This paper is prepared for staff use and is not for publication. The views expressed are those of the author and not necessarily those of the Bank.

INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT
INTERNATIONAL DEVELOPMENT ASSOCIATION
Economics Department Working Paper No.87
Dahomey Land Transport Study Models
September 4, 1970

This is the sixth in the series of Transport Planning Models Study papers. The Study, directed by Messrs. Jan de Weille and Leon H. Miller, is a continuing investigation of mathematical models developed for transport planning. Existing transport models are being analyzed, and revised and extended where practical. New models will be developed where needed. Eventually, the Study will include cases of models' application in specific transport planning studies and a critical review of the methodology.

The present paper presents the logic and concepts of the models used by N. D. Lea and Associates Ltd. and Lamarre Valois International Limitee in the Dahomey Land Transport Study, and discusses some of the problems encountered in the application.

The transport network model (Trans) is essentially the same model described in Economics Department Working Paper No. 61, Transport Network Model, while the highway model, with minor modifications, is that described in Working Paper 62, Highway Cost Performance Model. The optimization program (Opt) is a new model, designed to determine the best construction and maintenance level and to minimize the total construction, maintenance and vehicle operating costs for a transport link.

The Dahomey Land Transport Study was carried out between 1967 and 1969 by the Lea and Lamarre firms, under contract to the Bank, for the UNDP and the Government of Dahomey. The Lea firm produced a supplementary study in February 1970, Trans-Opt System, presenting the methodology used for the Dahomey study. The paper here presented was adapted from the methodological study by Mr. Leon H. Miller and edited by Mrs. Judy Mijares and Mrs. Suzy Henneman. Copies of the Trans-Opt System, with detailed technical information for users and programmers, can be obtained from the Sector and Projects Studies Division.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. CHOICE OF MODELS</td>
<td>1</td>
</tr>
<tr>
<td>Purpose and Criteria</td>
<td>1</td>
</tr>
<tr>
<td>Harvard Transport Model</td>
<td>2</td>
</tr>
<tr>
<td>Adaptation of Harvard Transport Model to Dahomey Study</td>
<td>5</td>
</tr>
<tr>
<td>The Trans-Opt System</td>
<td>6</td>
</tr>
<tr>
<td>II. THE TRANSPORT SIMULATION MODEL (TRANS)</td>
<td>8</td>
</tr>
<tr>
<td>General Characteristics</td>
<td>8</td>
</tr>
<tr>
<td>Data Inputs</td>
<td>9</td>
</tr>
<tr>
<td>General Operational Stages</td>
<td>11</td>
</tr>
<tr>
<td>The Operational Steps</td>
<td>14</td>
</tr>
<tr>
<td>III. THE LINK OPTIMIZATION PROGRAM (OPT)</td>
<td>22</td>
</tr>
<tr>
<td>General Characteristics</td>
<td>22</td>
</tr>
<tr>
<td>Data Inputs</td>
<td>23</td>
</tr>
<tr>
<td>General Operational Stages</td>
<td>25</td>
</tr>
<tr>
<td>The Operational Steps</td>
<td>29</td>
</tr>
<tr>
<td>IV. EVALUATION OF OPT OUTPUTS</td>
<td>38</td>
</tr>
<tr>
<td>Alternative Routes</td>
<td>38</td>
</tr>
<tr>
<td>New Facilities</td>
<td>39</td>
</tr>
<tr>
<td>Calculation of Benefits for Individual Improvements</td>
<td>40</td>
</tr>
<tr>
<td>Diverted Traffic</td>
<td>42</td>
</tr>
<tr>
<td>The Optimization Process</td>
<td>42</td>
</tr>
<tr>
<td>V. SIMULATION PROBLEMS IN DAHOMEY</td>
<td>46</td>
</tr>
<tr>
<td>Intrinsic Simulation Problems</td>
<td>46</td>
</tr>
<tr>
<td>Data Collection Problems</td>
<td>46</td>
</tr>
<tr>
<td>Program Limitations</td>
<td>49</td>
</tr>
<tr>
<td>Calibration Problems</td>
<td>50</td>
</tr>
<tr>
<td>APPENDIX: GLOSSARY OF TERMS</td>
<td>1 - 3</td>
</tr>
<tr>
<td>TABLE</td>
<td></td>
</tr>
<tr>
<td>1. Dahomey: Highway Maintenance Costs</td>
<td>26</td>
</tr>
<tr>
<td>Figures</td>
<td></td>
</tr>
<tr>
<td>1. Relationship of Harvard Transport Model and Trans</td>
<td>3</td>
</tr>
<tr>
<td>2. Trans Flow Chart</td>
<td>13</td>
</tr>
<tr>
<td>3. Opt Flow Chart</td>
<td>27</td>
</tr>
<tr>
<td>4. Standard Growth Curve Procedures</td>
<td>31</td>
</tr>
<tr>
<td>5. Volume Determination with Improved Transport Network</td>
<td>33</td>
</tr>
<tr>
<td>6. Section of Transport Network</td>
<td>39</td>
</tr>
<tr>
<td>7. Illustration of Optimization</td>
<td>43</td>
</tr>
</tbody>
</table>
DAHOMEY LAND TRANSPORT STUDY MODELS

I. CHOICE OF MODELS

Purpose and Criteria

1. The Trans-Opt system described in this paper is partly new (the Opt model) and partly derived from models developed at Harvard University\(^1\) (the Trans model). The system was applied by its authors, N.D. Lea and Associates Ltd and Lamarre Valois International Limitée, to the transport system in Dahomey during the period 1967-1969. The work was carried out under contract to the Bank for the UNDP and the Government of Dahomey.

2. The major object of the Dahomey Land Transport Study was to determine, under the existing and forecast socioeconomic conditions, the adequacy of the existing road and rail transport system, and to recommend on the basis of economic analyses a program of physical and operational improvements to the system. Because of the complex nature of the analyses and the large number of possible improvements to be considered, a computer program or package of programs was sought which could

(i) simulate the traffic which would use a given transport system under given socioeconomic conditions;

(ii) analyze the costs and benefits for the country as a whole which would result from a set of given improvements; and

(iii) select from many alternative potential improvements those which would provide the greatest net economic benefits to the community.

3. A number of computer simulation programs for distributing and assigning traffic over a transport network were considered. However, most of these programs simulated urban conditions; they distributed trips split into a limited number of categories and assigned them to a transport link-node network, often divided into independent systems representing different modes (e.g. private transport, public transport and sometimes goods transport).\(^2\) Most performed the distribution and assignment on the basis of minimum time paths, though some allowed inclusion of out-of-pocket costs with perhaps a simple relationship between vehicle operating cost and speed. They did not produce outputs suitable for

---

\(^1\) Components of the Harvard transport model are described in Economics Department Working Papers 60 through 64: Regional Macroeconomic Model, Transport Network Model, Highway Cost Performance Model, Railroad Cost Performance Model, and Transfer Cost Performance Model.

\(^2\) The transport and systems terms used in this paper are defined in the appendix, "Glossary of Terms."
economic analyses of alternative transport improvements. Most simulated one time period (e.g. peak or off-peak periods, or 24 hours), and would have to be repeated to simulate more than one period.

**Harvard Transport Model**

4. Only one computer model known at the time was specifically designed to simulate a whole country on an economic basis for each season of a year, and would handle both freight and passenger flows of many different kinds by several different types of vehicle, distribute and assign them to a single network including different categories of links (road, rail, etc.), and provide link and system outputs in terms of both freight or passenger flows and vehicles, and in terms of both financial and economic costs. This was the model developed at Harvard University and previously applied to an economic and transport study of Colombia. We refer to it as the Harvard transport model.

5. The Harvard transport model is composed of a macroeconomic model, a network model, and three modal cost models (See Fig. 1). The macroeconomic model is a complex program which simulates the entire economy of a country on a regional basis for a year at a time. It requires comprehensive input data, including a complete national input-output table relating the amount of each product produced to the amounts of other materials used in its manufacture. It provides tables of annual supply and demand of groups of commodities in each region, based on private consumption, plant and inventory investment, government expenditures, exports, and the input-output table; information from the previous year's simulation is used in some of the calculations.

6. The network model takes the regional supplies and demand by industry calculated by the macroeconomic model and breaks them down into supplies and demands of individual subcommodities by node and by season of the year. It then distributes the seasonal supply and demand of each subcommodity and assigns it to the transport network, on the basis of minimum cost routes as perceived by the shippers. After all commodities are assigned, cost-performance measures are calculated for each link and totaled for the whole transport system. Costs are revised according to pricing policies, supplies and demands are reaggregated, and the cost-performance measures are stored for use in simulating the next year. The highway, rail, and transfer models calculate and feed into the transport model information on link cost and performance.

7. Seven features of the network model influenced the decision to use it, subject to certain modifications, for simulation of traffic flows in the Dahomey Land Transport Study. First, up to 40 different commodities
FIGURE 1: RELATIONSHIP OF HARVARD TRANSPORT MODEL AND TRANS

HARVARD TRANSPORT MODEL

MACROECONOMIC MODEL
(Working Paper No. 60)

NETWORK MODEL
(Working Paper No. 61)

HIGHWAY COST MODEL (Working Paper No. 62)

RAIL COST MODEL (Working Paper No. 63)

TRANSFER COST MODEL (Working Paper No. 64)

Rail Cost Look-up Routine
Transfer Cost Look-up Routine

- TRANS MODEL -
may be handled; one or more categories of passenger trip as well as
different types of freight can be represented as commodities.
Distributions and assignments are performed in terms of units of
each commodity rather than by vehicles.

8. Second, up to five different vehicle classes can be defined,
and each commodity is assumed to travel by one of these classes. The
number of vehicles of each class required per day is determined for
each link by the total assigned flow of commodities which use that
class. In this way, similar commodities, such as vegetables, sacks
of grain, other produce and general merchandise can be simulated as
sharing the same vehicle, whereas dissimilar commodities such as bulk
petroleum, bulk shipments of ore or rock, and passengers will be
simulated as requiring different kinds of vehicles.

9. Third, the transport system of the region or country being
studied is represented by a single network of nodes and links, which
includes all available modes, i.e. types of facility, such as road,
air and water, and transfer facilities between modes.

10. Each link of the transport system is described in terms of a
number of characteristics, from which operating costs and other
performance measures such as travel time, delay time, probability of
loss and variability of travel time can be calculated for each vehicle
category. For each commodity, different values can be specified for
each measure of performance; for instance, a high value of delay time
can be specified for perishable produce. The quantities of the
commodity requiring transportation are distributed among appropriate
origins and destinations, and then assigned to the network, using
routes along which the total perceived cost of vehicle operation, of
travel time, and of the other performance measures is minimized.

11. The performance of a vehicle on a link is simulated on the
basis of vehicle load and operating characteristics, link characteris-
tics and the amount of other traffic on the link. As an example, the
characteristics of a road link which influence vehicle performance
can include such items as rate of rise and fall, design speed, type
of construction and condition of surface. Any of these characteristics
on any number of links can be changed, and the effect on flows through-
out the system determined by rerunning the program. In general, any
commodity can travel on any link of any mode, although travel by a mode
or by a group of links within a mode can be suppressed if desired.

12. Fourth, the program operates on modal supplies and demands of
each commodity for a particular year. The distribution and assignment
routines operate in terms of daily flows in each season. As well as
operating for a past year on historic data, the program can be run for a future year using forecasts of supplies and demands and of transport system characteristics.

13. Fifth, the available output includes tables of origin-destination (O-D) movements in each season to calibrate against O-D surveys; daily commodity and vehicle flows by class and season on each link for calibration against vehicle counts; and aggregate system performance measures for each season, from which can be determined such items as total number of vehicles required, vehicle operator costs and profits, and government tax revenues.

