A SYSTEM DYNAMICS APPROACH TO RURAL TRANSPORTATION PLANNING IN LESS DEVELOPED COUNTRIES

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DEDICATION

I would like to dedicate this work to the members of my beloved families -- especially , my father-in-law, and my eldest brother, , for their unstinting financial support and encouragement during my studies.

To my parents, who never stopped loving and believing in me, irrespective of my shortcomings.

To my beloved wife , and son , for their love, understanding and sacrifice throughout the difficult years of my studies.

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CHAPTER I

INTRODUCTION

1.1 The Role of Transportation in Economic Development

Essentially, transportation in terms of economic development is a derived demand and is dependent on the plans and objectives of the other sectors of the economy. Thus, the correct task of transportation planning may be stated as the accomplishment of all necessary movements at a minimum overall cost to the economy.

However, transportation, once implemented, has a significant influence on the demographic and economic sectors of a region (i.e., it tends to regulate or determine the market mechanism, and hence the eventual growth rate and specialization of a region). Transportation is therefore not merely a derived demand, but a determinant of new production possibilities. Transportation also has important non-economic roles, such as political, social and military cohesion of a country. As such, transportation is often regarded as the most important sector for economic development [1].

In developing countries, this concept of transportation as a determinant of new production possibilities and demographic change has long been recognized by those concerned with the planning of economic growth. In 1960, economist Walt Rostow [2], in his text, Stages of Economic Growth, stated:

> ". . . the preparation of a viable basis for a modern industrial structure requires that quite revolutionary changes be brought about in two non-industrial sectors: agriculture and social overhead capital, most notably in transport."

Also in 1962, E. K. Hawkins [3] echoed similar sentiments in his text, Road and Road Transport in an Underdeveloped Country:

> ". . . the one same generalization that can be made about the underdeveloped countries is that investment in transport and communications is a vital factor."

The search over the past twenty years has been for "appropriate" methodologies to evaluate the catalytic impacts of transportation investments in already identified-resource-endowed regions, in order to prioritize the allocation of limited funds, skills and equipment in less developed countries (LDCs).

1.2 Background and Problems of LDCs

Agriculture and agricultural-related industries dominate the economy of most less developed countries. The rate of development in LDCs, therefore, depends on the success of their agricultural programs. First, because agriculture provides the largest amount of employment; second, unless production and productivity in agriculture are increased to the point of meaningful surplus over national consumption needs, then the resources (e.g., labor, funds) necessary to make a push in the industrial sector would be lacking.

Each year at least 20% or as much as 40% of the LDCs budgets is spent on transportation or transportation-related projects, with the sincere belief that transportation is an obvious prerequisite for increased production and national integration. Yet it is not uncommon to observe large uninhabited, or at most sparsely populated, poorly accessible regions, and smaller zones, especially cities and/or towns with severe overcrowding. Also, very often, even within a mere hundred miles of travel, more than one mode of transportation are required to complete a trip. Veritable land masses are served as if they are islands because of the pattern of transportation development.

The above evidence points to the significant degree of uncoordinated national strategies for development. On the one hand, we have the national economic planners who are only concerned with the global or sectoral effects of their decisions and ignore their spatial consequences. On the other hand, we have the national physical planners, often located in the ministries of public works or construction; they are heavily "design" oriented and, at times, appear more concerned with the minimization of their budget than with the overall impact of their designs. National economic planners must be made more aware that most of their decisions are not spatially neutral, and physical planners must acknowledge the limits placed on their plans by the state of the national economy, if national spatial policies are to improve the national environment [4].

In most LDCs, the net effects of the current policies and practices of government is never considered, and this generally accentuates the tendency towards concentration. In addition, discrimination against the rural sector makes everything worse [4].

The premise of transportation planning has been that travel demand is repetitive and predictable and that the transport system should be designed to meet this future demand. Thus, the "predicted highest users benefits" per route very much decided where roads of shipping, or other modes are provided. This strategy has resulted in an overemphasis on high volume facilities and to the detriment, not only to accessibility per se of the rural regions, but also to the rate of which technological "know how" is transferred to these regions. Not surprising also, the resultant benefits of the high volume facilities were dissappointing [5], to say the least, since the concept of traffic volume (i.e., users benefits) used for the evaluation was more relevant to the industrialized countries that developed these methodologies. The value of passenger travel time saved and vehicle depreciation are questionable determinants of real benefits in countries with high unemployment rates and low vehicles per capita.

