Engineering-Economic Systems Analysis for Transport Planning in Dahomey, West Africa

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This paper reports on methodological advances achieved by the Dahomey Land Transport Study, recently carried out by a Canadian group under the auspices of the United Nations Development Program and the World Bank. The study employed an engineering-economic systems analysis aimed at the accomplishment of desirable future transport tasks at minimum true costs to society.

There was full integration between transport planning per se, and socioeconomic developments, especially in the crucial agricultural sector, to the target year 1990. Given population estimates, production and consumption quantities, both present and future, for each node, the "TRANS" Model calculated individual commodity surpluses and deficiencies throughout the country. It then simulated freight and passenger movements through the land transport network by applying a "minimum cost path" criterion. These calculated traffic flows for the current year were then compared with actual movements, obtained through O-D studies and counts, and the TRANS Model calibrated.

The TRANS Model output, link inventory information, and new proposal costs were all fed into the "OPT" Model. Its chief purpose was to confront various traffic loads generated by the TRANS Model with different technical network designs. It selected from those the one combination that promised to handle the total logistics task at minimum total costs, the cost streams being discounted at relevant trial interest rates over the planning period 1969 to 1990. Inherent in the OPT Model were economic-technical interactions between vehicle and road, as analyzed by Robley Winfrey and Jan de Weille; tax content and foreign exchange adjustments; and convergent iterative traffic assignment versus network design calculations.

•DAHOMEY shares boundaries with Togo, Upper Volta, Niger, and Nigeria. It extends 700 km (kilometers) north-south, but has a width of only 325 km in the north, and 125 km along the Atlantic Coast in the south. Dahomey has 700 km of paved and 5,400 km of unpaved roads, ranging from good national highways to quite miserable tracks. The well-run OCDN Railway, operated jointly by Dahomey and Niger, connects the capital and port city of Cotonou with the important inland center of Parakou. There are also short money-losing east-west railway lines in the south. Cotonou has a jet airport with good international services.

Independence in 1960 brought severe economic and political problems. For the last decade there has been stagnation in the production of three important export crops—

Paper sponsored by Committee on Highway Engineering Economy and presented at the 48th Annual Meeting.

palm oil, shelled groundnuts, and coffee. Only cotton fiber and tobacco have shown solid growth. Simultaneously, Dahomey has experienced growing demands for consumption goods, especially those imported goods that benefit the urban population and higher income classes. Thus, although 78 percent of imports were covered by exports in 1958, this proportion deteriorated to 40 percent by 1965. One must conclude that Dahomey has a weak, vulnerable economy burdened by severe, chronic, balance-of-trade deficits.

Demographic trends lend urgency to the economic problems. The Dahomey birthrate of 5.4 percent per annum is one of the highest in Africa. Although the country as a whole is certainly not too heavily settled, with a population of 2.3 million and an average density of 19.9 inhabitants per sq km, the biggest increases take place in the overpopulated southern regions. It is estimated that Dahomey will have 4.6 million people by 1993.

Troubled by a faltering economy, trade deficits, rapid population growth, political and social unrest, Dahomey needs assistance. In order to discover possible solutions in the transport sector of the economy, the Dahomey Land Transport Study was commissioned by the World Bank (IBRD), the executive agent of Dahomey, and the United Nations. The study called for rigorous economic analyses of the several possible highway and railway development programs in order "to assess the future role of the railroad in Dahomey and to develop a program for maintenance, rehabilitation, and improvement of the existing road network of Dahomey to meet the needs of national as well as international traffic." A Canadian consortium composed of N. D. Lea and Associates Ltd. as sponsors and Lamarre, Valois International Limitée were commissioned in 1967 on the project.

DATA GATHERING

The field work concentrated on collection of data for the analysis system.

Geocoding

A multipurpose network coding system, involving area and point numbering, was used for both broad socioeconomic and precise engineering analyses. All significant "nodes" and "links," including modal transfers and international connections, were numbered with allowance for new nodes and links.

Supply and Demand

Present and future supply-demand interactions of up to 40 commodities were estimated from available data by geonodes, applying an eclectic combination of interregional input-output (1, 2) and industrial complex analysis techniques (1) to Dahomey's goods exchange patterns with considerable geographic precision. From physical resource surveys, public-private development plans, market studies, and economic trend analyses, the 1975 and 1990 supply and demand interactions among the geonodes were estimated for each important commodity (Table 1).

Two categories of person trips—"public" and "private"—were analyzed by node as a function of socioeconomic attraction factors. Trip-making characteristics of people were obtained through roadside interviews at cordon lines placed around several representative zones. These characteristics were then related to demographic information.

Inventory of Facilities

Exact stock of the highway network was taken through an efficient photo inventory technique, used for the first time outside North America. It utilized a van equipped with an odometer, a survey speedometer, a ball bank indicator, an altimeter, a clock, a board showing the date and the two link nodes, and a motion picture camera. The camera was mounted in order to photograph both the driver's view of the road and the instrument readings and was set to expose one frame every 25 meters. The vehicle was then driven over all accessible roads in the network at maximum practical speed.

