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THE DEVELOPMENT OF ROADS IN EMERGING ECONOMIES:

A STUDY OF RIO GRANDE DO NORTE, BRAZIL

by

A. Bruce Bishop

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Logan, Utah Natal, RGN, Brazil

1966

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A. Bruce Bishop

A report submitted in partial fulfillment
of the requirements for the degree

of

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Plan B

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THE NATURE OF EMERGING ECONOMIES

Introduction

In the last decade a great deal of attention has come to be focused on the problems of underdeveloped countries and regions, and on the conditions and processes of economic growth. The magnitude of the problem of economic backwardness, which Barbara Ward (1962), C. P. Snow (1963, p. 41), and others refer to as the widening gap between the rich nations and the poor, is almost overwhelming.

A world map marking the areas of underdevelopment would include over 100 nations, having a total population of over 2 billion people who are existing in conditions of hunger and deprivation. Shelter is so meager that physical comfort has never been experienced. Life expectancies are less than maturity to manhood.

Now after centuries of indifference, passive suffering and toleration of circumstances, there is growing discontent, disorder, and violence, which in most cases cannot be traditionally ascribed to power struggles for autocratic rule, but rather is a manifestation of the struggle to escape from poverty and misery. Robert L. Heilbroner (1963, p. 10) refers to this struggle for economic development in our time as the "Great Ascent".

Characteristics of Underdevelopment

Practically all underdeveloped areas share common characteristics which are both the cause and the result of economic backwardness. These existing conditions of both cause and effect are classified into broad categories by Enke (1965, p. 39) in "Economics for Development".

Low per capita income

Per capita income is the most widely used index of the degree of economic development of a country. If the per capita income of a region is below a comfortable subsistence level, the region is classified as economically underdeveloped.

The consequences of low per capita income, reflected in the living conditions of the people, are malnutrition, poor health care due to lack of medical facilities and doctors, low literacy rate due to lack of educational facilities and teachers, and primitive shelter and sanitary conditions.

Inefficient agriculture

Inefficient agriculture means that a large portion of the labor force is needed to produce enough to meet minimum food requirements. With so much of the population tied to a subsistence agricultural economy, the labor cannot be freed to move to sectors of greater productivity. The result is a lack of capital formation as a base

for industrialization and economic growth.

Dualistic economy

The dualistic economy is characterized by an industrial and money economy in the larger population centers, and a subsistence agriculture and barter economy in the rural areas.

There exists little interchange or interaction between these sectors because of poor communication and transportation systems. As a result, news and ideas spread very slowly so there is little stimulus for development.

High birth rate

Two hinderances to economic development can be attributed to high birth rate. In the first place, the over population which exists substantially reduces the economic opportunities of the individual. Because the slowly growing resources and production must be spread over a rapidly increasing population, lower living standards are inevitable.

Secondly, high birth rates heavily weight the population towards the young and unproductive age group; hence, there are too few adults to carry the burden of economic production.

Capital Formation and Economic Development

Underdevelopment tends to feed itself in a vicious cycle composed of both the characteristic causes and results. Heilbroner

(1963, p. 59) describes this as follows:

> This complex multi-casuality of underdevelopment can be summarized in the often-used expression 'vicious circles.' It is not 'just' a lack of capital, or 'just' backward ways, or 'just' a population problem or even 'just' a political problem, which weighs upon the poorer nations. It is a combination of all of these, each aggravating the other. The troubles of underdevelopment feed upon themselves.

It is indeed difficult to raise the standard of living unless all aspects of this circular cause to effect, effect to cause relationship can be attacked simultaneously.

There is, of course, a need for some interim measures to deal with the problems of general social improvement such as education, controlling birth rate, providing better food, shelter, and public health conditions, but preparing an economy for what Rostow (1964, p. 7) calls the " take off", and then mounting a sustained period of economic growth and expansion is the only long range solution.

All writers on economic development agree that an important part of the necessary ingredients for "take off" and growth to economic maturity is a foundation of capital. Usually, this capital is thought of in the narrow sense of industrial capital made up of machinery and equipment for manufacturing and handling goods.

But even more basic to the preconditioning of a country for an economic "take off" is the development of "social capital" con-

sisting mainly of projects belonging to the public sector which are labor intensive, and require the use of a minimum of equipment and machinery. Such projects include dams, railways, simple buildings, irrigation works, water supply and waste disposal systems, and roads.

Heilbroner (1963, p. 77) points out that these "underpinnings of 'social capital' are essential if a further structure of complex industrial capital is to be secured."

To further emphasize this point, Rostow (1964, p. 17) states that in countries which have achieved a high degree of economic development, "The creation of the preconditions for take-off was largely a matter of building social overhead capital - railways, ports, and roads."

A recent report in Time Magazine (1966, p. 35) on some states in the Amazon region of Brazil shows the impact on the economy of a concerted road development program:

> . . . last year for the first time the precious highway link to the South, which had previously been closed during the rainy season, remained open. . . . In just over two years the Para government has rebuilt 870 miles of highway and asphalted another 370 miles. With new roads opening up new markets, industry is coming in; so far, 41 new projects worth $40 million have started up.

The significance of roads in particular, as social capital is again indicated by Rostow (1964, p. 24), because "where data exist on the level and pattern of capital formation in pre-take-off societies - and for the take-off as well - it is clear that a very high proportion

of total investment must go into transport and other social overhead outlays."

It is the purpose of this report to discuss the function of road development as an integral part of overall economic development, and to analyze the factors which govern decisions in road development.

BASIC APPROACH TO ROAD DEVELOPMENT IN EMERGING ECONOMIES

Roads as a Stimulus to Economic Progress

A road system which is continually being developed and expanded serves as a significant force for overcoming the inertia of the stagnant economy of an underdeveloped region.

A road system in poor condition has the effect of isolating communities, strangling the movement of materials, good, products, and the labor force into the places where these commodities are demanded. A direct result is the forcing of a large inefficient agricultural sector and a dualistic economy.

An improved highway transportation system directly attacks this particular cause and effect of underdevelopment.

1. More goods can flow at lower cost to and from the region.
    a. The goods and materials that must be imported can be hauled at lower costs.
    b. Goods that are produced can be more easily and less expensively transported to market places.
2. Labor force can be more mobile, going to areas where labor is demanded.
3. Revenue is generated through reduced road user costs

which stimulate the economy.

a. Creates a source of funds for highway development.

b. Highway development investment stimulates construction and related industries.

c. Stimulates employment.

4. Improved communication will stimulate the stagnant and isolated areas.

5. Improved highways stimulate growth in travel, transportation, and related industries.

Roadway Development Policies

In a road development program there are basically three policy areas that require consideration.

1. Maintenance - preserving quality level of the existing system.

2. Improvement - installation of higher pavement types, and requisite structural sections, as they become economically justifiable.

3. Expansion - extension of the system to provide wider benefits, and enhance opportunities of the economic growth through greater mobility of people and goods in the region.

Since resources and capital in underdeveloped areas are scarce and costly, achieving the proper balance in planning and

efficiently allocating resources to each aspect of this three point program requires sound engineering and economic analyses. Careful consideration must be given to the long run burden of maintenance of existing roads, the cost of road improvement compared to the revenue generated by that improvement, and the local increase of travel and economic activity which justify extension of the system into new areas.

Engineering Planning in Road Development

In planning a road and highway program for an underdeveloped area, three major factors must be taken into consideration.

1. The design must be on a technological level which personnel and equipment are capable of constructing.
2. The designs must be low cost since financing such projects in an underdeveloped area is difficult.
3. Maintenance must be simple and low cost, or the road system will soon decay through disrepair.

The purpose of engineering planning, then, is to analyze the determinant factors and policy objectives for a program of road development which are consistent with the level of use and the types of vehicles and loads expected in such usage, and which are compatible with the availability of local raw materials, labor, and technology required to meet basic design criteria.

The most logical type of low cost improvement program is

"stage construction" which is defined by Hewes and Oglesby (1963, p. 507) as "step by step improvement of a roadway structure as the expenditures are justified by the demands of increased traffic."

Economic Analysis of Road Development Alternatives

In undertaking economic evaluation of road development and construction programs, it is assumed that the people of a region, state or country want and need roads and are willing to mobilize the resources to construct and pay for them.

Millions of miles of roads in countries over the world attest that the general public has always demanded such facilities, and in general has vested authority in public bodies to provide and administer them.

Governmental administrators, engineers and planners, have the responsibility to minimize total road transportation costs which accrue through costs to the road user for operation of the vehicle, and costs to the taxpayer for construction and maintenance of the highways.

Minimization of total highway costs requires some type of economic comparison of various road improvement alternatives in order to have a basis for selection of the best mix of projects.

Methods of economic analysis

There are several methods of making an economic analysis which are essentially different paths to the same goal, and do in

fact generally lead to about the same conclusions for any given set of conditions. Each method has its strengths and weaknesses, and the method that is preferred is largely the decision of the agency or the individual conducting the study, depending on the nature of the study itself. The common methods of analysis are annual cost, present worth, rate of return, and benefit-cost ratio.

Benefit-cost ratio in highway economy studies

Calculation of the benefit-cost ratio. The benefit-cost ratio is computed as the ratio of the difference between the costs and benefits of the basic condition and various improvement alternatives, presented in terms of the formula by AASHO (1960, p. 27) is:

$$\text{Benefit-cost ratio} = \frac{R_o - R_1}{H_1 - H_o} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

R_o = annual road user cost for the basic condition

R_1 = annual road user cost for the improvement alternative

H_o = annual highway cost for the basic condition

H_1 = annual highway cost for the improvement alternative

In the case of roads, annual highway costs (H) are computed as the sum of the initial costs components of right-of-way, grading and road cross section, structures, and pavement, times their respective capital recovery factors for the service life of each item, plus maintenance. Representing this by formula

$$H = \left(\sum_i Ci\ Ki\right) + M \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

where

H = annual highway cost

C = initial capital cost component

K = capital recovery factor

M = annual maintenance cost

i = subscript to identify each initial cost component and the associated capital recovery factor.

The monetary return or revenue from highway investment actually comes in the form of negative costs, i.e. a savings to the road user in vehicle operation costs because of the improved highway facility. The formula for computing the annual road user costs given by AASHO (1960, p. 15) is:

$$R = 365 \cdot A \cdot L \cdot U \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where

R = annual road user cost for the road section

A = annual average daily traffic volume (ADT)

L = length of the section

U = combined unit operating and time costs per vehicle per unit length (mi or km) for the particular highway surface and operating conditions.

Benefit-cost ratios on additional investment. The benefit-cost ratio indicates the "preferable" alternative in terms of overall expenditures to benefits. The first benefit-cost ratio, however, does not indicate the full merit of other alternatives which require additional expenditure beyond that of the "preferable" alternative.

In such cases the calculation of the successive benefit-cost ratios will indicate whether or not the expenditure of additional

increments of capital costs or marginal costs are justified on the basis of resultant gain in benefits, i.e. marginal benefits. For this calculation the "preferable" alternative is used as a base, and the difference in road user and highways costs for alternatives of greater capital investment are compared for benefit-cost ratios on additional investment. Subsequent benefit-cost ratios greater than one show justification for the additional cost of that alternative.

Sensitivity of economic studies

Hewes and Oglesby (1963, p. 88) point out that the results of highway economic studies are extremely sensitive to a number of factors.

> Economy studies are based on forecasts of the costs of such items as construction, maintenance, and vehicle operation; furthermore, they incorporate more or less arbitrary assumptions regarding traffic growth, service life, and interest rate.

This means that the conclusions derived from economy studies are also sensitive to changes in any of these factors, but particularly to the value assumed for the interest rate. As a word of caution, a change in the interest rate may markedly affect the distribution of annual costs used in the denominator of the benefit-cost ratio, and thus the final conclusion of the study.

Basis for Decision in Highway Investment

The decision of a businessman to invest arises from the expactation that such investment will prove profitable. The spending

of money for highways or other public projects should meet the same standard. W. M. Gillespie as quoted by AASHO (1960, p. 10) and by Hewes and Oglesby (1963) gives the following as a criterion for highway investment decision:

> A minimum of expense is, of course, highly desirable; but the road which is truly the cheapest is not the one which has cost the least money, but the one which makes the most profitable returns in proportion to the amount expended on it.

This expected profitability on new investment is often referred to by the phrase "marginal efficiency of capital". Being confronted with a whole range of possible projects, that project which shows the highest marginal efficiency of capital will yield the highest net rate of return of the projects considered.

To apply this concept to highway investment decision, refer to Figure 1, after Kuhn (1959, p. 51), which shows the general relationships of marginal costs and benefits of highway investments.

The marginal costs and benefits arising from highway construction and use are shown on the ordinate and the quantities of highway services on the abscissa. Curve DBM is the marginal benefit curve, and ABN the marginal cost curve, and the difference between the curves represents the differential benefit or savings at the given quantity of highway service.

From this, it is obvious that the total area between the curves bounded by any two quantity levels of highway service represents the net earnings from providing one level of service over another.

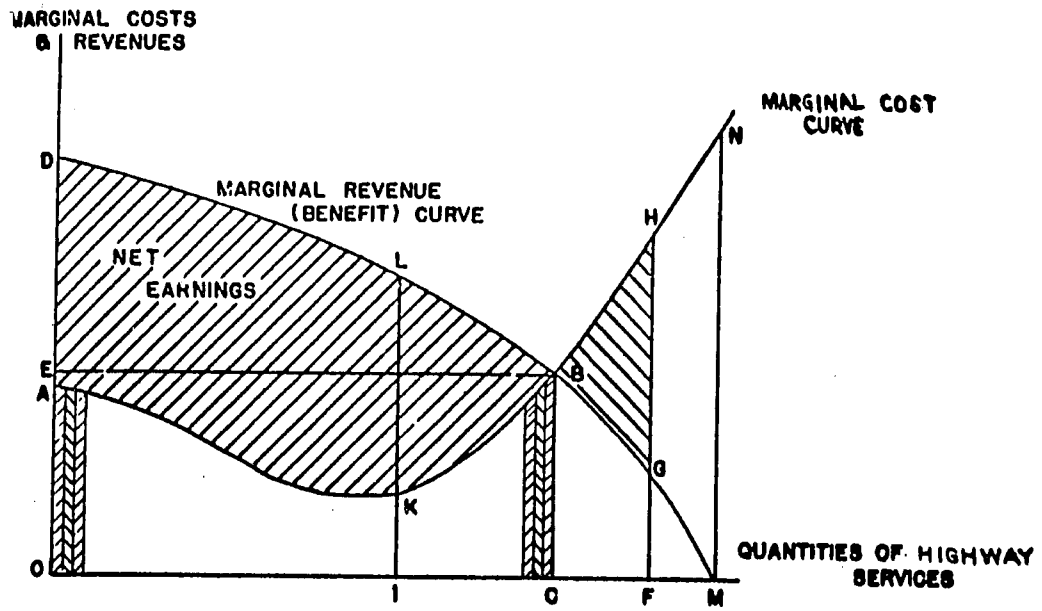

Figure 1. Marginal costs and revenue curves for highway services.

For maximization of net earnings, then, it is profitable to continue to add increments of investment in terms of highway services provided up to the level OC because for any value less than or greater than OC, the area of net earnings is reduced.

The level of highway service, OC, maximizing the earnings is determined by the point of intersection of the marginal highway cost and benefit curves, i. e. the point where marginal cost equals marginal benefits.

In the benefit-cost type of analaysis which, in the case of highway studies, compares the marginal costs and benefits of the array of possible projects; this point is identified by a benefit-cost ratio equal to one.

Therefore, all projects with a benefit-cost ratio of greater than one on the marginal investment are economically justifiable, and projects showing the highest ratios on marginal investment over a basic condition and subsequent alternatives will yield the greatest rate of return, or highest net earnings, and should deserve the highest priority.

SETTING FOR THE STUDY OF ROADS IN RIO GRANDE DO NORTE

In order to fully examine the subject of road development, a particular region has been selected for analysis. The case in point is the state of Rio Grande do Norte (also referred to hereafter as RGN), in Northeast Brazil.

It is hoped that developing an analysis based on the particular circumstances of Rio Grande do Norte, Brazil will not only result in specific recommendations for a program of development for RGN, but also point out in general those factors that must be considered in road development in underdeveloped lands.

Geographic Location and Historical Background

The state of Rio Grande do Norte is one of nine states (which comprise the region of the Northeast) situated on Brazil's large bulge into the Atlantic. The location of the Northeast in relation to the rest of Brazil, and of the state of RGN in relation to the Northeast, is shown in the maps of Figure 2 from Robock (1963, p. 19).

Brazil's Northeast is in many ways a country within a country. The south of Brazil, with its relatively high degree of industry and development of social capital, stands in striking contrast to the underdevelopment of the Northeast. Furthermore, many misunderstandings and misconceptions separate the regions because most Brazilians in

the south have no personal contact with their "Nordestino" countrymen, and relatively few "Nordestinos" have been to the south.

Figure 2. Map of the geographic location of Rio Grande do Norte, Brazil.

The Northeast was actually the earliest settled area in Brazil. The year 1532, when sugar cane established a world market, marked the beginning of the economic ups and downs of the region. Following

the collapse of the sugar market in the last half of the 17th century, cotton, gold, rubber and coffee rose and then fell due to rising competition in world markets. Finally, a shift of the economic center of gravity from the northeast to the south of Brazil left the Northeast little or no impetus for future economic progress.

Some Physiographic, Demographic, and Economic Characteristics of RGN

For a general description of the state of Rio Grande do Norte, the subdivision of the state by zones as outlined in "Plano Rodoviario Estadual", published by Departmento de Estradas de Rodagem, Rio Grande do Norte (1964a), DER-RGN is followed.