14. Sixth, it is possible to study the consequences of various policy changes, such as revision of rate structures on any mode; programs of improvements to existing links or construction of new links; changes in vehicle size or weight restrictions; changes in taxation, etc. The effects of such changes on transport movements as a whole are reflected in the aggregate system performance measures.

15. Seventh, two distribution routines are available: a gravity model formulation which is suitable for passenger trip distributions, in which all supply nodes ship to all demand nodes, and a linear programming routine which is suitable for distribution of individual commodities from their production points to locations where they are consumed or reprocessed: each supply node of a commodity supplies a limited number of demand nodes, so that the total perceived cost of distribution is minimized. The program also provides for insertion of additional distribution routines if desired.

**Adaptation of Harvard Transport Model to Dahomey Study**

16. Consideration was given to using the entire Harvard package in the Dahomey Land Transport Study in order to select worthwhile packages of improvements to the transport system. However, the amount of existing Dahomey information of the type required by the entire Harvard model was very small, and collection of the necessary data would have been expensive and time-consuming. Detailed studies would have had to be done on all aspects of the economy, and input-output factors would have had to be determined for each industry using information on raw material consumption and commodity production.

17. The macroeconomic and network models are run in combination for each year of the study period. The 24-year period covered by the Dahomey Study (1967 to 1990 inclusive) would have required running both models 24 times for any particular set of conditions; for each alternative set of transport improvements being evaluated the models would have had to be rerun for all years following the year of the first improvement. This procedure would have required an inordinate amount of computer time and expenditure, as both models are quite large and complex, and there were many alternative improvements to be considered. In addition,
the macroeconomic model had not yet been successfully calibrated in the Colombian Study, so there was no guarantee of the accuracy of its simulation procedures.

18. Because of limitations of time, cost and data availability, the macroeconomic model of the Harvard package was not chosen. But the desirable features of the network model led to the decision to use it. The package consisting of the network model, a modified highway cost model, and two look-up routines indicating unit costs for rail and transfer operations was given the name Trans (Transport Simulation). Instead of running the model for each of 24 years, it was decided to run it for two points in time only: a base year, the most recent year for which data were obtainable (1967); and a future year for which the required inputs would be predicted (1975).

19. An entirely new link optimization program, Opt, was devised to interpolate and extrapolate costs and volumes for other years and to perform link-by-link economic analyses of the alternative transport improvements, because there was no known existing program which could perform this type of operation.

The Trans-Opt System

20. The Trans-Opt system, then, is a package of two self-contained computer programs: a transport simulation program adapted from the Harvard package and a highway link optimization program. They are designed for use together, to analyze various alternative courses of action in developing an existing transport network, and to select a combination of capital and maintenance improvements that will give rise to a minimum present value of all incurred costs over a given period. The programs may also be used independently. In particular, the Trans program can be used to examine the transport system in any particular year and test the effects of various taxation, pricing and regulatory policies. The Trans program has the same concept and design as the transport network model of Working Paper 61 plus the highway submodel described in Working Paper 62 and the two look-up routines; the Opt program is unique.

21. The input information required for a Trans run consists of a link-by-link description of a link-node transport network representing the physical transport system, with information for calculating transport costs and performance, the taxation, pricing and regulatory policies, plus a list of seasonal supply and demand quantities by node for each commodity, i.e. freight categories and passengers. The
major output item is a table of assigned daily commodity flows by each link of the network.

22. For a run of Opt, the input required includes the assigned link flows produced by Trans, and descriptions and costs of the alternative improvements to the links under consideration. Opt analyzes each link pair in the network and selects the investment alternative which will minimize the present value of total cost for the link pair. The selection is made on the basis of traffic volumes derived from the input. Although Opt can calculate costs for existing standards on link pairs of road, rail and transfer modes, it can analyze alternative improved standards only for road link pairs. It can also select an optimum standard for proposed new road links.

23. The Trans and Opt models are described separately in detail in the next chapters.
II. THE TRANSPORT SIMULATION MODEL (TRANS)

General Characteristics

1. Trans is a mathematical model which can simulate the movement of goods and/or passengers on a multimodal transport system for each season of a given year. It is in the form of a computer program which can presently be run on either an IBM 7094, a UNIVAC 1108 or a Burroughs 5500 computer.

2. Each commodity is assigned to one of the five vehicle classes. For each season, each commodity, through its vehicle class, is assigned to the network along paths of minimum cost, as perceived by the shippers, by one of two distribution routines. When all the commodities have been assigned to the network, the costs, times, and other transportation performance measures are calculated for each vehicle class on each link in each season. The available output includes origin-destination tables of costs, flows, etc., by commodity in each season; costs, flows, etc. in each season on each link of the system, and aggregate systems performance measures by season.

3. The Trans program as used in the Dahomey Study has certain capacity limitations. It can handle up to:

- 300 one-way links
- 149 nodes
- 40 commodities
- 20 supply nodes per commodity
- 40 demand nodes per commodity
- 10 mode-submode combinations
- 5 vehicle classes
- 4 seasons

Some of these limits could be extended by means of programming changes.

4. Before the Trans model can be used it has to be calibrated to ensure that it can in fact accurately simulate the transportation system. This is done by iteratively running the model using data for current conditions, and comparing the resulting flows and performance data with those actually measured in the field. After suitable programming and data modifications have been made, the model is ready to forecast future traffic on the basis of projected changes in supply and demand patterns and in the transport system characteristics.

5. The Trans model can be used in one of two ways. First, it can be used on its own to analyze the transport situation in one specific year or to give a better understanding of the interaction between the various parts of the system and to point out areas for improvement.
Second, Trans can be run as part of the Trans-Opt System, the output from Trans for different years and networks being used as input to the Opt program, which determines an optimum network.

Data Inputs

6. The information required to run the model for a particular country or region consists in a description of the transportation network, a description of the vehicles operating on the network, a description of the commodities to be moved on the network, and a series of equations and parameters relating the performance of the vehicles to the characteristics of the network and to the amount and type of traffic using the network.

7. The network is described in terms of links and nodes; the links represent transportation routes—road, rail, air, etc., and intermodal transfer facilities—and the nodes represent points where two or more routes join and points where traffic is generated or attracted. The links are described by their characteristics—mode, length, rise and fall, etc. The vehicles are divided into five classes which are described by characteristics such as weight, capacity, power, etc., as they relate to each mode considered. The commodities are described by their transportation preference characteristics, i.e., the relative importance of travel cost, travel time, probability of loss, etc., and by the nodes where they are supplied and the nodes where they are demanded. Passengers are considered as one or more separate commodities.

8. The data required to run the Trans program are divided into ten categories or data types; for the first run of a study all data types must be supplied but in subsequent runs only the input data types which differ from the previous run need to be specified. The highway mode is the only mode for which a separate cost model is used (data type (4)); rail and transfer link costs are determined in a simpler way, described further below.

9. The ten data types are:

   (1) General Data. Information regarding the input of other data types and the optional outputs is required; also basic dimensions for the program, including number of commodities, number of nodes and links in the transport network, number and lengths of seasons and number of vehicle categories.

   (2) Node Names. Each node of the transport system may be given a code name if desired.
(3) Preliminary Link Performance Measures. In the first of a series of iterations, approximate unit values of travel cost and up to four other performance measures (travel time, waiting time, variability of travel time and probability of loss) are required; in subsequent iterations, performance measures calculated on the basis of traffic assigned to the network in the previous iteration are used.

(4) Highway Cost Model Data. Items required include characteristics of up to five classes of highway vehicle, such as the weight, horsepower, carrying capacity, vehicle cost, unit costs of fuel, oil, maintenance, tires, etc.; also parameters for use in equations relating vehicle speed and fuel consumption to rate of rise and fall, speed to volume and capacity, and operating costs to condition of road surface.

(5) Commodity Data. Descriptive information for each commodity to be distributed is needed, including a code name, the unit value of the commodity, the vehicle class by which it travels, the distribution model to be used and a series of commodity preference factors which indicate the relative values placed by a shipper (or a traveler in the case of a commodity representing passenger trips) on each of the performance measures given in data type (3).

(6) Mode Data. Each link of the network must be assigned a mode-submode identification number as defined in the appendix. This data type defines the mode-and-submode combinations allowed in the network, up to a maximum of ten in number. Also for each submode it defines the number of working hours per day (used in vehicle availability calculations) and fixed cost for pricing policy (used in link tariff computations).

(7) Vehicle Data. Details on the number and payload (carrying capacity) of vehicles of each category on each submode are required for conversion between tons and vehicles and for calculation of vehicle availability for system performance measures. Other vehicle-mode data are described in detail in the Trans users' manual of the consultant's report.
(8) **Rate Table.** Details are required of the pricing policies in force on each mode and submode within the network. The rates charged may be specified as either cost-based or flat-rate.

(9) **Commodity Supply and Demand.** The annual quantities of each commodity supplied and demanded by node are needed; also, for each supply node a unit price representing the production cost (or a "terminal cost" for passengers) and the percentage supplied in each season are required.

(10) **Link Characteristics.** This is equivalent to a link-by-link description of the transport network. Each link, which represents one direction of an actual facility, is described by its start and end node numbers, mode and submode identification and a series of link characteristics from which the unit performance measures for each vehicle category on the link can be calculated. For highway links the characteristics include link length, surface type, design speed, rise and fall, construction class and seasonal delay factors. These are used in conjunction with the vehicle characteristics from data type (4) to calculate the link performance measures. Links are described in pairs representing opposite directions of a transport facility.

**General Operational Stages**

10. Once the data for a link-by-link description of the physical network is provided, the highway cost model and table-up routines for rail and transfer links determine initial estimates of costs, tariffs, and other performance measures for travel in each season on each link of the network. This is the first step in the first iteration of the Trans model, and is shown at the top of the operations column in Fig. 2, a flow chart of the model. All thirteen operational steps are described in more detail in the next section. At this initial stage, these costs and performance measures can only be estimated, because the actual volumes and types of traffic necessary to calculate their true values are not known until several iterations of the whole Trans model's operations have been performed.

11. While the original Harvard transport model offered both simple and sophisticated cost-performance models for transfer, road and rail links, and gave a simple universal model for other modes such as air, water and pipeline, the Dahomey application uses a sophisticated model for highway only, with some modifications. Of the performance measures used in the Harvard model, only transport cost to the shipper was considered; the other measures were set to zero (waiting time, travel time, variability of travel time, probability of loss). There is one exception: the highway cost model derives travel time in its operating cost calculations.
12. The highway cost model used to make the initial estimate is similar to the one described in Economics Department Working Paper 62, *Highway Cost Performance Model*, as taken from the original Harvard highway model. This model is part of the Trans model in the sense that it produces link cost information used in Trans, but it may also be operated independently. While derived from the Harvard model, it contains many modifications of the relationships used. The procedures used to calculate the various elements of operating cost, e.g. fuel cost, tire wear cost, depreciation cost, etc., were reviewed carefully; the available literature on vehicle operating costs was studied, and where it was thought worthwhile, improvements or additions were made. The equations used in the Trans model and their derivations are given in Chapter 5 of the Trans users' manual and also in Appendix E of the Dahomey Land Transport Study final report. The parameters used were derived partly from the Harvard model, partly from the literature and partly from collected information and empirical observation in Dahomey.

13. For the transfer links, a table look-up routine selects the cost per ton of commodity transferred for each vehicle category directly from the input link characteristics; each cost is multiplied by an efficiency factor, also a link characteristic. The unit costs used were obtained from studies of the operations of road-rail transfer facilities in Dahomey. It was not possible to obtain all the data required for the sophisticated transfer model, nor was there time to write any complex new model to simulate transfers.