With the aid of a special analytical projector, the resulting color films could be shown at simulated driving speeds of 0 to 1500 kph (kilometers per hour). The highway

TABLE 1

SAMPLE SUPPLY-DEMAND FLOWS AMONG ECONOMIC NODES

Supply						Demand		
Analysis Node Number	Economic Node Number	Tons	Price (CFA Francs)	Percent in Season 1	Percent in Season 2	Analysis Node Number	Economic Node Number	Tons
			Raw Cotton—North—1967					
65	52001	487	25	20	80	61	51001	3510
67	52003	161	25	20	80	75	54001	2740
71	53001	1485	25	20	80	83	62001	1030
72	53002	161	25	20	80			
74	53009	1218	25	20	80		Total	7280
75	54001	326	25	20	80			
76	54004	220	25	20	80			
77	56001	2082	25	20	80			
78	57001	110	25	20	80			
81	61001	7	25	20	80			
83	62001	515	25	20	80			
85	62004	386	25	20	80			
87	63001	6	25	20	80			
88	64001	77	25	20	80			
92	65001	39	25	20	80			
	Total	7280						
			Raw Cotton—South—1967					
10	14001	92	30	15	85	39	41002	3520
20	22001	465	30	15	85	57	45001	1500
32	33002	372	30	15	85			
37	34007	372	30	15	85		Total	5020
38	41001	373	30	15	85			
44	41011	368	30	15	85			
49	42002	239	30	15	85			
50	43001	686	30	15	85			
54	44001	184	30	15	85			
55	44003	262	30	15	85			
57	45001	710	30	15	85			
58	45002	212	30	15	85			
59	45009	322	30	15	85			
60	45010	363	30	15	85			
	Total	5020						
			Cotton Fiber—1967					
39	41002	1230	90	25	75	13	21001	215
57	45001	525	90	25	75	113	75000	3240
61	51001	350	90	25	75			
75	54001	1000	90	25	75		Total	3455
83	62001	350	90	25	75			
	Total	3455						

TABLE 2

TECHNICAL CLASSIFICATION OF ROADS

Name	Symbol	No. Lanes	Width Meters Base	Width Meters Surface	Surface Type	Design Speed (kph)	Remarks
Track	P	1	3	0	Dirt	60	Built by one pass of bulldozer, with temporary structures (culverts and drainage pipes) and a bare minimum of earthwork. No imported materials.
One-lane "terre de barre" road	TB1	1	4.0	3.5	Loose	80	Built on a minimum embankment using either in-place or imported "terre de barre" which is a natural red sandy clay. At least two provisions for passing per kilometer. Existing rain gate regulations still apply.
Two-lane "terre de barre" road	TB2	2	7.0	6.0	Loose	80	Use either in-place or imported "terre de barre". Existing rain gate regulations still apply.
One-lane laterite road	T1	1	4.0	3.5	Loose	80	Imported laterite surface on minimum embankment. Rain gate regulations remain.
Two-lane laterite road	T2	2	7.0	6.0	Loose	80	Imported laterite surface. Rain gate regulations remain.
One-lane paved road	B1	1	9.0	3.5	Hard	100	Asphalt surfacing by double seal coat or 50 kg/m^2 of sand asphalt. Imported base (7m) of sufficient strength to permit all-weather use.
Two-lane paved road	B2	2	9.0	6.0	Hard	100	Asphalt surfacing by double seal coat or 50 kg/m^2 of sand asphalt. Imported base (7m) of sufficient strength to permit all-weather use.

TABLE 3

CHARACTERISTICS OF SELECTED STANDARD MOTOR VEHICLES

Characteristics	Class 1 Niger	Class 2 General	Class 3 Special	Class 4 Common	Class 5 Private
Weight (kg)	10, 500	4, 450	12, 000	1, 450	850
Horsepower SAE	210	120	240	75	53
Payload (kg)	16, 700	4, 900	14, 500	1, 100	460
Vehicle cost (000 CFA franc)	4, 320	1, 650	6, 130	612	462
Life[a] (000 km)	500	400	500	250	150
Annual travel[a] (000 km)	75	60	75	50	30
Average speed[a] (km/hr)	55	60	55	65	65
Crew wages (CFA franc/hr)	90	80	120	90	—
Crew size	3	2	2	2	1
Maintenance cost:					
Parts (CFA franc/km)[a]	5.18	4.13	7.36	.73	.46
Labor (CFA franc/km)[a]	1.50	1.10	1.55	.38	.30
Insurance cost (000 CFA franc)	1, 180	350	1, 220	120	50
Oil cost (CFA franc/km)	1.54	1.08	1.85	0.23	0.15
Average fuel cost[a] (CFA franc/km)	6.70	4.40	5.90	2.20	1.40
Number of tires	10	8	10	4	4
Tire cost (000 CFA franc)	36.50	26.10	38.00	9.50	4.40
Tire wear factor[b]	.00067	.00033	.00067	.00021	.00025

[a]For paved roads.
[b]This factor is applied to a tire-life constant related to surface type to give the tire wear in a formula which also includes speed.

inventory specialist viewed these films in the field office and coded the pertinent inventory data for each of the 220 road links in the Dahomey network. A rating panel assigned each link to one of the seven technical road classes shown in Table 2. Throughout the project, the easily stored inventory films were found very useful for refreshing memories, for checking field conditions, and for briefing staff members and decision-makers.

Physical inventory data for the railway system, both fixed installations and rolling stock, were readily obtained from OCDN sources.

Traffic Flow and Vehicle Data

Traffic counts and origin-destination roadside interview surveys generated information on the flows of goods, people, and vehicles over the existing highway network. Corresponding railway traffic data were obtained from OCDN records.

Vehicle registration records yielded data on the number, type, and characteristics of vehicles using Dahomey's highways. Further information was obtained through interviews with truck operators, oil companies, vehicle dealers, and truck drivers at roadside stations. For the analysis, five composite vehicle types were developed, as shown in Table 3.

Capital and Maintenance Costs

Capital costs required to raise each highway link to successively higher standards, as well as costs of constructing railway links, were estimated on the basis of unit prices, quantities, and construction techniques appropriate for the specific location.

Railway and road maintenance costs were derived from Dahomey records, and were adjusted as required for indicated changes in methods and productivity. Three highway maintenance conditions were analyzed throughout: (a) normal maintenance, which permits vehicle operations over the road for most of the year under best conditions expected for the surface type; (b) minimum maintenance, which insures pavement preservation, but involves rather poor operating conditions, at least during certain periods; and (c) zero maintenance, a frequently encountered condition that results in deterioration to a lower classification for the road link within a given time span.

