM(6C),DUMMY(420),ETC(20),FTC(20),SKL(20),FOR
1(20),IDICT(9),F1C(900),LUM(80)

C WORKS IN IDICT: NETWORK,CBLIGATCRY,OPTIONAL,PERCENTAGE,MIMIMUM,SLIPAGE,GENERA
C TE
DATA IDICT/3,7,332439,342131,343539,352437,322833,3r33128,262433/
DATA F1C/900*/
WRITE(10,4) F10
WRITE(10,5) P10
WRITE(10,6) F10
ILIM=0
JMAX=0
DC 51 I=1,30
IAA(I)=0
51 CONTINUE
DO 61 I=1,30
DC 62 N=1,20
TCSF(I1,N)=0.
62 CONTINUE
61 CONTINUE
C ASSIGN DATA TO THE VARIABLES
C READ THE BASIC FILE
READ(10*)NLINK,NODE,NREC,NY,JIM,RATE,VCAP,LEUM,LST,MDIS,COSTMA,FO
1CAM,SKLAMA
10 CALL MATCH(ITYPE,IDICT,K,RK,1)
GC TO (100,100,100,100,18,95),ITYPE
18 IK1=K
GO TO (20,30,50,80,40,90),IK1
C NETWORK STRATEGIES
20 CALL MATCH(ITYPE,IDICT,K,RK,0)
GO TO (10,25,110,20,20),IYPE
25 NULIM=K
GC TO 10
C OBLIGATORY LINKS
30 KK=0
35 CALL MATCH(ITYPE,IDICT,K,RK,0)
GO TO (39,38,120,35,35),IYPE
39 KK=KK+1
IAA(KK)=K
GC TO 35
39 ILIM=KK
JMAX=ILIM
GO TO 10
C INCREMENTAL SLIPPAGE
40 CALL MATCH(ITYPE,IDICT,K,RK,0)
GO TO (10,48,45,40,40),IYPE
45 K=KK
48 NADD=K
C OPTIONAL LINKS
50 KK=0
55 CALL MATCH (ITYPE, IDICT, K, RK, ?)
   GC TO (60, 58, 130, 55, 55), ITYPE
58 RK=KK+1
   J=ILIM+KK
   IAA(J)=K
   GC TO 55
60 JMAX=ILIM+KK
   GC TO 10
C PERCENTAGE CF N.S.
70 CALL MATCH (ITYPE, IDICT, K, RK, ?)
   GC TC (10, 140, 75, 70, 70), ITYPE
75 PERC2=KK
   GC TO 10
80 CALL MATCH (ITYPE, IDICT, K, RK, ?)
   GC TO (10, 85, 150, 80, 80), ITYPE
85 MINCHI=K
   GC TC 10
100 WRITE (6, 105)
105 FORMAT (/,' ERROR IN COMMAND CARD')
   GC TO 10
110 WRITE (6, 115)
115 FORMAT (/,' ERROR IN NETWORK CARD')
   GC TO 10
120 WRITE (6, 125)
125 FORMAT (/,' ERROR IN OBLIGATORY LINKS CARD')
   GC TO 10
130 WRITE (6, 135)
135 FORMAT (/,' ERROR IN OPTIONAL LINKS CARD')
   GC TO 10
140 WRITE (6, 145)
145 FORMAT (/,' ERROR IN PERCENTAGE CARD')
   GC TO 10
150 WRITE (6, 155)
155  FORMAT(/, ERROR IN CRITICAL INDEX CARD/)  
GO TO 10
95  CALL EXIT
90  CONTINUE
    CALL BUDGET(JMAX)
    NUMCUM(1)=1
    DC 250 I=1,JMAX
    LINK=IAA(I)
    NUMBER(I)=LST(LINK)
    NN=NUMBER(I)
    NUMCUM(I+1)=NUMCUM(I)+X
    LAUC=10*(LINK-1)
    DO 240 II=1,NN
    LAU=LAUC+II
    DO 230 K=1,NY
        CCST(K,J)=FTC(K)
        FCREIG(K,J)=FOR(K)
        SKILLE(K,J)=SKL(K)
    230 CONTINUE
    NSLIM(J)=NSLIM
    NCRIT(J)=NCRIT
    NSLIM=0
    NCRIT=0
    DO 225 K=1,NY
        FTC(K)=0.
        FOR(K)=0.
        SKL(K)=0.
    225 CONTINUE
240 CONTINUE
250 CONTINUE
    N1=NUMCUM(JMAX+1)-1
    DO 2 J=1,NEREG
    DO 3 I=1,NY
        SEC01(J,I)=0.
GEFO1(I,J)=0.
GESKI(J,I)=0.
PECOST(1,J,I)=0.
REFORE(1,J,I)=0.
RESKIL(1,J,I)=0.
CONTINUE
CONTINUE
CONTINUE
CONTINUE
NUMAX=NUMIM*FORCE
RETURN
END
SUBROUTINE ZERO
COMMON /AVE/ GEC1(10,20), GECO2(10,20), GEFO1(10,20), GEFO2(10,20),
GESK1(10,20), GESK2(10,20)
COMMON /PFG/ NREG
COMMON /YEA/ NY, NUMLIS
DC 20 K=1, NREG
DC 19 I=1, NY
GECO1(K,I)=0.
GECO2(K,I)=0.
GEFO1(K,I)=0.
GEFO2(K,I)=0.
GESK1(K,I)=0.
GESK2(K,I)=0.
19 CONTINUE
20 CONTINUE
RETURN
END
SUBROUTINE BUDGET(JMAX)
COMMON/IM/ CCSTMA (10,20), FOCAMA (10,20), SKLAMA (10,20)
COMMON/LS/NLSIMA (10C), NUMBER (30), MDIS (30)
COMMON/FILE/ NLINK, NREG, LST (30), IAA (30)
COMMON/YEA/ NY, NUMDIS
COMMON/EXP/TCOS (3C,20), BCOST (20)
INTEGER*2 IAA
DIMENSION DUMMY (420), FTC (20), FTC (20), SKL (20), FCR (20), DUM (80)
DC 10
10 CONTINUE
DC 160 I=1, NLINK
LAUC=10* (1-1)
LAU=LAUC+1
DC 30 K=1, 20
40 CONTINUE
50 CONTINUE
READ (11*IAU) DUMMY, FTC, FIC, SKL, FOR, DUM, ISTP, NCRIT, NSLTM