14. In the rail model as in the transfer model, a relatively simple table look-up routine finds the cost per ton, per unit distance for each vehicle category. The unit costs coded on the link characteristics are derived from a study of rates and costs in 1967, and from forecasts for 1975 based on assumed likely rail traffic volumes. The complex Harvard rail model was not used for lack of time and facilities for obtaining the necessary data. Nor was there time to write or adapt a more complicated model than the one actually used. For example, a model which could calculate average costs per ton-kilometer from the fixed system costs and the marginal transport costs, as a function of the total traffic on the rail system, would have been more accurate and would have eliminated the need to manually calculate the average transport costs.

15. The operating costs thus calculated for all links are then converted to shipping charges by application of a pricing policy. This section of the program, taken from Harvard transport model with no changes, is the second item in the operations column of Fig. 2.
16. After estimating the initial link costs and performance and the link tariffs, the next eleven operations listed fall into two stages. In the first stage, the network flows are calculated. For each commodity, the transport costs, that is, the resistance to travel as perceived by the shipper of the commodity, called the R-Factor, is estimated for each link in the network, and the minimum paths (paths of least cost resistance) between all origins and destinations of the commodity are calculated. Then, from the seasonal supply and demand data for each commodity at the various nodes, the model determines the distribution pattern of each commodity, using either an inverse impedance (gravity type) model or a linear programming formulation. The flows of each commodity are then assigned to the paths of minimum cost and the resulting flows are aggregated for all commodities on each link of the network according to vehicle class to show the link utilization.

17. The second stage is to recalculate the link cost and performance measures by analyzing each link by season. Determination of these measures includes the updated calculation of tariffs using the appropriate pricing policy. The measures are aggregated over all links to provide total systems cost and performance measures classified by mode and submode, vehicle category and season.

18. The revised link cost and performance measures may be re-input to the program to give a new distribution and assignment of the commodities. The model may be iterated in this way several times to provide a progressively capacity-restrained assignment; the number of iterations required must be specified in the input. The flows and the performance measures resulting from the final iteration are the ones used for further analysis in the Opt model.

19. These are the general stages. In the next section, we retrace one by one the operational steps as shown in Fig. 2 (p. 13). Readers not concerned with detail may wish to skip this section and resume reading on p. .

The Operational Steps

Calculate Initial Link Costs and Performance

20. At the beginning of any iteration, there must be an Initial Link File containing the Link Performance Vector (LPV) items necessary for calculation of the R-Factors to be used in the commodity distribution and assignment procedures. In second and subsequent iterations of a run the Initial Link File is the Final Link File generated in the previous iteration. However, on the first iteration of a run, a new file must be generated using Link Characteristics Vectors (LCV) read from cards, an assumed Link Utilization Vector (LUV) and approximate or preliminary unit LPVs (PLPVs). The following procedure is followed for each season, for each pair of links whose LCVs are read from cards.
21. Preliminary LUVs of 50 tons per day for each vehicle class are assigned to each link; these are divided by the payload of each class to give the number of vehicles. These arbitrary volumes have no effect on the calculation of the initial LPVs. The LPVs are calculated for each season by three simple models (originated or adapted specifically for the Dahomey Land Transport Study), one each for highway, rail, and transfer modes. These models take the Preliminary Link Performance Measures (PLPVs) from input data type(3) and operate on pairs of links representing the same trip in opposite directions.

22. After the LPVs have been calculated for each link for each season by one of the above modal models, the fifth item of the LPV for each vehicle class and each season, which at this point contains the operating cost per ton, is adjusted to reflect the actual rate charged to the shipper by means of the rate table (data type(8)). If the entry in the rate table for the corresponding vehicle category and mode-submode number is negative, the calculated cost in the LPV is multiplied by the absolute value of the entry. If the entry is positive, the value in the LPV is replaced by the table entry times the length of the link (set to one distance unit for a transfer link) plus a fixed cost for that submode (defined in the mode table - data type(6)). In this way the tariffs can be either proportional to the actual costs incurred by the carrier or a flat rate per unit distance.

23. At this point in the program, after these steps have been performed for all links and for all seasons, the Initial Link File (Output 5 in Fig. 2) containing the LCVs and the initial values for the LUVs and the LPVs for each season is available.

24. For each commodity and each season, a table of R-Factors for each link is calculated. The R-Factor for a particular commodity on a particular link is the total perceived shipper's cost, i.e., the sum of the products of each item of the Commodity Preference Vector (CPV) for the commodity and the corresponding item of the LPV of the link, for the appropriate season and vehicle category. R-Factors are in money units per ton. (In the Dahomey Land Transport Study the R-Factor represented simply the transport charge for traveling the link.)

25. At this point in the program tables can be printed out of the F-Factor Components (Output 6) and of the total R-Factors (Output 9) for each link of the network, for each commodity and each season.
Determine Minimum Paths

26. This step is carried out in turn for each commodity in each season. For each supply node of the commodity being considered, a "tree" is built from the supply node to all other nodes in the network such that the accumulated R-Factors along any path from the supply node are minimized. The values of the cumulative R-Factors along the minimum paths are stored, as are values of cumulative transport charge (or C-Factors) along the same paths. (In the Dahomey Land Transport Study, the C-Factors were identical to the R-Factors). The "trees" are built without regard for mode or submode of the component links; only the R-Factor values are used. Commodities may be discouraged from using certain modes, submodes or links by creating artificially high R-Factors, e.g. by manipulating the rate table, LCVs or CPVs.

Calculate O-D Cumulative R-Factors and Tariffs

27. After "trees" have been calculated for each supply node of the commodity, origin-destination (O-D) tables are constructed of the total cumulative R-Factors and C-Factors between each supply node and each demand node. Various operations are performed on these tables for the purpose of obtaining summary reports. The table which is used in the distribution phase of the program has the production cost at the supply node added to each element of the O-D cumulative R-Factor table.

Calculate Seasonal Supply and Demand

28. The supplies and demands input on cards (data type (9)) are in terms of tons per year at each supply and demand node for each commodity. For each supply node, the production cost per ton and the percentage supplied in each season are specified. The program then operates as follows on this information: if the total annual quantity demanded for each commodity is not equal to the total supply, the demand at each node is adjusted by a common factor so that total demand equals total supply.

29. The quantity supplied in each season is computed for each supply node by applying the percentages specified in the input to the annual supply at the node. The demand in each season at each demand node is calculated from the annual demand at the node by applying the ratio of total supply for the season to total supply for the year, i.e. the seasonal split at all demand nodes of a commodity is assumed to be the same.
30. The tons supplied and demanded and the production cost per ton at each supply node are divided by the value of the commodity specified in the commodity data (data type (5)), giving supply and demand in money units per season and unit production cost as a proportion of the value. The supply and demand in money units per season by node and the unit production cost for each commodity in each season comprise the Supply-Demand File, which is written on tape for use in each iteration and may also be printed out as the Supply-Demand Report.

31. For the distribution phase of the program, the supply and demand data are required in a slightly different form from the way they are stored in the Supply-Demand File. The quantities supplied and demanded of the commodity under consideration are extracted from the Supply-Demand File and converted from money units per season to tons per day, using the days per season from data type (1) and the commodity value per ton from data type (5); the quantities are also divided by the transport coefficient specified for the commodity in data type (5).

32. In addition, the production cost at each supply node, stored on the file as production cost per unit value, is multiplied by the commodity value and by the homogeneity coefficient, also from data type (5). (In the Dahomey Study both the transport coefficient and the homogeneity coefficient were initially set to unity; however, the transport coefficient was changed during the calibration process.) At this point the Supply-Demand Balance Sheet (Output 8), which summarizes the results of these calculations, can be printed out.

Distribute Commodities

33. This step is carried out separately for each commodity in each season. The choice of distribution model for each commodity is made in data type (5). Two alternatives are available; they are the inverse impedance or gravity distribution model, and the linear programming distribution model. The first kind of model is useful for distributing either passenger trips or goods of a general nature, both of which must be distributed over the entire transport network. It produces a flow matrix in which each supply node sends passenger trips or goods to every demand node. An option is available, however, which will suppress distribution from a node to itself, when the node has both supply and demand of the same commodity. The program does this by applying a large value to the appropriate O-D R-Factor.

34. The gravity model requires a table of origin-destination cumulative R-Factors including the production cost at each origin, the supply and demand by node in tons per day of each commodity, and the R-Factor exponent as specified for the commodity in data type (5). Production from each supply node in turn is distributed to all the demand nodes in proportion to the quantity demanded and in inverse proportion to the origin-destination cumulative R-Factor, raised to the exponent.
specified for that commodity.\footnote{1}

After all supply nodes have been treated in this way, the total flow distributed to each demand node will not in general be equal to the total demand. Adjusted demand R-Factor ratios are used to calculate new values of the flows from node to node.\footnote{2} This process is automatically repeated, or iterated, until the total of the absolute errors in distributed demand at all the demand nodes is less than or equal to one percent.\footnote{3} The number of iterations is limited to 20 but usually less than 10 are required. The final values of the flows from node to node form an origin-destination matrix table of flows in tons per day of the commodity being treated.

\footnote{1} This may be represented by the equation:

\[ F_{i,j} = \frac{S_i \cdot D_j / (R_{i,j})^b}{\sum_j D_j / (R_{i,j})^b} \]

where \( F_{i,j} \) = flow from node \( i \) to node \( j \)
\( S_i \) = supply at node \( i \)
\( D_j \) = demand at node \( j \)
\( R_{i,j} \) = cumulative R-Factor from node \( i \) to node \( j \)

including the production cost at \( i \)

\( b = \) R-Factor exponent (data type \( v \)).

\footnote{2} In other words, the value of \( \sum_i (F_{i,j}) \) will not be equal to the value of \( D_j \) at each demand node \( j \). Accordingly, the values of the ratio \( D_j / (R_{i,j}) \) for each demand node \( j \) are adjusted by applying the ratio \( D_j / \sum_i (F_{i,j}) \); these adjusted values are used to calculate new values of \( F_{i,j} \) according to the same equation.

\footnote{3} In other words, until

\[ \sum_j \left\{ \left| \sum_i (F_{i,j}) - D_j \right| \right\} \leq 0.01 \sum_j (D_j). \]
The other kind of distribution model, the linear programming (LP) model, is useful when the commodity to be distributed is homogeneous, that is, when goods produced at all supply points are assumed to be identical in quality, and the point of origin is immaterial to the buyer. The model minimizes the total cost of distribution; goods flow from each supply node to only a limited number of demand nodes with no cross-hauls, i.e. no opposing flows on the same link pair. A node with both supply and demand may supply itself.

In general, no two supply nodes supply to the same two demand nodes, but when all four minimum paths linking two supply nodes with two demand nodes have the same cost, there is an infinite number of possible distributions of flow within a certain range for which the total cost is at a constant minimum. This situation can result in two supply nodes supplying the same two demand nodes, depending on which distribution the computer happens to select.

The LP model first selects the supply node for which the difference between the two smallest cumulative R-Factors is least; then, from that supply node to the demand node for which the cumulative R-Factor is least, it assigns a flow equal to whichever is less: the supply at the supply node or the demand at the demand node. This supply and demand node pair is now removed from further consideration, and the process continues until all the supply has been distributed.

The program then examines every combination of supply-and-demand node pairs to determine whether the total decision cost (the aggregate product of the R-Factor and the corresponding O-D flow) can be reduced by redistributing the flows between pairs of nodes. This is repeated until no further cost reduction can be effected, i.e. until the total decision cost on two successive iterations is the same. The resulting matrix of origin-destination flows in tons per day is returned to the main program. The total decision cost at the end of each iteration of the distribution is printed out.