For each technical class of road and for both normal and minimum maintenance, the annual cost was expressed in an equation of the form

$$C = A + Bn$$

where

C = total annual maintenance cost in CFA francs per km,
A = constant maintenance cost in CFA francs per km,
B = variable maintenance cost in CFA francs per km per vehicle per year, and
n = traffic flow in equivalent vehicles per year.

For example, in southern Dahomey the maintenance costs (excluding taxes) for 2-lane roads were as follows:

Laterite	— Normal	C	=	22,000	+	870n
	— Minimum	C	=	14,000	+	470n
Terre de Barre	— Normal	C	=	22,000	+	530n
	— Minimum	C	=	14,000	+	320n
Paved	— Normal	C	=	176,000	+	34n
	— Minimum	C	=	14,000	+	400n

ROAD INVENTORY RESULTS

In 1967, the highway network in Dahomey comprised about 4,200 km, excluding urban streets. The network was subdivided as follows:

P	Track	1,340 km
TB1 and T1	One-lane earth	1,150 km
TB2 and T2	Two-lane earth	1,010 km
B1	One-lane paved	330 km
B2	Two-lane paved	370 km

Lack of maintenance and inadequate drainage structures are, with few exceptions, outstanding characteristics of all Dahomey roads.

Table 4 shows a portion of the road inventory data. Each link is identified by two node numbers. Village names are given where applicable. Link lengths, accurate to ±10 meters, are followed by the operating speed, defined as the average speed of the inventory vehicle excluding the influence of traffic. Roughness speed, determined by the inventory specialist, is the speed at which the driver can operate the vehicle when road surface roughness is the only limitation. It indicates the vehicle operating cost coefficient for the particular surface condition, and, when compared with the operating speed, it also indicates alignment. The maintenance level is shown as "A" for adequate, "M" for minimum, or "0" for zero. Each road is marked as "corrugation prone," a common Dahomey condition, or not. The seasonal delay factor is expressed as the reciprocal of the percentage of time the road is open during the rainy season.

VEHICLE COSTS

Vehicle costs had a very heavy influence in highway economy studies. They were determined by using the highway operating cost program that is part of the TRANS Model. When given the commodity and people flows, as well as the highway link's physical condition, this program calculated the number, types and operating costs of the required vehicles. Unit cost information, determined in Dahomey for the five standard classes of vehicles (see Table 3), was used as input.

TABLE 4

PORTION OF ROAD INVENTORY

Link				Length (km)	Speed		Administrative Class	Inventory Class	Maintenance Level	Rise and Fall (m)	Corrugation Proneness	Seasonal Delay Factor	Culverts	Structures
Code		Name			Operating (kph)	Roughness (kh)								
From	To	From	To											
64003	64701	Birni	x	39.22	44	50	PR	P	M	701	No	1.07	14	0
64004	64005	Kerou	Briniaro	10.16	44	50	RN8	P	M	85	No	1.07	2	0
64005	64502	Briniaro	–	34.59	46	50	RN8	P	M	354	No	1.07	4	0
65001	65002	Tanguiéta	Tayakou	10.71	83	90	RN9	T1	M	79	Yes	1.08	4	0
65001	65007	Tanguiéta	Batia	40.44	42	50	PR	P	M	360	Yes	9.99	5	0
65001	65702	Tanguiéta	x	13.98	86	90	PNIE	T2	M	116	Yes	1.08	7	1
65002	65502	Tayakou	–	16.52	68	80	RN9	T1	M	119	Yes	1.08	4	1
65003	65502	Datori	–	35.00	40	45	RN9	P	O	463	No	1.08	5	0
65006	65702	Porga	x	46.25	80	90	RNIE	T2	M	281	Yes	1.08	4	2

Cost and Performance Equations

The fuel cost equation considered vehicle type, the load being carried, the road link length, the rate of rise and fall, the surface type, and the unit cost for gasoline or diesel fuel. Free speed for each link was calculated by vehicle type using an equation that related it to curb weight, horsepower, load carried, rate of rise and fall, surface type, and design speed of the link. Average running speed was derived from free speed of the vehicle, equivalent daily traffic volume (with a truck counting as 2.5 automobiles), and daily road capacity (maximum traffic volume that can maintain a speed of 40 kph in the peak hour). The tire wear equation related the cost of this item to average running speed; surface type and length of link; and the unit costs of tires. Travel time over each link was calculated from average running speed and a seasonal delay coefficient. This factor was estimated from rainfall records and allowed in a simplified form for temporary and full-time road closures during the wet season. Depreciation and interest costs were calculated from total annual and lifetime vehicle-kilometers, the average year-round operating speed and the average running speed (adjusted for seasonal delays), the capital cost of the vehicle, and length and surface type of the road link. A 12 percent interest rate was assumed. Oil costs were derived from average oil consumption for each vehicle type, link length and surface type, and the unit cost of oil. Crew costs were calculated for each vehicle class from the number of crew members, the average hourly wage paid to each, and the travel time on the link. Vehicle maintenance costs were based on the cost of spare parts, the hours of maintenance labor required for each km traveled; the wage rate for maintenance labor, and the link length and surface type. Fixed costs considered the annual costs of insurance, licensing and overhead, link length, average annual km traveled, and average operating and running speeds of the vehicle.

Congestion Adjustments

Congestion causes costs to rise not only by reducing travel speed, but also by the necessity for frequent speed changes. Allowance was made for this effect by applying the standard operating costs only to the zero traffic condition with double these values at capacity and with these two points describing a linear function. This assumption was considered acceptable for this study where selection is between one-lane and two-lane roads. It would not be suitable for choices among two-, four-, and six-lane roads. Assumed capacities in equivalent vehicles were

Two-lane roads	10,000	vpd	one way
One-lane paved	2,000	vpd	one way
One-lane laterite	500	vpd	one way

Road Surface Coefficients

These were related to the de Weille performance coefficients for "paved," "gravel," and "earth" (3). For adequately maintained hardtop roads, the de Weille coefficient for paved was used. For loose top adequately maintained, the gravel cost index was interpolated one-third toward paved. For hard or loose top with minimum maintenance, the gravel coefficient was moved halfway toward earth. For a maintained track the earth index was used, and for an unmaintained track the earth coefficient was doubled. This important cost interval scale was set by a panel of international experts after much research and discussion.