The meteorological characteristics of the state are responsible for causing two basic zones, the Litoral (coastal) and Sertão (inland). The major distinction between the zones is that the Sertão lies within the so called "drought polygon" of the Northeast, the area so delineated in Figure 3. This region sufferes almost annually from droughts of varying severity which completely disrupt the economy of the region.

Meteorological data available in "Anuario Estitistico do Brasil" (1965, p. 21) shows that in the Litoral Zone, the mean annual temperature recorded at Natal for 1964 was 79 F, while in the Sertão the mean annual temperature is probably near 90 F.

Recorded precipitation for 1964, again at Natal in the Coastal Zone, was 88.1 inches, while in the Sertão Zone annual precipitation may be 1/4 to 1/3 of this amount or less.

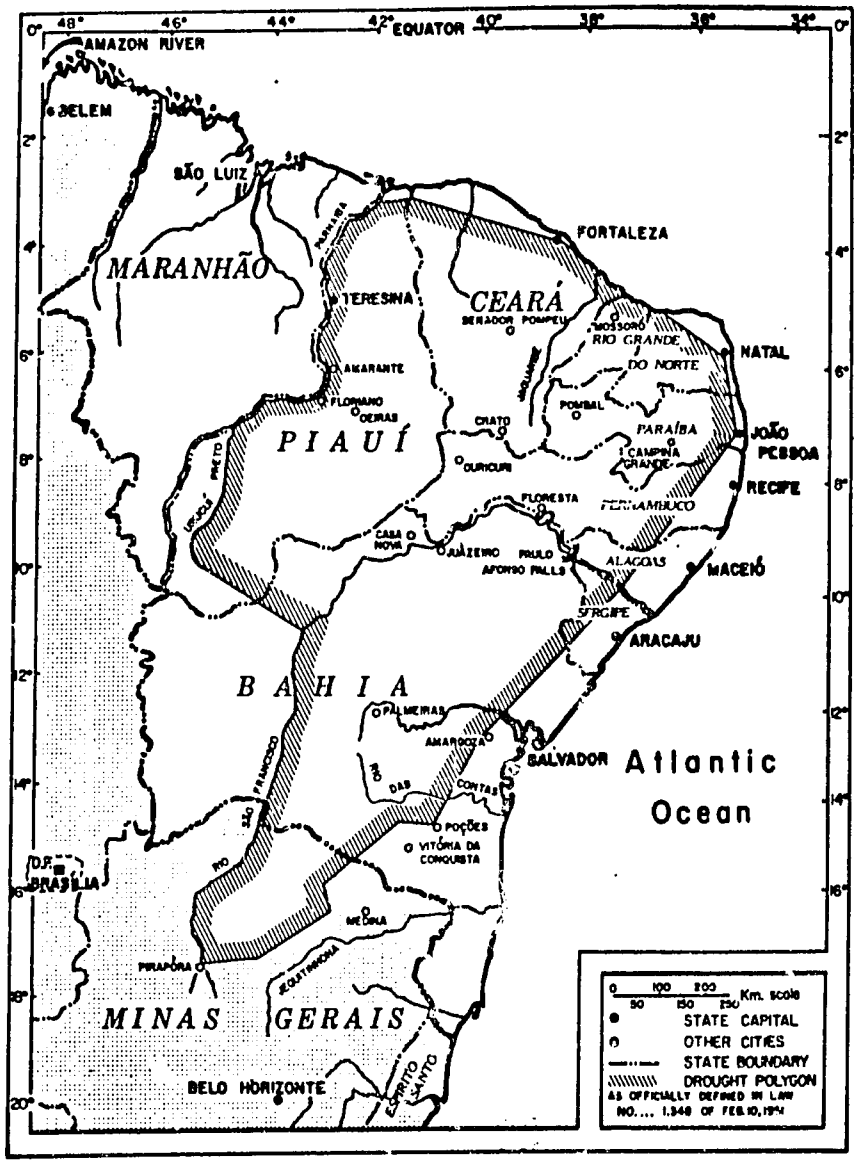

Figure 3. Northeast Brazil drought polygon.

The terrain of the state is very flat, with the exception of the Serrana (mountain) Region where there are some low mountainous areas. The Sertão Zone is principally covered with thick brush wood from 5 to 15 feet high. The lower wet areas have stands of palms, basically the carnauba type.

Table 1 presents a summary of the geographic and demographic characteristics of the regions in each zone together with the basic commodities produced in each region as derived from discussion of the regions of RGN by DER-RGN (1964a).

Table 1. Regional characteristics of Rio Grande do Norte

Region	Area $(km)^2$	Pop.	Municipalities	Economic Commodities
LITORAL ZONE				
Litoranea	6,590	376,339	20[a]	Fruit crops[b]
Salineira	7,292	95,665	15[a]	Salt
SERTÃO ZONE				
Agreste	7,577	212,459	23	Fruit and small crops, cattle
Centro Norte	7,057	71,787	18	Cotton, sm.. crops[c] cattle, pigs, goats
Apodí	10,074	118,891	15[a]	Cattle, dairy prod. sm. crops
Serido	9,532	146,290	26	Cotton, cattle, mineral mining
Serrana	5,021	136,277	23	Cotton, sm. crops animals.
TOTAL	53,143	1,157,708	140	

[a] Approximate
[b] Fruit crops: bananas, oranges, pimento, tangerines, pineapples, sugar cane and avocados.
[c] Small crops: rice, potatoes (sweet), beans, corn and mandioca.

As Table 1 indicates, the economy of the region is principally agricultural, mostly on small scale subsistance levels with the exception of the few large land owners.

There is also a crowding of population on the land. In comparison to the state of Utah, which has similar agricultural conditions in many ways, RGN has over 1,150,000 people on 53,000 square kilometers of land while Utah has just over 1,000,000 on 210,000 square kilometers.

The Northeast and RGN as an Underdeveloped Area

The state of RGN, like the entire Northeast, possesses all the characteristic causes and results of underdevelopment. An examination of the living conditions of a majority of the people leaves no doubt as to the seriousness of the problem.

Data presented in Table 2 for the various states of Brazil shows the per capita income for the states of the Northeast to be about 50 percent of the national average, and even further below the average of the states of the industrialized south (Guanabara and São Paulo).

In comparison with per capita incomes in the rest of the underdeveloped world as presented by Bhagwati (1966) and Heilbroner (1963), only the peoples of Asia and most of Africa are in poorer condition.

As a reflection of the low per capita income, the literacy rate is less than the world average of 56 percent given by Bhagwati (1966, p. 32). The economy of RGN is largely agrarian, and with the exception of the few large plantation owners, the bulk of the agrarian population and labor forces are at a subsistence level. There also

exists some dualism in the economic structure of RGN, particularly the rural areas where the open market place thrives.

Table 2. Per capita income for states of Brazil

States	Per Capita Income-1960	
	Cr.$	$US[b]
Amazonas	24 898.0	131
Para	15 703.6	83
Maranhao	9 213.6	49
Piaui	7 710.2	41
Ceara	8 714.9	63
Rio Grande do Norte	15 177.3	80
Paraiba	14 430.2	76
Pernambuco	16 194.2	85
Alagoas	13 526.2	71
Sergipe	14 652.8	77
Babia	14 913.3	78
Minas Gerais	18 991.2	100
Espirito Santo	17 285.1	91
Rio de Janeiro	25 449.9	134
Guanabara	77 963.1	410
Sao Paulo	47 600.7	250
Parana	29 651.2	156
Santa Caterina	23 996.7	126
Rio Grande do Sul	32 136.0	169
Mato Grosso	20 909.4	110
Goias	14 718.8	77
Brazil	27 005.4	142

[a] Anuário Estatístico do Brasil-1965
[b] Exchange rate in 1960 was CR$190 per U. S. $1.00

Population growth is a problem in RGN, and also the public health problems of sickness, disease, and malnutrition are cause for concern. Data from DER-RGN (1964a) give an infant mortality

rate of between 200-250 per 1000 live births for all regions in the state. This high rate indicates lack of adequate medical facilities and trained personnel, in addition to prevalance of disease and malnutrition.

The Need for Improved Roads in RGN

All of these characteristic causes and problems of under-development are beginning to be attacked by the Brazilians, in some cases with American assistance.

There is a determined effort on the part of the Brazilian Federal Government to supply the aid and assistance necessary to combat some of the specific economic problems of the Northeast. In 1945, DNOCS (Departmento Nacional de Obras Contra as Secas - National Department of Work Against the Drought) became the designated agency, supplanting several previous agencies, to administer government programs to alleviate the severity of the droughts which almost annually disrupt the economy in the Northeast.

SUDENE (Superintendency for Development of the Northeast) has been a rather active force for the planning of development programs, and in reviewing and approving social and industrial development proposals for funds from various lending agencies, such as the Bank of Northeast Brazil (BNB).

Offering support to the Brazilian agencies concerned with development of the Northeast are the Alliance for Progress, and USAID. Under AID direction are the special RITA (Rural Industrial Technical

Assistance) type projects which are assisting with industrial development in the Northeast.

However, if any of these projects are to make a significant impact on the economy of the region, consideration must be given to the upgrading of roads as the essential part of the structure of social capital so that goods and materials can flow efficiently to and from the population centers of the Northeast.

Existing Road Conditions in RGN

The early development of the present road system can be attributed to a sufficient number of vehicles traveling the same route, and over the years pioneering roads into existence by repeated use. Later these roads evolved into state and federal roads with some improvement. However, little or no maintenance results in continual problems with erosion, washouts, ruts and bumps, making many sections of these roads virtually impassable, particularly during the rainy season of the year.

Road surface and construction types

The general conditions of the existing roads in RGN fall into four basic categories:

Asphalt surface. The asphalt surfaced roads are of the low type surface constructed from a road mix asphalt concrete with the control on materials and workmanship not being extremely rigid.

Most road sections which now have asphalt surfaces are Federal roads and sections for which asphalt surfacing is planned are also Federal roads.

Rock or laid brick type surface. Some roads near the capital city of Natal are constructed of cut stone laid in the same manner as brick to form a brick surface type road. This type of construction is used a great deal for city streets.

Graded earth surface. Part of the state road system is earth roads improved by realigning and light grading.

Upon completion, such roads provide a fairly good riding surface. However, following completion, no maintenance or upkeep work is performed, and after a season of traffic wear there are many washed-out and rutted spots, making the road extremely rough riding. In quality, these surfaces have disintegrated into more the natural type of road considered in the third classification.

Unimproved earth surface. Falling in this classification are most of the State roads and virtually all the municipal roads. These types of roads have been worn into existence by vehicles following the same route until it has become established as a byway. These natural roads have never received any grading or construction, and, therefore, become almost impassible during rainy periods, and are subject to dust and its associated problems during the dry season. The roads are very rough and can only be traveled at slow speeds.

The map of the appendix shows the location of the State and

Federal road systems for RGN which are used as road study sections for this report. Table 23 gives the surface condition and length for each of these road sections.

Administration and allocation of state road funds

The roads in the state of Rio Grande do Norte fall into three administrative categories:

1. Federal roads
2. State roads
3. Municipal roads

Once construction on Federal roads has been completed, they pass under the Department de Estradas de Rodagem (DER), and, therefore, under the juridiction of the Governor and the State Government. State roads, of course, fall under the DER. The municipal roads are under the direction of the Prefeitura (mayor) of the Municipality.

Under the present organization, state road funds are allocated between the DER-RGN and the municipalities. State Road Department (DER) funds are used for the administration of the department, construction of roads, and maintenance of existing state roads.

Funds are allocated to municipalities on the basis of population, area, and kilometers of roadway, and are used for construction and maintenance of roads within the municipalities themselves.

Recalling from Table 1 that there are 140 municipalites in RGN, the amount of money available to any particular municipality

on which to operate a road construction or maintenance program is extremely small. Such small operating budgets for each municipality has the following consequences.

1. Money is not sufficient to purchase any major pieces of equipment required for good road maintenance and construction work.
2. If equipment could be purchased, there is no trained personnel to operate or maintain such equipment.
3. There is not sufficient money to retain a trained road engineer to organize a program, or to direct and supervise construction and maintenance.

For a road development program to be fully successful, solutions to the problem of fund allocation and administration must be explored. Perhaps an intermunicipal administrative agency operated through the state government can be impowered to determine what road projects and maintenance operations are to be carried out in each municipality. Men and equipment can then be dispatched from pools located in various parts of the state on a pre-scheduled basis to carry out such projects. This would eliminate the waste and possible misexpenditure of funds that may occur under the present system.

Under a system of pools, funds would be available to purchase needed equipment, and employ competent operators and maintenance men. For work requiring unskilled labor, a stipulation that workers be employed from the municipality itself is justified since such projects

should provide employment for workers in the municipality.

Programming and Implementing Road Development for RGN

The background and characteristics of RGN is typical of most underdeveloped regions because of its lack of capital equipment, low level of technology, and limited financial resources. These factors definitely set limits and bounds on programming and implementing road development in the state. The problem then becomes one of achieving the maximum in road development and its associated benefits within the construction capabilities and financial capabilities of RGN.

A "stage construction" program for RGN

The idea of "stage construction" discussed previously in this report is compatible with the limiting factors mentioned in the preceeding paragraph. The levels of roadway improvement specifically considered in the analysis of a development program for RGN are:

Stage 1 - graded and conditioned earth surface

Stage 2 - gravel surface, or soil-cement as an alternative

Stage 3 - bituminous surface treatment (BST) over existing gravel base

Stage 4 - higher type pavement

With the idea of stage construction forming the technical basis for analysis, the reamining planning determinants involve the establishing of economic criteria by which to measure whether or not expenditures for a particular road section are justified, and the planning and con-

struction priority to be given to each of the sections.

Benefit-cost ratio analysis for RGN

For the purpose of this report, the benefit-cost ratio has been selected to compare each stage of road construction and improvement in RGN. This method is generally favored by most highway engineers as well as other analysts in the public works field.

The following sections of this report are concerned with an analysis of the factors included in the capital costs of highways, and the unit vehicle operating costs which determine road user costs. With these initial cost imput factors, calculations of the associated annual costs can be made for each of the road study sections in RGN. Annual road use and highway costs are used to calculate the marginal annual costs and benefits generated by successively higher levels of improvement for the road study sections.

Each of these steps of analysis and subsequent calculations ultimately leads to determining the benefit-cost ratio for each of the road study sections in RGN.

The benefit ratio provides an adequate comparison of the merit of the various "stages of construction" on the road study sections. For this reason it is useful for the purpose of priority ranking for improvement projects for various road sections, and in establishing a general criterion with respect to justifying successively higher types of pavements.

FACTORS IN CAPITAL COSTS OF HIGHWAYS

The cost elements that must be considered in arriving at total highway costs are:

1. Right-of-way
2. Bridges, drainage or other structures
3. Structural section and surfacing
4. Maintenance and operation.

There are, of course, many specific items under each of these classifications, but a detailed cost estimate is not justified unless a particular road section is under study.

The choice of construction methods and pavement types is one of economic alternatives. Possible road improvement alternatives are exemplified by successive upgrading of the riding surface by incorporation into the system of higher type of pavement and the required supporting structural section.

Reasonable values for the life and cost of each of these elements are estimated from available sources of data for roads in the United States and abroad and modified according to data available for RGN, and the conditions which prevail there.

Basic Construction Costs Adapted for RGN

Unfortunately, data from Northeast Brazil on average intitial

costs per kilometer of various types of highway construction are difficult to obtain. Therefore, this study falls back for its source of cost information on "Highway Statistics 1960" published by the U. S. Dept. of Commerce, Bureau of Public Roads (1962), presented in Table 3.

Table 3. Average bid prices on Federal Aid highway contracts awarded during calendar year 1960.

Item	Weighted Average Thickness	Weighted Average Unit Price
	Inches	Dollars
Bases:		
Gravel and clay gravel	9.02	0.61
Macadam or stone	8.60	0.95
Bituminous concrete	4.92	1.20
Portland cement concrete	8.33	4.82
Surfaces:		
Gravel and clay gravel	3.50	0.30
Macadam or stone	6.06	0.61
Bituminous surface treatment	0.58	0.25
Bituminous road-mix	3.15	0.63
Bituminous plant-mix, medium	3.41	0.91
Bituminous penetration	2.00	0.56
Bituminous concrete	2.83	1.12
Portland cement concrete	9.04	4.31

This source should be a reasonbly good average estimator of probable highway construction cost in Northeast Brazil on this basis:

1. The construction materials going into the roadway section in RGN are on a par cost level with similar material in the U. S., or are slightly higher.

2. Capital equipment for road construction is more costly, but less is used in preference to labor. Some of this equipment has been made available through AID Projects and the Alliance for Progress as part of economic aid programs.

3. Cost of labor is considerably less, although much more is used in preference to capital.

These factors tend to be price compensating and thus cost are taken to be comparable to U. S. prices.

Since data going into initial cost estimates are for 1960, it must be updated to account for price increases over the five year period. For this purpose, the Engineering News Record (ENR) average construction cost index for the years 1960 and 1965 is used as a ratio for an increase factor. The ENR index is also compared with the construction cost index of Brazil. The increase in the Brazilian index when adjusted for inflation is on the same order of magnitude as the increase in the ENR index, as is shown in Table 4.

Table 4. Construction cost indices for the U. S. and Brazil

Year	ENR Index for U. S.[a]	Construction Index-Brazil[b]	Exchange Rate Cr$ per $US	Adjusted Index
1960	830	402	190	2.12
1965	975	4500	1848	2.44
Ratio	1.17			1.14

[a] Source: Engineering News Record, 1960-1965
[b] Source: Anuário Estatístico do Brasil-1965

As an average between the U. S. and Brazilian values, the construction cost increase factor used to update the 1960 construction cost prices is taken as 1.155.