The basic output from either distribution model is an O-D matrix of flows in tons per day. Some further calculations are made to provide O-D matrices of transport charges and ton-kilometers or ton-miles. These outputs are referred to collectively as Origin-Destination Flow Tables.

Assign Commodities

This step is carried out for each commodity in each season immediately after distribution. The same minimum path "trees" as derived for the distribution models are used to assign the distributed flows to the transport network.
Aggregate Commodity Flows

42. All commodities assigned to each link in each season are accumulated into one of five vehicle categories, the category chosen for each commodity being that specified for the commodity in data type (5). The turn volume (the volume continuing through a node) at the end of the link are accumulated in the same way. After these calculations are completed there is a complete list of flows and turns (in tons per day) on each link for each season. These volumes are used to replace the corresponding LUV elements of the Initial Link File, creating a new Intermediate Link File; the flows and turns to the nearest ton may also be printed out as the Flow-Turn Table.

Determine Vehicle Flows

43. This step is carried out separately for each link and each season. The aggregated commodity flows and the associated turns calculated as above for each link are converted to vehicle flows by dividing the commodity flow in each vehicle category by the vehicle payload (from data type (7) ) for that category, for the particular mode and submode involved. The numbers of vehicles in each category for opposite directions of a link pair are then compared and the number of vehicles in the heavier direction of flow for each category is assumed to be the number of vehicles required for both directions. This information is used to further update the Intermediate Link File. This step is not necessary for highway as it is carried out by the highway model. For rail, however, it is necessary as the rail cost look-up routine does not recalculate the vehicles required.

Recalculate Link Costs and Performance

44. In this section of the program, the LPVs are recalculated by mode for each link on the basis of the newly assigned flows to give the Final Link File; performance information is also accumulated to provide systems performance measures. For the transfer links, the cost per ton in each direction for each vehicle class is obtained directly from the LCV. These costs are multiplied by the efficiency factor and placed in the fifth LPV location for the corresponding vehicle classes, for each direction of the link pair, for the appropriate season.

45. For both directions of a road link pair, the highway cost model supplies new values of travel time and travel cost, and also updates vehicles per day to allow for backhaul of empty or partly loaded vehicles. The vehicle Performance Measures produced during these calculations can be printed out. The rail table look-up routine gives for each link the cost per ton per unit distance by commodity and vehicle class. These are multiplied by the length of the link to give the link transport cost for each vehicle category.
Recalculate Link Tariffs

46. After the LPVs of each link pair have been updated for each season, the Rate Table (data type (8)) is used to convert the operating cost per ton for each vehicle category to the tariff charged to the shipper. At this point in the program, after link costs and tariffs have been calculated for all links and for all seasons, the Final Link File containing the LCVs and the final updated values for the LUVs and the LPVs for each season is available as an optional printed output and as a magnetic tape which can be used as input to a further iteration of Trans or as input to the Opt program.

Calculate Systems Performance Measures

47. The following quantities are calculated for each link and added into accumulating totals, according to vehicle category and subnode, for each season:

- ton-hours of waiting = tons/day x waiting time;
- ton-hours of travel = tons/day x travel time;
- vehicle-miles = vehicles/day x link length;
- vehicle-hours = vehicles/day x travel time;
- ton-miles = tons/day x link length;
- revenue = tons/day x tariff charged/ton;
- cost = tons/day x operating cost/ton;
- vehicle-hours required = vehicles/day x travel time;
- vehicle-hours available = vehicles on this submode (data type (7)) x hours per day on submode (data type (6)).

In each season vehicle-hours required is increased by the excess, if any, of hours required over hours available in the previous season. The number of vehicles in data type (7) is also modified between iterations. The results of these calculations can be printed out as the Systems Performance Measures (Output 16).

48. After calculating systems performance measures for each season, the program performs various calculations using input from data type (7) (vehicle data). These calculations, while part of the Harvard network model, are not very useful to the Trans user. The tables produced are not included in the output descriptions; further details of the calculations may be obtained from the Trans Programmers' Manual.

Check for Further Iterations

49. After all the preceding calculations have been performed, the program checks whether any more iterations are required. If so, the Final Link File becomes the new Initial Link File, and the computations are repeated using the newly-updated LPVs as a basis for the distribution and assignment. If all iterations have been completed, the program is terminated. The tapes containing the Supply-Demand File data and the Final Link File data from the last iteration may be retrieved for future use in Trans or Opt runs.
III. THE LINK OPTIMIZATION PROGRAM (OPT)

General Characteristics

1. While the Trans program is the same as the Harvard network model presented in Working Paper 61, Opt is unique to the Dahomey study. It performs a link-by-link analysis of a transport network, selecting for each section of facility, from several given road maintenance and construction alternatives, an optimum road standard for which the total discounted present value of all costs over the period studied is a minimum. Highway, rail and transfer links are included as in Trans, but separate maintenance costs are distinguished and maintenance and construction alternatives offered for highway links only. The existing rail and transfer facilities are thus taken to be optimal and no changes in them are considered.

2. The program analyzes one pair of links, representing both directions of a transport facility, at a time. It calculates and prints for each link pair detailed yearly costs, both for the existing network, and for the given alternative link standards using the improved network traffic flows. All costs are discounted, and the program selects as optimum the standard which gives the lowest present value total cost (including operating, maintenance, capital and secondary costs). In addition, summary tables are printed from which costs and benefits to the network as a whole can be determined from the selected packages of optimum improvements.

3. If input data to Opt are obtained from Trans outputs, these data will be subject to the limitations imposed by Trans, such as 300 links (150 pairs) and 149 nodes. Opt itself can handle any number of links, with node numbers up to 999, but can only handle five vehicle categories as in Trans. In its present form it is limited to two seasons; slight modifications would enable it to handle up to four seasons as in Trans.

4. The output from Opt may be used to estimate the costs and benefits of individual improvement projects for evaluation on the basis of benefit/cost ratios, rates of return, etc. For projects which cause diversion of traffic from one route to another, including any proposed new facilities, further Opt runs are required. If the link standards selected by Opt are significantly different from those assumed in deriving the improved network input flow data, a revised improved network may be defined, from which a new set of flows can be obtained for use in a further run of Opt.
Data Inputs

5. The program requires as input the present and forecast future flows on each link of an existing transport network, and forecast flows on an improved network which includes proposed additions and improvements to the existing network. These flow data may be obtained directly from runs of Trans, or may be determined independently of Trans and input directly into the Opt program. Also required are the characteristics and capital costs of alternative improvements for each link, vehicle operating cost parameters, highway maintenance cost equations and selected growth curves for determining costs in each year.

6. Five types of input data are required for a run of Opt: general data, link data, link improvement specifications, highway cost model data and highway maintenance equations.

7. The general data includes:

   The base or present year;
   The forecast or future year;
   The length of the study period;
   The year for completion of all link improvements;
   Earliest year for beginning capital expenditure;
   Size of network to be analyzed;
   Discount rates for present value calculations;
   Year to which costs are to be discounted;
   Average annual percentage increase in traffic volumes;
   Number of days in each season;
   Step function growth curves.

8. The link data includes for every link pair in the network being analyzed:

   i. Flows (in tons/day by vehicle category, direction and season) resulting from the assignment of supplies and demands forecast for the future year to an improved network, including any proposed new links;

   ii. Flows in the present year on the existing transport network, as either measured or simulated; also, the existing link characteristics for each direction as required by the operating and maintenance cost models;

   iii. Flows resulting from the assignment of the forecast supplies and demands (as in (i) above) to the existing network (as in (ii) above).
9. These data may be supplied on three magnetic tape files produced by three runs of Trans, or alternatively they may be determined by some other method and coded manually for direct input by punched cards. If it is desired to have the improved network identical to the existing network it is possible to use a single Trans tape to represent both the first and third files; this option is not available for manually-coded input.

10. For any road link pair, one or more alternative improvements may be specified; the following link improvement specifications are required for each alternative considered:

i. Link characteristics: construction class, distance, design speed, rise and fall, delay factor and delay seasons;

ii. Capital cost of improvement;

iii. Length of construction period in years;

iv. Secondary costs or benefits (negative costs) expected in the forecast year;

v. Salvage value of improved facility at end of study period;

vi. Specification of growth curves to be used in interpolation and extrapolation of costs and volumes;

vii. Mode and submode of link pair.

The same information must be supplied in describing alternative standards for a proposed new link pair; also for new links the region of the country must be given, for use in selecting maintenance equations.

11. The data required for the Highway Link Cost Model are the same as those used in Trans. Briefly, they consist in:

i. Unit definitions - for weight, distance, rise and fall and fuel units.

ii. Rise and fall factors - for travel time and fuel consumption.

iii. Capacities - by road construction class.

iv. Road surface factors - for speed, tire wear, depreciation, oil consumption, vehicle maintenance and fuel consumption.

v. Vehicle parameters - physical characteristics and unit costs for each category of vehicle.
12. The highway maintenance cost equations in the present version of the program are listed in Table 3. These formulas were derived for use in the Dahomey Land Transport Study; the values of the coefficients would have to be changed in order to use the Opt program for different conditions, although it is likely that the same general form using a fixed cost plus a cost variable with traffic could be retained. The network is split into two regions for maintenance calculation purposes, to reflect differences in the availability of materials (gravel, sand, etc.) and/or variations in labor costs. The region in which each link lies is one of the link characteristic items.

13. Cost equations are not shown for zero maintenance, as this level implies no expenditure on maintenance. Only minimum maintenance is considered for construction of one-lane track; since the program requires a cost for adequate maintenance, this is set equal to the cost of minimum maintenance.

General Operational Stages

14. We now present in general terms the operations of the Opt program, with reference to the flow chart shown in Fig. 3. Fuller details of the actual computational procedures are given in the next section.

15. The program begins by reading general data, defining such items as the base or present year for the study, the length of the study period, the future year for which traffic forecasts have been made, the year in which any link improvements become effective and the desired discount rates. Then the program performs the computations described in the following four sections for each pair of network links (representing two directions of an actual transport facility). If the link pair under consideration is a proposed future addition to the network, the cost calculations making use of the existing link characteristics (length, rise and fall, construction class, maintenance level, etc.) are not performed.