Operating Cost Comparisons

The highway operating cost program was run to calculate costs for each vehicle class on typical links at various standards. For control purposes, these were compared with vehicle costs obtained by the British Road Research Laboratory (4) for Rhodesia and Zambia (Table 5). Except for different splits among maintenance, labor, and parts, the agreement is quite good. Table 6 compares Dahomey model operating costs on two-lane paved highways with various international results. It appears that these other studies may not have given enough attention to the influence of road maintenance. In any event, the comparisons suggests that the Dahomey model generates reliable vehicle operating costs.

SIMULATION AND ANALYSIS

The analytical work involved two computer programs, "TRANS" and "OPT." TRANS is an adaptation of the transport sector of a model developed by Harvard University (5, 6, 7). OPT was written for this project. Both programs were run on an IBM 360-65 computer in Toronto.

Transport Program

TRANS receives as input the people and commodity supply and demand data by location for a particular year, a description of the transport system, highway vehicle operating cost relationships, and tables containing costs on railway and transfer links. It calculates internally an origin-destination matrix for the commodities, and assigns the flows to the transport system links on the basis of minimum costs as perceived by the shipper or user. The output consists of flows and costs by vehicle type for each link in the system and overall systems performance measures.

TRANS was calibrated for Dahomey in 1967, using the existing physical transport system characteristics and a cost-based rate structure. Adjustments were made to insure that the model simulated reality as indicated by 1967 traffic counts, roadside interviews, and other traffic records for that year.

TABLE 5

INTERNATIONAL TRUCK COST COMPARISONS
($1.00 = 250 CFA francs)

Item	Truck Operating Costs[a] (CFA francs per vehicle-km, tax excluded)							
	Rhodesia[b]		Dahomey Model[c]		Zambia[d]		Dahomey Model[e]	
Crew	2.4[f]		3.9[f]		4.9		3.7	
Fuel	4.1		4.4		6.1		6.0	
Oil	0.5		1.5		–		–	
Tires	7.3		5.8		0.8		1.5	
Maintenance[g]								
Parts	3.2	6.2	5.2	6.7	3.8	7.4	6.5	8.3
Labor	3.0		1.5		3.6		1.8	
Depreciation	2.9		7.3		4.7		6.9	
Total	23.4		29.6		22.9		25.4	

[a]Excluding interest, insurance, license, and overhead.
[b]17.6 ton truck, 50 percent load factor on paved surface (from 5).
[c]18.5 ton truck, 40 percent load factor on adequately maintained pavement.
[d]10.7 ton truck on "good gravel" (from 5).
[e]Average between Class 1 (16.7 ton effective payload) and 2 (4.9 ton) trucks on laterite with adequate maintenance.
[f]More crew in Dahomey.
[g]Different emphases on parts and labor.
[h]Probably better maintenance in Rhodesia.

TABLE 6

INTERNATIONAL COMPARISON OF TRUCK COSTS ON TWO-LANE PAVED ROADS

Source	CFA Franc per Ton-Km (including taxes)
Ministère de la Coopération, Niger	6.8
SEDES Study, Niger	6.3
BCEOM data for Cameroon	7.0
National Transportation Study, Greece	5.6
Quote from international trucking company for Dahomey	4.0
Dahomey Highway operating cost model	
Adequate maintenance	5.0
Minimum maintenance	8.0

Link Optimization Program

OPT requires as input the traffic flows for the present (in this project 1967) on each link of the existing system, and the future traffic flows on each link of the system to be optimized. These data are usually obtained from three TRANS runs. In addition, the capital costs of upgrading each link to successively higher standards, the vehicle and road maintenance cost formulas and the traffic growth formulas to be used for each link, must all be specified.

OPT then calculates the vehicle flows and the total transportation costs, including vehicle operating costs, road maintenance costs, and the road upgrading costs on each link for each year of the period being considered. The results are printed for each link of each year, with the present worth for up to nine selected discount rates. For each discount rate on each link, the maintenance level and construction class are selected that correspond to the minimum present worth of all transportation costs on that link. Total transport costs for the entire system are printed out for three assumptions: first, when no changes are made in the system; second, when only maintenance improvements are made; and third, when all cost-minimizing improvements are made. These "option displays," automatically generated by OPT, are of direct value in policy discussions and decisions.

The link optimization program thus selects the optimum construction and maintenance levels for each link of a given network, with given traffic volumes and a given opportunity cost of capital.

The selection criterion is minimum total cost where cost includes vehicle operating costs (without tax); road construction costs (without tax); road maintenance costs (without tax); government subsidies; other costs and benefits, if any (either positive or negative); and exchange and shadow price adjustments, if any. Under flexible resource adjustment assumptions, this is equivalent, in the long run, to the maximization of the net present value of benefits.

Network Optimization

Cost minimization or net benefit maximization in present value terms is achieved for a transport network by using the TRANS and OPT models iteratively as follows:

1. TRANS is run for the future year with the existing network plus all proposed new links, with all road links at an assumed uniform standard.
2. The resulting flows are fed into OPT, which gives as output the optimum standard to which each link should be upgraded and the optimum maintenance level.
3. The standards and projects determined in step 2 are applied to the road system to form an improved system. Because improvements result in changes in traffic volumes on the various links in the system, the TRANS Model is run again to obtain new future year traffic assignments for the improved system.
4. OPT is then re-run to determine the optimum configuration of each link with the revised traffic volumes, thus taking account of the interdependencies among the various links. The improvement possibilities that were rejected in step 2 have an opportunity of being selected in step 4, if the changes in traffic volumes make them relatively more attractive.
5. Steps 3 and 4 are repeated as an iterative procedure until there are no further improvements to the system.