Right-of-Way

The roadways under consideration in this report comprise the primary system of the state. These roads are under State and Federal jurisdiction, and in the growth of the system right-of-ways have been established.

Because the terrain over most parts of the state is flat, the problems with allignment and grade are minimal and the majority of the roads now in service can be improved on existing and established right-of-ways with very little need to acquire new ones.

Since most of this land has been acquired at no real cost to the taxpayer, the cost of right-of-ways is taken to be negligible.

Structures

Again, because of the terrain features in RGN, the structures required for an efficient road system are minimal.

It is further assumed that the few structures that are required will adequately accommodate subsequent improvements in the structural section and riding surface of the road.

On the basis of these facts, the costs of structures will not be considered in the annual costs of the roadway improvement alternatives.

Structural Section and Surfacing

Design of average structural section

The prepared base and surface provide the load carrying capacity of the road cross section.

It is beyond the scope and purpose of this report to analyze in detail each of the factors on the highway sections which would dictate required structural design sections and the final expenditures required to construct such a section. Specific design of the road profile and cross section for particular portions of roadway would require extensive field surveys and tests which have not to this time been undertaken.

As a basis for analyzing highway construction costs, an average design cross section is specified by using methods based on soil classification groups. The costs for various types of base preparation and surfacing are then estimated on the basis of this average design cross section.

General soil classification for RGN. Most of the soil in the state may be broadly classified as fine grained of low or medium plasticity. The extended Casagrande Soil Classification System would place them as ML, MI, CL, and CI soils, which gives them a rating of fair as a road foundation material.

There is one region which is more mountainous and rocky where the soil by Casegrande description is gravelly-sand or sand with excess fines, GF and SF, and is classified as good for road foundation. There also exists some low geographic regions composed of clays of high

plasticity probably in the MH or CH group, which have poor road foundation characteristics. However, since the distribution of the high plasticity clays balances off with the gravelly and sandy soils as an overall average, the design section is based on fine grained soils of low and medium plasticity.

Correlation of soil classification methods. From "Soil Mechanis for Road Engineers" (1961, p. 81) a correlation of the soil classification methods is given in Figure 4. Superimposed on this are the ranges which are taken to be a reasonable average for RGN which can be used for arriving at average design sections for the road construction.

For purposes of designing average structural sectors, the following generalized soil conditions are proposed.

Casagrande Classification:	ML, CL, MI, CI
BPR Classification:	A-4 to A-6
Average CBR:	10
Soil Support Value:	6
Modulus of Subgrade Reaction:	200
Group Index 8-16 max:	use 12

Design by group index method. For final design, impirical methods based on soil strength test would be superior. However, for this study, since only general soil classification for average conditions are available, the BPR group-index method for designing thicknesses of structural sections is adequate.

The group index design chart of Davis and Jones (1954, p. 41)

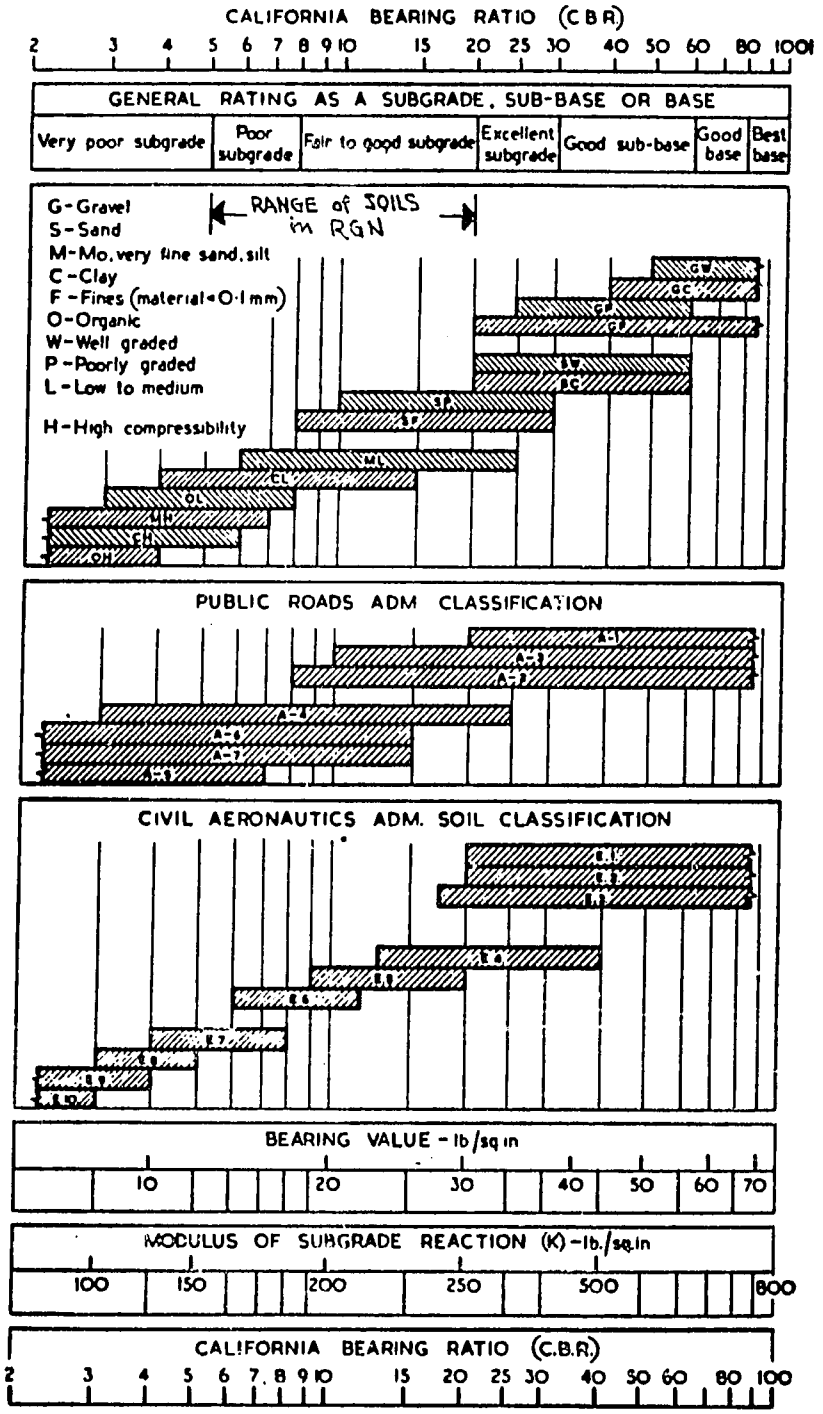

Figure 4. Approximate correlation of the Casagrande, P. R. and C. A. A. classifications on the basis of bearing capacity.

correlates the two most important variables, the soil classification group-index, and volume of commercial traffic, for arriving at design thicknesses. Applying this to the conditions for RGN with an overall average group-index of 12, the required design thicknesses at various traffic volumes are read from Figure 5. These design thcknesses are presented in Table 5.

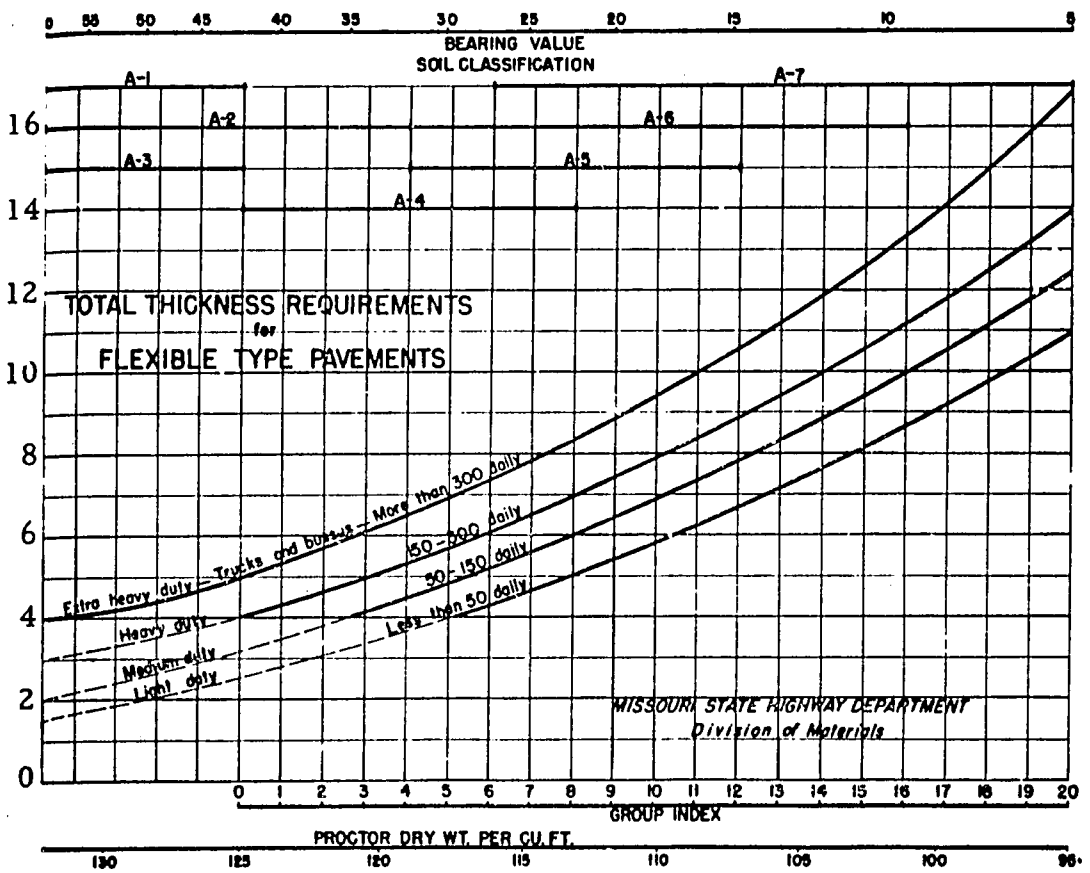

Figure 5. Group index method design chart for thickness of structural section.

Table 5. Design thickness for roads: Group-index of 12

Daily Volume of Trucks and Buses	Total Average Daily Volume[a]	Total Thickness of Base and Surface
0-50	0-100	7 in.
50-150	100-300	8 in.
150-300	300-600	9 in.
>300	>600	11 in.

[a] The traffic volume studies in Table 22 indicate an average volume distribution of about 50 percent cars and 50 percent trucks. From this data, the daily volume of commercial vehicles is doubled to give the corresponding ranges of total average daily volume.

Initital cost of base and surfacing

The levels of road improvement for which initial cost are established are grading and conditioning, gravel surface, soil cement, and bituminous surface treated.

In calculating initial cost for various base and surface types, it is assumed that lane width normally varies between 9 and 12 feet with an average of 10 1/2 feet selected for this study. All roads, unless otherwise specified, are two lane with a total width of 21 feet. Although this is on the narrow side for two lane roads with provision for passing, the very light traffic volumes do not justify a wider roadway in present planning development. On this basis, the square yards of base and surface per kilometer of roadway is calculated as:

$$7 \text{ yds width} \times 1760 \text{ yds/mi} \times \frac{1 \text{ mi}}{1.609 \text{ km}} = 7670 \frac{\text{yd}^2}{\text{km}}$$

Grading and conditioning. The most basic level of road construction on natural unimproved roads consists of grading and generally improving the natural earth road surface. This operation is accomplished by grading and crowning the road, limited leveling with small cuts and fills as can be accomplished by a motor grader, and providing some ditching for drainage at the road's edge.

Nominal cost for improvements of this nature is taken at $2000 per kilometer.

Gravel surface. The next higher level of road construction is improvement of the load carrying capacity of the base and the resistance of the surface to wear by placing and compacting a material of better quality than that of the sub-base.

Using the costs from the Bureau of Public Roads (1962) of Table 3, and adjusting for thickness and price increase, the initial costs for gravel and sand-clay roads are calculated as follows:

	Weighted Av. Thickness	Cost/yd^2
Base:		
Gravel and clay gravel	9.02"	$ .61
Surface:		
Gravel and clay gravel	3.50"	.30
TOTAL	12.52"	$ .91

From the weighted average thickness and construction costs per square yard, the initial costs per kilometer are calculated for gravel and sand clay roads in Table 6.

Table 6. Initial costs of gravel and sand-clay roads.

Traffic	Thickness	Ratio of Weighted Av. Thickness	Cost/yd^2	Price Increase Factor	Yd^2/km	Cost/km
0-100	7"	.56	$ .91	1.155	7670	$4510
100-300	8"	.64	.91	1.155	7670	5160
300-600	9"	.72	.91	1.155	7670	5800
600	11"	.88	.91	1.155	7670	7100

Treated surfaces - portland cement stabilization. There are three feasible ways of strengthening the base and surface of earth roads in RGN. Both sodium chloride and calcium chloride are plentiful resources in the area, as well as lime stone and its derivative product of hydrated lime. Also, there are ample resources available in the area for production of portland cement. For the economic study of this report only portland cement stabilization is considered in detail.

Recommendations for cement stabilization of soils in the range of A-4 to A-6 on the AASHO classification is between 10 and 14 percent by volume. Using 12 percent as an average cement requirement, the quanitity required per square yard for a depth of one-half foot is:

$$3' \times 3' \times \frac{6''}{12''} \text{ depth} \times \frac{12}{100} \text{ cement content} =$$

.54 bags of cement or 1 cubic foot[1]

[1] One bag of cement equals 1 cubic foot of cement.

The price of portland cement in Brazil is computed from data given in "Anuário Estatístico do Brasil" (1965, p. 204), in Table 7.

Table 7. Average price of portland cement in Brazil

Year	Tons Produced	Value in Cr$	Cr$/$U. S.	$U. S.	$/Ton
1962	121,732	1,110,671,000	390.52	2,846,650	28.38
1963	54,266	842,972,000	577.65	1,459,312	26.89
1964	46,162	1,686,397,000	1,293.42	1,303,827	28.25

While the price of Brazilian produced cement has increased, imported cement has dropped in price from $28/Ton in 1962 to $21/Ton in 1964.

Using this information, but giving a little more weight to prevailing Brazilian prices, the price per ton with price increase factor is assumed to be $27.50.

At the nominal depth of 6 inches and a cement content, by volume, of 12 percent, the cost per kilometer is computed as:

$$\frac{7670\ yd^2}{km} \times \frac{.54\ cu.\ ft.}{yd^2} \times \frac{94\ lb.}{cu.\ ft.} \times \frac{1}{2000\ lb/Ton} \times \frac{\$27.50}{Ton} = \frac{\$5350}{km}$$

Computation of the total price per kilometer is made on the premise that the cost of materials, labor, and equipment other than portland cement is that quoted for construction of gravel and clay bases.

Recognizing that cement-treated bases do have greater stability than untreated compacted soils, from the gravel equivalent concept of the State of California (1964), the required design thickness is reduced by dividing by a factor of 1.2, the value for Class C cement treated base in order to compute the costs presented in Table 8.

Table 8. Cost for cement stabilized soil construction.

Traffic	Adjusted Thickness	Weighted Average Thickness	Ratio	Base Cost Cost/ km[a]	Base Cost Adjusted cost	Cement Cost/ km[b]	Total Cost
100	6"	9.02	.67	$5400	$3620	$5350	$ 8970
100-300	6.5"	9.02	.72	5400	3920	5800	9720
300-600	7.5"	9.02	.84	5400	4500	6700	11200
600	9"	9.02	1.0	5400	5400	8000	13400

[a] Base cost for construction is calculated as $0.61 per square yard x 1.155 cost increase factor x 7670 square yard per kilometer x 9.02" nominal depth = $5400/km.

[b] Cost of cement per kilometer is adjusted for required depth by multiplying the base cost of $5350 by the ratio of the required depth to the 6 inch nominal depth.

Bituminous surface treatment. The Asphalt Institute Handbook "Asphalt Surface Treatments" (1964, p. 1) defines a bituminous surface treatment as an application of asphalt to any type of road surface followed by an application of aggregate of nearly uniform size. The Asphalt Institute (1962, p. 226) points out that a surface treatment is not a pavement in itself. It generally only slightly increases the structural strength of the section, but mostly provides an all weather, abrasion resistant wearing surface.

On this basis the required total design thicknesses will remain constant for sections with BST, but, of course, the BST will replace an equivalent amount of the base material in making up the total design thickness.

Again with regard to asphalts, Brazilian prices are comparable to American prices, as the following data from "Anuário Estatístico do Brasil" (1965, p. 194) indicate:

Year	Tons	Value $U. S.	$/Ton
1962	10,259	$408,000	$39.76
1963	5,216	254,000	48.50
1964	8,717	410,000	47.03

U. S. prices for the same period are comparable as indicated in "Pavement Cost Study" of the Asphalt Institute (1956), Table III.

With this justification then, data from the Bureau of Public Roads (1962, p. 203) are taken as a reasonable estimate of average unit price, and price per kilometer is calculated as follows:

$$\frac{yd^2}{\$0.25} \times \frac{IF}{1.155} \times \frac{yd^2/km}{7670} = \frac{Cost/km}{\$2,200}$$

Maintenance

Highway maintenance may be simply defined as preserving and keeping each roadway as nearly as possible to its original condition when constructed.

In the state of RGN, as is characteristic of many underdeveloped areas, road maintenance is at an extremely low level, or is entirely

neglected. These poor maintenance practices are due to a lack of equipment, lack of understanding of techniques or technology, and improper planning of programs and expenditure of funds.

The effect of poor maintenance is pointed out by Betz (1965, p. 4) in his article "Highway Maintenance Costs--A Consideration for Developing Areas".