L=MDIS (I)
DC 50 KK=1, NY
BCOST (KK) = BCOST (KK) + FTC (KK)
A = COSTMA (I, KK)
A1 = A - FTC (KK)
IF (A1. LE. 0.) GO TO 200
COSTMA (L, KK) = A1
B = FOCAMA (L, KK)
B1 = B - FCR (KK)
IF (B1. LE. 0.) GO TO 210
FOCAMA (L, KK) = B1
L = SKLAMA (L, KK)
D1 = D - SKL (KK)
IF (D1. LE. 0.) GO TO 220
SKLAMA (L, KK) = D1
50 CONTINUE
100 CONTINUE
   GC TO 250
200 WRITE(6,205) L,KK
205 FORMAT(3X,'THE AVAILABLE BUDGET FOR REGION ',I2,' AND THE YEAR '1',I2,' HAS BEEN EXHAUSTED')
   GC TO 240
220 WRITE(6,225) L,KK
225 FORMAT(3X,'THE AVAILABLE SKILLED LABOR FOR REGION ',I2,' AND YEAR '1AR',I2,' HAS BEEN EXHAUSTED')
   GC TO 240
210 WRITE(6,215) L,KK
215 FORMAT(3X,'THE AVAILABLE FOREIGN EXCHANGE FOR REGION ',I2,' AN '1D YEAR ',I2,' HAS BEEN EXHAUSTED')
240 CONTINUE
   CALL EXIT
250 CONTINUE
   RETURN
END
COMMON/GFN/NLINK,NODE,JIM,NS,VTIME(30,7),FALOD(30,7),BRECT(20),LBEG
1G(30),LEND(30),LOD(30,3C),LIA(30,3C),VCAP(7),ICPT,IVF,ISIM(20),IG
2RAP(20)
COMMON/CD/IPATH(7,30,15),VEC(30,7),VFC(30,7)
COMMON/INK/TT(30,7),CFG(30,7),FOFC(30,7),CAP(30),SPD(30,7),BLN(30
1),TRAPP(30),TEP(30,7),RAFF(30),VHTRA(30,7),DSPR(30)
COMMON/ZEI/ATT(20,7),ECC(20,7),POC(20,7),ETC(20),EUS(20),CP(20),ET
1C(20),RAP(20),DSP(20)
COMMON/ED/Demand(20,7),FIA(7),PRICE(7),VALT(7),BVEC(20,7),BVFC(20
1,7)
DIMENSION IDICT(9),LST(30),MDIS(30),COSTMA(10,20),PGCAMA(10,20),SK
1LAMA(10,20),NETS(30)
DIMENSION NRANK(30),NWSTR(30,30),NWSTL(30,30),TCOST(30,20),IAA(30
2),SPEED(7),TCTBEN(30),FLOAD(7),FPRC(20),SKL(20),DUM(420),ETCB(20)
INTEGER*2 IAA
C WORDS IN IDICT: ANALYSIS,EVALUATE,ALL,SIMULATION,DELETE,RANK,PRINT
DATA IDICT/3,7,203320,244125,203317,382832,232431,372033,353728/
DATA NFIS/30*0/
DC 10 I=1,30
DO 8 K=1,7
VTIME(I,K)=0.
FALOD(I,K)=0.
8 CONTINUE
10 CONTINUE
DC 11 I=1,20
ISIM(I)=0
IRAF(I)=0
11 CONTINUE
READ (10 '1) NLINK,NODE,NREG,NY,JIM,RATE,VCAP,LBEG,LEND,LST,MDIS,COST
1MA,PGCAMA,SKLAMA,IOPT,NRANK
READ (10 '2) LLA
RFAI (10 '3) LCD
READ (10'4) NWSTR
READ (10'5) NWSL.
READ (10'6) TCCST, BCOST, IAA
IRI=RATE/100.
MI=0
IRANK=0
IEASE=C
LASTNS=0
DO 17 I=1,7
   IF (VCAP(I) .EQ. 0) GO TO 16
   CONTINUE
17    CONTINUE
16   IVF=I-1
20   CALL MATCH (ITYPE, IDICT, K, RK, 1)
   GO TO (100, 100, 100, 100, 22, 150), ITYPE
22  IK1=K
   GC TO (25, 30, 30, 70, 50, 60, 150), IK1
C ANALYSIS OF EASE NETWORK
25  IBASE=1
   GO TO 20
30   CALL MATCH (ITYPE, IDICT, K, RK, 0)
   GO TO (38, 37, 35, 30, 40), ITYPE
C N.S. TO BE EVALUATED
35  K=RK
37  MI=MI+1
   NFTS(MI)=K
   LASTNS=MI
   GO TO 20
38  IF (I .EQ. C) GO TO 110
   GO TO 20
C EVALUATE ALL STRATEGIES GENERATED
40   CALL MATCH (ITYPE, IDICT, K, RK, 0)
   GO TO (20, 47, 45, 40, 40), ITYPE
45  K=RK
47   LASTNS=K
   DC 48 IK=1, LASTNS
XIETS(IK)=IK
48 CONTINUE
   GO TO 20
C YEARS OF SIMULATION
70 KK=0
71 CALL MATCH(ITYPE,IDICT,K,RK,0)
   GO TO (20,77,75,71,71),ITYPE
75 K=RK
77 KK=KK+1
   ISIM(KK)=K
   GO TO 71
C DELETE THE STORED RANKING OF N.S.
50 DO 55 II=1,30
      NRANK(II)=0
55 CONTINUE
   GO TO 20
60 IRANK=1
   GO TO 50
C ERROR FORMATS
100 WRITE(6,105)
105 FORMAT(/' ERROR IN FCAMATS' )
   GO TO 20
110 WRITE(6,115)
115 FCAMATS(/' NONE NS NUMBER' )
   GO TO 20
C YEARS TO BE PRINTED
150 KK=0
152 CALL MATCH(ITYPE,IDICT,K,RK,0)
   GO TO (151,157,155,152,152),ITYPE
155 K=RK
157 KK=KK+1
   IGRAF(KK)=K
   GO TO 152
151 CONTINUE
   DO 180 I=1,JIM
   DO 165 IV=1,7
VALT(IV) = 0.
FLOAD(IV) = 0.