It should be noted that the procedure does not simply test complete exogenous packages. New packages are formulated by the procedure itself, when it optimizes each link while taking account of the interdependencies among the various links. The only improvements that must be introduced exogenously by judgment are completely new links.

Several possibilities for improving the network by the addition of new links may be compared by optimizing each network by the use of the five steps and then comparing the resulting network efficiency measurements.

The procedure for evaluating network packages in Dahomey was as follows:

1. Two separate test networks consisting of the existing network with some new links added and some existing links removed were chosen by judgment. This judgment was based on the input data and preliminary runs of the programs.
2. Each of the test networks was optimized using the iterative procedure described above.
3. A series of subanalyses was performed using the link optimization program to determine if new links were justified.
4. The two networks in their optimized condition were compared and the better one selected.

SAMPLE RESULTS

Table 7 shows part of the OPT printed output for the highway (node 20) link between Bimbereke and Berouboue. This is presently a two-lane laterite road (construction class 5).

TABLE 7

OPTIMIZATION OF LINK BETWEEN 65 (BIMBE) AND 66 (BEROU) - MODE 20

PRESENT CONDITIONS - CONSTRUCTION CLASS 5

(a)

LINK CHARACTERISTICS DISTANCE KM	DESIGN SPEED KPH	RISE -FALL FT	REGION	DELAY SEASON	DELAY FACTOR	INTERPOLATIONS VOL.PRES. SYSTEM	VOL.IMPR. SYSTEM	CST.PRES. SYSTEM	CST.IMPR SYSTEM
37.20	100.00	1200.00	NORTH	1	1.00	5	5	5	5

	OPERATING COST			MAINTENANCE COST		CAPITAL	OTH. COSTS	TOTAL COST			DAILY
YR	M/L 1	M/L 2	M/L 3	M/L 1	M/L 2	COST	+ BENEFITS	M/L 1	M/L 2	M/L 3	VOLUME
67	0.	66.891	0.	0.	1.866	0.	0.	0.	68.757	0.	113
68	0.	80.732	0.	0.	2.114	0.	0.	0.	82.846	0.	133
69	0.	94.911	0.	0.	2.368	0.	0.	0.	97.280	0.	155
70	0.	108.753	0.	0.	2.617	0.	0.	0.	111.369	0.	176
71	0.	115.842	0.	0.	2.744	0.	0.	0.	118.586	0.	186
72	0.	120.906	0.	0.	2.834	0.	0.	0.	123.740	0.	194
73	0.	125.970	0.	0.	2.925	0.	0.	0.	128.895	0.	201
74	0.	134.410	0.	0.	3.076	0.	0.	0.	137.486	0.	214
75	0.	138.461	0.	0.	3.149	0.	0.	0.	141.610	0.	220
76	0.	131.372	0.	0.	3.022	0.	0.	0.	134.394	0.	210
77	0.	123.269	0.	0.	2.877	0.	0.	0.	126.146	0.	197
78	0.	114.829	0.	0.	2.725	0.	0.	0.	117.555	0.	185
79	0.	106.389	0.	0.	2.574	0.	0.	0.	108.964	0.	172
80	0.	97.950	0.	0.	2.423	0.	0.	0.	100.372	0.	159
81	0.	103.013	0.	0.	2.514	0.	0.	0.	105.527	0.	167
82	0.	108.753	0.	0.	2.617	0.	0.	0.	111.369	0.	176
83	0.	114.154	0.	0.	2.713	0.	0.	0.	116.860	0.	184
84	0.	120.568	0.	0.	2.828	0.	0.	0.	123.397	0.	193
85	0.	126.645	0.	0.	2.937	0.	0.	0.	129.582	0.	202
86	0.	133.397	0.	0.	3.058	0.	0.	0.	136.455	0.	213
87	0.	141.162	0.	0.	3.197	0.	0.	0.	144.359	0.	224
88	0.	148.589	0.	0.	3.331	0.	0.	0.	151.920	0.	236
89	0.	156.691	0.	0.	3.476	0.	0.	0.	160.167	0.	248
90	0.	165.131	0.	0.	3.627	0.	0.	0.	168.758	0.	260

(b) PRESENT VALUES

DISC RATE										
5.0	0.	1585.04	0.	0.	37.62	0.	0.	0.	1622.65	0.
8.0	0.	1179.94	0.	0.	28.17	0.	0.	0.	1208.12	0.
10.0	0.	991.14	0.	0.	23.76	0.	0.	0.	1014.90	0.
12.0	0.	845.76	0.	0.	20.35	0.	0.	0.	866.11	0.
15.0	0.	683.99	0.	0.	16.55	0.	0.	0.	700.54	0.
20.0	0.	507.62	0.	0.	12.39	0.	0.	0.	520.01	0.
30.0	0.	323.02	0.	0.	8.01	0.	0.	0.	331.03	0.
40.0	0.	231.58	0.	0.	5.82	0.	0.	0.	237.39	0.
50.0	0.	178.40	0.	0.	4.53	0.	0.	0.	182.94	0.