> The consequences of improper maintenance are many. The most obvious, as previously mentioned, is disintegration of the facility and the premature loss of a large initial investment. Furthermore, it will adversely affect the costs of the highway user. This means not only a decrease in anticipated user benefits, but possibly much more subtle consequences as well. The highway can affect social, politcal, and economic activities. Economic development is most sensitive to highway user costs; for example, the encouragement of decentralization of industry or the development of cash crop economies can be influenced by relatively small changes in user costs such as those incurred by poor highway maintenance.

Earth and gravel roads

Compatible with the low surface type, maintenance on earth and gravel roads can be accomplished by using relatively unskilled labor and minimal equipment requirements, usually including trucks, tractors, draging devices, and motor graders.

There is a wide variety of data available on maintenance costs for earth surface roads. In analyzing maintenance cost on low and intermediate surface types in the U. S. and developing areas, Betz (1965, p. 6) states that unpaved roads have an annual average maintenance cost of $800/mile, but that maintenance costs increase with increases in traffic. Radzikowski (1949, 1957) also notes an increase

in maintenance costs with increasing traffic. An example is maintenance costs in Kenya for gravel roads from Betz (1965, p. 17), in Table 9.

Table 9. Maintenance costs for Kenya.

Road Type	Veh/Day	Maintenance Cost (£/mi/yr)	Maintenance Cost $/mi/yr
	Gravel		
1	0-50	168	470
2	50-100	191	535
3	100-200	214	600
4	200-300	275	770
5	300	395	1110
	Bituminous Surface		
12-ft		200	560
20 to 22-ft		265	745

On the basis of this information then, the average maintenance cost per year for RGN is taken at the values shown in Table 10.

Table 10. Maintenance costs for earth and gravel road in RGN.

Maintenance - Earth and Gravel Roads		
Traffic Volume	$/mile	$/km.
0-100	450	280
100-300	600	375
300-600	800	500
600	1000	625

It is considered that the same load of maintenance is also required on cement and stabilized roads, and so maintenance costs are comparable.

Bituminous surface treated roads

Maintenance on bituminous surface treated roads is, of course, more specialized. The small local failure can be repaired routinely by patching crews with some cold mix asphalt, and about the same equipment required for gravel roads.

The maintenance operation requiring more technical equipment is the periodic resealing of asphalt treated surface. Labor requirements for this operation necessitate the use of trained crews, and in addition to the normal equipment cited for gravel roads, asphalt tanks with heaters, asphalt hauling tanks, aggregate distributing devices for haul trucks, and rollers are also required. Specialization of labor and equipment, as well as higher material costs, significantly increase maintenance of BST roads.

Since the maintenance practices and requirements for BST - roads and mixed bituminous roads are well established, there is not quite the variation in costs that exists for earth surfaces. On BST roads, Betz (1965, p. 6) states that annual maintenance costs are on the order of $1200 per mile per year, indicating a decided differential between paved and unpaved roads.

Data for states in the U.S. shows total maintenance costs ranging from about $890 to $1600 with the pavement component

ranging between $480-$1000. For the RGN case, pavement is the principal component and other factors are minor.

Again as in the case of earth roads, information indicates that maintenance costs increase with increasing traffic volumes. Data from Nigeria by Betz (1965, p. 19), on maintenance of BST roads, presented in Table 11, make this clear.

Table 11. Estimates of annual maintenance costs in Nigeria.

Surface Type	Veh/Day	Normal Main. ($/mi)	Resealing Cost ($/mi/yr)	Total Main. ($/mi)
Gravel	0- 100	420	-	420
12-ft surface treatment	100- 300	280	590	870
18-ft surface treatment	300-1000	420	1120	1580
22-ft surface treatment	1000-2000	560	1340	1900
24-ft pre-mixed bit. surface	>2000	560	1340	1900

Modifying this information for the purpose of this report, maintenance costs for BST roads in RGN for various traffic volumes are taken as the values given in Table 12.

Table 12. Maintenance cost for BST roads in RGN.

Traffic	$/mile	$/km
0- 100	$ 600	$ 375
100- 300	800	500
300- 600	1000	625
600-1500	1200	750
1500-3000	1400	875
3000	1600	1000

ANNUAL COSTS OF HIGHWAY IMPROVEMENTS

With the initial cost components and operation and maintenance expenditures for the various road surface type established in the previous section of the repot, attention is turned to the summarization of the annual costs of various "stages of improvement".

In the procedure outlined by Grant and Ireson (1960), the annual costs are allocated by distributing the initial cost over the life of the project by applying the capital recovery factor K, where

$$K = \frac{i(1 + i)^n}{(1 + i)^n - 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

at a reasonable interest rate.

Interest Rate on Highway Investments

For the purposes of this report, the interest rate adopted is that commonly applied by international lending agencies on development loans to various countries. Enke (1965, p. 494, 512) lists the going rate on development loans from the Export-Import Bank as 6 percent or slightly less, and from the International Bank for Reconstruction and Development (IBRD) at between 4 and 6 percent. The IBRD particularly favors loans for development of social capital where people pay for the services. On this basis, 6 percent is adopted as the interest rate.

Service Life of Road Surface Types

It is necessary to know the average life expectancy of various road surface types in order to choose a proper value for "n" in the formula for the capital recover factor.

Road life studies for various types of road surfaces were begun in several states in the U. S. during the late 1930's. A study by Farrel and Patric (1948, p. 45) on probable average service life for different surfaces grouped by construction years from 1900 to 1945 shows a significant decrease over those years in road service life. This is due primarily to the increase of traffic and wheel loads over the years.

However, since these early studies average service lives for road surfaces have stablized to relatively constant values as indicated by a more recent study in Public Roads (1956, p. 20).

A summary of service lives for various pavement types as presented by Farrel and Patric (1948), and Public Roads (1956) is given in Table 13. The service lives assumed for conditions in RGN are presented in the third column of Table 13.

The Problem of Inflation

Since about 1960, the Brazilian economy has been subjected to tremendous inflationary pressures. In 1960, the Brazilian monetary unit, the Cruzeiro (Cr$) had a value on the world monetary market of Cr$ 190 per $1 U. S. In January of 1966 the exchange value was Cr$

Table 13. Road surface service life in years.

Surface	BBR Study	Study of Farrell & Patric	Assumed Value for RGN
Low Type			
Soil Surface	4.0	4.5	4.0
Gravel or Stone	7.5	5.9	7.0
Cement Stabilized			10.0
Intermediate			
BST	11.7	7.4	12.0
Mixed BST (7" sect)	12.5	12.3	
Mixed BST (7" sect)	18.5	16.0	15.0
High Type			
Bit. Concrete	20.3	18.1	18.0
Portland Cement	27.0	26.1	25.0
Brick or Block	19.6	20.2	20.0

2,200 per $1 U.S. Inflation is seen in terms of rising prices, or a decrease in the purchasing power of the monetary unit.

With inflation at a rate of 30 to 40 percent per annum, and sometimes greater, it is indeed valid to ask if some account for this should not be made in the cost data and economic analysis.

Senate Document 97, an agreement on standards for water resource development cited by Lee and Grant (1965) states:

> The prices used for project evaluation should reflect the exchange values expected to prevail at the time costs are incurred and benefits accrued.

R. R. Lee and E. L. Grant (1965) summarize the opinion of several government agencies and noted economists on the subject of

price increases due to inflation and conclude that an inflation rate should not be included for the following reasons:

1. Future dollars to pay for future expenses will also be inflated and there is no net change.
2. The rate of inflation (if any) in the future is not known.
3. Inflated future benefits make uneconomic projects appear justified.

In view of these opinions, there seems to be no justification for including inflation, even at Brazil's present high rate, in an economic study of highways or other public works projects.

Annual Highway Cost Computations

Using the values established in previous sections of this report, the annual highway cost (H) is computed according to Formula 2.

Since the cost of right-of-way and structure is taken to be zero, the formula reduces to

$$H = CK + M \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5)$$

where

H = annual highway cost

C = initial cost of structural section and surface

K = capital recovery factor

M = annual maintenance cost.

Table 14 contains the annual cost computations for each level of road improvement.

Table 14. Annual costs of levels of road improvement.

Pavement Type & Description	Pavement Life	Percent Interest Rate	Capital Recovery Factor	Initial Cost	Annual Cost	Maintenance	Total Annual Cost
Reconditioning & Grading	yrs.			$	$	$	$
0-100	4	6	.2886	2000	580	280	860
100-225	4	6	.2886	2000	580	380	950
225-450	4	6	.2886	2000	580	500	1080
> 450	4	6	.2886	2000	580	620	1200
Gravel Surface							
0-100	7	6	.1791	4510	810	280	1090
100-225	7	6	.1791	5160	920	380	1300
225-450	7	6	.1791	5800	1040	500	1540
> 450	7	6	.1791	7100	1270	630	1900
Cement Stabilized							
0-100	10	6	.1359	8970	1220	280	1500
100-225	10	6	.1359	8720	1320	380	1700
225-450	10	6	.1359	11,200	1520	500	2020
> 450	10	6	.1359	13,400	1820	630	2450
Double BST							
0-100	11	6	.1268	6400	810	380	1190
100-225	11	6	.1268	7000	890	500	1390
225-450	11	6	.1268	7600	960	630	1590
450-1500	11	6	.1268	8800	1120	750	1870
1500-3000	11	6	.1268	8800	1120	870	1990
> 3000	11	6	.1268	8800	1120	1000	2120

Marginal Annual Costs of Improvements

The highway costs portion of the benefit ratio, i.e. the denominator in Formula 1, is calculated by finding the difference in annual highway costs of one alternative over another.

The successive "stages of improvement" represent the construction alternatives for RGN, and the required marginal costs are calculated as the difference in annual cost of a particular stage and the next lower stage at various traffic volumes.

The annual costs over the range of traffic volumes for each level of improvement and the associated marginal costs to achieve that improvement are given in Table 15.

Table 15. Summary of annual and marginal highway cost, in dollars.

Traffic Volume	Unimproved[a]	Grad. & Rec.[b]	Gravel[c]	H_1-H_2	BST[d]	H_2-H_3	Soil Cement[e]	H_1-H_4
0- 100	0	860	1090	230	1190	100	1500	640
100- 225	0	950	1300	350	1390	90	1700	750
225- 450	0	1080	1540	460	1590	50	2020	940
450-1500	0	1200	1900	700	1870	-30	2450	1250
1500-3000	0				1990	-90		
3000	0				2120	-220		

[a] Unimproved is the basic condition H_o.
[b] Graded and reconditioned is the first stage of improvement H_1, and also represents the marginal cost over the basic condition H_1-H_o.
[c] Gravel is the second stage of improvement H_2.
[d] BST is the third stage of improvement H_3.
[e] Soil cement as an alternative to gravel is designated H_4.

FACTORS IN UNIT VEHICLE OPERATING COSTS

Analysis of Vehicle Operating Cost Factors for RGN

The unit vehicle operating cost is a function of several factors which are considered to be direct expenses associated with the operation of a vehicle. These cost input factors are fuel, oil and lubricants, tires, depreciation, maintenance and repair, time, and comfort and convenience.

Naturally, costs vary widely for any specific vehicle, but in the aggregate, input costs for an average vehicle can be determined as a function of prevailing prices, traffic conditions under which the vehicle is operated, condition of the road surface, grade and alignment of the roadway, and operating speed of the vehicle.

Extensive investigation correlating cost input factors as a function of these variables is contained in "Road User Benefit Analyses for Highway Improvements," AASHO (1960). The basis for adjusting the data and costs presented in AASHO (1960) to conditions in RGN is discussed in the following paragrpahs.

For conversion of prices, it should be noted that the legal exchange rate of Brazilian Cruzeiros (Cr$) for American dollars as of January 1966 was $1 = Cr$2200. This is used as a base for computing unit prices to be used in the analysis.

Fuel

The current price of gasoline is Cr$ 170 per liter. Converting this to cents per gallon

$$\frac{170 \text{ Cr\$/liter}}{2200 \text{ Cr\$/\$US}} \times 3.785 \frac{\text{liter}}{\text{gal}} = \$ \ .292/\text{gal}.$$

The manual on "Road User Benefits Analysis for Highway Improvements" AASHO (1960, p. 110) states that 3 to 5 miles less per gallon is to be expected on loose surface roads. Since most of the road surface conditions in this area are loose surfaces in poor condition, or entirely unimproved, it is to be expected that there may be reduction by as much as 5 miles per gallon.

Because traffic is light, vehicle operation for the most part can be considered "free". However, extremely poor road conditions, such as ruts, potholes, and washouts, require a vehicle operator to do a great deal of slowing, braking, and accelerating, as is to be expected in "restricted" operation in heavy traffic.

As a reasonable compromise of these conditions, for all earth surface roads, operation will be considered "free" and a reduction of 5 miles per gallon applied. The "free" operation data for fuel consumption costs from AASHO (1960, p. 109) adjusted to this value, and using the current Brazilian price for gasoline, is presented in Figure 6. The terrain over the entire state is flat, so the curve from 0-3 percent is used.

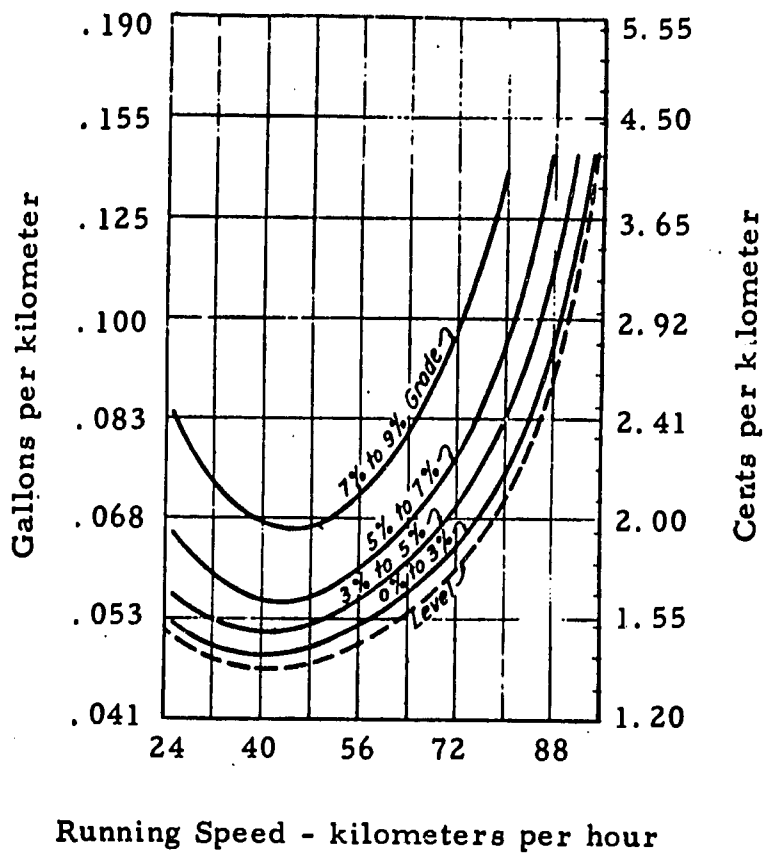

Figure 6. Estimated fuel consumption - Free operation on earth surface roads.

Oil and lubricants

The current price of oil and lubricants is Cr$ 800 per quart. Converting this to dollars per quart:

$$\frac{\text{Cr\$ } 800}{\text{qt}} \times \frac{1}{\text{Cr\$ } 2200/\$\text{US}} = \$ \ .40 \text{ per quart}$$

The relationship between the mileage per quart obtained over a range of running speeds for various types of surface has been determined and is presented in the graph of Figure 7 from AASHO (1960, p. 115), which is adjusted for RGN prices.

The costs of oil and lubricants per kilometer can be read directly for the various running speeds and surface types.

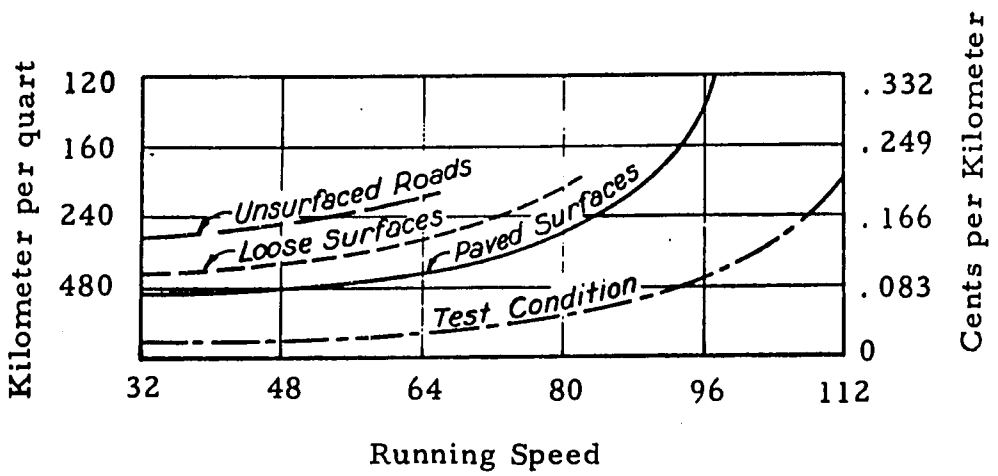

Figure 7. Estimated cost of oil in relation to speed and road surface conditions.

Tires

The current cost of a single auto tire in RGN averages Cr$ 35,000, so a set of four tires is Cr$ 140,000. Converting to U. S. dollars the price is:

$$\frac{Cr\$\,140,000}{Cr\$\,2200/\$US} = \$63.50$$

Data from many tests have resulted in the curves of Figure 8 from AASHO (1960, p. 122) showing the tire life as a function of operating speed on various types of road surface.