165 CONTINUE
JIMC = I
READ (12, JIMC) DEMAND, FLA, FRICE, VALT, FLOAD
DO 170 IV = 1, 7
FLOAD(I, IV) = FLOAD(IV)
VALT(I, IV) = VALT(IV)
170 CONTINUE

C START ANALYSIS OF THE EASE NETWORK
IF (IBASE.EQ.0) GO TO 200
CALL EASENE(NY)

C START ANALYSIS OF EACH N.S.
200 CONTINUE
DO 1000 LJ = 1, LASTNS
I = NETS(LJ)
WRITE (6, 600) I
600 FORMAT (/3X, 'NETWORK STRATEGY', I2, '/', 30X, 18 ('*'))
ISTP = 0
ACBEN = 0.
DO 800 IYR = 1, NY
EXP = 0.
BENEFF = 0.
WRITE (6, 666) IYR
666 FORMAT (/3X, 'YEAR', I5, '/', 30X, 9 ('-'))
DO 995 IL = 1, 30
DC 994 LK = 1, 7
VFHTPA(IL, LK) = 0.
994 CONTINUE
995 CONTINUE
IF (IYR .EQ. 1) GC TO 205
II = IYR - 1
DIF = TCOST(I, IYR) - TCOST(I, II)
IF (DIF .GE. 1000.) GO TO 205
IF (DIF .LT. -1000.) GO TO 205
DO 166 JJ=1,20
IF(ISIM(JJ).EQ.IYR) GC TO 205
IF(IGRAF(JJ).EQ.IYR) GC TO 205
166 CONTINUE
GC TO 400
205 CONTINUE
C ZERO ARRAYS OF VEHICLE COSTS
DO 215 J=1,30
DC 216 IV=1,7
VPC(J,IV)=0.
VPC(J,IV)=0.
210 CONTINUE
215 CONTINUE
DC 216 IV=1,7
DO 217 J=1,30
DC 218 JJ=1,15
IPATH(IV,J, JJ)=0
218 CONTINUE
217 CONTINUE
216 CONTINUE
C ZERO ARRAYS
DC 230 J=1,30
RLEN(J)=0.
RAPP(J)=0.
DSFR(J)=0.
TRAFF(J)=0.
CAP(J)=0.
DO 235 IV=1,7
TEF(J, IV)=0.
TT(J, IV)=0.
ECPC(J, IV)=0.
EPC(J, IV)=0.
SPD(J, IV)=0.
235 CONTINUE
230 CONTINUE
DO 300 KK=1,NLINK
CALL ZEIIANK
DC 240 JJ=1,30
IB=IAA(JJ)
IF(IB.EQ.KK) GO TO 245
240 CONTINUE
IK=IYR
242 LAUC=10*(KK-1)
LAU=LAUC+1
READ(11*LAU) ATT,EOC,FCC,ETC,PTC,SKL,POP,DIS,CF,RAF,DSP
GO TO 260
245 ISTR=NWSL(I,KK)
LAUC=10*(KK-1)
LAU=LAUC+ISTR
READ(11*LAU) ATT,EOC,FCC,ETC,PTC,SKL,FOR,DIS,CF,RAF,DSP
IF(NWSL(I,KK).NE.0) GO TO 250
IK=IYR
GO TO 260
250 ISL=NWSL(I,KK)
IF(IYR.GT.ISL) GO TO 255
K1=PTC(1)
K2=PTC(2)
IF(K1.GT.K2) GO TO 248
IK=1
GO TO 260
248 IK=1
GO TO 242
255 IK=IYR-ISL
GO TO 240
260 CONTINUE
DC 265 IJ=1,7
SPEED(IJ)=0.
265 CONTINUE
DO 270 IV=1,IYR
TT(KK,IV)=ATT(IK,IV)
OPC(KK,IV)=FCC(IK,IV)
OPC(KK,IV)=ECC(IK,IV)
IF(ATT(IK,IV).EQ.0.) GO TO 270
SPEED(IV) = DIS(IK) / ATT(IK, IV)
SPD(KK, IV) = SPEED(IV)

270 CONTINUE
CAP(KK) = CP(IK)
RAFF(KK) = RAFF(IK)
LSPR(KK) = DSP(IK)
RLEN(KK) = DIS(IK)

290 CONTINUE
RDI = 3.67 - 0.027 * DSP(IK)
RCC = RDI * RAFF(IK)
RK1 = SPEED(1)

DC 425 IV = 2, IVF
IF(SPEED(IV).EQ.0.) GO TO 425
RK2 = SPEED(IV)

TEF(KK, IV) = (POC* (RK1 - RK2) / 10.) + 2.

425 CONTINUE
TEF(KK, 1) = 1.

300 CONTINUE
C COMPUTE TRANSPORT COSTS

NS = 1
DC 320 IV = 1, IVF
CALL ROUTE(IYR, IV)

320 CONTINUE
325 CALL COST(IYR)

460 CS = 0.
IF(IOPT.EQ.1) GO TO 2000

DO 500 J = 1, JIM
JIMC = J
CALL ZEDM
READ(12) JIMC, DEMAND, ELA, ERICF, VALT, FLOAD, BVEC, BVFC
IF(BVFC(IYR, 1).GT.PRICE(1)) GO TO 480
DC 450 IV = 1, IVF
DIF = BVEC(IYR, IV) - VEC(J, IV)
IF(DIF.GT.0.99 OR. DIF.LE.-99) GO TO 451
CS = CS + 0.
GO TO 450
451 DEM=0.
    IF (DEMAND(IYR,IV).EQ.0.) GC TC 450
    DEM=DEMAND(IYR,IV) *((VFC(J,IV)/BVFC(IYR,IV))**(-ELA(IV)))
    IF (IV.GT.2) GO TO 455
    A=365.*0.5*(DEM+DEMAND(IYR,IV)) *(BVEC(IYR,IV)-VEC(J,IV))
    CS=CS+A
    GC TO 450
455 A=365.*(0.5*(DEM+DEMAND(IYR,IV)) *(BVEC(IYR,IV)-VEC(J,IV)))/VCAP(IV)
    CS=CS+A
    CONTINUE
    GO TC 500
480 DC 485 IV=1,IVF
    IF (VEC(J,IV).GE.PRICE(IV)) GO TO 500
481 DEM=0.
    IF (DEMAND(IYR,IV).EQ.0.) GO TO 485
    DEM=DEMAND(IYR,IV) *((VFC(J,IV)/PRICE(IV))**(-ELA(IV)))
    IF (IV.GT.2) GO TO 482
    A=365.*0.5*(DEMAND(IYR,IV)+DEM) *(PRICE(IV)-VEC(J,IV))
    CS=CS+A
    GO TO 485
482 A=365.*(0.5*((DEMAND(IYF,IV)+DEM)/(VCAP(IV)*FALOD(J,IV)))*(PRICE(IV)-VEC(J,IV)))
    CS=CS+A
    CONTINUE
    GO TC 500
    CONTINUE
    GC TC 599
2000 CONTINUE
    DO 2500 J=1,JIM
    JINC=J
    CALL ZEDMEM
    READ(12,JINC) DEMAND, ELA, PRICE, VAL, PLCAD, BVEC, BVFC
    IF (BVFC(IYR,1).GE.PRICE(1)) GC TC 2480
    DO 2450 IV=1,IVP
    DIF=BVEC(IYR,IV)-VFC(J,IV)
    IF (DIF.GT.0.0 OR.DIF.LT.-0.9) GO TO 2451
CS = CS + 0.
GO TO 2450

2451 DEM = 0.
IF(DEMAND(IYF,IV) .EQ. 0.) GO TO 2450
DEM = DEMAND(IYF,IV) * ((VSC(J,IV) / BVSC(IYR,IV)) ** (-ELA(IV)))
A = 365. * 0.5 * (DEM + DEMAND(IYR,IV)) * (VSC(J,IV) / BVSC(IYR,IV) - VEC(J,IV))
CS = CS + A