1.3 The Needs of LDCs

Because a road, a rail or shipping route is built to stimulate economic growth, the appropriate basis of measuring benefits would seem to be the increases in production, employment and services instead of traffic flows per day. However, once this approach is taken, accompanying investments must also be considered since a road or other transport facility by itself is not sufficient to increase production. Thus, the value of the output and input which may be attributed to the road alone may no longer be of primary interest. Of overriding interest is the increase in total output, together with the accomplishment of other goals, that can be attributed to the integrated set of investments. Under these circumstances, traffic (existing, attracted, and generated) is a poor surrogate for determining feasibility, and the main reason for estimating traffic volume is to determine what type of facility should be constructed [6]. Furthermore, the impacts of the integrated set of investments imply a data base involving disciplines other than transportation.

Specifically then, these direct and induced impacts of transportation and related investments on the nation's production and shifts in population need to be evaluated, if long-term benefits are to be realized. A comprehensive and coordinated (system) planning approach may specifically indicate the above needs.

1.4 Objectives

There are definite linkages and feedback between the transport sector and the other main socio-economic sectors in any region, and this feedback is even more pronounced, it is contended [1], in poorly accessible agri-based regions. The question then arises, what level of transportation is required, within the given budgetary and other constraints, to positively influence output and effectively reduce undesired urban in-migration?

It is the intent of this research to explicitly incorporate the transportation activity (variable) in a comprehensive system model; and study the impacts of various investment strategies in transportation and related inputs on the economy as a whole through the methodology of system dynamics and the technique of computer simulation.

Specifically, the objectives are:

(a) To develop computer simulation submodels, using the methodology of system dynamics, for the main sectors of an agriculturally based economy.

(b) To link the submodels to form a single comprehensive model, thereby accounting for the inter-relationships and interactions of the different sectors of the economy.

(c) To apply the model to Guyana, an agriculturally based, less developed country, as a tool for strategic transportation planning to determine the impacts of transportation and related investments on the economy as a whole.

(d) To use the model to determine the appropriate data base for transportation planning in LDCs.

1.5 Scope and Organization

Conceptually then, an agri-based economy depends on mobility and accessibility. If the desired level of transport is not provided, the economy is likely to stagnate at a subsistence level and produce possible unwanted urban in-migration. Furthermore, decision makers in LDCs invariably have to choose among several projects because of their lack of funds and necessary skills to satisfy the numerous demands of the nation. Because a significant portion of their funds, at times, comes from foreign agencies, they (LDCs) must produce feasibility studies to justify the requested loans. Even these apart, the very nature of transportation (i.e., high initial cost and not easily transferable) demands astute allocation of funds if the growth of the other sectors, for example, health, education, etc., are not to be compromized. Thus, any proposed methodology for the evaluation process should provide explicitly, the answers to questions of: rate of return and prioritization of investments, impacts on production, employment, income and migration, among others, for various policies.

The conceptual model will first be developed, then the model will be calibrated with data from Guyana, and finally used to evaluate the socio-economic impacts of the following policies for the country: (1) the continuation of the status quo, i.e., maintenance of the current facilities and "sporadic" infusion of small sums of developmental funds in the scenario (which is the case in most LDCs); (2) investment in transportation; (3) investment in transportation and drainage and irrigation (an integrated package); and (4) extensive sensitivity analyses to determine which of the variables "drives" the model in order to identify a more appropriate data base for future model building and planning.

The dissertation consists of seven chapters. In Chapter 2 the current state of the art for planning of low volume transportation is discussed, and a brief overview of the basics of system dynamics are also provided. The intent in this chapter is to place system dynamics in perspective to the current state of the art, thereby identifying the need for this approach. The conceptual submodels and comprehensive model, with their intra-and inter-sectoral linkages and feedbacks are developed and explained in Chapter 3. Chapter 4 is devoted to model calibration and application to the Guyana scenario under various investment strategies. In Chapter 5 the results of the outputs from Chapter 4 are analyzed to determine the policy and region with the most desirable socio-economic impacts on the nation. In Chapter 6 extensive sensitivity analyses are undertaken to complement the limited data base (a problem of LDCs) and to identify the data most pertinent to the planning process. Finally, in Chapter 7, the conclusions, recommendations and possible extensions of the developed model are addressed.