The scale on the right hand side of the graph shows the cost per kilometer using the price established for the set of four tires.

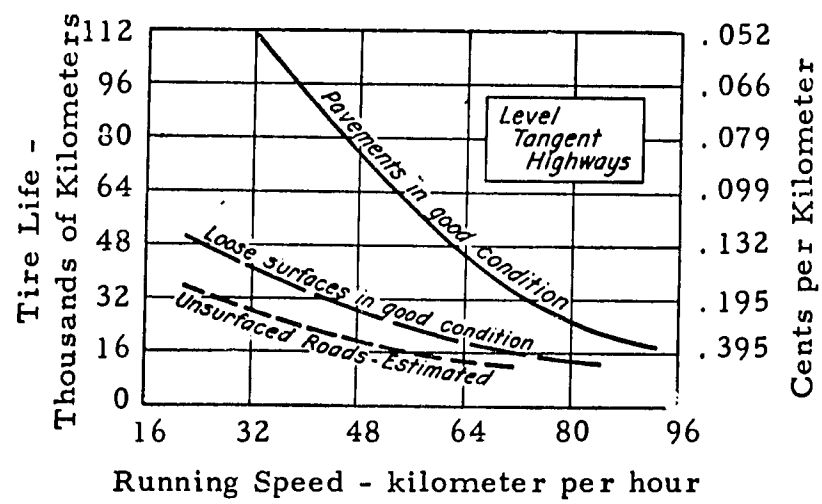

Figure 8. Tire life mileage and cost in relation to speed and road surface conditions.

Depreciation

The makes and models of cars available to the consumers in RGN, Brazil are limited. Three main makes of cars are sold in the area and each one of them takes about one-third of the market:

Make	Price	
	Cr$	$US
Volkswagen	6,000,000	2730
DKW	8,000,000	3640
Rural	6,500,000	2960
TOTAL		9330

Average Price $3110

Using the same assumptions made by AASHO (1960, p. 126), half of the depreciation is attributed to outdating of the models, and the other one-half to the wear and tear which is assessed as part of the road user costs.

The assumption that the vehicle life is ten years and 100,000 miles is modified to ten years and 100,000 km. This is justified because of greater wear and tear on vehicles associated with roads that are in the very rough unimproved condition.

Cost of depreciation per km is:

$$\frac{\$3110}{2} \times \frac{1}{100,000 \text{ km}} = \$ .016/\text{km}$$

Maintenance and repair

Again referring to the AASHO (1960, p. 125) studies, data presented there gave vehicle maintenance and repair cost for a base year, which should further be adjusted upward by 50 percent to account for price increases. The costs are given as follows:

Surface Type	Cost: ¢/mi.	Adjusted Cost
Paved	.80 x 150%	1.20 ¢/km
Graded	1.20 x 150%	1.80 ¢/km
Unimproved	1.60 x 150%	2.40 ¢/km

These figures are used as indicated with the following adjustment and justification: The cost of spare parts and tools is higher in RGN being on the same order as the difference in retail price of a new automobile in RGN and in the U. S.; but on the other hand, labor is much cheaper. Because the road surface conditions are really much poorer for comparable surface types, the costs will be taken per kilometer rather than per mile.

Time

Certainly the saving of costs associated with time is one of the greatest benefits of a road improvement program for RGN. Since the large majority of consumer goods brought into the markets of RGN, as well as those goods produced locally which are sold in other outside areas, are transported by truck, an improved roadway system would result in large savings of time in the moving of these goods. Savings in time are directly proportional to savings in money in the use of commercial vehicles because more paying load can be hauled per hour while operating costs such as wages for drivers, rental of equipment, or even fixed cost, remain unchanged.

With little data aviable from this region with which to make a judgment of time value, the data compiled by AASHO (1960, p. 129-136) for time costs are used to make a reasonable approximation. The assumed time costs for RGN are summarized in Table 16.

Table 16. Time costs for various speeds and surface types.

Surface Types	Speed	¢ per mi.	¢ per km
Asphalt	70	4.80	3.0
Gravel	55	5.60	3.5
Graded	40	6.40	4.0
Unimproved	25	9.60	6.0

Comfort and convenience

Costs assigned to comfort and convenience of motorists are difficult to evaluate, particularly for this region and people.

Undoubtedly, as roads are improved, people will travel with greater comfort and convenience, and as a result of the increased comfort in travel, more and more people will travel in the future. However, because of the problems of evaluation, no costs will be assigned to comfort and convenience.

Average Running Speed and Road Conditions for RGN

The road conditions in RGN have been divided into four basic classes. With respect to experience with these conditions, the average running speeds are established as follows:

Surface Type	Average Running Speed
Asphalt Paved	70 km/hr.
Gravel & Soil Cement	55 km/hr.
Graded	40 km/hr.
Unimproved	25 km/hr.

Total of Unit Vehicle Operating Costs for RGN

By interpreting the graphs and charts of vehicle operating cost factors for the running speeds and road conditions in RGN, the following vehicle operating costs, presented in Table 17, are established for calculating annual road user costs for the road study section.

Table 17. Total unit vehicle operating costs.

Surface Type	Running Speed km/hr.	Operating Costs Factors						Total Cost ¢/km
		Gas	Oil	Tires	Deprc.	Maint.	Time	
BST (Asph)	70	1.25	.115	.195	1.6	1.2	3.0	7.360
Soil Cements	55	1.32	.110	.290	1.6	1.5	3.5	8.320
Gravel	55	1.32	.110	.290	1.6	1.5	3.5	8.320
Graded	40	1.46	.110	.195	1.6	1.8	4.0	9.165
Unimproved	25	1.55	.146	.195	1.6	2.4	6.0	11.891

ANNUAL ROAD USER BENEFITS FROM HIGHWAY IMPROVEMENTS

Annual Road User Costs for Highway Sections

The road user cost input factors as specified by Formula 3 are:

A = annual average daily traffic

L = section length

U = unit vehicle operating cost

Naturally, the case study for RGN requires the determination of reasonable estimates for these factors for the conditions that exist there.

Average daily traffic

The traffic volume factor "A" used in Formula 3 for calculating annual road user cost is determined by traffic surveys on the roads which are under consideration for improvement.

Since unit operating costs are based on automobile costs, in order to adjust the average daily traffic volume to account for the higher road user cost for trucks and busses the following formula from AASHO (1960, p. 29) is applied by recognizing that average daily traffic volume $A = A_P + A_T$ where A_P is the volume of passenger vehicles, and A_T the volume of trucks.

Then

$$A_e = A_P + F\,A_T$$

where:

A_e = equivalent average daily traffic considering the adjustment for higher operating costs of trucks

F = ratio of operating cost of trucks to cars

The range of the F-ratio for trucks and busses is given by AASHO (1960, p. 29), as shown in Table 18.

Table 18. Ratio of truck operating costs to passenger cars.

Vehicle Type	F-Ratio
Single Unit Trucks	2-4
Busses	2-4

For the conditions of RGN, an F valve of 4 is used to calculate A_e for use in determining road user costs.

The data on average daily traffic volumes (A) is taken from a study by the RGN Departmento de Estradas de Rodagem, DER-RGN (1964b) titled "Boletim Informativo de Serviço de Trafego Rodoviario."

The bulletin gives data on the average and maximum number of vehicles per day, and the hourly maximum during the sample period. It also includes the composition of traffic in terms of cars, trucks weighing less than 6 tons, trucks weighing greater than 6 tons, and busses. This data is presented in Table 22 which also contains the ADT adjusted for trucks and busses to give A_e.

Section length

The lengths for the road sections which are analyzed on the state and federal highway system of RGN, are taken directly as recorded on or as sclaed from the maps included in the report of DER-RGN (1964a).

These data on section length are recorded in the appropriate columns of Table 23.

Computing annual road user costs

Using the values established in the preceeding section of this report on unit vehicle operating costs, the annual road user costs (R) are computed by Formula 3, which becomes

$$R = 365 \times A_e \times L \times U$$

where

A_e = the equivalent average daily traffic volume from Table 22.

The factors involved in the calculation of the road user cost for each of the road sections in RGN, and the computed total annual road user cost for that section, are given in Table 23.

Road User Benefits

The road user benefit portion of the benefit-cost ratio, i.e. the numerator in Formula 1, is calculated as the difference in annual road user costs associated with one level or "stage" of pavement improvement over another. Since the road user costs are reduced by

traveling on higher "stages" of pavement, the difference is actually a negative cost, or in other words, a savings or marginal revenue which accrues as benefits to the road user.

The computation of the anticipated annual road user benefits for each of the road sections in RGN if it were to be improved to higher types of pavement surface is found by first calculating the road user costs for each of the surface types following the same proceedure used for calculating road user costs on the existing sections given in Table 23, but reducing the vehicle operating costs to the rate which is consistant with the improved surface type given in Table 17. Then, the marginal revenue, or benefits, generated by each successive improvement in road way surface is the difference in road user costs of one level of surface improvement over another.

The calculation and summary of marginal revenue or benefits for improved sections of the roads studied in RGN is presented in Table 24.

BENEFIT-COST RATIOS FOR ROAD STUDY SECTIONS

Benefit-Cost Ratios and Program Evaluation for RGN

In emerging economies under conditions of capital rationing, a program evaluation procedure is of greater significance than evaluation of single projects. The separate projects within a program can be combined in alternative project mixes which lend themselves to integrated development systems. Project mixes within the program can then be evaluated to determine which system will yield optimal benefits within the restraints imposed by resource scarcity.

The purpose of the calculation of marginal costs and benefits in previous chapters of this report is to arrive at a ratio of benefits to the incremental costs for projects on specific road sections which can be used as a tool to evaluate optimal systems of project mixes.

Table 25 contains a summary of the annual marginal cost and benefit at each of the "stages of improvement" for the road study sections in RGN, and the corresponding benefit-cost ratio as calculated by Formula 1. Table 19, which follows, is a summary of all road sections with benefit-cost ratio of greater than one for the initial level of improvement. These road sections are considered to be economically feasible candidates for improvement.

Table 19. Road sections having benefit-cost ratio greater than 1.

Road	Section	Surface	Length km	Average Daily Traffic	Benefit Ratios		
					Graded	Gravel	BST
BR 11	Parnamirm - Macaíba	Unim.	14	400	7.00	5.09	53.5
BR 53	Tangará - S. José de Campestre	Unim.	18	172	5.00	4.21	18.7
BR 12	Santa Cruz - Currais Novos	Graded	54	195	--	4.44	19.7
BR 12	Currais Novos - Acarí	Unim.	21	154	4.22	3.55	15.7
BR 11	Quixabeirinha - Mossoró	Graded	40	146	--	4.06	18.0
RN 11	Acarí - Parelhas	Unim.	30	129	3.99	3.36	14.9
RN 12	Caicó - Jardim de Piranhas	Unim.	29	174	3.88	4.50	11.8
LIG	Gancho - Santo Antonio	Unim.	4	139	3.80	3.20	14.1
BR 11	S. José de Mipibu - Goininha	Graded	23	156	--	3.38	15.0
RN 3	Santa Luzia - Ceara Mirim	Unim.	19	125	3.29	2.76	12.2
BR 53	S. José de Campestre - Passa e Fica	Unim.	16	95	3.22	3.73	9.79
BR 53	Angicos - Pixore	Unim.	22	87	3.12	3.62	9.51
RN 11	Parelhas - Equador	Unim.	35	90	3.09	3.58	9.40

Table 19. Continued.

Road	Section	Surface	Length km	Average Daily Traffic	Benefit Ratios		
					Graded	Gravel	BST
RN 4	Jandaira - Macau	Unim.	64	80	3.05	3.54	9.29
LIG	Santo Antonio - São Gonçalo	Unim.	4	98	2.99	3.45	9.10
BR 11	Lages - Quixabeirinha	Graded	105	118	--	2.97	13.2
BR 11	Richuelo - Lages	Graded	52	86	--	2.96	7.78
BR 11	Macaiba - Riachuelo	Graded	48	80	--	2.76	7.26
BR 12	Acari - Jardim do Serido	Unim.	21	85	2.68	3.11	8.17
BR 12	Jardim do Serido - Caicó	Graded	40	80	--	2.56	6.72
BR 53	Cerro Coro - Ligação	Unim.	20	74	2.45	2.84	7.46
BR 53	Entrada p. Bodo - Cerro Coro	Unim.	18	73	2.41	2.78	7.33
RN 4	Natal - Ceará Mirim	Graded	27	663	--	2.40	7.77
BR 11	Goininha - Canguaretàma	Unim.	15	101	--	2.26	10.0
BR 11	Canguaretama Border PB	Unim.	13	101	--	2.26	10.0
BR 53	Pixoré - Entrada p. Bodo	Unim.	15	63	2.22	2.57	6.76

Table 19. Continued.

Road	Section	Surface	Length km	Average Daily Traffic	Benefit Ratios		
					Graded	Gravel	BST
BR 12	Caicó - Serra Negra do Norte	Unim.	50	80	2.21	2.56	6.72
RN 4	Taipu - João Câmara	Unim.	26	67	2.06	2.39	6.26
RN 4	Ceará Mirim - Taipu	Graded	24	446	--	1.77	4.65
RN 14	Caicó - Jacurutu	Unim.	52	54	1.66	1.93	5.07
RN 3	Ceará Mirim - Riachuelo	Unim.	44	42	1.49	1.73	4.54
RN 4	João Câmara - Jandaira	Unim.	40	41	1.41	1.63	4.30
RN 2	Marias - São Paulo de Potengy	Unim.	30	48	1.39	1.61	4.23
RN 13	Jucurí - Apodí	Unim.	67	43	1.37	1.58	4.16
RN 13	Pau de Ferros - Varzinha	Unim.	20	50	1.27	1.48	3.87
LIG	Cana Brava - Vera Cruz	Unim.	14	34	1.23	1.42	3.74
LIG	Macíba - Cana Brava	Unim.	10	34	1.08	1.26	3.31
RN 7	Goininha - Espírito Santo	Unim.	10	38	1.06	-.23	3.24

Table 19. Continued.

Road	Section	Surface	Length km	Average Daily Traffic	Benefit Ratios		
					Graded	Gravel	BST
LIG	São Gonçalo - Macíaba	Unim.	.6	43	1.05	1.22	3.20
RN 13	Malencia-Itaú	Unim.	15	34	1.05	1.22	3.21
RN 2	São Paulo do Potengy Entrada p. Barcelona	Unim.	19	33	1.01	1.16	3.16

Effect on Benefit-Cost Ratio of Normal Growth in Traffic Volumes

In calculating the road user benefits and costs, no account of the normal growth in traffic volume over the life of the project is included.

Generally for such studies, a linear increase in traffic volumes of a certain percent per year is projected over the life of the project, and then an average of the initial and final volumes is used as the average annual traffic volume.

However, the problem under consideration here is slightly different from the normal analysis of one alternative as opposed to another. This study is to determine which road sections are now candidates for a basic type of improvement program, and which are not; and then to answer the questions of what level of improvement is justified on the basis of benefits returned on the investment, and finally on the basis of future anticipated increases in traffic volume, when can those sections that are not now ready be considered as candidates for improvement.

To answer these questions, it is more logical to calculate all the benefit-cost ratios for the basic conditions as they now exist, so that projects are judged on their current merit.

Although annual highway costs will increase due to higher maintenance costs associated with larger traffic volumes as is indicated by the data in Tables 10 and 12, these increases will be far

outweighed by the increased revenue generated by growth in traffic volumes.

Consequently, the annual growth in traffic has an overall effect of magnifying the benefit-cost ratio.

The percent increase in automotive gasoline consumption serves as an indication of the percent increase in traffic on the roadways of RGN, Brazil. Table 20, "Anuário Estatístico do Brasil" (1965), shows

Table 20. Automotive gasoline consumption in RGN

Year	Liters Consumed	Annual Increase	% Increase
1962	42,713,000	4,706,000	11
1963	47,418,000	4,320,000	9
1964	51,738,000		

about a 10 percent increase per year in gasoline consumption which could be interpreted as a 10 percent increase in vehicle miles traveled or in traffic volume.

There are two possible alternative applications of this 10 percent increase to extrapolate future traffic volumes; either a linear increase of 10 percent per year, or an exponential increase analogous to the compound interest formula of 10 percent compounded annually.