2455 CONTINUE
GO TO 2500

2480 DC 2485 IV = 1, IVF
IF(VEC(J,IV) .GE. PRICE(IV)) GO TO 2500

2481 DEM = 0.
IF(DEMAND(IYF,IV) .EQ. 0.) GO TO 2485
DEM = DEMAND(IYF,IV) * ((VEC(J,IV) / PRICE(IV)) ** (-ELA(IV)))
A = 365. * 0.5 * (DEM + DEMAND(IYR,IV) + DEM) * (PRICE(IV) - VEC(J,IV))
CS = CS + A

2485 CONTINUE

2500 CONTINUE

599 IT = IYR - 1
EXP = TCOST(I, IYR) - BCOST(IYR)
BENEF = CS + EXP
ACBEN = ACBEN + BENEF * (1. + RATE) ** (-IT)

603 WRITE(6, 601)
601 FORMAT(8X, 'BENEFITS', 15X, 'EXPENDITURES', 13X, 'NET BENEFITS', 9X, 'ACCUMULATED NET BENEFITS (NPV)', ')
WRITE(6, 602) CS, EXP, BENEF, ACBEN
602 FORMAT(2X, 3(F23.5, 5X), 9X, F20.5)

800 CONTINUE
TOTBEN(I) = ACBEN
WRITE(6, 622) TOTBEN(I)

622 FORMAT(2X, 'THE TOTAL NET BENEFITS (NPV) ARE:', F20.5)

1300 CONTINUE
C B N K
IF(IRANK .EQ. 0.) GO TO 1300
NN = 0
KK = 1
R1= -1000000000.
1150 DO 1200 MM=1, LSTNS
II = NETS (MM)
DO 1450 K=1, KK
IF (NRANK(K).EQ.II) GO TO 1200
1450 CONTINUE
R2= TOTBEN (II)
IF (R1.GE.R2) GO TO 1200
IMAX=II
R1= TOTBEN (II)
GO TO 1200
1200 CONTINUE
1100 CONTINUE
NN= NN+1
KK= NN
NRANK (KK)= IMAX
IF (KK.EQ.LASTNS) GO TO 1250
R1= -1000000000.
GO TO 1150
1250 WRITE (6, 605)
605 FORMAT (/ / 4X, 'RANK OF THE NETWORK STRATEGIES', / , 10X, 'RANK', 5X, 'N.
1S.', 5X, 'TIAL NET BENEFITS (NPV)' )
DO 1230 LJ=1, LSTNS
IN= NRANK (LJ)
WRITE (6, 610) LJ, IN, TOTBEN (IN)
610 FORMAT (11X, I2, 7X, I2, 6X, F15.5)
1230 CONTINUE
1300 CONTINUE
WRITE (10, 1) NLINK, NCDE, NNEG, NY, JIM, RATE, VCAP, LBEG, LEND, LST, MDIS, COS
1MA, FOCAMA, SKLAMA, IOPT, NRANK
CALL EXIT
9999 SICE
END
SUBROUTINE BASENE(NY)

C ANALYZE BASE NETWORK
COMMON/GEN/NLINK,NODE,JIM,N5,VTIME(30,7),FALCD(30,7),BCOST(20),LBE
1G(30),VESK(30),LLD(30,3C),LLA(30,30),VECAP(7),IOPT,IVP,ISIM(20),IG
ZRAPF(20)
COMMON/INK/TT(30,7),CP(30,7),FOPC(30,7),CAP(30),SPD(30,7),RLEN(30)
1,RAFF(30),TIF(30,7),VEHTA(30,7),DSPR(30)
COMMON/CD/IPATH(7,30,15),VE(30,7),VE(30,7)
COMMON/ZEL/ATT(20,7),EOC(20,7),POC(20,7),FHC(20),DIS(20),CP(20),ET
1C(20),RAF(20),DSP(20)
COMMON/ZEL/DEMAND(20,7),ELA(7),PRICE(7),VALT(7),BVEC(20,7),BVPC(20
1,7)
DIMENSION SPEED(7),SKL(20),FOR(20),FLOAD(7)
WRITE(6,400)
400 FORMAT(/'BASE NETWORK ANALYSIS','/30X,21('*'))
NS=0
DO 300 IY=1,NY
DC 992 LL=1,30
DO 991 LL=1,7
VEHTA(LL,LK)=0.
991 CONTINUE
992 CONTINUE
IF(IY.EQ.1) GO TO 40
II=IY-1
DIF=BCOST(IY)-BCOST(II)
IF(DIF.GE.1000.) GO TO 40
IF(DIF.LE.-1000.) GO TO 40
DO 166 JJ=1,20
IF(ISIM(JJ).EQ.IY) GO TO 40
166 CONTINUE
GO TO 150
40 CONTINUE
DC 157 JJ=1,20
IF(IGRAF(JJ).EQ.IY) GO TO 41
167 CONTINUE
GO TO 42
41 WRITE(6,666) IYR
666 PGMMAT(/,3X,'YEAR',15,/,3X,9(' '))