Calculate Costs for Existing Network

16. Using traffic flows by commodity category, direction and season assigned to the existing transport network for both the present year and the given forecast year, together with the existing link characteristics, the program applies the highway cost model, rail and transfer look-up routines, and a traffic growth curve procedure to obtain the total annual vehicle operating cost on the link pair for each year of the study period.
Table 1: DAHOMEY: HIGHWAY MAINTENANCE COSTS

<table>
<thead>
<tr>
<th>Construction Class</th>
<th>Maintenance Level</th>
<th>Region</th>
<th>Annual Maintenance Cost per Kilometer 1/ (thousand CFA francs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-lane track</td>
<td>Minimum to South</td>
<td>0.50 n</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequate North</td>
<td>0.42 n</td>
<td></td>
</tr>
<tr>
<td>One-lane terre de barre</td>
<td>Minimum South</td>
<td>5.8 + 0.32 n</td>
<td></td>
</tr>
<tr>
<td>(in situ material)</td>
<td>Adequate North</td>
<td>9.1 + 0.53 n</td>
<td></td>
</tr>
<tr>
<td>Two-lane terre de barre</td>
<td>Minimum South</td>
<td>14.0 + 0.32 n</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequate North</td>
<td>22.0 + 0.53 n</td>
<td></td>
</tr>
<tr>
<td>One-lane laterite or</td>
<td>Minimum South</td>
<td>12.9 + 0.47 n</td>
<td></td>
</tr>
<tr>
<td>gravel (Imported Material)</td>
<td>Adequate North</td>
<td>10.8 + 0.32 n</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minimum South</td>
<td>17.7 + 0.87 n</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequate North</td>
<td>15.1 + 0.61 n</td>
<td></td>
</tr>
<tr>
<td>Two-lane laterite or</td>
<td>Minimum South</td>
<td>14.0 + 0.47 n</td>
<td></td>
</tr>
<tr>
<td>gravel</td>
<td>Adequate North</td>
<td>14.0 + 0.32 n</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minimum South</td>
<td>22.0 + 0.87 n</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequate North</td>
<td>22.0 + 0.61 n</td>
<td></td>
</tr>
<tr>
<td>One-lane paved</td>
<td>Minimum South</td>
<td>12.0 + 0.40 n</td>
<td></td>
</tr>
<tr>
<td>(with gravel shoulders)</td>
<td>Adequate and North</td>
<td>154.0 + 0.105 n</td>
<td></td>
</tr>
<tr>
<td>Two-lane paved</td>
<td>Minimum South</td>
<td>14.0 + 0.40 n</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequate and North</td>
<td>176.0 + 0.034 n</td>
<td></td>
</tr>
</tbody>
</table>

1/ Average two-way daily vehicle flow = n.
FIGURE 3  OPT FLOW CHART

INPUTS

1. GENERAL DATA
2. LINK FLOWS & CHARACTERISTICS EXISTING NETWORK
3. LINK IMPROVEMENT SPECIFICATIONS
4. HIGHWAY COST MODEL DATA
5. HIGHWAY MAINTENANCE EQUATIONS

OUTPUTS

START

TOTAL SYSTEM OUTPUTS

FOR EACH LINK PAIR

CALCULATE COSTS FOR EXISTING NETWORK

PRESENT CONDITIONS

Accumulate

"EXISTING SYSTEM"

CALCULATE COSTS FOR "IMPROVED" NETWORK EXISTING LINK

"ALTERNATIVE No. 0"

Accumulate

FOR EACH ALTERNATIVE

CALCULATE COSTS FOR ALTERNATIVE IMPROVEMENT (WITH IMPROVED NETWORK)

ALTERNATIVE No.1 (2,3,etc.)

LEAST COST IMPROVED SYSTEM

SELECT OPTIMUM ALTERNATIVE

MINIMUM P.V. TOTAL COST ALTERNATIVES

END
In a similar way, the average daily two-way vehicle flow is calculated for each year, from which, by application of a maintenance cost equation, the annual facility maintenance cost is computed for the highway links. (In the case of rail and transfer links, maintenance costs are included in the operating costs.)

17. The year-by-year operating and maintenance costs are then discounted to present values at each of the given discount rates. The costs, both year-by-year and discounted, are printed out.

18. These calculations are performed to provide a "do-nothing" base cost from which benefits accruing to the network as a result of the total package of link improvements can be calculated.

**Calculate Costs for Improved Network Using Existing Link Characteristics.**

19. The program next obtains the link flow assigned to an improved network for the future forecast year; this network includes any new links proposed for future construction, and the flows come either from a Trans-produced tape or from manually-input data. After invention of a value for the flow in the present year on the improved network, similar procedures to those described in the preceding paragraph are used to obtain annual operating and maintenance costs for each year of the study period. The existing link characteristics are used for these calculations, except that for road links the calculations are performed for three possible levels of maintenance - zero, minimum and adequate. The costs and flows up to the year in which it is assumed all improvements will be implemented are set equal to those calculated for the existing network. The operating, maintenance and total costs for each road maintenance level, both year-by-year and discounted to present values, are then printed out.

**Calculate Costs for Alternative Improvements, Revised Link Characteristics.**

20. One or more alternative improvements to each road link pair may be specified. Each is described in the input in terms of its link characteristics, capital costs, construction period, secondary costs or benefits expected in the forecast year and salvage value at the end of the study period.

21. Using the improved network link flows, derived as described in the preceding section, and the revised link characteristics, the program calculates year-by-year operating and maintenance costs for each alternative improvement at each of the maintenance levels. In addition, the capital expenditure is assigned to the appropriate year or years, the salvage value is assigned as a negative capital cost in the final year of the study period, and the year-by-year secondary costs or benefits (negative costs) are calculated in proportion to vehicle volume. As above, all volumes and costs (except capital) up to the improvement implementation year are set equal to those on the existing network.
Year-by-year and present value operating costs, maintenance costs, capital costs, secondary costs or benefits and total costs are printed out for each maintenance level of each alternative.

Select Optimum Alternative

22. For each discount rate, the program selects from the improvement alternatives and existing standard the highway construction standard and the maintenance level which give the least present value total discounted cost (including operating, maintenance, capital and secondary costs or benefits). The standard and maintenance levels selected at a discount rate corresponding to the opportunity cost of capital are assumed to define the optimum conditions under which the link pair should operate after the implementation date and for the remainder of the study period. The standard selected at each discount rate is indicated in an output table.

23. For rail and transfer links, no changes in construction standard or maintenance level are considered.

Compile Summary Tables

24. As each link pair is processed, certain present value costs are accumulated. After all links have been analyzed, three summary tables containing present value network operating costs, maintenance costs, capital costs, benefits and total costs at each discount rate for transfer, highway and rail modes are printed, assuming: (1) that the existing network is retained unchanged throughout the study period; (2) that only maintenance is optimized with no capital improvements; (3) that the optimum improvement and maintenance level is selected for each link pair.

The Operational Steps

Traffic Flows on Existing Network

25. The daily flows by vehicle category, direction and season are added and averaged over all seasons to obtain average total daily flows. One of two growth curve procedures is used to calculate the average daily two-way total flow on the link pair for each year of the study period. For rail and transfer links the flows are in tons and for highway links in vehicles. The length of the study period is specified in the program input; it may be a maximum of 25 years, beginning with the present or base year.
26. There are two standard growth curve procedures. Their common purpose is to take values of flows on costs for the present and forecast years and compute values for each year of the study period. The use of the two procedures with daily volumes is illustrated in Fig. 4. In the first procedure (curve 1), an exponential growth curve is fitted between the two given values. The annual growth rate from the present to the forecast year in this procedure depends entirely on the relative values of the volumes in the two years. If the present year volume is very small in relation to the forecast year volume, a very large annual growth rate is implied; a zero value for the present volume would imply an infinite growth rate. To avoid this, if the ratio of the present volume to the forecast volume is less than 0.1, the program automatically substitutes a straight line interpolation. In the second procedure a linear interpolation is used (curve 2). In both procedures, the volumes after the forecast year up to the last year L are extrapolated on the basis of a constant annual increase.

Costs on Existing Network

27. Using the link characteristics and the flows by vehicle category, direction and season, the cost calculating procedure corresponding to the mode of the link pair is applied to calculate values of the total daily operating cost on the link pair in each season for both the present year and the forecast year; this calculation assumes no changes will be made in any of the link characteristics in the existing network. The highway cost model and rail and transfer look-up routines are the same as those used in Trans. The total annual operating cost is obtained by multiplying the number of days in each season by the daily costs for each season and adding the results.

28. The growth curve procedure is now used again to calculate the annual operating costs on the link pair for each year of the study period. The procedure is exactly the same as described above for volumes, except that when extrapolating beyond the forecast year for road links, the cost is increased at a faster rate than the volume to take account of congestion. In addition to being increased at the given traffic growth rate, the cost is also increased for each year in proportion to the value of \( (1 + V/C) \) where \( V/C \) is the ratio of the one-way average daily vehicle volume in the year to the one-way daily capacity, both measured in equivalent passenger cars.

29. The highway cost model from Trans is also used to calculate the maintenance costs. For highway link pairs the appropriate maintenance equation corresponding to the construction class, maintenance level and region of the country of the link pair (which are link characteristics) is applied to the vehicle flows for each year of the study period.

1/ In addition to the two standard growth procedures, up to 15 step-function growth curves can be input to conform to specific forecast growth patterns; any of these curves may be chosen for a particular link pair. Input for each step-function curve consists of an entry for each year of the study period.
Figure 4: STANDARD GROWTH CURVE PROCEDURES

Daily Volume

Exponential curve - 1

Straight line - 2

Given values: A, B

P = present year
F = forecast year
L = year after forecast period
(calculated as in the previous subsection) to obtain the annual maintenance costs for the link for each year of the study period. The maintenance equations in the present program are those in Table 1. Maintenance costs for rail and transfer links are included as part of the operating costs.

30. The annual operating and maintenance costs are added together to provide a total cost for each year of the study period. The annual operating, maintenance and total costs for each year are then discounted at each of the given discount rates (up to nine different rates can be input) to give the total present value of each type of cost at the specified discount year.

31. If the link pair being analyzed represents a proposed new highway facility to be included in the improved network, there will be no record of it in the existing network files. In this case, a description of the first of the one or more proposed standards for the new link pair is obtained and flows by vehicle category, direction and season are obtained from the first type of link data. The program skips the calculations described so far for the existing network and continues with those described in the following section. New links of other than highway mode are not allowed.

Traffic Flows on Improved Network

32. The calculations described up to this point have been based on the assumption that the existing network would be retained with no changes whatsoever for the duration of the study period. The alternative construction standards and maintenance levels for each road link pair are now evaluated on the assumption that the traffic flows appropriate to the improved transport network will apply to each year after the specified improvement year. Up to and including that year, the costs and volumes already calculated for the existing network will apply. Although alternative construction and maintenance standards are not analyzed for rail and transfer links, most of the ensuing description is applicable to the calculation of costs and volumes on these links in the improved network.

33. The method of obtaining yearly volumes on the improved network is illustrated in Figure 5. The horizontal axis represents the year; the vertical axis represents the daily flow in one direction by one vehicle category in one season. The point A represents the flow for the improved network in the forecast year. Likewise point B represents the flow for the existing network in the present year, and point C represents the flow for the existing network in the forecast year.
Figure 5: VOLUME DETERMINATION WITH IMPROVED TRANSPORT NETWORK

Daily Volume

Improved Network

Existing Network

P = present year
Y = year in which improvements completed
F = forecast year
L = year after forecast period
34. The point D has a fictitious value representing the flow which would occur in the present year if the improved network were in existence. It is calculated assuming that the difference between the flows on the improved and existing networks in the forecast year (A minus C) is greater than the difference between the flows on the two networks in the present year (D minus B), in the same ratio that average traffic volumes in the forecast year are greater than those in the present year. The average annual traffic increase used in this calculation is an input item from data type (1); it is the same value that is used for extrapolation of vehicle volumes in the standard growth curve procedures. If the calculation gives a negative value, as can happen if A is less than C, the D flow is set to zero. For new link pairs, the B and C flows are assumed to be zero.

35. When the above calculations have been performed to obtain D flows for each vehicle category, direction and season, the program computes the average year-round daily two-way total volume in vehicles (in tons for rail and transfer links). Then, using this value and the corresponding value derived from A flows, the growth curve procedure is applied to obtain average daily volumes for each year of the study period.

36. If the vertical axis of Fig. 5 is now pictured as representing the total average daily two-way flow (i.e. for all vehicle categories in both directions and all seasons), then the curve drawn through points B and C and projected to year L represents the year-by-year average daily flow previously calculated for the existing network as described in the previous two subsections. The curve passing through points D and A represents the flows on the improved network calculated as described above. This curve could for any particular link be either above or below the existing network curve.

37. Point Y on the horizontal axis represents the year in which construction of all improvements to the existing network is assumed to be completed. (Year Y must be later than the present year). From year P to year Y inclusive, it is assumed that the volumes on the link pair will follow the growth curve for the existing network. In year Y + 1, i.e. the first year in which the improved network is in operation, the average daily volume is assumed to jump to the value on the improved network curve, then follow this curve for the remainder of the study period, as shown by the heavy composite line in Fig. 5.