ALTERNATIVE NO. 0 - CONSTRUCTION CLASS 5

(c) PRESENT VALUES

DISC RATE										
5.0	1265.38	1579.46	1941.29	61.92	37.17	0.	0.	1327.31	1616.63	1949.19
8.0	956.21	1176.01	1429.26	45.20	27.86	0.	0.	1001.41	1203.88	1436.61
10.0	811.34	987.97	1191.49	37.45	23.51	0.	0.	848.79	1011.49	1198.50
12.0	699.26	843.17	1008.98	31.51	20.15	0.	0.	730.77	863.32	1015.68
15.0	573.76	682.04	806.81	24.95	16.40	0.	0.	598.71	698.44	813.08
20.0	435.39	506.34	588.10	17.90	12.29	0.	0.	453.29	518.63	593.75
30.0	287.33	322.38	362.78	10.73	7.96	0.	0.	298.06	330.34	367.46
40.0	211.61	231.22	253.81	7.34	5.79	0.	0.	218.95	237.01	257.77
50.0	166.30	178.19	191.89	5.46	4.52	0.	0.	171.76	182.70	195.29

(d)

ALTERNATIVE NO. 1 - CONSTRUCTION CLASS 6

YR	OPERATING COST M/L 1	OPERATING COST M/L 2	OPERATING COST M/L 3	MAINTENANCE COST M/L 1	MAINTENANCE COST M/L 2	CAPITAL COST	OTH. COSTS + BENEFITS	TOTAL COST M/L 1	TOTAL COST M/L 2	TOTAL COST M/L 3	DAILY VOLUME
67	66.891	66.891	66.891	1.866	1.866	0.	0.	68.757	68.757	68.757	113
68	80.732	80.732	80.732	2.114	2.114	0.	0.	82.846	82.846	82.846	133
69	94.911	94.911	94.911	2.368	2.368	50,600	0.	147.880	147.880	147.880	155
70	108.753	108.753	108.753	2.617	2.617	50.600	0.	161.969	161.969	161.969	176
71	77.166	126.652	162.883	6.463	3.174	0.	0.	83.629	129.826	162.883	183
72	80.741	132.526	170.430	6.493	3.285	0.	0.	87.234	135.811	170.430	190
73	84.317	138.400	177.977	6.522	3.397	0.	0.	90.839	141.797	177.977	198
74	90.276	148.190	190.556	6.571	3.584	0.	0.	96.847	151.774	190.556	210
75	93.136	152.889	196.593	6.595	3.673	0.	0.	99.731	156.563	196.593	216
76	88.131	144.666	186.027	6.553	3.517	0.	0.	94.684	148.183	186.027	206
77	82.410	135.267	173.952	6.506	3.338	0.	0.	88.916	138.605	173.952	194
78	76.451	125.477	161.374	6.457	3.151	0.	0.	82.908	128.628	161.374	181
79	70.491	115.687	148.796	6.408	2.965	0.	0.	76.900	118.652	148.796	169
80	64.532	105.897	136.217	6.359	2.778	0.	0.	70.892	108.675	136.217	156
81	68.108	111.771	143.764	6.389	2.890	0.	0.	74.497	114.661	143.764	164
82	72.160	118.428	152.318	6.422	3.017	0.	0.	78.582	121.445	152.318	172
83	75.974	124.694	160.368	6.453	3.136	0.	0.	82.427	127.830	160.368	180
84	80.503	132.134	169.927	6.491	3.278	0.	0.	86.994	135.412	169.927	190
85	84.794	139.183	178.984	6.526	3.412	0.	0.	91.319	142.596	178.984	199
86	89.561	147.015	189.046	6.565	3.562	0.	0.	96.126	150.577	189.046	209
87	95.043	156.022	200.618	6.610	3.733	0.	0.	101.653	159.755	200.618	220
88	100.287	164.638	211.687	6.653	3.897	0.	0.	106.941	168.535	211.687	231
89	106.008	174.036	223.762	6.700	4.076	0.	0.	112.708	178.113	223.762	243
90	111.967	183.826	236.340	6.749	4.263	0.	0.	118.717	188.089	236.340	256

(e) PRESENT VALUES

DISC RATE										
5.0	1162.35	1710.10	2110.95	74.68	42.40	85.34	0.	1322.37	1837.83	2204.18
8.0	883.92	1267.16	1547.63	54.32	31.52	77.36	0.	1015.60	1376.03	1632.33
10.0	753.19	1061.11	1286.46	44.85	26.45	72.58	0.	870.62	1160.13	1366.05
12.0	651.84	902.69	1086.27	37.59	22.54	68.17	0.	757.60	993.40	1161.15
15.0	538.05	726.78	864.91	29.55	18.20	62.20	0.	629.80	807.18	933.38
20.0	411.97	535.63	626.13	20.93	13.47	53.68	0.	486.59	602.79	685.47
30.0	275.76	336.85	381.57	12.23	8.54	40.75	0.	328.74	386.14	427.00
40.0	205.14	239.31	264.32	8.18	6.12	31.61	0.	244.93	277.04	299.88
50.0	162.37	183.09	198.25	5.97	4.71	24.99	0.	193.33	212.79	226.64

ALTERNATIVE NO. 2 - CONSTRUCTION CLASS 7

(f) PRESENT VALUES

DISC RATE										
5.0	1081.27	1579.46	1941.29	77.56	43.16	148.50	0.	1307.34	1771.12	2097.69
8.0	827.36	1176.01	1429.26	56.37	32.05	134.62	0.	1018.35	1342.68	1571.22
10.0	707.80	987.97	1191.49	46.51	26.88	126.29	0.	880.61	1141.15	1324.79
12.0	614.90	843.17	1008.98	38.95	22.09	118.63	0.	772.48	984.69	1134.31
15.0	510.28	682.04	806.81	30.58	18.46	108.24	0.	649.10	808.74	921.32
20.0	393.80	506.34	588.10	21.61	13.65	93.42	0.	508.82	613.40	687.17
30.0	266.78	322.38	362.78	12.57	8.63	70.91	0.	350.25	401.92	438.37
40.0	200.12	231.22	253.81	8.37	6.16	55.01	0.	263.50	292.39	312.78
50.0	159.33	178.19	191.89	6.08	4.74	43.48	0.	208.90	226.41	238.77