CHAPTER 2

A REVIEW OF PRINCIPAL PLANNING APPROACHES

Model building is a rational attempt to forecast the future behavior of a system. Past transportation planning models based on the analyses and solutions of the demand component of the transport system have not been able to deal with some significant long-term induced problems, such as pollution, traffic jams, urban blight, etc., in the developed countries. Furthermore, the application of basically similar techniques for transportation planning to less developed countries has led to the funding of high-volume roads and to the apparent neglect of low-volume transportation facilities and their concomitant developmental impacts on the other sectors of the economy.

Recently, the limitations of component analyses have been realized, and within the past twenty years, several comprehensive models have been developed to account for the total system impacts. These models were developed based on linear programming technqiue, input-output technique, or system dynamics methodology. These three approaches will be briefly reviewed in this chapter according to the following outline. Sections 2.1 to 2.3 are devoted to a critical review of the present state of the art in planning (i.e., the main models in terms of their structures, variables and applications). Section 2.4 places the proposed system dynamics approach in perspective. Finally, Section 2.5 provides a brief overview of the basics of system dynamics methodology.

2.1 The Traditional Approaches

There are basically two main approaches for estimating benefits of road and related investments in rural regions: (a) road user's savings; and (b) producer's surplus.

Road user's savings approach focuses on traffic volume and cost of transport and is best suited for high-volume roads. The methodology follows closely the "4-step" procedure used in urban transportation planning, i.e., (1) trip generation, (2) trip distribution, (3) mode choice analysis, and (4) route assignment. Benefits are estimated in terms of the difference in operating costs between that of the traffic on the new road and that of an alternative road, or on the same road before improvements. In areas of low traffic and low economic activities, the user's savings based on traffic volume is a poor indicator of the impact of the investment. Empirical evidence has shown that indirect benefits are significantly larger than direct users benefits [7]. Furthermore, the quantifications of operating costs (used in the users benefits approach) on dirt roads and/or poorly maintained roads are difficult at best and can seriously influence the decision.

Producer's surplus method quantifies the developmental impact of transport cost savings and complementary investments within the area of influence of a road. The net income (producer's surplus) of farmers and transporters prior to the proposed investment is determined from an analysis of baseline data on crop land area and yields, production costs, ex-farm prices, marketed output and local consumption, together with transport costs and prices. Changes in these data are then forecasted if the proposed investment is made and subtracted from those changes that would have occurred without the investment. By these means, a benefit can be accumulated year by year and compared with the cost of the project. A calculation is then made of the rate of return of the package of investments in transport combined with other complementary investments [8,9].

Both user's savings and producer's surplus approaches assume that production will express itself directly through the transport price mechanism. The complex set of interrelationships,which exist among production and transport factors, is not brought out by either method. The approaches are unidirectional -- results of one step (phase) of the model is fed into the next step -- and neither causalities nor feed-backs among the sectors of the rural economy are addressed by these techniques. Moreover, investments (and their impacts) are treated as if they are spatially neutral in the sense that only the region where the investments are made is affected. Empirical evidence, however, has attested to two trends from transport (especially road) investments in low economic activity regions: (a) transport has significant non-economic impacts -- for example, inter-regional migration and accelerated transfer of "knowhow" among others; and (b) transport is but only one component (albeit a necessary one) for the development of a region. That is, transport equals development is a misconception [4,5,7]. Thus, in the traditional approaches, benefits are measured too specifically and attributed too narrowly. These findings have resulted in researchers calling for a more comprehensive approach to the evaluation of transport investments. Odier [10], in his discussion of benefits, states that road construction affects the nation as a whole and . . . "efforts must be made to assess them as a whole, which results in the first place in the concept of the effects on national income, and in the second place in the customary classification into direct and indirect effects." Harrall [11], in his paper, "Preparation and Appraisal of Transport Projects," points out that:

> ". . . the value of transport is measured by the degree to which it contributes to goals in other sectors of the economy, and that sound investment analysis requires a greater awareness of the interrelationships between transportation and the other sectors it serves."

The system dynamics methodology proposed in this research has the capabilities to incorporate explicitly intra and inter-sectoral relationships and feedback phenomenon. However, before an outline of the system dynamics methodology is presented, the pros and cons of two other approaches -- (1) Linear Programming; and (2) Input/Output -- that have gone beyond the traditional methods are presented.