C ZERO ARRAYS
42 DO 45 J=1,30
   DO 48 IV=1,7
      VEC(J,IV)=0.
      VFC(J,IV)=0.
43 CONTINUE
45 CONTINUE
   DO 50 IV=1,7
      CONTINUE
   DO 60 JJ=1,15
      IFATH(IV,J,JJ)=0.
50 CONTINUE
55 CONTINUE
   DC 70 J=1,30
   RLEN(J)=C.
   RAPP(J)=0.
   DSFR(J)=0.
   TRAPP(J)=0.
   CAP(J)=C.
   DO 65 IV=1,7
      CONTINUE
   SPD(J,IV)=0.
   TFC(J,IV)=0.
   TIL(J,IV)=0.
   OPC(J,IV)=0.
   BOFC(J,IV)=0.
65 CONTINUE
70 CONTINUE
   DO 100 KK=1,NLINK
      CALL ZELINK
   CONTINUE
   DC 105 IV=1,7
   SPEED(IV)=0.
100 CONTINUE
   LAU=10*(KK-1)+1
READ(11,LAU) ATT, FOC, FOC, ETC, FTC, SKL, FOR, DIS, CP, RAF, DSP
DO 110 IV=1, IVP
TT(KK, IV) = ATT(IYR, IV)
OCF(KK, IV) = FOC(IYR, IV)
2OCF(KK, IV) = FOC(IYR, IV)
IF (ATT(IYR, IV) .EQ. 0.) GO TO 110
AT(ATT, IYR, IV)
SPEEL(IV) = DIS(IYR) / AT
SPD(KK, IV) = SPEEL(IV)
CCNTINUE
PAFF(KK) = PF (IYR)
DSPR(KK) = DSP(IYR)
CAP(KK) = CF(IYR)
PLFN(KK) = TFS(IYR)
R1 = 3.67 - 0.27 * DSP(IYR)
ROC = RDI* RAF(IYR)
RK1 = SPEED(1)
DC 425 IV=2, IVF
IF (SPEED(IV) .EQ. 0.) GO TO 425
RK2 = SPEED(IV)
TEF(KK, IV) = (POC * (RK1-RK2) / 10.) + 2.
425 CCNTINUE
TEF(KK, 1) = 1.
100 CCNTINUE
DO 120 IV=1, IVF
CALL ECUTE(IYR, IV)
120 CCNTINUE
125 CALL CCST(IYR)
GC TO 260
150 CCNTINUE
DO 190 I=1, JIM
JIMC=I
CALL ZEEEM
READ(12*JIMC) DEMAND, FIA, PRICE, VAIL, FLOAD, BVEC, BVFC
II=IYR-1
DC 170 IV=1, IVF
R1=0.
R2=C.
R1=BVEC (II, IV)
R2=BVFC (II, IV)
BVEC (IYR, IV) = R1
BVFC (IYR, IV) = R2
CONTINUE
JIMC=I
WRITE (12, JIMC) DEMAND, ELA, PRICE, VALT, FLOAD, BVEC, BVFC
CONTINUE
GC TO 300
CONTINUE
DC 290 I=1, JIM
JIMC=I
CALL ZEEDM
READ (12, JIMC) DEMAND, ELA, PRICE, VALT, FLOAD, BVEC, BVFC
II=IYR-1
DC 280 IV=1, IVF
BVFC (IYF, IV) = VEC (I, IV)
BVFC (IYR, IV) = VFC (I, IV)
IF (IYR.EQ. 1) GO TO 280
DEMAND (IYF, IV) = DEMAND (IYF, IV) * ((BVFC (IYR, IV) / BVFC (II, IV)) ** (-ELA (I YF))
CONTINUE
JIMC=I
WRITE (12, JIMC) DEMAND, ELA, PRICE, VALT, FLOAD, BVEC, BVFC
IF (IYR.EQ. 1) GO TO 290
DO 320 KO=1, NCDE
DC 310 KD=1, NODE
IF (LOD (KO, KD). EQ. 1) GC TO 330
CONTINUE
GO TO 290
WRITE (6, 335) KO, KE, (IV, IV=1, IVF)
SUBROUTINE RCUTE(IYF,IV)
C
 THIS SUBROUTINE SEARCHES FOR THE MINIMUM COST ROUTE
 COMMON/GEN/NODE,JINS,VTIME(30,7),PALOD(30,7),BCOST(20),LBE
1G(30),LEN(30),LOD(30,30),LLA(30,30),VCAP(7),IOPT,IVF,ISIM(20),IG
2RAF(20)
 COMMON/OD/IPATH(7,30,15),VFC(30,7),VFQ(30,7)
 COMMON/LINK/TT(30,7),OPC(30,7),EOPC(30,7),CAP(30),SPD(30,7),RLEN(30
1),TRAFF(30),TEF(30,7),PAFF(30),VEHTPA(30,7),LSPP(30)
 COMMON/ZED/DEMAND(20,7),FLA(7),PRICE(7),VALT(7),BVFC(20,7),BVPC(20
1,7)
 DIMENSION CROUTE(30,30),TROUTE(30,30),LROUTE(30,30)
C
 CONSTRUCT PATH COST AND LABEL MATRICES
 DC 10 KO=1,30
 DO 8 KD=1,30
 CROUTE(KC,KD)=1000000.
 TROUTE(KO,KD)=1000000.
 8 CONTINUE
10 CONTINUE
 DC 20 I=1,NLINK
 KC=LBEG(I)
 KD=LEND(I)
 IF (OPC(I,IV) .EQ. 0.) GO TO 20
 CROUTE(KC,KD)=OPC(I,IV)
 CROUTE(KC,KD)=CPC(I,IV)
 TROUTE(KO,KD)=TT(I,IV)
 TROUTE(KD,KO)=TT(I,IV)
20 CONTINUE
 DC 40 KC=1,NODE
 DC 30 KE=1,NODE
 LROUTE(KC,KE)=KO
30 CONTINUE
40 CONTINUE
C
 START SEARCH OF MINIMUM PATH
 DO 90 IP=1,NODE
 DC 90 KC=1,NODE
 IF (KO,EQ.IP) GO TO 90