Costs with Improved Network, Using Existing Link Characteristics

38. For all except new links, the program now calculates year-by-year costs and discounted present values assuming that the improved network is implemented at the end of year Y, but that the existing construction standard for the particular link pair being analyzed is retained. The procedure for obtaining yearly operating costs can be illustrated by reference to Fig. 5. Points B and C will now represent total annual operating costs for the link pair on the existing network, already calculated as described above.
39. For road link pairs, point A represents the total annual operating cost for the link pair, using the flows for the improved network in the forecast years and the existing link characteristics (including the existing maintenance level) for the existing network in the present year. Values for point A are also calculated for the other two maintenance levels. Likewise, point D represents the annual operating cost corresponding to the fictitious flows (by vehicle category, direction and season) which would occur in the present year if the improved network were in existence. Point D is also calculated for three maintenance levels, the other link characteristics being the same as for the existing network in the present year.

40. For each of the three maintenance levels, improved network operating costs for each year are calculated by the growth curve procedure from costs A and D. As with volumes, the composite operating cost curve is assumed to follow the operating costs of the existing network from year P to year Y, then from year Y + 1 onwards it follows the improved network operating cost curve, as shown by the heavy line, for each of the alternative maintenance levels.

41. For rail and transfer link pairs the procedure is much as described above, except that only one value of operating cost for each of the points A and D is calculated as there is assumed to be only one possible maintenance level on these links.

42. The average daily volumes calculated for the improved network are used to obtain annual link maintenance costs on highway links for each maintenance level from year Y + 1 to year L inclusive. The maintenance costs for years P to Y are set equal to those calculated for the existing network. Maintenance cost calculations are not required for rail and transfer links as the maintenance costs are included in the operating costs.

43. The annual operating and maintenance costs are added together to provide a total cost for each year of the study period. The annual operating, maintenance and total costs for all years of the study period are then discounted at each of the given discount rates to give the total present value of each type of cost at the specified discount year.

Costs for Alternative Improvements, Revised Link Characteristics

44. If there are no improvements specified for the link pair in data type 3, as is the case for rail and transfer links and for any road links which are already at the maximum standard or are not being considered for improvement, the program proceeds to selection of the optimum standard.
For all other existing link pairs the next step is to calculate costs for each proposed capital improvement in turn; in the case of new link pairs each of the alternative proposed construction standards is analyzed.

45. Improvements to existing links usually consist in upgrading to a higher construction class, but can also consist of shortening the link, improving the vertical or horizontal alignment, or improving drainage on sections subject to seasonal flooding, all without changing the construction class. The improvements over the existing conditions are completely specified by the revised link characteristics given in the input, which also gives the corresponding capital expenditure and the period over which the construction cost is spread.

46. The year-by-year operating and maintenance costs for each of the possible three maintenance levels are calculated and discounted in exactly the same way as described in the preceding subsection, with the exception that the link characteristics used in calculating costs corresponding to points A and D are the revised characteristics.

47. The capital cost is also considered; if the construction is specified as being completed in a single year, the whole cost is assigned to year Y, the last year before implementation of any improvements. If the expenditure is to be spread over more than one year, it is divided evenly and spread backwards from year Y. For instance, if the construction period were given as three years, one third of the total cost would be assigned to each of the years (Y - 2), (Y - 1) and Y. Expenditures cannot be assigned further back than a given input year, equal to or later than the first year P. Any salvage value specified for the improvement is considered as a negative capital cost in the last year of the study period (year L).

48. A value for other (or secondary) costs and benefits, which may be either positive or negative, may be given in the data input. This is taken as the annual value for the forecast year F; values for other years from Y + 1 to L are calculated in proportion to the two-way daily volume.

49. The annual operating and maintenance costs and the capital costs and other costs and benefits, if any, are added together for each year of the study period. All annual costs, including the totals and the individual components, are then discounted at each of the given discount rates to give total present values of each type of cost at the specified discount year.
Selection of Optimum Standard

50. After detailed costs have been calculated and discounted to present values for each maintenance level and each alternative construction standard, including the alternative of keeping the link pair at its existing standard, the program selects for each discount rate the alternative standard and maintenance level combination which gives rise to the least present value total cost. The alternative number, the construction class, the optimum maintenance level and the present value total cost of the standards selected at all the discount rates are printed out in a table. In the case of railway and transfer link pairs, no changes in construction standard or maintenance level are considered, hence the standard chosen must be the same as the existing standard.

51. Allowance was made for the use of up to nine different discount rates in selecting the optimum standard for each link in order to show the effect of different opportunity costs of capital on the selection of improvement projects, and to enable calculation of the rate of return of a project (the interest rate at which discounted benefits would equal the discounted cost). If a realistic opportunity cost of capital, e.g. 10 percent per annum, produced a package of improvements too large for the available budget, a higher rate could be used to select a smaller package, by elimination of the projects with the lowest rates of return. There would be no point in considering projects with a lower rate of return than the actual opportunity cost of capital, unless it could be shown that they would become economically sound if constructed at a later date.

52. Discount rates ranging from 5 to 50 percent per annum were used in the Dahomey analysis; this enabled selection of a package of projects within the allowable budget, and also enabled the projects to be ranked in order of importance according to their rates of return. Some of the projects had rates of return over 50 percent which could not be calculated exactly, but this gave a sufficient indication of their urgency.

53. A more in-depth discussion of the optimization process and the problems it entails is given in the last section of the next chapter.

System Cost Summaries

54. As the program processes each link pair, it accumulates the present value costs for use in producing three summary tables of present value total system costs after all link pairs have been analyzed. For each mode (transfer, highway and railway) and each discount rate, total accumulated present values of operating cost, maintenance cost, capital cost, other costs and benefits and total cost are printed.
IV. EVALUATION OF OPT OUTPUTS

1. We have described the operation of Opt as itemized on the flow chart, Fig. 3 (p. 27). Two groups of problems arise in evaluating the Opt outputs that require special attention, one in connection with the evaluation of links, and the other in optimization. Other problems, those inherent in simulation models, and those specific to the Dahomey application, are covered in the next chapter.

2. Since Opt analyzes each pair of highway links independently, solely on the basis of the commodity flow volumes, some additional subjective evaluation is required in situations where there are obvious interactions between two or more link pairs, whether in formulating a revised improved network for another iteration of Trans and Opt, or in analyzing costs and benefits for drawing up actual implementation plans. Four types of such situations are described in the first four sections below.

3. Because it is the result of an iteration process, the optimization solution in Opt is a function of the starting point selected. The closer the chosen starting point is to the actual optimum, the fewer iterations will be required. Furthermore, an optimum arrived at by iteration may be only a local rather than an overall optimum. The problem then lies in the choice of the starting point. This is discussed in the last section.

**Alternative Routes**

4. Fig. 6 represents a small section of the transport network, consisting of four links connecting four nodes, A, B, C and D. Suppose that the link characteristics chosen for input to the Trans run, which supplied link flows to the Opt run whose output is being evaluated, were such that traffic traveling between nodes A and D was assigned via node B. Suppose also on this basis that Opt recommended (at a realistic discount rate) that links AB and BD be upgraded to a higher standard and that AC and CD be left at their present standard.

5. It is possible that if the traffic between A and D were to travel via node C instead of B, a lower present value total cost could be obtained by upgrading links AC and CD rather than AB and BD.

6. If it can be shown by simple, approximate analysis that improvement of links AB and BD is definitely the lowest cost solution, then the standards selected by Opt should be used in the improved network description of the next Trans run; if the current iteration is the last, the values printed in the Opt output report may be used to calculate such items as benefit/cost ratios and rates of return for the individual improvements.
7. If it is not clear which solution gives the lower present value cost, then it is necessary to rerun Opt for the four links involved, using manually-coded flow data as described in the Opt users' manual, with the traffic between A and D assigned to the alternative route. Addition of total present value costs at the appropriate discount rate for the four links will show which solution is cheaper.

8. If it is clear from simple calculation that upgrading of AC and CD is the lowest cost solution, then the appropriate link characteristics should be used for Trans input in the next iteration. If detailed costs are required for benefit/cost and rate of return analyses, a run of Opt for the links involved is required, as described in the preceding paragraph.

New Facilities

9. For link pairs representing new sections of facility proposed for inclusion in the future transport system, Opt selects an optimum standard based solely on the flow assigned to the link pair in the preceding Trans run. If it is not obvious from the Opt output that the new facility is definitely justified, the question can usually be resolved by means of a subanalysis using Opt with manually-coded link flow data, in a similar way to that described above. The link pairs...
on which flow is likely to be influenced by the presence or absence of the new link pair are identified, and the flows which would occur without the new link pair are estimated and input to Opt. The total present value costs with and without the new facility for all the links involved are compared to see whether its construction is justified.

10. If the presence or absence of a proposed new facility, e.g. a new river crossing connecting populated areas, will affect traffic patterns over a major part of the network, it may be necessary to do a complete rerun of Trans and Opt without the new link pair. Comparison of present value total costs for the whole network will indicate whether or not the facility is justified, and what the net benefits are.

**Calculation of Benefits for Individual Improvements**

11. In selecting the optimum standard (at a particular discount rate) for a road link pair, Opt assumes that whatever standard is chosen, there will be no effect on the flows or costs of transport on any other links in the network. If this assumption is substantially correct for a particular link pair, then it is a relatively easy matter to calculate the present value benefit resulting from the improvement selected, assuming that Opt selects as optimum a standard higher than the existing standard.

12. The total net benefit at a particular discount rate is the difference between the present value total cost (vehicle operating plus road maintenance costs) or maintaining the road at its existing standard and maintenance level for the duration of the study period, and the present value total cost (operating plus maintenance plus capital cost, plus other costs and benefits), assuming the optimum improved standard and optimum maintenance level for the same discount rate are implemented in a given year and retained for the remainder of the study period. At each discount rate Opt automatically picks the alternative with the greatest present value net benefit.

13. If Opt selects a higher maintenance level than presently exists as well as a higher physical standard, the total net benefit can be considered as attributable partly to the maintenance improvement and partly to the capital improvement. The portion of the benefit attributable to capital may be approximated by taking the difference between the total present value cost for existing condition and the total present value cost for the optimum improvement -- but at the maintenance level of the optimum improvement. The difference between the costs for the existing and optimum maintenance levels will then be the net benefit attributable to maintenance improvement.
14. The gross benefit due to capital is obtained by adding the present value of the capital cost to the net benefit; this gives the reduction in the present value of all costs other than capital as a result of the capital expenditure. The benefit/cost ratio is the ratio of present value gross benefit to present value capital cost; this provides a measure of the desirability of the improvement. Generally, the improvement selected by Opt at a discount rate corresponding to the current opportunity cost of capital is the one selected for further analysis and/or implementation. If none of the alternative improvements analysed has a ratio greater than 1.0, Opt will recommend retention of the existing standard, possibly with a change in the maintenance level.

15. Although Opt selects the improvement with the greatest net benefit at each discount rate, it does not necessarily select the one with the greatest benefit/cost ratio. A lower-cost improvement may have a lower net benefit but a much higher ratio of gross benefit to capital cost.

16. Another criterion for measuring the desirability of an improvement project is the rate of return. This is the discount rate at which the present value net benefit would be zero, i.e. the gross benefit/cost ratio would be 1.0. This may be obtained by calculating the benefits at several of the discount rates for which present value costs are given in the Opt output, and interpolating (or extrapolating) to find the rate at which the net benefit is zero. The rate of return is quite closely related to the benefit/cost ratio; any improvement project with a rate of return greater than the opportunity cost of capital is a desirable project.

17. It is generally considered that projects with the greatest present value net benefits are the ones which should be implemented; however, if the amount of capital available is limited, the benefit/cost ratio or rate of return criteria may be used to select a package of improvement projects within the available budget.