(g)

MINIMUM P.V. TOTAL COST ALTERNATIVES FOR LINK 65 - 66

DISC RATE	ALT NO.	CONST CLASS	MAINT LEVEL	TOTAL COST
5.0	2	7	1	1307.34
8.0	0	5	1	1001.41
10.0	0	5	1	848.79
12.0	0	5	1	730.77
15.0	0	5	1	598.71
20.0	0	5	1	453.29
30.0	0	5	1	298.06
40.0	0	5	1	218.95
50.0	0	5	1	171.76

Part (a) and (b) of the table assume that the present conditions of minimum maintenance (M/L 2) of a two-lane laterite road (class 5) will remain unchanged. The vehicle operating cost and road maintenance cost (shown in millions of CFA francs) have been calculated for vehicle volumes predicted on the assumption that the whole transportation system is maintained in its present condition. The "total cost" entries are the sum of the operating and maintenance costs in each year. The vehicle operating costs are seen to be overwhelmingly larger than the road maintenance costs. The last column lists the predicted average daily two-way vehicle volume in each year.

Part (c), "Alternative No. 0," shows the effects of changing the maintenance level only on this link, while at the same time introducing a package of new links and improvements elsewhere in the network. In this particular case, the volumes are almost the same as in the "do nothing" case, because there is no suitable alternative route, either existing or proposed, to which traffic might divert.

From the present value costs, at 10 percent discount, it is seen that for an increase in maintenance expenditure from 23.51 to 37.45 million CFA francs, a decrease in operating cost from 987.97 to 811.34 million CFA francs is obtained. This gives a ratio of vehicle operating "benefits" to increased maintenance costs of about 12.7 at this discount rate. In almost every case in the Dahomey Study, a very favorable return was shown by maintenance programs, a theory long put forward by transportation engineers and economists.

Parts (d) and (e) show costs obtained by upgrading the link to "Construction Class 6," which is a one-lane paved road. The cost of the improvement—101.2 million CFA francs—is spread over the two years 1969 and 1970, and changes in operating and maintenance costs begin in 1971. There is also provision for inserting other benefits and/or costs resulting from the capital improvement, e.g., the value of extra production as a result of improved transportation.

Part (f) shows similar results for upgrading to "Construction Class 7," which is a two-lane paved road at a cost of 176.1 million CFA francs, spread over two years.

Summary Part (g) shows that at 5 percent discount rate, the total present value cost of two lanes paved at M/L 1 is less than for any of the other standards considered whereas at higher discount rates the two-lane gravel road remains the least cost solution. On this particular link, the highest present values for total costs are obtained by improvement of the road to a one-lane or two-lane paved standard (depending on the discount rate) and abandoning maintenance (M/L 3). Building the road to high standards and then letting it go to ruin through deficient maintenance is a very wasteful practice. Unfortunately, this is precisely what often happens in less developed countries. The reason appears to be that money can be obtained more easily through foreign aid for prestigious road construction than local budget resources can be mobilized for the more productive maintenance costs.

EVALUATION

This section contains an evaluation of the merit of the systems analysis approach used in Dahomey and of the direction that future developments might take.

Advantages of Systems Analysis

With the Dahomey-type systems analysis it becomes practical to carry out much more significant sensitivity tests. For example, the effect of a 20 percent rate change on the railway brought about major changes in the optimum highway network. In the absence of systems analysis, sensitivity tests are usually selected for the ease of calculation rather than for their true significance.

After working with the systems analysis methodology for one project, the staff became aware of some of the substantial built-in errors of the presystems methodology. The network effects were found to be quite significant. When a change was made in one link the evaluation of the effects on all other links, which is not done without systems analysis, was found to be meaningful. The concept of relating specific generated and diverted traffic to each facility change is seen to be meaningless for most links in a system.

The system requires a more rigorous analysis and permits much more significant cross-checking of various data sources. For example, the vehicle-kilometers, vehicle-hours, and vehicle operating costs may be checked against fuel consumption, vehicle registration, vehicle utilization, and user tax revenues.

Maintenance now shows up in its proper perspective and is evaluated against capital intensive projects in an equitable and rigorous fashion.

Need for Permanent Data System

The effort that is being expended throughout the world on "one shot" data gathering for transportation planning is very large. Quite possibly it is as great as would be required to operate permanent data systems. The systems analysis has given a broad overview of the requirements for precision for the various data. Some information types are kept with unnecessary and expensive detail whereas others are sadly and unnecessarily lacking. It would be most helpful, and much less difficult than first appears, to establish an international data system for transportation planning, which could be adopted and carried on at moderate cost by each country.

Systems Analysis as a Permanent Planning Tool

It is quite practical to establish an analysis system, such as the one used in Dahomey, on a continuing basis as a permanently useful planning tool. The system would be maintained operational so that, at any time, any proposed change from the adopted program could be evaluated quickly by a rerun of the programs. Basic input data would be revised periodically, forecasts checked against realized results, and the system continuously refined. It might be given a thorough overhaul once in five years.

Such a planning system would be action-oriented with short lines of communication to the decision-makers. Long, tiresome, action-delaying studies would become a thing of the past. Any proposed budget or program change could be evaluated and reported in a few days within the context of the ongoing analysis system.

The achievement of short lines of communication between decision-makers and the analysts is expected to be much more productive than seeking a completely rigorous analysis of all theoretical possibilities.

The total number of policy choices is staggeringly large: several modes with many physical standards within each mode; selection of links; selection of networks; resource scarcities; cost of money; budgeting and programming options over time; and pricing, administrative, and operational policies. The theoretical combinations are many millions for a simple system. The analyst must exercise judgment in seeking the optimum system. Would there not be a great advantage in getting the decision-maker involved in exercising these judgments? It is practical now for underdeveloped countries that are willing to give dominant importance to economic evaluation criteria. It will soon be possible, also, for more developed countries that are willing to invest substantially for social reasons.