DO 8C KE=1,NODE
IF (KD.EQ.IP) GO TO 8C
IF (KD.EQ.KO) GO TO 8C
C1=CROUTE(KC,IP)+CROUTE(IP,KE)
C2=CROUTE(KC,KD)
IF (C1.GE.C2) GO TO 8C
CROUTE(KC,KD)=C1
LRCOUTE(KO,KD)=IP
TROUTE(KO,KD)=TROUTE(KC,IP)+TROUTE(IP,KD)
80 CONTINUE
90 CONTINUE
100 CONTINUE
DO 260 KO=1,NODE
DO 190 KD=1,NODE
I=LCD(KC,KD)
IF (I.EQ.0) GO TO 190
K=16
IO=KO
II=KD
180 J=LROUTE(IO,ID)
186 CONTINUE
IK=LLA(ID,J)
IF (IK.NE.0) GO TO 185
J1=J
J2=ID
J=LROUTE(J1,J2)
185 K=K-1
IFATH(I,IV,K)=IK
VEC(I,IV)=VPC(I,IV)+FECF(IK,IV)
VPC(I,IV)=VPC(I,IV)+OPC(IK,IV)
IF (J.EQ.KC) GO TO 170
II=J
GO TO 180
170 A=TRoute(KC,KD)*VTIME(I,IV)*Vcap(IV)*PALOD(I,IV)
VEC(I,IV)=VEC(I,IV)+A
VFC(I, IV) = VFC(I, IV) + A
190 CONTINUE
200 CONTINUE
C ASSIGN TRAFFIC ON LINKS
DO 300 I = 1, JMAX
DO 310 JJ = 1, 20
DO 305 JJ = 1, 7
DEMAND(I, JJ) = 0.
305 CONTINUE
310 CONTINUE
JMAX = 1
READ(12, *), DEMAND, ELA, PRICE
IF (VEC(I, IV), GT. PRICE(IV)) GO TO 300
IF (OPT(I, EQ.1)) GO TO 275
IF (IV, GT. 2) GO TO 270
275 TRAFFIC(IYR, IV)
285 DO 280 KK = 1, 15
K = 16 - KK
IF (IPATH(IV, I, K) .EQ. 0) GO TO 300
LINK = IPATH(IV, I, K)
TRAFFIC(LINK) = TRAFFIC(LINK) + TRAFFIC * TEP(LINK, IV)
VEHTRA(LINK, IV) = VEHTRA(LINK, IV) + TRAFFIC
280 CONTINUE
GO TO 300
270 TRAFFIC = TRAFFIC(IYR, IV) / (VCAP(IV) * PALOD(I, IV)) + 1
TRAFFIC = TRAFFIC
GO TO 285
300 CONTINUE
RETURN
END
SUBROUTINE COST (IYR)
COMPUTES THE NEW COST IF CONGESTION OCCURS IN A LINK
COMMON/GEN/NLINK, NODE, INT, IN, DTIME (30,7), FCACHE (30,7), BCOST (20), LBE
1G (30), LEND (30), LD (30, 3), LLA (30, 30), VCAP (7), IOPT, IVF, ISIM (20), IG
2RAF (20)
COMMON/CD/IPATH (7, 30, 15), VR (30, 7), VCL (30, 7)
COMMON/LINK/TT (30, 7), OPC (30, 7), EOPC (30, 7), CAP (30), SPD (30, 7), RLEN (30
1), TRAFF (30, 7), TEF (30, 7), RAFF (30), VEHTRA (30, 7), DSFR (30)
DIMENSION VCL (5), VEHNO (5), PCVEH (5), AAT (30, 7), IPROUTE (30), AT (5)
DATA AAT /210*0.
DC 200 I=1, NLINK
IF (TRAFF I, EQ, 0 ) GO TO 20C
TOTCAP=CAP (I)*16.
VCL (1) =.10*CAP (I)
VOL (2) =.30*CAP (I)
VCL (3) =.50*CAP (I)
VOL (4) =.70*CAP (I)
VCL (5) =.90*CAP (I)
VOLCAP=TRAFF I, TOTCAP
IF (VOLCAP, GE, .90) GC IC 9C
IF (VOLCAP, LE, .10) GO TO 80
A =.10*TCCAP
RVCL =.25* (VOLCAP-.10)
VEHNO (1) =A * (1-RVOL)**4
VEHNO (2) =12. *A *RVOL *((1-RVOL)**3)
VEHNO (3) =30. *A * (RVOL**2) * ((1-RVCL)**2)
VEHNO (4) =28. *A * (RVOL**3) * (1-RVCL)
VEHNO (5) =9. *A * (RVOL**4)
GO TO 95
90 DC 91 IF = 1, 4
VEHNO (IF) = 0.
91 CONTINUE
VEHNO (5) = TRAFF I
VCL (5) = TRAFF I, 16.
GO TO 95
80 DC 81 IF = 2, 5
VFHNO(IF)=0.
81 CONTINUE
VFHNO(I)=TRAFF(I)
VCL(I)=IFAPF(I)/16.
95 CONTINUE
DO 150 IV=1,IVF
DO 100 IP=1,5
PCVEH(IP)=VFHNO(IP)/TRAFF(I)
VF=DSPR(I)
VEL=V-V*VCL(IP)/CAP(IP)
IF(VEL.GT.0.10*V) VEL=6.10*V
IF(VFL.GT.SPD(I,IV)) GC TO 150
AT(IP)=(RLEN(I)/VEL)-(RLEN(I)/SPD(I,IV))
VFHNO(IF)=VFHTRA(I,IV)*PCVEH(IP)
150 CONTINUE
TOTT=0.
DO 120 IP=1,5
TOTT=TOTT+VFHNO(IP)*AT(IP)
120 CONTINUE
AAT(I,IV)=TOTT/VFHTRA(I,IV)
150 CONTINUE
DO 300 IV=1,IVF
DO 166 JJ=1,20
IF(IGRAF(JJ).EQ.IYF) GC TO 604
166 CONTINUE
GO TO 650
600 FORMAT(/2X,'MINIMUM COST ROUTES OF VEHICLE TYPE:',I5,'/17X,'O-D P
1AIR #',10X,'ROUTE (LINKS NUMBERS)')
650 DO 290 I=1,IJM
DO 220 LO=1,NODE
DO 210 LD=1,NODE
IF(I.EQ.LCD(LC,LD)) GC TO 215
210 CONTINUE
220 CONTINUE
DO 270 L= 1, 30
IROUTE(I) = 0
270 CONTINUE
KK = 0
DO 280 K= 1, 15
IF(IPATH(IV, I, K) .EQ. 0) GO TO 280
KK = KK + 1
IROUTE(KK) = IPATH(IV, I, K)
LINK = IPATH(IV, I, K)
IF(AAT(LINK, IV) .EQ. 0.) GO TO 280
A = AAT(LINK, IV) * VTIME(I, IV) * VCAP(IV) * FAILOD(I, IV)
VEC(I, IV) = VEC(I, IV) + A
VFC(I, IV) = VFC(I, IV) + A
280 CONTINUE
DO 167 JJ= 1, 20
IF(IGRAF(JJ) .EQ. 0) GO TO 605
167 CONTINUE
GO TO 290
605 WRITE(6, 610) IV, LO, LD, (IROUTE(K), K=1, KK)
610 FORMAT (I2, 9X, I2, ' ', I2, 13X, 15I2)
290 CONTINUE
DO 168 JJ= 1, 20
IF(IGRAF(JJ) .EQ. 0) GO TO 301
168 CONTINUE
GO TO 500
301 WRITE(6, 615) (IV, IV=1, IVF)
615 FORMAT (/20X, 'ECONOMIC VEHICLE OPERATING COSTS', /, 20X, 'VEHICLE TYPE
15', /4X, 'C-D #', 6X, 7(4X, I2, 4X))
DC 410 LC=1, NCDE
DC 420 LD=1, NODE
I=LOD(LC, ID)
IF(I .EQ. 0) GO TO 420
WRITE(6, 620) LO, LD, (VEC(I, IV), IV=1, IVF)
620 FORMAT (4X, I2, ' ', I2, 6X, 7(F10.4))
420 CONTINUE
410 CONTINUE
   WRITE (6, 625) (IV, IV=1, IVF)
   625 FORMAT (/20X, 'FINANCIAL VEHICLE OPERATING COSTS',/ 20X, 'VEHICLE TYP
   ES', /, 4X, 'O-D #', 6X, 7(4X, I2, 4X))
   DO 450 IO=1, NODE
   DC 460 ID=1, NODE
   I=LOC(ID, LO)
   IF (I.EQ.O) GC TO 460
   WRITE (6, 630) LO, LD, (VFC (I, IV), IV=1, IVF)
   630 FORMAT (4X, I2, ' - ', I2, 6X, 7(F10.4))
   460 CONTINUE
   450 CONTINUE
   WRITE (6, 640) (L, L=1, IVF)
   640 FORMAT (/30X, 'TOTAL TRAFFIC ON LINKS', /, 2X, 'LINK', 5X, 'IN PCU', 5X, 7(1*CF TYPE: ', I2, 3X))
   DC 500 I=1, NLINK
   WRITE (6, 645) I, TRAFF (I), (VEHTRA(I, IV), IV=1, IVF)
   645 FORMAT (3X, I2, 3X, F10.3, 4X, 7(F8.0, 5X))
   500 CONTINUE
   RETURN
END
SUBROUTINE ZELINK
COMMON/ZEL/ATT(20,7), FCC(20,7), FOC(20,7), FTC(20), DIS(20), CP(20), 3T
1C(20), RAF(20), DSP(20)
DO 50 I = 1, 20
   FTC(I) = 0.
   BTC(I) = 0.
   DIS(I) = 0.
   RAF(I) = 0.
   DSP(I) = 0.
   CE(I) = 0.
   DO 20 J = 1, 7
      ATT(I, J) = 0.
      FOC(I, J) = 0.
      FCC(I, J) = 0.
   20 CONTINUE
50 CONTINUE
RETURN
END
SUBROUTINE ZEDEM
COMMON/ZED/DEMAND(20,7),ELA(7),PRICE(7),VALT(7),BVEC(20,7),BVFC(20,7)
DO 5 I=1,20
DC 30 J=1,7
DEMAND(I,J)=0.
EVEC(I,J)=0.
BVFC(I,J)=0.
30 CONTINUE
CONTINUE
DO 20 I=1,7
ELA(I)=0.
VALT(I)=0.
PRICE(I)=0.
20 CONTINUE
RETURN
END
SUBROUTINE MATCH (NATCH, LIST, K, RK, LARG)