Figure 9 shows a graphic comparison of expected future traffic volumes based on each of these two assumptions. Growth rate in the U.S. and other advanced countries has followed more closely the

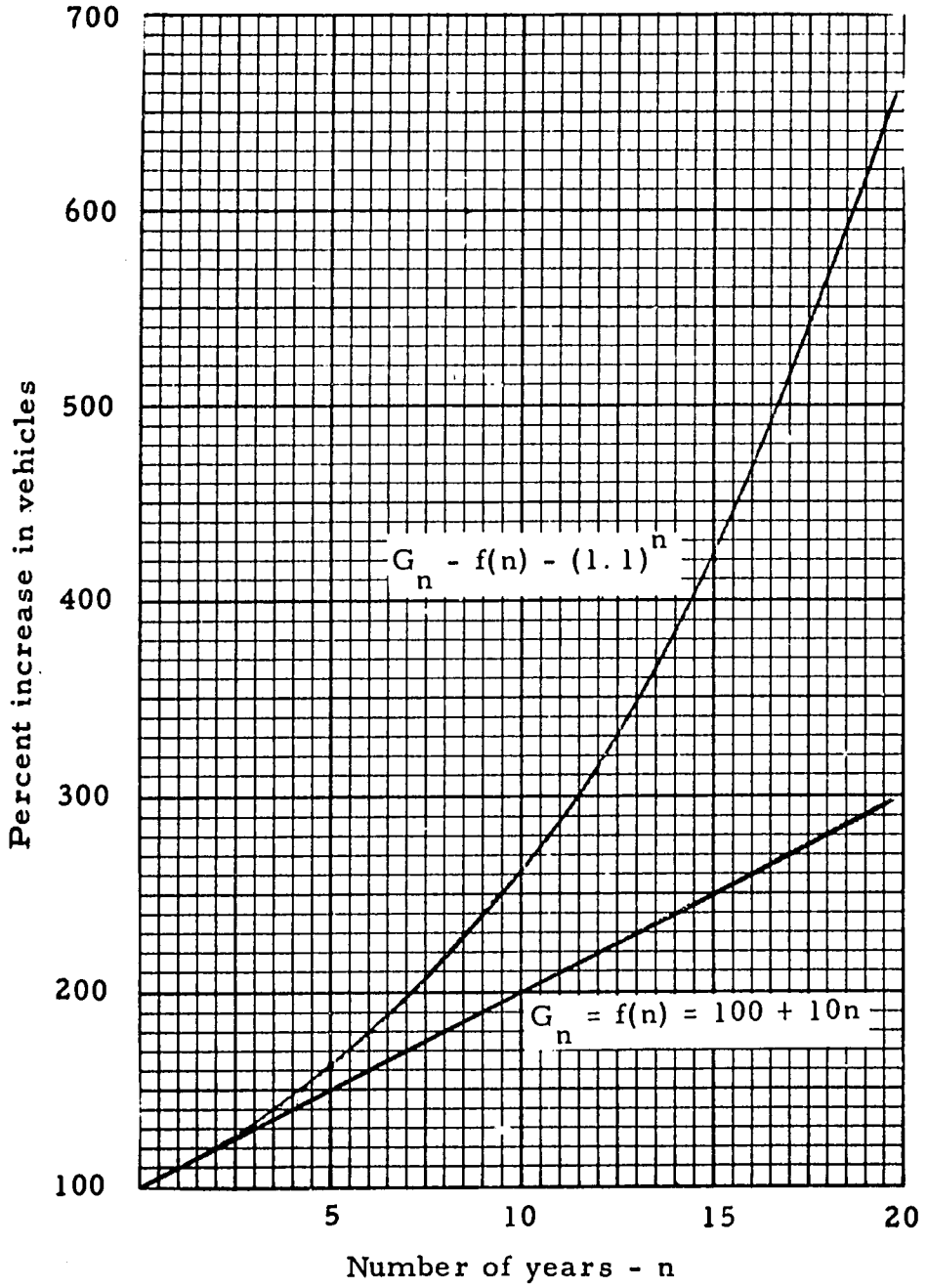

Figure 9. Traffic volume increase functions.

the compounded growth rate curve.

Increase of benefit-cost ratio from traffic growth

Neglecting the slight increases in maintenance costs for increasing traffic volumes, to find the benefit ratio for the overall life of any "stage" of the improvement program, one approach is to find a factor for the yearly average increase in vehicles and multiply this times the benefit-cost ratio.

For either case of growth assumptions, this average can be represented as

$$\bar{G} = \frac{\int_0^n f(n)\, dn}{n} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \qquad (6)$$

where

$f(n)$ = the increase function, linear or exponential

n = number of years.

Then $\bar{G}$ times the present benefit ratio gives the overall benefit ratio for the project life.

Traffic growth and the demand for future improvements

On the basis of anticipated traffic growth, it is possible to estimate the future time that projects for which the benefit-cost ratios are less than one, and consequently are not now economically justifiable, should be considered for improvement.

If the traffic volume A has grown over n years to G_n where G_n is obtained from Figure 9, then the road user costs from For-

ula 3 are:

$$365\ G_n \times A \times L \times U = G_n\ R$$

so the benefits become $G_n R_o - G_n R_1$, and the benefit-cost ratio is

$$BCR = \frac{G_n R_o - G_n R_1}{H_1 - H_o} = G_n\ BCR_o.$$

For the new benefit-cost ratio to equal 1 for any G_n, the initial benefit-cost ratio BCR_o must be

$$\frac{1}{G_n} = BCR_o.$$

From this relationship, the curves of Figure 10 are plotted using each of the alternative traffic increase functions, f(n).

This relationship serves as an aid to planning future improvements. For any road section, the number of years until the present benefit-cost ratio becomes one, and improvement of the section becomes justified, can be read from Figure 10 directly.

Other factors, of course, will influence the growth of traffic volume on any particular road section, so this type of planning analysis should continually be checked and updated by actual traffic volume studies.

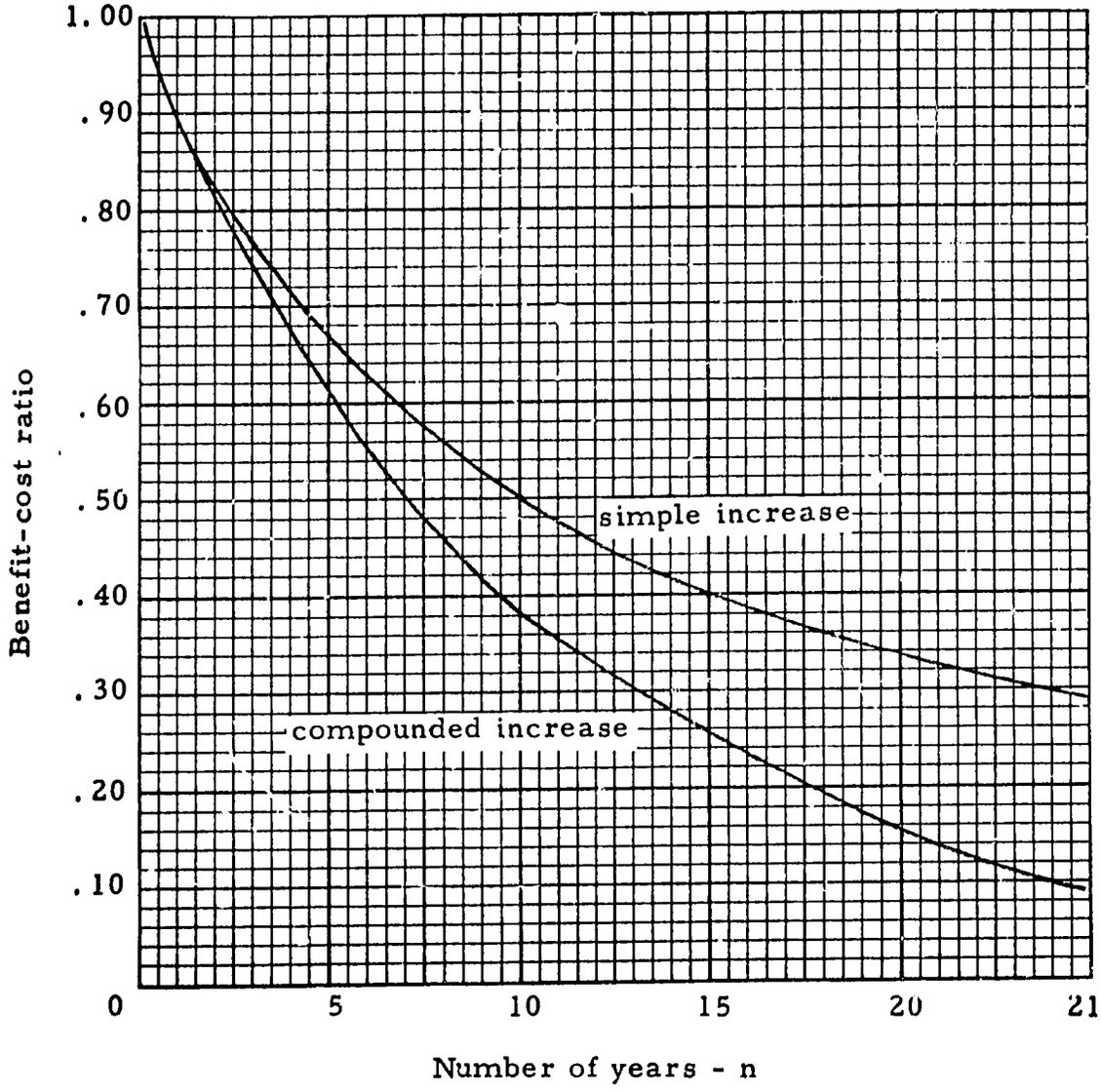

Figure 10. Years required for present benefit-cost ratio to yield "one" at an ADT increase of 10 % per year.

CONCLUSIONS

1. The condition on a majority of the roads in RGN are such that the road user is essentially paying for roads that he does not have due to excessively high road user costs associated with poor roads.

2. As Table 21 indicates, there are 1195 kilometers of roads including 753 kilometers of unimproved surface and 442 kilometers of graded earth surface, on which improvements are justified on the basis of the present benefit-cost ratio.

Table 21. Summary of costs and benefits of economically feasible projects.

Improvement Class	Kilometer	Cost of Improvement	Savings in Road User Costs	Net Revenue Generated	Overall Benefit-Cost Ratio
Graded and Reconditioned	753	$675,280	$1,746,280	$1,071,000	2.586
Gravel Surface	442	120,050	389,690	269,640	3.246
TOTAL	1195	795,330	2,135,970	1,340,640	2.686

These improvements become even more attractive when viewed in terms of increasing traffic volumes.

3. Traffic volume increase over the next ten years will bring the remainder of the present primary system to a level at which improvements will be justified.

4. The improved roads and increased traffic volumes will create demands for expansion of road services. Intermediate and long range planning should be undertaken now to prepare for future needs.

SUMMARY

This report has considered the process of road development in emerging economies. Road development in general, and in RGN in particular, is discussed in considerable depth. However, because of the scope of this report, it has not been possible to view the problem within the breadth of the framework of an overall economic development plan comprised of development objectives for all sectors of the economy. The logical sequel to this report would be to analyze the anticipated contribution of road development in terms of overall development planning and resource allocation.

The objectives, goals, and methods of road improvement program in emerging economies are widely different from those of a mature economy. The road development program for RGN, as an emerging economy, employs the concept of successive project generations. Each "stage of construction", in addition to meeting the requirements of the present, prepares the ground for subsequent levels of improvement. This type of development program does not require at the outset the construction of expensive features, but rather is based on growth where growth establishes present needs and future improvements.

Most highway improvements in the mature economy are justified on the basis of greater safety, less accidents, increased

efficiency in traffic movement, and reduced road user costs. The greatest incidence of benefits in the developing regions is on the economic infrastructure itself, which accrue in the form of increased land values, greater accessibility to markets, more efficient and economical movement of goods and people, and improved communication, rather than in direct highway user benefits. The impact of these benefits are felt through an increase in the gross output of society valued in non-economic as well as economic terms.

The economic analyses of this study using the benefit-cost ratio are of a traditional engineering approach. Such analyses, by nature of their more direct application to developed economies, do not consider the intangible benefits which are difficult to quantify, but which, in the long run, have the most significant effect on the development potential of a region, particularly since these types of benefits usually act as catalysts for future development.

Nevertheless, for the purpose of evaluating, ranking, and establishing priority, road development projects should be subdivided into self-sustained, benefit yielding "stages of improvement", and analyzed quantitatively with app e methods. Applying this system of analysis to RGN, in considering purely quantitative factors, there are a large number of road sections on which investment in road improvement will definitely yield a profitable return in terms of substantial savings in road user costs without consideration of the inherent social benefits.

Quantitative analysis then provides a basis for highway decision, but ultimate ranking will seldom be the straightforward outcome of calculations, since it should also include a weighing of semi-quantitative and qualitative factors. The correct overall yardstick for evaluations and final decisions in a road development program requires a synthesis of both tangible and intangible benefits in which the respective weights attached to each are dependent on the objectives of the overall development program, conditioned in turn by the socio-political values of society.

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APPENDIX

Table 22. Traffic volume studies and analysis for road sections in RGN.

Road	Section	Vehicles/Day Av.	Vehicles/Day Max.	Composition of ADT: Cars	Trucks <6T	Trucks >6T	Bus	Total Truck	Truck-Car Conversion	Total A_e ADT
BR 9	Mossoró - Upanema	26	60	11	1	14	0	15	60	71
9	Upanema - Augusto Severo	25	60	13	1	11	0	12	48	71
9	Augusto Severo - Janduís	17	53	11	1	5	0	6	24	35
BR 11	Natal - Parnamirim	1425	2187	1110	57	185	73	315	1260	2370
11	Parnamirim - S. José de Mipibu	259	353	140	26	80	13	119	476	616
11	S. José de Mipibu - Goianinha	156	218	80	9	59	8	76	304	384
11	Goianinha - Canguaretama	101	219	49	6	41	5	52	208	257
BR 11	Parnamirim - Macaíba	400[a]	--	280	20	80	20	120	480	760
11	Macaíba - Raichuêlo	80[a]	--	38	5	30	7	42	168	206
11	Raichuêlo Lages	86	106	41	5	32	8	45	180	221
11	Lages - Quixabeirinha	118	200	45	8	58	7	73	292	337
11	Quixabeirinha - Mossoró	146	200	41	4	95	6	105	420	461

Table 22. Continued.

Road	Section	Vehicles/Day Av.	Vehicles/Day Max.	Composition of ADT: Cars	Trucks <6T	Trucks >6T	Bus	Total Truck	Truck-Car Conversion	Total A_e ADT
BR 12	Natal - Macaíba	883	1140	565	53	212	53	318	1272	1837
12	Macaíba - Serra Caiada	489	758	298	19	132	39	190	760	1058
12	Serra Caiada - Santa Cruz	246	298	133	15	83	15	113	452	585
12	Santa Cruz - Currais Novos	195	298	92	10	88	5	103	412	504
12	Currais Novos - Acarí	154	314	71	3	74	6	83	332	403
12	Acarí - Jardim do Serido	85	137	36	3	44	2	49	196	232
12	Jardim do Serido - Caicó	80	131	43	4	29	4	37	148	191
BR 53	Mossoró - Quixabeirinha[b]	146	200	41	4	95	6	105	420	461
53	Quixabeirinha - Angicos[b]	118	200	45	8	58	7	73	292	337
53	Angicos - Pixoré	87	154	26	3	57	1	61	244	270
53	Pixoré - Entrada para Bodó	63	94	20	1	42	0	43	172	192
53	Entrada para Bodó- Cerro Cora	73	100	28	2	43	0	45	180	208
53	Cerro Cora - Ligação	74	100	28	2	44	0	46	184	212

Table 22. Continued.

Road	Section	Vehicles/Day Av.	Vehicles/Day Max.	Composition of ADT: Cars	Truck <6T	Truck >6T	Bus	Total Truck	Truck-Car Conversion	Total A_e ADT
53	Ligação - Santa Cruz[c]	195	298	92	10	88	5	103	412	504
53	Santa Cruz - Tangará[c]	246	298	133	15	83	15	113	452	585
53	Tangará - S. José de Campestre	172	274	70	12	83	7	102	408	478
53	S. José de Campestre - Passa e Fica	95	274	34	6	53	2	61	244	278
BR 64	Caicó - Florânia	12	29	7	3	2	0	5	20	27
64	Florânia - São Vincente	39	64	28	6	5	0	11	44	72
64	São Vincente - Currais Novos	38	64	30	3	5	0	8	32	62
RN 2	Marias S. Pedro - S. Paulo do Potengy	48	73	24	4	14	6	24	96	120
2	S. Paulo do Potengy - Entrada p. Barcelona	33	73	15	3	11	4	18	72	87
2	Entrada p. Barcelona - São Tomé	22	46	12	2	6	2	10	40	52
RN 3	Touros - Santa Luzia	17[a]	--	8	1	7	1	9	36	44
3	Santa Luzia - Ceará Mirim	125	311	62	11	49	3	63	252	314
3	Ceará Mirim - Raichuêlo	42	91	13	12	17	0	29	116	129

Table 22. Continued.

Road	Section	Vehicles/Day Av.	Vehicles/Day Max.	Composition of ADT: Cars	Trucks < 6T	Trucks > 6T	Bus	Total Truck	Truck-Car Conversion	Total A_e ADT
RN 4	Natal - Ceará Mirim	663	1212	391	40	186	46	272	1088	1479
4	Ceará Mirim - Taipu	446[a]	976[a]	300	22	94	30	146	584	884
4	Taipu - Morada Nova	67	119	30	10	22	5	37	148	178
4	Morada Nova - Baixa do Meic	41	84	14	6	18	3	27	108	122
4	Gancho - Gameleira	230	397	118	18	76	18	112	448	678
4	Gameleira - Aureira Direita	80	127	34	6	36	4	46	184	264
4	Aureira Direita - Baixa do Afonso	56	75	20	6	29	1	36	144	200
RN 5	Nova Cruz - São Antonio	30	58	17	3	7	3	13	52	69
5	São Antonio - Januario Cicco	20[a]	--	10	2	8	0	10	40	50
5	Januario Cicco - Caida	20[a]	--	10	2	8	0	10	40	50
5	Caida - S. Paulo do Potengy	17	20	9	1	7	0	8	32	41
5	S. Paulo do Potengy - Raichuêlo	14	20	7	1	6	0	7	28	35

Table 22. Continued.