Overestimating Stimulated Production

It was found difficult in Dahomey to verify empirically the dynamic interactions that, according to economic doctrine, should exist between transport costs and commodity supply and demand. It is commonly reasoned in the literature that if transport costs go down, this will stimulate production. But in many instances, agricultural producers in Dahomey did not seem significantly motivated by changes in transport services. They were more concerned with labor, production techniques, credit, markets, and other factors of more immediate interest to them. Analytical tests revealed that the final impact of transport improvements is often slight anyway. Given a unitary elasticity of supply of a product, and a 30 percent transport cost component in final market price, and a 10 percent truck rate reduction passed on to the shipper, the result would be a mere 3 percent growth in production. Few producers occupy themselves with such minute adjustments. This meant that in the Dahomey Study not as much use could be made of the dynamic capabilities of the computer programs as one would have liked.

Selecting Transport Policy Tools

The results indicate that the use of road improvements as the dominant policy instrument may be highly overrated. Using the link analyzed in Table 7 as an example, with 10 percent discounting and adequate maintenance, the vehicle operating cost varies from 80 percent to 96 percent of the total cost for the several schemes. For the minimum total cost scheme, vehicle operating costs are 96 percent of the total costs. Preoccupation with the road part of the costs thus appears very restrictive. It is quite possible that the entire vehicle part including management, driver training, vehicle maintenance and operations, vehicle design, and fleet upgrading, offers much richer opportunities for overall road transport economies.

Better Motor Vehicle Cost Data Needed

The coefficients relating vehicle operating costs to the road surface condition are of crucial importance to any such analysis. Yet the international data base from which such coefficients are derived is very limited indeed. This is one of the most urgent subjects for intensive research.

CONCLUSION

To conclude, the Dahomey Study was an interesting and productive experience. There is great scope for applications elsewhere and for further improvements in systems planning techniques.

ACKNOWLEDGMENTS

The work involved many professionals in an interdisciplinary team. Therefore it is difficult to acknowledge specifically all contributions, but special gratitude is owed to the following: Adrian Duncan, Peter Engelmann, Vincent Hogg, Herman G. van der Tak, Jan de Weille of IBRD; Brendan Parsons and C. Major Wright of UNDP; Yves Beauregard of Lamarre, Valois International Limitée, Montreal; Lionel Odier of BCEOM and Bernard Broca of SOFRERAIL, Paris, France; Frank Sutcliffe of Per Hall Associates, Montreal, the project manager; Basil Coukis, Center of Planning and Economic Research, Athens, Greece, who worked with William Griffiths and Peter Martin on the socio-economic aspects of the study; and Mal Tanton and his systems analysis group at N. D. Lea and Associates Limited, Toronto. There are many others who contributed greatly. Sincerest thanks are given to all of them.

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Discussion

GERALD F. RISELEY, Systems Engineer, Texas Instruments Incorporated—The transportation system planning evaluation model put forth in this paper is one of considerable comprehensiveness. The design of the model around the minimum cost path gets to the true problem—getting item A from point C at the lowest cost considering all influencing factors.

On the premise of minimum cost path, the two main criteria for evaluating such a model are (a) the completeness of accounting for all cost factors, and presenting them accurately; and (b) the actual design of the model itself, and how well it "fits" the real life situation.

Because of the nature of the limitations of presenting design data in a research paper, one cannot assay the model design per se, but can only make general comments. A major item of concern is taking into consideration factors other than that of basic cost. One factor is the availability of a given system with respect to strikes, war, and natural disasters. Consideration must also be given to a public or private operation basis. These factors must be considered, quantified, and made available as "plug in" variables.

Another consideration is the actual subsystem definition. No mention was given of two important modes—air transportation and water transportation. These would naturally have to include the developing costs, future growth data, etc., But nevertheless, they are viable alternatives, and should be considered.

The paper does not identify such items as how the railroad terminal costs were factored into the model and how possible hybrid systems might be handled. For example, by using the piggyback system of truck/rail, could the model make predictions of the minimum cost route by outputting an answer such as 200 miles by train, then 20 miles by road, etc.?

Once such a transportation model is broadened, optimized, and made scalable, it will be an important tool for aiding transportation planners. The authors and their team members deserve considerable credit for selecting such an ambitious approach and doing a commendable job.

TILLO E. KUHN, Closure—Mr. Riseley's discussion points are important ones. The capacity for sensitivity tests is an integral part of the model used for the Dahomey Study. The "fail-safe" reactions of any given transport system to strikes, war, and natural disasters could be examined, if desired, although this was not actually done in this particular case. However, other variations in parameters (for example, changes in production patterns or world market conditions for export crops) were explored. Many other options, such as public or private operation of the transport systems components, organizational reform, or even fiscal, monetary, and foreign exchange policies, were considered and can be played through with the aid of computer simulation techniques.

In the Dahomey study both air and water transportation were excluded from the terms of reference set by the clients. However, terminal, transfer, and possible hybird transport systems aspects formed, in fact, part of the Dahomey analysis. The important north-south route through Dahomey between the Atlantic port of Cotonou and the land-locked Republic of Niger provides a perfect example. The simulation model moved petroleum and manufactured goods from ship to rail terminal, by train to the end of the line in Parakou, then through unloading, storage, and loading processes to tractor-trailer combinations or tank trucks, and finally by road to their destinations in Niger. Groundnuts, uranium, and other southbound exports from Niger were handled in the reverse sequence in the analyses.

In short, any operation that can be quantified can also be accommodated within the model. As Mr. Riseley suggests, the Dahomey prototype in the meantime has been considerably broadened and improved for other international applications. Norman D. Lea and I feel that we are just beginning to exploit the immense potential of systems simulations based on high-powered field research and preferably also permanent data banks.