MATCH READS A CARD IN 8CA1 FORMAT INTO JBUF, CONVERTS EACH COLUMN TO AN INTEGER COIF IN IBUF, AND DECODES EACH LOGICAL FIELD ON THE CARD. THE LAST USEABLE COLUMN IS INDICATED BY THE DATA SPECIFICATION FOR 'LASTCC'.

EACH CODE NUMBER REPRESENTS A CHARACTER AND IS FORMED INTO LIST WORDS BY COMBINING THE CODE TIMES SOME POWER OF 100. THUS IF A WORD MAY CONTAIN 4 CHARACTERS, (LIST(1)=4), AND THE WORD 'TH' IS TO BE REPRESENTED, THE CODED WORD IS 39272414, BLANK PADDED (14) ON THE RIGHT.

LIST=DICTIONARY ADDRESS (INTEGER ARRAY)
- LIST(1)=NUMBER OF CHARACTERS/WORD
- LIST(2)=NUMBER OF LIST WORDS IN DICTIONARY
- LIST(3)....TO LIST(N) ARE CODED WORDS
- TOTAL LENGTH=LIST(2)+2 INTEGER WORDS

NATCH=
- 1, END OF STATEMENT
- 2, INTEGER NUMBER
- 3, FLOAT NUMBER
- 4, WORD NOT IN DICTIONARY
- 5, WORD IN DICTIONARY

CODE IS INTEGER DECIMAL, 00 TO 45, AS INDICATED BELOW.

THE CODES ARE AS FOLLOWS...

<table>
<thead>
<tr>
<th>CODE</th>
<th>CHARACTER REPRESENTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
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<tr>
<td>2</td>
<td>2</td>
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<tr>
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<td>8</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>
K=POSITION OF WORD IN DICTIONARY (EXCLUSIVE OF FIRST 2 CONTROL
WORDS) IF MATCH=5
=NUMBER IF MATCH=2
=SUBSCRIPT IN JBUF OF FIRST CHARACTER OF UNRECOGNIZED WORD
IF MATCH=4
R=REAL NUMBER IF MATCH=3

LARG=0, READ NEXT FIELD ON CARD
   =1, READ NEW CARD-FIRST FIELD

' $' IS CONTINUATION CARD MARK
$ IN CC1 IS A COMMENT CARD

THE MAXIMUM NUMBER OF CHARACTERS PER WORD DEPENDS ON THE
ALLOWABLE NUMBER OF DECIMAL DIGITS PER INTEGER WORD.
IN SUBROUTINE CODES
THE ABOVE CODES ARE SET BY A DATA SPECIFICATION FOR LET(1-46)
LET(I) HAS THE CHARACTER REPRESENTATION (1H) OF THE CHARACTER
WITH CODE I-1. THUS LET(21)=1HA.

INTEGER LIST(7)
INTEGER BLANK, COMMA, PLUS, MINUS, DP
DIMENSION LET(46), IBUF(80)