18. When interaction is present between two or more links which are recommended for improvement, estimation of benefits is more difficult, and approximations often have to be made. The problem of diversion of traffic from one route to another as a result of facility improvements is discussed in the next section.
Diverted Traffic

19. In some situations, an improvement to a particular link pair, besides providing benefits to traffic which would flow on the link pair even without the improvement, will draw traffic from other routes. If the per-unit benefits to this diverted traffic are assumed to be the same as those for the traffic already on the link pair, which is what is done in the procedure of the previous section, overestimation of the benefits occurs. The path which the diverted traffic would have followed without the improvement must have a lower transport operating cost than a path via the link pair being analyzed, otherwise it would not have been assigned to that path; hence, the unit benefit to this traffic must be less than that to the nondiverted traffic.

20. If the diverted traffic in the forecast year can easily be identified, and the cost that would be incurred by this traffic without the improvement can be closely approximated, then a reasonable estimate can be made of the present value of the benefits accruing to the diverted traffic over the study period. In most cases, however, the situation is complicated by improvements to other link pairs in the immediate area and by diversion of traffic from several different routes, so that only rough approximations can be made. An assumption that unit benefits to diverted traffic will be one-half of those to the traffic which would in any case use the link pair will average out to be approximately correct.

21. This discussion has referred only to benefits to traffic, i.e. reductions in vehicle operating costs; the associated variations in facility maintenance costs are nearly always negligible in comparison with the operating costs, and usually have no effect on the selection of optimum standards.

The Optimization Process

22. The Opt procedure for optimizing a transport network does not claim always to produce the lowest possible cost solution; it is rather a method of successive approximations to a minimum, the final solution reached being a function of the starting point selected for the optimization process.

23. The problem of optimization may be described in general terms with reference to Fig. 7. The vertical axis (dependent variable) represents the quantity to be optimized. In this case, optimization involves minimization and the quantity to be minimized is the present value total network cost. The horizontal axis represents some independent variable parameter of the system to be optimized. There might in fact be a multi-dimensional relationship between the cost (or whatever quantity is to be optimized) and various system parameters, but a two-dimensional relationship is assumed for simplicity in this example.
24. To provide a starting point for the optimization procedure, an approximation is made of the value of the variable parameter which would produce an optimum value of the quantity being minimized. Referring to Fig. 7, if point A were chosen, an analysis would be performed to determine whether this did in fact provide an optimum value, or whether by adopting a new value for the variable parameter, e.g. corresponding to point A on the figure, a closer approximation to the optimum could be obtained.

![Diagram of Optimization Process](attachment:image.png)

Figure 7: ILLUSTRATION OF OPTIMIZATION

This procedure would be repeated, or iterated, to give a series of points, A', A'', etc., until successive points showed no significant reduction in the quantity being minimized, i.e. until point B on the diagram were reached, or at least closely approached. It is clear that the closer the guessed starting point is to point B, the fewer iterations will be required to reach or approach the optimum.

25. If point C of Fig. 7 were selected as the starting point, the iterative procedure just described would lead to identification of optimum point D. In the diagram, point D is lower, therefore "more optimum" than point B. Hence, it is seen that selection of the starting point is also very important from the point of view of arriving at the
best of several local optima. In other words, this procedure will only locate the lowest point in whatever valley the starting point is located and not necessarily the overall or global minimum. Thus, there is no assurance of having a global minimum, but if the same minimum is found using a selection of starting points, the analyst can be confident that an optimal solution has been found.1/

26. The same arguments can be applied to the location of optimum (maximum or minimum) points on a three-dimensional surface, or to multi-dimensional functions. The more independent variables there are and the more complex the relationship, the more difficult it is to choose a set of values for a starting point which will lead to location of the "best possible" optimum. In summary, to obtain a good solution to the optimization problem, skill and judgment are required in selecting the appropriate starting point.

27. There are three basic approaches that can be used in the selection of a set of link characteristics to be used as the starting point situation in the optimization process: to use the existing network, to set all links to the same standard, or to adopt arbitrary link characteristics.

28. The existing network characteristics may be used as a starting point for the optimization process. If no new link pairs are to be considered, the improved network will be identical to the existing network on the first iteration. In each subsequent iteration, of course, the improved network would be revised in accordance with the standards selected by Opt. The disadvantage of this method is that it tends to favor selection by Opt of improvements to link pairs which are already at a relatively high standard, since Trans will tend to assign more traffic to these links than to lower-standard ones. If proposed new link pairs are to be analyzed, a separate Trans run is required; in the improved network description, the existing links will have the same characteristics as before while arbitrary characteristics must be supplied for the new link pairs. If their characteristics are set to correspond to the highest of the alternative standards to be studied by Opt, they will have the greatest chance of being accepted.

29. If all road links in the improved network description (including proposed new link pairs) are given the same standard, e.g. midway in the range of standards being considered, each link pair will have an

1/ It has not been proven in practice that different formulations of the initial improved network characteristics in fact lead to different optimum improvement packages after several iterations of Trans and Opt; in some situations they would probably all converge to the same solution.
equal chance of being selected for improvement, as the traffic assignment will effectively be on a minimum-distance basis, independent of the existing link surface characteristics. This is not necessarily a realistic approach, since facilities presently at a relatively high standard will be cheaper to upgrade to a given higher standard than will low-standard ones with poor alignments and/or inadequate roadbeds; hence the former should be favored to some degree. Care should be taken with this method if rail and transfer links are also included in the network, to ensure that unreasonable distortions of travel distribution patterns do not occur.

30. The best, but most difficult, approach is to attempt to second-guess the Opt program by choosing, for the initial improved network, characteristics corresponding to the standards considered most likely to be selected as optimum. If done intelligently, this method can improve the speed of convergence and reduce the total number of Trans-Opt iterations required, and may also avoid selection of a second-best local optimum. Alternatively, each link pair may be set to the highest of the alternative standards considered (link pairs with no alternative improvements would be given their existing characteristics). This would tend to favor major improvements to facilities on the first Opt run.
V. SIMULATION PROBLEMS IN DAHOMEY

1. From the various methods available for forecasting transport flows, such as applying growth factors to measured link volumes or to O-D flows, the simulation by computer of flows using supply and demand quantities and a mathematical representation of the transport network was selected as the best for use in the Dahomey Land Transport Study. Simulation enables the effect of physical changes to the transport system on commodity and traffic flow patterns to be realistically evaluated. Nonetheless problems both inherent in simulation and specific to Dahomey arise in the application of a simulation model.

Intrinsic Simulation Problems

2. In any attempt to simulate traffic flows, the shipper's decision-making process is complex and not always rational. The shipper's knowledge will be imperfect; some traffic may often be captive, e.g. government traffic may travel on government railroad rather than on private trucks even though the latter may provide better service at lower cost. Highway rate structures are quite often flexible: the rate charged may vary from day to day and mile to mile along the highway depending on loads available and a host of other reasons. The seasonal peaking of different commodities may be quite different. Using only three or four representative seasons is bound to blur the picture and reduce the accuracy of the simulation.

3. Another major area of difficulty is calibration. The calibration process is difficult enough using only cost as in Dahomey, but if other parameters such as travel time, waiting time, probability of loss and variability of travel time are also used, the problem becomes very complex and can only be done if a detailed understanding of the shipper's decision-making process is known.

4. Three further problems were encountered in collecting data and in assessing how realistically the simulation reproduced actual conditions in Dahomey.

Data Collection Problems

5. The first problem was the collection of reliable information on the existing (1967) situation in Dahomey; obtaining reliable estimates of 1975 conditions presented further problems. Particularly in coding the supply and demand for input to the program, the main difficulty lay in forecasting supply and demand quantities for 1975. In general, recent trends were extrapolated, with allowance made for published plans for construction of new plants and factories, and expansion of certain industries.
6. However, with a relatively unstable and underdeveloped society such as exists in Dahomey, there is considerable uncertainty attached to any forecast, even for only eight years in the future. The assumption made in the study that a constant growth in traffic would occur from 1975 to 1990 was subject to even greater uncertainties, although because of the discounting procedure used in selecting improvement projects, costs in later years had a less significant effect on the analysis. The estimation of passenger trip generations from cordon surveys around three towns would have been more reliable if more and longer surveys could have been conducted; this was not possible because of insufficient qualified personnel and local currency.

7. Collection of data on the existing road system was done using photography techniques. The results were generally satisfactory, enabling measurement of type, width and condition of road surface and structures, total rise and fall and accurate distances. Some mechanical problems were encountered with the equipment, and the quality of the films was not as good as desired, but these difficulties were overcome.

8. A considerable amount of judgment had to be used in assessing the construction class and maintenance level of each link, out of five possible construction classes and three maintenance levels for each class. These limitations were not due to lack of computer storage, but they represented a maximum number of categories into which links could reasonably be differentiated for calculation of operating, maintenance and capital costs. Many of the links did not fall into clear classifications; for instance, on some the width varied or fell in between the widths specified for one-lane and two-lane roads, while others had deteriorated so much that they were effectively in a lower class than that in which they had been constructed. The maintenance level was hard to determine accurately from the inventory films; a road in good condition could have been well maintained, or could have been built quite recently and not had any maintenance. For a proper assessment of maintenance levels, a history of the maintenance of each link would have been helpful, but this was not available.

9. To account for rainy season road closures, a travel time factor was calculated from tables of frequency and quantity of rainfall for each climatic region, and coded as a link characteristic for all loose-surfaced roads; the program applied these factors to the travel times of all vehicles on such links in the rainy season. Because the length of each season had to be specified for the whole country, it was not possible to represent the variation in length and timing of the seasons in different parts of the country. An average rainy season of April 1 to October 31 (214 days) was selected.

10. Also, it was not possible to show the variation in rain gate regulations for different sizes of vehicles; heavy trucks are held back during rains, while small vehicles are allowed to travel, but the latter
are probably still delayed to some extent. The values used were intended to be reasonable values for the average proportional increase in travel time of all vehicles. A further problem arose in trying to simulate the effects of extended periods of closure on certain links due to floods or washouts; a delay factor of 9.99 was used, which meant that the delay was proportional to the link length, when it should have depended only on the closure at one point. However, any more accurate simulation would be difficult because the average delay in any year would depend on the particular rainfall pattern and on the current condition of the drainage structures.

11. Collection of data on road vehicle operating characteristics and costs by interviewing operators was not too satisfactory, largely owing to lack of knowledge of actual costs on the part of the operators; only a few of the larger trucking companies kept any records of vehicle operating expenditures. To derive the parameters required by the highway cost model, reference had to be made to other studies of operating costs in Africa and elsewhere.

12. Information on rate structures for road transport of both goods and passengers was also collected by interviewing operators of vehicle fleets. Apart from the rates for transit traffic, which are fixed by agreement, the quoted rates varied widely. In many cases, rates are negotiated on the spot, and they tend to be lower on busier routes where there is more competition. Because of the nonuniformity of the rates, a rate structure based on vehicle operating cost (including taxes) plus a percentage for profit (for private cars the percentage was zero) was used in the economic analysis.

13. Derivation of costs of maintenance and of capital improvements for road links presented no major problems, although considerable field and laboratory work and analysis of previous Dahomey practices were necessary.

14. A separate substudy of the Dahomey railway operations provided information on fixed and marginal costs of rail transport, on transfer costs, and on the present rate structures. From these, average costs per ton-km. for each vehicle category on each rail link were calculated for direct input to the program, for both 1967 and 1975 using the existing and approximate forecast volumes. A more sophisticated cost model could have been written to apportion the fixed costs according to the total traffic on the system, providing more accurate unit costs. This was not done because of time and budget limitations and because there was only one rail line, which was considered to have little in the way of competition, although it later turned out that the assignment of some commodities was very sensitive to rail rates.
15. For similar reasons, no sophisticated transfer model was used. Typical transfer costs per ton for each category of goods obtained from the rail reports were coded directly on to the various road/rail transfer links. Since travel time was not considered as a distribution parameter, no measurement of simulation of time was made for rail and transfer links.