Road	Section	Vehicles/Day Av.	Vehicles/Day Max.	Composition of ADT: Cars	Trucks < 6T	Trucks > 6T	Bus	Total Truck	Truck-Car Conversion	Total A_e ADT
5	Raichuelo – Barrêto	16	26	5	2	9	0	11	44	49
5	Barrêto - João Câmara	18	28	7	2	9	0	11	44	51
5	João Câmara - Quiemadas	24	45	10	5	9	0	14	56	66
5	Quiemadas - Parazinho	17	37	7	2	8	0	10	40	47
5	Parazinho - S. Bento do Norte	18	39	9	1	8	0	9	36	45
RN 7	Goianinho - Espírito Santo	38	78	20	9	9	0	18	72	92
7	Espírito Santo - Vareza	20	38	12	3	4	0	8	32	44
7	Vareza - São Antonio	18	38	12	2	4	0	6	24	36
7	São Antonio - S. José de Campestre	32	58	15	4	10	3	17	68	83
RN 11	Acarí - Parelhas	129	150	45	6	70	8	84	336	381
11	Parelhas - Equador	90	124	31	4	50	5	49	236	267
RN 12	Caicó - Jardim de Piranhas	174	339	120	9	40	5	54	216	336

Table 22. Continued.

Road	Section	Vehicles/Day Av.	Vehicles/Day Max.	Composition of ADT: Cars	Truck < 6T	Truck > 6T	Bus	Total Truck	Truck-Car Conversion	Total Ae ADT
RN 13	Mossoró-Jucurí - Apodí	43	73	18	8	16	1	25	100	118
13	Apodí - Malencia	33	48	16	2	14	1	17	68	84
13	Malencia - Itaú	34	53	15	2	17	0	19	76	91
13	Itaú - Pau de Ferros	29	44	13	1	15	0	16	64	77
13	Pau de Ferros - Varzinha	50	135	30	3	17	0	20	80	110
13	Varzinha - José de Penha	30[a]	69	18	1	11	0	12	48	66
13	José de Penha - Placas	25	40	16	1	8	0	9	36	52
13	Placas - Luiz Gomez	21	36	16	1	4	0	5	20	36
RN 14	Caicó - Jacurutú	54	135	24	5	25	0	30	120	144
LIG 1	Natal - Gancho	(Incorporated in RN 4 Natal-Ceara Mirim)								
1	Gancho - Santo Antonio	139	186	83	17	35	4	56	224	363
1	Santo Antonio - São Gonçalo	98	131	58	18	18	4	40	160	258

Table 22. Continued.

Road	Section	Vehicles/Day Av.	Vehicles/Day Max.	Composition of ADT: Cars	Truck < 6T	Truck > 6T	Bus	Total Truck	Truck-Car Conversion	Total Ae ADT
1	São Gonçalo - Macaíba	43	98	31	5	5	2	12	48	91
1	Macaíba - Cana Brava	34	69	19	3	7	5	15	60	94
1	Cana Brava - Vera Cruz	34	66	16	3	10	5	18	72	106
1	Vera Cruz - Lagôa de Pedras	20	32	9	3	5	3	11	44	66
1	Lagôa de Pedras - São Antonio	27	44	17	3	4	3	10	40	67

[a] Estimated
[b] Combined with BR 11
[c] Combined with BR 12

Table 23. Annual road user cost for road study sections under existing conditions.

Road	Sections	Surface Condition	Average Running Speed	A_e	Section Length	Vehicle Operating Cost	Days Per Year	Annual Road User Cost
			km/hr		km	¢/km		$/yr
BR 9	Areia Branca - Mossoró	Unim.	25	50[a]	42	11.891	365	91,480
9	Mossoró - Upanema	Unim.	25	71	52	11.891		160,240
9	Upanema - Augusto Servo	Unim.	25	61	26	11.891		61,840
9	Augusto Servo - Janduís	Imim.	25	35	20	11.891		30,380
9	Janduís - Border PB	Unim.	25	35	10	11.891		15,190
BR 11	Parnamirim - Macaíba	Unim.	25	760	14	11.891	365	461,800
11	Macaíba- Riachuelo	Graded	40	206	48	9.165		330,780
11	Riachuelo Lages	Graded	40	221	52	9.165		384.430
11	Lages - Quixabeirinha	Graded	40	337	105	9.165		1,183,710
11	Quixabeirinha - Mossoró	Graded	40	561	40	9.165		616,860
BR 11	Natal -	Cut Stone	55	2370	6	8.320	365	431,830
11	Parnamirim	Asphalt	75	2370	12	7.360		763,490

Table 23. Continued.

Road	Section	Surface Condition	Average Running Speed	A_e	Section Length	Vehicle Operating Cost	Days per Year	Annual Road User Cost
			km/hr		km	¢/km		$/yr
11	Parnamirim - S. José de Mipibu	Asphalt	75	616	19	7.360	365	314,200
11	S. José de Mipibu - Goininha	Graded	40	384	23	9.165		295,450
11	Goininha - Canguaretma	Graded	40	257	16	9.165		137,560
11	Canguaretma - Border RGN/PB	Graded	40	257	13	9.165		111,760
BR 12	Natal - Macaíba	Cut Stone	55	1837	22	8.320	365	1,227,290
12	Macaíba - Serra Caida	Asphalt	75	1058	50	7.360		1,420,140
12	Serra Caida - Santa Cruz	Asphalt	75	585	51	7.360		643,900
12	Santa Cruz - Currais Novos	Graded	40	504	54	9.165		910,440
12	Currais Novos - Acarí	Unim.	25	403	21	11.891		367,310
12	Acarí - Jardim de Serido	Unim.	25	232	21	11.891		211,460
12	Jardim de Serido - Caicó	Graded	40	191	40	9.165		255,580
12	Caicó - Serra Negra do Norte Border RN/PB	Unim.	25	191	50	11.891		414,490

Table 23. Continued.

Road	Section	Surface Condition	Average Running Speed	A_e	Section Length	Vehicle Operating Cost	Days per Year	Annual Road User Cost
			km/hr		km	¢/km		$/yr
BR 53	Mossoró - Angicos			(Combined with BR-11)			365	
53	Angicos - Pixoré	Unim.	25	270	22	11.891		257,810
53	Pixoré - Entrada p. Bodó	Unim.	25	192	15	11.891		125,000
53	Entrada p. Bodó- Cerro Cora	Unim.	25	208	18	11.891		162,500
53	Cerro Cora - Ligação	Unim.	25	212	20	11.891		184,030
53	Ligação - Tangará			(Combined with BR-12)				
53	Tangará - São José de Campestre	Unim.	25	478	18	11.891		373,430
53	São José de Campestre - Passa e Fica	Unim.	25	278	16	11.891		193,050
53	Mossoró - Boarder Ceara	Unim.	25	278	50	11.891		603,290
BR 64	Caicó - Florânia	Unim.	25	27	50	11.891	365	58,590
64	Florânia - São Vincente	Unim.	25	72	18	11.891		56,250
64	São Vincente - Currais Novos	Unim.	25	62	21	11.891		56,510

Table 23. Continued.

Road	Section	Surface Condition	Average Running Speed	A_e	Section Length	Vehicle Operating Cost	Days per Year	Annual Road User Cost
			km/hr		km	¢/km		$/yr
RN 2	Marias to São Pedro - São Paulo do Potengy	Unim.	25	120	30	11.891	365	156,250
2	São Paulo do Potengy- Entrada p. Barcelona	Unim.	25	87	19	11.891		71,740
2	Entrada p. Barcelona- São Tomé	Unim.	25	52	18	11.891		40,620
RN 3	Touros - Santa Luzia	Unim.	25	44	30	11.891	365	57,290
3	Santa Luzia - Ceara Mirim	Unim.	25	314	19	11.891		258,940
3	Ceara Mirim - Riachûelo	Unim.	25	129	44	11.891		246,350
RN 4	Natal - Ceara Mirim	Graded	40	1479	27	9.165	365	1,335,850
4	Ceara Mirim - Taipu	Graded	40	884	24	9.165		709,720
4	Taipu - João Câmara	Unim.	25	178	26	11.891		200,870
4	João Câmara - Jandaira	Unim.	25	122	40	11.891		211,800
4	Jandaira - Macau	Unim.	25	264	64	11.891		733,320

Table 23. Continued.

Road	Section	Surface Condition	Average Running Speed	A_e	Section Length	Vehicle Operating Cost	Days per Year	Annual Road User Cost
			km/hr		km	¢/km		$/yr
RN 5	Nova Cruz - São Antonio	Unim.	25	69	24	11.891	365	71,870
5	São Antonio - Januario Cicco	Unim.	25	50	25	11.891		54.259
5	Januario Cicco - Caida	Unim.	25	50	22	11.891		47,740
5	Caida - São Paulo do Potengy	Unim.	25	51	30	11.891		53.380
5	São Paulo do Potengy - Riachûelo	Unim.	25	35	18	11.891		27,340
5	Riachûelo - Barrêto	Unim.	25	49	20	11.891		42,530
5	Barrêto - João Câmara	Unim.	25	51	18	11.891		39,840
5	João Câmara - Quiemadas	Unim.	25	66	16	11.891		45,830
5	Quiemadas - Parazinho	Unim.	25	47	16	11.891		32,640
5	Parazinho - São Bento do Norte	Unim.	25	45	40	11.891		78,120
RN 7	Goianinho - Espírito Santo	Unim.	25	92	10	11.891	365	39,930
7	Espírito Santo - Váreza	Unim.	25	44	5	11.891		9,550
7	Váreza - São Antonio	Unim.	25	36	20	11.891		31,250

Table 23. Continued.

Road	Section	Surface Condition	Average Running Speed	A_e	Section Length	Vehicle Operating Cost	Days per Year	Annual Road User Cost
			km/hr		km	¢/km		$/yr
7	São Antonio - São Jose de Campestre	Unim.	25	83	21	11.891		75,650
RN 11	Acarí - Parelhas	Unim.	25	381	30	11.891	365	496,000
11	Parelhas - Equador	Unim.	25	267	35	11.891		405,590
RN 13	Mossoró - Apodí	Unim.	25	118	67	11.891	365	343,140
13	Apodí - Malencia	Unim.	25	84	15	11.891		54,690
13	Malencia - Itaú	Unim.	25	91	15	11.891		59,240
13	Itaú - Pau de Ferros	Unim.	25	77	42	11.891		140,360
13	Pau de Ferros - Varzinha	Unim.	25	110	20	11.891		95,480
13	Varzinha - José de Penha	Unim.	25	66	10	11.891		28,650
13	José de Penha - Placas	Unim.	25	52	11	11.891		24,830
13	Placas - Luiz Gomes	Unim.	25	36	10	11.891		15,620

Table 23. Continued.

Road	Section	Surface Condition	Average Running Speed	A_e	Section Length	Vehicle Operating Cost	Year per Year	Annual Road User Cost
RN 14	Caicó - Jacurutú		km/hr		km	¢/km		$/yr
		Unim.	25	144	52	11.891	365	325,000
LIG 1	Natal - Gancho			Combined with RN-4)			365	
1	Gancho - Santo Antonio	Unim.	25	363	4	11.891		63,020
1	Santo Antonio - São Gonçalo	Unim.	25	258	4	11.891		44,700
1	São Gonçalo - Macaíba	Unim.	25	91	6	11.891		23,700
1	Macaíba - Cana Brava	Unim.	25	94	10	11.891		40,800
1	Cana Brava - Vera Cruz	Unim.	25	106	14	11.891		64,410
1	Vera Cruz - Lagôa de Pedras	Unim.	25	66	13	11.891		37,240
1	Lagôa de Pedras - São Antonio	Unim.	25	67	18	11.891		52,340

Table 24. Annual road user costs and benefits for road sections if improved in dollars.

Road	Section	Unimproved R_o	Graded & Recondition R_1	R_o-R_1	Gravel R_2	R_1-R_2	BST R_3	R_2-R_3
BR 9	Areia Branca - Mossoró	91,140	70,250	20,890	63,770	6,480	56,380	7,390
9	Mossoró - Upanema	160,250	123,510	36,730	112,120	11,390	99,110	13,010
9	Upanema - Augusto Servo	61,840	53,060	8,780	48,160	4,900	42,580	5,580
9	Agusuto Servo - Janduis	30,380	23,420	6,960	21,260	2,160	18,790	2,470
9	Janduis - Border PB	15,190	11,710	3,480	10,630	1,080	9,400	1,230
BR 11	Parnamirim - Macaíba	461,800	355,930	105,870	323,120	32,810	285,640	37,480
11	Macaíba - Riachuelo	--	330,780	--	300,280	30,500	265,450	34,830
11	Riachuelo - Lages	--	384,430	--	348,990	35;440	308,410	40,480
11	Lages - Quixabeirinha	--	1,183,710	--	1,074,570	109,140	949,940	124,630
11	Quixabeirinha - Mossoró	--	616,860	--	559,990	56,870	495,040	64,950
BR 11	Natal	--	--	--	--	--	431,830	--
11	Parnamirim	--	--	--	--	--	763,490	--

Table 24. Continued.

Road	Section	Unimproved R_o	Graded & Recondition R_1	R_o-R_1	Gravel R_2	R_1-R_2	BST R_3	R_2-R_3
11	Parnamirim - S. José de Mipibu	--	--	--	--	--	314,200	--
11	S. José de Mipibu-Goininha	--	295,450	--	268,210	27,240	237.100	31,110
11	Goininha - Canguaretéma	--	137,560	--	124,870	12,690	110,390	14,480
11	Canguaretema - Border RGN/PB	--	111,760	--	101,460	10,300	89,690	11,770
BR 12	Natal - Macaíba	--	--	--	1,227,290	--	1,084,950	--
12	Macaíba - Serra Caida	--	--	--	--	--	1,420,140	--
12	Serra Caida - Santa Cruz	--	--	--	--	--	643,900	--
12	Santa Cruz-Currais Novos	--	910,440	--	826,500	83,940	730,640	95,860
12	Currais Novos - Acarí	367,310	283,110	84,200	257,000	26,110	227,200	29,800
12	Acarí - Jardim do Serido	211,460	162,980	48,480	147,950	15,030	130,790	17,160
12	Jardim de Serido - Caicó	--	255,580	--	232,010	23,570	205,100	26,910
12	Caicó - Serra Negra do Norte Border RN/PB	414,490	319,470	95,020	290,010	29,460	256,380	33,630

Table 24. Continued.

Road	Section	Unim. proved R_o	Graded & Recondition R_1	R_o-R_1	Gravel R_2	R_1-R_2	BST R_3	R_2-R_3
BR 53	Mossoró - Angicos	(Combined with BR-11)						
53	Angicos - Pixoré	257,810	198,710	59,100	180,390	18,320	159,460	20,930
53	Pixoré - Entrada p. Bodó	125,000	96,340	28,660	87,460	8,880	77,320	10,140
53	Entrada p. Bodó - Cerro Cora	162,500	125,250	37,250	113,700	11,550	100,510	13,190
53	Cerro Cora - Ligação	184,030	141,840	42,190	128,760	13,080	113,830	14,930
53	Ligação - Tangará	(Combined with BR-12)						
53	Tangará - S. José de Campestre	373,430	287,820	85,610	261,290	26,530	230,980	30,310
53	S. José de Campestre - Passa e Fica	193,050	148,800	44,250	135,080	13,720	119,410	15,670
53	Mossoró - Border Ceará	603,290	464,990	138,300	422,120	42,870	373,160	48,960
BR 64	Caicó - Florânia	58,590	45,160	13,430	41,000	4,170	36,250	4,760
64	Florânia - São Vincente	56,250	43,350	12,900	39,360	3,990	34,790	4,570
64	São Vincente - Currais Novos	56,510	43,550	12,960	39,540	4,010	35,950	4,590

Table 24. Continued.

Road	Section	Unim. proved R_o	Graded & Recondition R_1	R_o-R_1	Gravel R_2	R_1-R_2	BST R_3	R_2-R_3
RN 2	Marias to S. Pedro - S. Paulo do Potengy	156,250	120,430	35,820	109,320	11,110	96,640	12,680
2	S. Paulo do Potengy - Entrada p. Barcelona	71,740	55,300	16,440	50,200	5,100	44,380	5,820
2	Entrada p. Barcelona - São Tomé	40,620	31,310	9,310	28,420	2,890	25,130	3,290
RN 3	Touros - Santa Luzia	57,290	44,160	13,130	40,090	4,070	35,440	4,650
3	Santa Luzia - Ceara Mirim	258,940	199,580	59,360	181,180	18,400	160,160	21,020
3	Ceara Mirim - Raichûelo	246,350	189,880	56,470	172,370	17,510	152,380	19,990
RN 4	Natal - Ceará Mirim	--	1,335,850	--	1,212,690	123,160	1,072,030	140,660
4	Ceará Mirim - Taipu	--	709,720	--	644,290	65,430	560,560	74,730
4	Taipu - João Câmara (Morrda Nova)	200,870	154,820	46,050	140,540	14,280	124,240	16,300
4	João Câmara - Jandaira (Bana do Meio)	211,800	163,250	48,550	148,200	15,050	131,010	17,190
4	Jandaira - Macau (Areia Direita)	733,320	565,210	168,110	513,100	52,110	453,590	59,510

Table 24. Continued.

Road	Section	Unimproved R_o	Graded & Recondition R_1	R_o-R_1	Gravel R_2	R_1-R_2	BST R_3	R_2-R_3
RN 5	Nova Cruz - São Antonio	71,870	53,400	16,470	50,290	3,110	44,460	5,830
5	São Antonio - Januario Cicco	54,250	41,820	12,430	37,960	3,860	33,560	4,400
5	Januario Cicco - Caida	47,740	36,800	10,940	33,400	3,400	29,530	3,870
5	Caida - S. Paulo do Potengy	53,380	41,150	12,230	37,350	3,750	33,020	4,330
5	S. Paulo do Potengy - Raichûelo	27,340	21,070	6,270	19,130	1,940	16,910	2,220
5	Raichûelo - Barrêto	42,530	32,780	9,750	29,760	3,020	26,310	3,450
5	Barrêto - João Câmara	39,840	30,710	9,130	27,880	2,830	24,640	3,240
5	João Câmara - Quiemadas	45,830	35,330	10,500	32,070	3,260	28,350	3,720
5	Quiemadas - Parazinho	32,640	25,160	7,480	22,840	2,320	20,190	2,650
5	Parazinho - S. Bento do Norte	78,120	60,210	17,910	54,660	5,550	48,320	6,340
RN 7	Goianinho - Espírito Santo	39,930	30,780	9,150	27,940	2,840	24,700	3,250
7	Espírito Santo - Váreza	9,550	7,360	2,190	6,680	680	5,910	770
7	Váreza - São Antonio	31,250	24,090	7,160	21,860	2,230	19,330	2,530

Table 24. Continued.