DATA LASTC, IREAD, IPRINT, BLANK, COMMA, PLUS, MINUS, DP/80, 5, 6, 14, 13, 10,
$11, 12/

ENTRY POINT-CHECK OF CODE
ANUMB=0.0
L=LARG
IF (L. EQ. 0) GO TO 110
L=1, READ NEW CARD, CONVERT TO DECIMAL CODE, SET BUFFER POINTER IC
C TO FIRST NON-BLANK CHAR.
DE 800 ISS=1,80
IBUF(ISS)=LET(15)
800 CONTINUE
READ(1,PEAD,1000,ERR=801,END=802)IBUF
1000 FORMAT(80A1)
GC TC 801
802 NATCH=6
GC TO 280
801 DO 101 I=1,80
DO 102 J=1,46
IF(IBUF(I)-LET(J)) 102,10C3,102
102 CONTINUE
C NO MATCH-ILLEGAL CHARACTER,SET=50 IN IBUF
IBUF(I)=50
GC TO 101
C MATCHED
103 IBUF(I)=J-1
101 CONTINUE
C SET IC AS FIRST NON-BLANK COLUMN
DO 104 I=1,LASTC
IF(IBUF(I)-BLANK) 105,104,105
104 CONTINUE
105 IC=I
C POINTER IS ALWAYS SET TO FIRST CHARACTER OF NEW FIELD ON LEAVING
C MATCH OR BY READING A NEW CARD-IT MAY BE LEFT PAST THE LAST
C RECOGNIZEABLE COLUMN,IASC
110 ICAR=IBUF(IC)
IF(ICAR=IASC) 115,115,120
C END OF STATEMENT
120 NATCH=1
280 RETURN
C OK-CHECK IF NEW FIELD IS A NUMBER,C-9,+,,-,OR.
115 IF(ICAR=12) 125,125,300
C
NUMBER FOUND-SET INITIAL PARAMETERS
DECIMAL POINT=NO
125 IEP=0
NEGATIVE=NO
ISGN=0
NO SIGNIFICANT DIGIT YET
ISG=0
NUMERICAL VALUE OF NUMBER (REAL OR INTEGER)
NUMB=0
SAVE START OF NUMBER
ICSTR =IC
IS FIRST CHAR A PLUS SIGN-IGNORE IF YES
IF(ICAP=PLUS) 126,130,126
CHECK IF MINUS SIGN-SET ISIGN=1 IF YES
126 IF(ICAP-MINUS) 135,127,135
127 ISGN=1
LEADING PLUS OR MINUS SIGN-BUMP CARD COLUMN POINTER-CHECK
IF END OF FIELD
C
THIS IS GENERAL CC BUMPER SECTION OF CODE
130 IC=IC+1
ICAR=ICBUF(IC)
IF(IC-LASTC )135,135,140
CHECK IF CC IS BLANK OR CCMMA
135 IF(ICAP=BLANK) 145,140,145
145 IF(ICAP=CCMMA) 150,140,150
150 NOT END OF FIELD-IS IT A DIGIT...
150 IF(ICAP=3) 155,155,160
155 DIGIT 0-9,DECIMAL POINT YET...
155 IF(IDP=1) 165,170,165
ALREADY HAVE DP,N IS THUS NEGATIVE,NUMBER IN ANUMB
170 ANUMB=ANUMB+FLOAT(ICAR)*(10.**N)
N=N-1
GO TO 130
NO DP YET,IS DIGIT A ZERO...
165 IF(ICAP) 175,180,175
C NOT ZERO, THUS IT IS SIGNIFICANT
175 ISIG=1
GO TO 185
C ZERO-CHECK IF SIGNIFICANT, IF NOT SKIP.
180 IF(ISIG=1)130,185,130
185 NUMB=10*NUMB+ICAR
GO TO 130
C CHARACTER NOT DIGIT IS IT DP...
190 IF(ICAR=DP)195,190,195
C YES, WAS ONE GIVEN PREVIOUSLY...
195 IF(IDP=1)200,99,200
200 N=-1
IDP=1
ANUMB=NUMB
GO TO 130
C NOT DIGIT OR DP, IS IT E..., IF NOT, ERROR(99)
195 IF(ICAR=24)99,205,99
C EXPONENT PLUS OR MINUS N1, N2
205 IF(IDP=1)210,214,210
C NO DP YET, FLOAT NUMBER
210 ANUMB=NUMB
IEP=1
214 I=1
C SIGN OF EXPONENT=PLUS
IEP=+1
C VALUE OF EXPONENT=0
IEP=0
C NEXT COLUMN
215 IC=IC+1
ICAR=IBUF(IC)
IF(IC-LASTIC)216,216,99
216 IF(ICAR=ELANK)217,99,217
217 IF(ICAR=CCMA)218,99,218
218 GO TO (220,225), I
C CHARACTER AFTER E, IS IT PLUS, MINUS, OR DIGIT...
220 IF (ICAR-PLUS) 225, 230, 235
235 IF (ICAR-MINUS) 99, 240, 99
C MINUS SIGN
240 IEP=-1
C HERE FOR PLUS SIGN ALSO
C RESET SWITCH AND GET NEXT COLUMN
C
230 I=2
GO TO 215
C FIRST OF CNE OR TWO EXPONENT DIGITS
225 IF (ICAR-9) 226, 226, 99
226 IEX=ICAR
I=1
223 IC=IC+1
ICAR=IBUF (IC)
IF (IC-IASTC) 231, 231, 250
231 IF (ICAR-BLANK) 227, 250, 227
227 IF (ICAR-CMMA) 228, 250, 228
228 GO TO (224, 99), I
224 IF (ICAR-9) 229, 229, 99
229 I=2
IEX=10*IEX+ICAR
GO TO 223
C END OF E FORM-MULTIPLY NUMBER BY EXPONENT
250 ANUMB=ANUMB* (10** (IEP*IEX))
C
C END OF NUMBER, POINTER AT BLANK, CMMA, OR EOC
C
C IEP=0, INTEGER IN NUMB-ILP=1, READ IN ANUMB
140 IF (ISGN-1) 144, 141, 144
C NEGATE-CHECK IF INTEGER OR REAL
141 IF (IDP) 142, 143, 142
C REAL
142 ANUMB=-ANUMB
GO TO 144
C INTEGER
143 NUMB=-NUMB
NATCH=IELF+2
K=NUMB
PK=ANUMB

POINTER AT BLANK, COMMA, CE EOC-BUMP TO A NON-BLANK, NON-COMMA
CHARACTER OR LEAVE AT EOC—THIS SECTION OF CCEE IS USED
BEFORE RETURNING
270 IF (IC-LASTC) 271, 271, 280
271 IC = IC + 1
272 IF (IBUF (IC) - BLANK) 273, 271, 273
273 IF (IBUF (IC) - COMMA) 280, 271, 280

FIRST CHAR IS NOT EOC, NUMBER IS IT $...
300 IF (IC-AR-17) 330, 120, 330

BY ELIMINATION, THE FIELD IS A WORD—SAVE IC AND GET END OF WORD.
FORM PACKED WORD IN DECIMAL CODE TO COMPARE AGAINST LIST—NEED
FIRST WORD IN LIST AS NUMBER OF CHARACTERS IN WORD.
BLANK PAD ON RIGHT.
330 ICSTR = IC
410 IC = IC + 1
415 ICAR = IBUF (IC)
420 LEND = IC - 1
425 IF (ICAR-BLANK) 430, 410, 410

END OF FIELD
430 USE LIST FIRST
435 NC = LIST (1)
440 GET CHARACTERS IN WORD
445 NCW = IEND+1-ICSTR
450 NCW1 = NCW + 1
460 IENP = IC - 1
C CHECK IF FIELDS IS SHORTER THAN DICTIONARY WORDS
IF (NCW-NC) > 440, 455, 455
C SHORTER - BLANK PAD
440 DO 445 I = 1, NCW
   IJK = ICSIF + I - 1
445 IWD = 100*IWD + IBUF (IJK)
   DC 450 I = NCW1, NC
450 IWD = 100*IWD + BLANK
   GC TO 465
C NCW, GE, NC
455 DO 460 I = 1, NC
   IJK = ICSIF + I - 1
460 IWD = 100*IWD + IBUF (IJK)
C NOW IWD CONTAINS NC CHARACTERS TO COMPARE
C TO DICTIONARY WORDS
465 NWDS = LIST (2)
   DC 475 I = 1, NWDS
   IF (IWD = LIST (I+2)) 475, 475
475 CONTINUE
C WORD NOT FOUND IN DICTIONARY
   MATCH = 4
   K = ICSIF
   GO TO 270
C WORD FOUND IN DICTIONARY
480 K = I
   MATCH = 5
   GO TO 270
C ERROR IN NUMBER FIELD
99 WRITE (I4, 999)
   K = ICSIF
   MATCH = 4
   GO TO 270
999 FORMAT (25H ERROR IN NUMERIC FIELD.)
REFERENCES


42. SAUTI Consulting Engineers, "Asela-Dodola Road, Feasibility Study", Imperial Ethiopian Government, Imperial Highway Authority (1971)