Program Limitations

16. It was found possible to construct a network within the program limitations of 300 one-way links and 149 nodes (increased from 99 in the Harvard transport model) to represent all the major roads in Dahomey, plus the simple rail system and appropriate transfers between road and rail. However, most feeder roads linking villages or production centers to main highways had to be omitted; these were considered separately in the Final Report. Extra nodes were inserted where possible at changes in the surface type or condition on road links, but in many cases a road section consisting of short stretches of different standards had to be approximated by a single link of one standard. Of approximately 6,000 km. of roads in Dahomey, about 4,700 km. were inventoried and 3,650 km. were included in the simulation network.

17. The limit of 20 supply nodes and 40 demand nodes for each commodity was less restrictive for most of the specific freight commodities, with a limited number of production and consumption points, than for the miscellaneous commodities and, in particular, for the passenger trips which are generated wherever there is population. Of the 115 nodes in the Dahomey transport network, 79 were economic nodes; 76 of these represented zones within Dahomey, all containing population and all generating passenger trips.

18. Because of the limitations, passenger trip attractions had to be aggregated to 40 nodes. Passenger trip productions were assumed to be equal to the attractions at each node, but these had to be further aggregated to only 20 nodes. Though the aggregations were done to minimize the distortions in assigned vehicle volumes, there were still places where the number of passenger vehicles assigned to a link was too high or too low as a result of the passenger trip aggregations. In a few cases, trips were assigned to a completely different route when their origins were combined with another node. In the detailed analyses of certain of the recommended improvement projects, carried out in Phase II of the Study, allowance was made for the errors caused by aggregation, but no allowance was made in the Phase I calculations.

19. Some of the more important freight commodities, notably raw cotton and palm products, which were produced in more than 20 zones, were split into two groups by area of production, e.g. north or south for raw cotton and east or west for palm. This meant that the quantities
of each group consumed at each demand node had to be predetermined, but since there was only a small number of demand nodes, representing processing plants, there was no great problem in achieving a reasonable manual distribution. Some other general agricultural commodities such as unshelled groundnuts, corn and yams, and a miscellaneous commodity category comprising minor commercial agricultural products, were aggregated to give 20 supply nodes, as for passenger trips. Commodities representing miscellaneous imports also had their demand quantities aggregated to give no more than 40 demand nodes.

Calibration Problems

20. One of the main sources of inaccuracies and uncertainties in the Dahomey Study procedures was the imperfect calibration of Trans; this arose largely because of inadequate information on the existing movements of goods and persons. Attempts to calibrate Trans for 1967 by comparing observed and simulated traffic volumes and commodity origins and destinations on links are described below. Calibration by trip length frequency distribution is also discussed, although this was not done for the Dahomey Study.

Link Volume Calibration

21. Vehicle counts had been made at various times in the past by several different agencies at different points on the road network. In addition, a roadside interview survey and counting program was conducted as part of the Dahomey Study during October and November, 1967. This program was intended to be of longer duration, to obtain reliable daily averages and seasonal variations, but was curtailed owing to lack of qualified personnel and of local funds.

22. Comparison of simulated with counted volumes on individual links produced a wide range of results, but the general tendency was to underestimate the 1967 traffic, especially of the general type of medium-sized truck, used for carrying assorted commodities. The large trucks carrying commodities in transit and the tank trucks carrying petroleum products were more accurately simulated, since flows of these commodities were recorded when entering or leaving the country. Minor problems were encountered in matching the vehicle categories used in various surveys to those defined for the computer analysis. To bring the volume of general trucks up to the average level of the counts, the input volumes of all commodities using them had to be increased by 85 percent. Minor adjustments of less than 15 percent were also made to the volumes of passenger trips to improve agreement between simulated and observed passenger vehicle volumes.
23. There are several possible reasons contributing to the large undersimulation of general truck volumes. Firstly, non-simulation of local traffic could account for part of the discrepancy. Because of the relatively coarse nature of the network used, and the simulation of traffic flows between a limited number of economic nodes representing quite large zones, it was not possible to simulate all the traffic using the transport system. Local traffic, consisting of short distance travel within the zones, particularly in and around towns, was not simulated.

24. Secondly, the counts may well be inaccurate. The quality of the counting procedures in Dahomey is thought to be low, as was demonstrated by widely differing results obtained from different interview stations on the same route during the 1967 survey. Thirdly, it is possible that not all commodities which travel between towns were accounted for in the supply and demand input; however, some allowance was made for these by including miscellaneous commodities, and the effect of any items left out is not thought to be significant. It is also possible that the commodity flows are reasonable, but that the assumed vehicle payload is too high. However, the effective payloads used in the model were derived from observed values at the interview stations; while the average load factors of similar vehicles may vary in different parts of the country, it is considered that the values adopted were reasonable country-wide averages.

25. The major reason for the undersimulation is thought to be the use of the linear programming distribution procedure for all freight commodities. This assumes that each commodity is entirely homogeneous, i.e. production from any supply zone is identical and substitutable, and that each commodity is distributed between its supply and demand zones at minimum total cost for that commodity, with no crosshauls. While the first assumption may be true for low value commodities for which transport forms a significant part of delivered cost, such as sand or gravel, it becomes less true for higher value commodities for which transport cost is less important, and for which consumer brand or quality preference is a factor, and for nonhomogeneous commodities such as the miscellaneous classifications.

26. The assumption of total cost minimization, however, represents an ideal to be approached. In general neither the individual shipper nor the individual transporter has sufficient knowledge of the overall situation to fully minimize distribution costs and eliminate crosshauls. It is possible that the inverse impedance (gravity) model would have given a more realistic distribution, but the problem then would have been determination of the correct exponent. With a high exponent, results are similar to the linear programming distribution. A gravity model with a high exponent for low value commodities and a lower exponent for high value commodities might have provided better results than the linear programming distribution.
Origin-Destination Calibration

27. An attempt was made to establish existing origin-destination patterns of commodities (including passengers) by conducting sample roadside interviews at 16 points spread throughout Dahomey. However, the results obtained were so inconsistent that they could not be used effectively for calibration. The sample was not intrinsically representative because of seasonal variations and the small sample size. More careful information collection covering a longer period would have provided more reliable information.

Trip Length Calibration

28. A widely used calibration procedure, particularly for urban studies, is the comparison of simulated and observed trip length frequency distributions for each type of trip. Since Trans was not equipped to calculate trip length frequencies, this check was not made in the Dahomey Study. If it could have been done, it would have been possible to judge whether in fact the linear programming distribution was causing undersimulation of traffic by simulating too many short trips. Such a comparison would also have been useful for calibrating passenger trip distribution, as it would have indicated whether the exponent used in the gravity model distribution was reasonable.
APPENDIX

GLOSSARY OF TERMS

NODE: A point at which two or more transport facilities intersect and/or at which commodities may be supplied or demanded. The nodes in the transport network must be numbered in a consecutive series and may also be given alphanumeric names.

LINK: A link joins one node to another and represents one direction of a section of a transport facility. Two links are required to describe the section in both directions. Any number of links may radiate from a node. All nodes and links in a network must be interconnected.

COMMODITY: A category of freight requiring transportation, or a type of passenger trip. The commodities are numbered in a consecutive series and may also have alphanumeric names.

MODE AND SUBMODE: Each link is classified as to type by a two-digit number, the first of which represents the mode. The Harvard transport program provided for six modes: transfer, road, rail, water, air and pipeline; the present version of Trans can only handle the first three. The second digit of the mode identification is the submode, or the subcategory of the mode. An example of the use of the submode is to identify links under different jurisdictions within a mode - the total system times, costs, etc., are accumulated by submode, and tax revenues, etc., can be assigned to the appropriate jurisdiction. Also, factors can be applied by submode to transport charges to encourage or suppress travel by certain vehicle categories on certain links.

VEHICLE CATEGORY: Up to five vehicle categories are allowed; each category must be defined for all modes. Each commodity is assigned to travel by one vehicle category; although the assigned path may change from one mode to another, each commodity remains in the same category. Any number of commodities may travel by the same vehicle category as long as they are compatible; the daily total of all commodities assigned by a particular vehicle category to a link determines the daily flow of vehicles of that category required to carry the commodities.

As an example, the categories may be chosen to represent vehicles for three types of freight - bulk, general and liquid, also public passenger vehicles and private passenger vehicles. Although physical vehicles do not exist on transfer links, the same category distinction is maintained. Cost-performance models for each mode use the assigned flows and the characteristics of both links and vehicles to calculate operating costs and performance for each vehicle category.
LINK CHARACTERISTICS VECTOR (LCV): The LCV of each link contains details of the physical characteristics of the transport facilities which the link represents, insofar as they determine costs and other performance measures of transport over the link. Up to 14 characteristic items are allowed in the LCV. The LCV items used in the Dahomey Land Transport Study for links of each mode are defined in the description of data type (10) input in the Users' Manual. For example, the LCV for road links includes information on link length, surface type, rise and fall, design speed, construction class, maintenance level, etc.

LINK UTILIZATION VECTOR (LUV): For each link for each season the LUV contains five items for each vehicle category:

1. The flow in tons per day (total for all commodities using the particular vehicle category);
2. The flow in vehicles per day;
3. The number of vehicles per day taking the first turn of the end of the link;
4. The number of vehicles per day taking the second turn;
5. The number of vehicles per day taking the third and all other turns.

LINK PERFORMANCE VECTOR (LPV): For each link, for each season, the LPV contains five items for each vehicle category:

1. The waiting time in hours on the link;
2. The travel time in hours on the link;
3. The standard deviation of travel time in hours on the link;
4. The probability of loss on the link;
5. The transport tariff per ton of commodity in money units (m.u.) on the link.

LINK FILE: A link file is a complete list of all link-related information, which is written on magnetic tape, and used for reference throughout the program. For each link, it contains the link start and end node numbers, the mode-submode identification and the LCV; then, for each season in turn, the LUV by vehicle category and item and the LPV by vehicle category and item. Link pairs representing opposite directions of the same facility appear consecutively.

COMMODITY PREFERENCE VECTOR (CPV): For each commodity, the CPV contains five items:

1. The value to the shipper of waiting time in m.u. per ton per hour;
2. The value to the shipper of travel time in m.u. per ton per hour;
3. The value to the shipper of variability of travel time in m.u. per ton per hour;
4. The replacement value to the shipper in case of loss of the commodity in m.u. per ton;
5. A rate factor which indicates the importance of transport charge to the shipper of the commodity.

Throughout the Dahomey Land Transport Study, the first four items were given a value of zero and the last a value of 1.0, hence all distributions and assignments were performed on the basis of minimum transport charge.

R-FACTOR: The R-Factor of a link, for a particular season and commodity, is the sum of the products of the appropriate seasonal LPV items and the corresponding items of the CPV, i.e. the total perceived cost to the shipper of transporting a ton of the commodity over the link. The perceived cost is a combination of the costs of waiting time, travel time, variability of travel time and probability of loss of the commodity, and the transport charge. The R-Factor of a link is the parameter upon which minimum path trees are built for each commodity, for use in the distribution and assignment routines. In the Dahomey Land Transport Study, the R-Factor represented only the transport charge; all other cost items were zero as a result of setting the first four CPV items to zero.

SUPPLY-DEMAND FILE: This is a list by seasons, stored on magnetic tape, of the quantities of each commodity supplied and demanded by node and the cost of production at each supply node.