Road	Section	Unimproved R_o	Graded & Recondition R_1	R_o-R_1	Gravel R_2	R_1-R_2	BST R_3	R_2-R_3
7	São Antonio - S. Jose de Campestre	75,650	58,310	17,340	52,930	5,380	46,790	6,140
RN 11	Acarí - Parelhas	496,090	382,360	113,730	347,110	35,250	306,850	40,260
11	Parelhas - Equador	405,590	312,710	92,980	283,790	28,820	250,870	32,920
RN 13	Mossoró - Apodí	343,140	264,470	78,670	240,090	24,380	212,240	27,850
13	Apodí - Malencia	54,690	42,150	12,540	38,26-	3,890	33,830	4,430
13	Malencia - Itaú	59,250	45,660	13,580	41,450	4,210	36,640	4,810
13	Itaú - Pau de Ferros	140,360	108,180	32,180	98,210	9,970	86,820	11,390
13	Pau de Ferros - Varzinha	95,480	73,600	21,880	66,810	6,790	59,060	7,750
13	Varzinha - José de Penha	28,650	22,080	6,570	20,050	2,040	17,720	2,320
13	José de Penha - Placas	24,830	19,130	5,700	17,370	1,760	15,360	2,010
13	Placas - Luiz Gomes	15,620	12,040	3,580	10,930	1,110	9,660	1,270

Table 24. Continued.

Road	Section	Unimproved R_o	Graded & Recondition R_1	R_o-R_1	Gravel R_2	R_1-R_2	BST R_3	R_2-R_3
RN 14	Caicó - Jacurutú	325,000	250,490	74,510	227,400	23,090	201,020	26,380
LIG 1	Natal - Gancho			(Combined with RN-4)				
1	Gancho - Santo Antonio	63,020	48,570	14,1450	44,090	4,480	38,980	5,110
1	Santo Antonio - São Gonçalo	44,790	34,520	10,270	31,340	3,180	27,700	3,640
1	São Gonçalo - Macaíba	23,700	18,260	5,440	16,580	1,680	14,660	1,920
1	Macaíba - Cana Brava	40,780	31,450	8,330	28,550	2,900	25,240	3,310
1	Cana Brava - Vera Cruz	64,410	49,640	14,770	45,070	4,570	39,840	5,230
1	Vera Cruz - Logôa de Pedras	37,240	28,700	8,540	26,060	2,640	23,030	3,030
1	Logoa de Pedras - São Antonio	52,340	40,340	12,000	36,620	3,720	32,380	4,240

Table 25. Benefit-cost ratios for road study sections in RGN.

Road	Section	Graded and Conditioned			Gravel			Bituminous Surface Treatment		
		H_1-H_o	P_o-R_1	BCR	H_2-H_1	R_1-R_2	BCR	H_3-H_2	R_2-R_3	BCR
BR 9	Areia Branca - Mossoró	$ 36,120	$ 20,890	.58	--	--	--	--	--	--
9	Mossoró - Upanema	44,720	36,730	.82	--	--	--	--	--	--
9	Upanema - Augusto Servo	22,360	8,780	.39	--	--	--	--	--	--
9	Agusto Servo - Janduis	17,200	6,960	.40	--	--	--	--	--	--
9	Janduis - Border PB	8,600	3,480	.40	--	--	--	--	--	--
BR 11	Parnamirim - Macaíba	15,120	105,870	7.00	6,440	32,810	5.09	700	37,480	53.5
11	Macaíba - Riachuelo	--	--	--	11,040	30,500	2.76	4,800	34,830	7.26
11	Riachuelo - Lages	--	--	--	11,960	35,440	2.96	5,200	40,480	7.78
11	Lages - Quixabeirinha	--	--	--	36,750	109,140	2.97	9,450	124,630	13.2
11	Quixabeirinha - Mossoró	--	--	--	14,000	56,870	4.06	3,600	64,950	18.0
BR 11	Natal -	--	--	--	--	--	--	--	--	--
11	Parnamirim	--	--	--	--	--	--	--	--	--

Table 25. Continued.

Road	Section	Graded and Conditioned			Gravel			Bituminous Surface Treatment		
		H_1-H_o	R_o-R_1	BCR	H_2-H_1	R_1-R_2	BCR	H_3-H_2	R_2-R_3	BCR
		$	$		$	$		$	$	
11	Paranmirim - S. Jose de Mipibu	--	--	--	--	--	--	--	--	--
11	S. Jose de Mipibu - Goininha	--	--	--	8,050	27,240	3.38	2,070	31,110	15.0
11	Goininha - Canguaretma	--	--	--	5,600	12,690	2.26	1,440	14,480	10.0
11	Canguaretma - Border RGN/PB	--	--	--	4,550	10,300	2.26	1,170	11,770	10.0
BR 12	Natal - Macaíba	--	--	--	--	--	--	--	--	--
12	Macaiba - Serra Caida	--	--	--	--	--	--	--	--	--
12	Serra Caida - Santa Cruz	--	--	--	--	--	--	--	--	--
12	Santa Cruz - Currais Novos	--	--	--	18,900	83,940	4.44	4,860	95,860	19.7
12	Currais Novos - Acarí	19,950	84,200	4.22	7,350	26,110	3.55	1,890	29,800	15.7
12	Acarí - Jardim do Serido	18060	48,480	2.68	4,830	15,030	3.11	2,100	17,160	8.17
12	Jardim do Serido - Caicó	--	--	--	9,200	23,570	2.56	4,000	26,910	6.72
12	Caicó - Sr. Ng. do Norte Border RN/PB	43,000	95,020	2.21	11,500	29,460	2.56	5,000	33,630	6.72

Table 25. Continued.

Road	Section	Graded and Conditioned			Gravel			Bituminous Surface Treatment		
		H_1-H_o	R_o-R_1	BCR	H_2-H_1	R_1-R_2	BCR	H_3-H_2	R_2-R_3	BCR
BR 53	Mossoró - Angicos	$	$		$	$		$	$	
					(Combined with BR-11)					
53	Angicos - Pixoré	18,920	59,100	3.12	5,060	18,320	3.62	2,200	20,930	9.51
53	Pixore - Entrada p. Bodô	12,900	28,660	2.22	3,450	8,880	2.57	1,500	10,140	6.76
53	Entrada p. Bodô-Cerro Cora	15,480	37,250	2.41	4,140	11,550	2.78	1,800	13,190	7.33
53	Cerro Cora - Ligação	17,200	42,190	2.45	4,600	13,080	2.84	2,000	14,930	7.46
53	Ligação - Tangará				(Combined with BR-11)					
53	Tangará - S. J. de Campestre	17,100	85,610	5.00	6,300	26,530	4.21	1,620	30,310	18.7
53	S. J. de Campestre - Passa e Fica	13,760	44,250	3.22	3,680	13,720	3.73	1,600	15,670	9.79
53	Mossoró - Border Ceará	43,000	138,300	3.22	11,500	42,810	3.73	5,000	48,930	9.79
BR 64	Caicó - Florânia	43,000	13,430	.31	--	--	--	--	--	--
64	Florânia - São Vincente	15,480	12,900	.83	--	--	--	--	--	--
64	São Vincente - Currais Novos	18,060	12,960	.72	--	--	--	--	--	--

Table 25. Continued.

Road	Section	Graded and Conditioned			Gravel			Bituminous Surface Treatment		
		H_1-H_o	R_o-R_1	BCR	H_2-H_1	R_1-R_2	BCR	H_3-H_2	R_2-R_3	BCR
		$	$		$	$		$	$	
RN 2	Marias - S. Paulo do Potengy	12,800	35,820	1.39	6,900	11,110	1.61	3,000	12,680	4.24
2	S. Paulo do Potengy - Entr. p. Barcelona	16,340	16,440	1.01	4,370	5,100	1.16	1,900	5,820	3.06
2	Entr. p. Barcelona - São Tomé	15,480	9,310	.60	--	--	--	--	--	--
RN 3	Touros - Santa Luzia	25,800	13,130	.51	--	--	--	--	--	--
3	Santa Luzia - Ceara Mirim	18,050	59,360	3.29	6,650	18,400	2.76	1,710	21,020	12.2
3	Ceara Mirim - Raichûelo	37,840	56,470	1.49	10,120	17,510	1.73	4,400	19,990	4.54
RN 4	Natal - Ceará Mirim	--	--	--	51,300	123,160	2.40	18,090	140,660	7.77
4	Ceará Mirim - Taipu	--	--	--	36,960	65,430	1.77	17,080	74,730	4.65
4	Taipu - João Câmara	22,360	46,050	2.06	5,980	14,280	2.39	2,600	16,300	6.26
4	João Câmara - Jandaira	35,500	48,550	1.41	9,200	15,050	1.63	4,000	17,190	4.30
4	Jandaira - Macau	55,040	168,110	3.05	14,720	52,110	3.54	6,400	59,510	9.29

Table 25. Continued.

Road	Section	Graded and Conditioned			Gravel			Bituminous Surface Treatment		
		H_1-H_o	R_o-R_1	BCR	H_2-H_1	R_1-R_2	BCR	H_3-H_2	R_2-R_3	BCR
		$	$		$	$		$	$	
RN 5	Nova Cruz - Sao Antonio	20,640	16,470	.80	--	--	--	--	--	--
5	Sao Antonio - Januario Cicco	21,500	12,430	.58	--	--	--	--	--	--
5	Januario Cicco - Caida	18,920	10,940	.58	--	--	--	--	--	--
5	Caida - S. P. do Potengy	25,800	12,230	.47	--	--	--	--	--	--
5	S. P. do Potengy - Riachûelo	15,480	6,270	.41	--	--	--	--	--	--
5	Riachûelo - Barrêto	17,200	9,750	.57	--	--	--	--	--	--
5	Barrêto - João Câmara	15,480	9,130	.59	--	--	--	--	--	--
5	João Câmara - Quiemadas	13,760	10,500	.76	--	--	--	--	--	--
5	Quiemadas - Parazinho	13,760	7,480	.54	--	--	--	--	--	--
5	Parazinho - S. Bento do Norte	34,400	17,910	.52	--	--	--	--	--	--
RN 7	Goianinho - Espírito Santo	8,600	9,150	1.06	2,300	2,840	1.23	1,000	3,240	3.24
7	Espírito Santo - Váreza	4,300	2,190	.51	--	--	--	--	--	--
7	Váreza - São Antonio	17,200	7,160	.42	--	--	--	--	--	--

Table 25. Continued.

Road	Section	Graded and Conditioned			Gravel			Bituminous Surface Treatment		
		H_1-H_o	R_o-R_1	BCR	H_2-H_1	R_1-R_2	BCR	H_3-H_2	R_2-R_3	BCR
7	São Antonio - S. J. de Campestre	$ 18,060	$ 17,340	.96	--	--	--	--	--	--
RN 11	Acarí - Paralhas	28,500	113,730	3.99	10,500	32,250	3.36	2,700	40,260	14.9
11	Parelhas - Equador	30,100	92,980	3.09	8,050	28,820	3.58	3,500	32,920	9.40
RN 13	Mossoró-Jucuri - Apodí	57,620	78,670	1.37	15,410	24,380	1.58	6,700	27,850	4.16
13	Apodí - Malencia	12,900	12,540	.97	--	--	--	--	--	--
13	Malencia - Itaú	12,900	13,580	1.05	3,450	4,210	1.22	1,500	4,810	3.21
13	Itaú - Pau de Ferros	36,120	32,180	.89	--	--	--	--	--	--
13	Pau de Ferros - Varzinha	17,200	21,880	1.27	4,600	6,790	1.48	2,000	7,750	3.87
13	Varzinha- José de Penha	8,600	6,570	.76	--	--	--	--	--	--
13	José de Penha - Placas	9,460	5,700	.60	--	--	--	--	--	--
13	Placas - Luiz Gomes	8,600	3,580	.42	--	--	--	--	--	--

Table 25. Continued.

Road	Section	Graded and Conditioned			Gravel			Bituminous Surface Treatment		
		H_1-H_o	R_o-R_1	BCR	H_2-H_1	R_1-R_2	BCR	H_3-H_2	R_2-R_3	BCR
RN 14	Caicó - Jacurutú	$ 44,720	$ 74,510	1.66	$ 11.960	$ 23,090	1.93	$ 5,200	$ 26,380	5.07
LIG 1	Natal - Gancho				(Combined with RN-4)					
1	Gancho - Santo Antonio	3,800	14,450	3.80	1,400	4,480	3.20	360	5,110	14.1
1	Santo Antionio - São Gonçalo	3,440	10,270	2.99	920	3,180	3.45	400	3,640	9.10
1	São Gonçalo - Macaíba	5,160	5.440	1.05	1,380	1,680	1.22	600	1,920	3.20
1	Macaíba - Cana Brava	8,600	9,330	1.08	2,300	2,900	1.26	1,000	3,310	3.31
1	Cana Brava - Vera Cruz	12,040	14,770	1.23	3,220	4,570	1.42	1,400	5,230	3.74
1	Vera Cruz - Legôa de Pedras	11,180	8,540	.76	--	--	--	--	--	--
1	Legôa de Pedras - São Antonio	15,480	12,000	.78	--	--	--	--	--	--

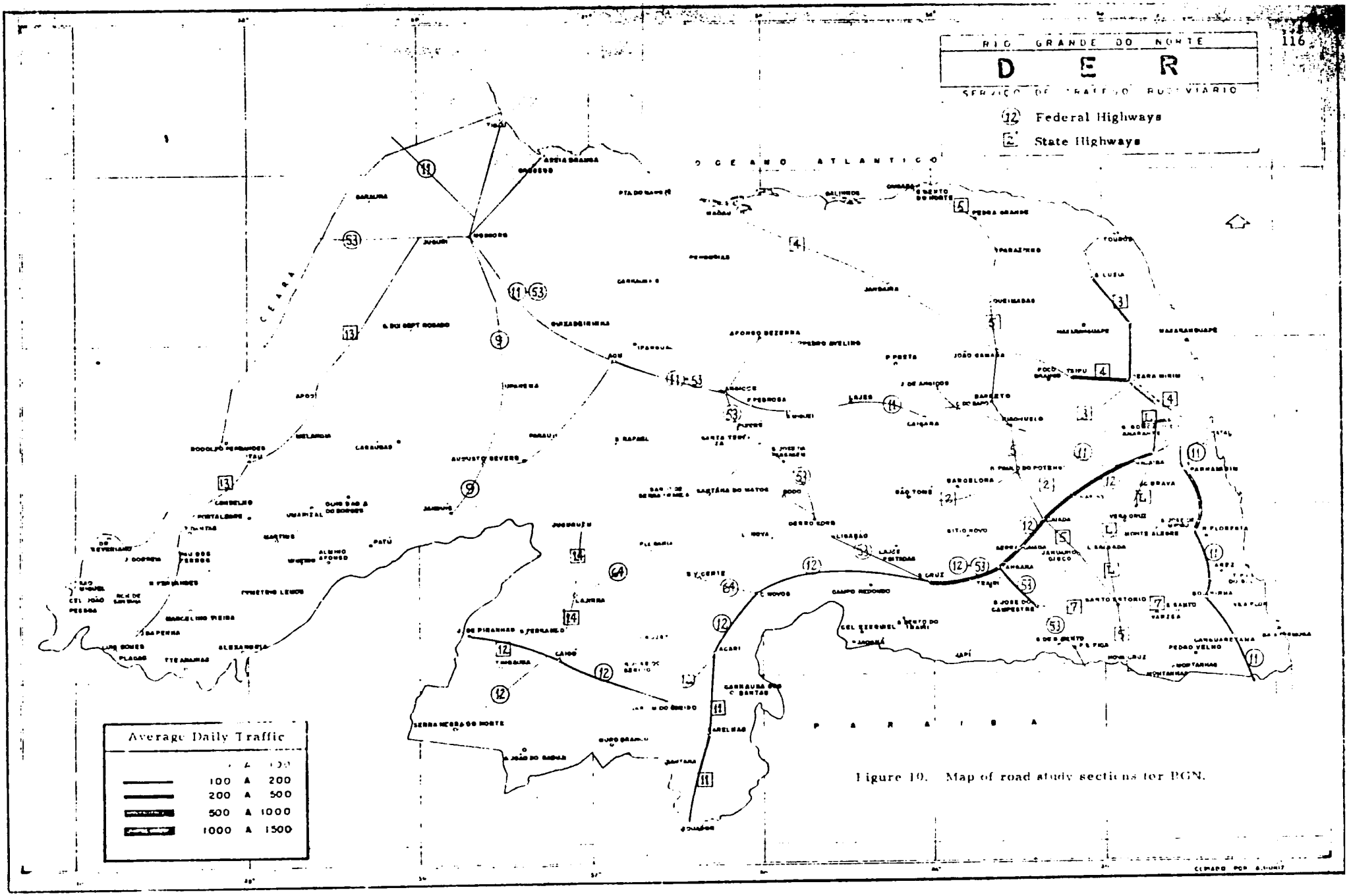

Figure 10. Map of road study sections for RGN.