2.2 Linear Programming (LP) Technique

In the LP approach, the transport variables are explicitly incorporated in the models. The models measure the benefits from resource savings, increases in output, or changes in cropping patterns which result from an improvement in the transport system under varying price and technology assumptions given local or regional resource constraints. The regional economic activity, without transport investment, is expressed as a constrained maximization problem, and then with investment in transportation. The programming solutions of the two problems are then compared to show the impact of the investments [12,13].

Typically, a linear programming problem for a developing region may be formulated as follows [14]:

$$\text{Maximize } Z = C_i X_i + C_t Y_t \qquad (1)$$

Subject to:

$$AX_i + DY_t \leq B_i \qquad (2)$$

$$FX_i - GY_t = 0 \qquad (3)$$

$$X_i,\ Y_t \geq 0 \qquad (4)$$

where:

C_i = net contribution to the economy of one unit of the main activities of the region;

X_i = a unit of the main activities of the region ($i = 1, \ldots n$; n = number of activities except transportation);

C_t = net contribution of one unit of the transport activity;

Y_t = a unit of transport activity for the mode under consideration;

A = input coefficients in terms of time, person hours, and materials, etc., or the amount of resources consumed, by unit measure of each activity in the region;

D = input coefficients of resources consumed by one unit of the transport activity under consideration;

B_i = maximum available resources in the region;

F = demand coefficients for transport by the economic activities of the region (ton-miles); and

G = supply coefficients for transport by the transport activity of the region (ton-miles).

Equation (1) is the objective function that the model optimizes. Equation (2) is the constraint equation that guarantees that no more than the available resources can be consumed. Equation (3) is the equilibrium equation, i.e., the demand for transportation by all the activities must be balanced by the supply of transportation. An optimal solution occurs when the demand for transportation equals the supply, i.e., the quality and level of transportation influence the total net benefits of the region. Equation (4) guarantees no negative outputs by any of the activities.

The approach can be characterized as an exercise in comparative statics. The essential features of an agricultural economy are carefully identified and modeled. Then by varying factors such as cost parameters and product prices, the impacts these would have on profitability of various levels of investment in the primary decision variable, namely, the density of the farm-to-market road network are determined.

The methodology suffers from the typical weaknesses of the LP technique, such as fixed coefficients, divisibility, non-dynamic, etc. Furthermore, no indication is given as to when optimality is achieved, nor the spatial impacts of the investments. Nevertheless, the model does provide significant insight into what factors (resources) are constraining the growth rate of the region and also a quantification of the benefits optimal allocation of the regional resources. The method is best suited for regions where the minimum infrastructure and some form of economic activities are already in place, and transportation is perceived to be the main constraint to accelerated economic growth.

2.3 The Input/Output Method

Input-Output analysis, originally developed by Leontief [15], is a name given to a modeling procedure in which the output product of each industrial sector is set equal to the input consumption of that product by other industries and consumers. The models can be interpreted in terms of the block diagram and matrix algebra techniques so familiar to systems engineers.

The concept of input-output analysis can be illustrated in the following example. Suppose there are four industries with output rates X_1, X_2, X_3 and X_4 units of value per unit of time. The output of each industry is used by itself, by the other three industries and by the consumers. The interindustries transaction can be shown in a tabular form in Table 2.1. In matrix form, the output of each sector can be expressed as:

$$X_i = \sum_{j=1}^{4} a_{ij} X_j + Y_i$$

where:

X_i = value of the output of the ith industry;

a_{ij} = technological coefficient where i refers to the column and j to the rows;

TABLE 2.1 - Interindustry Transaction Matrix

	Purchasing Sectors					Demand Sector	
	Intermediate Demand						
Producting Sectors	X_1	X_2	X_3	X_4	Total	Final Demand	Total Demand
X_1 X_2 X_3 X_4			$a_{ij}X_i$		$\Sigma a_{ij}X_j$	Y_i	X_i
Total Inter Industry Demand			$\sum_{i=1}^{4} a_{ij}X_i$				
Primary Inputs (Value Added)			P_i				
Total Production			$\sum_{i=1}^{4} a_{ij}X_i + P_i$				

Y_i = the value of the final demand for the output of the ith industry (sector);

P_i = the value of the primary factors (e.g., land, labor, etc.) used by the ith industry; and

$a_{ij}X_i$ = the value of j output that is sold to the ith industry.

The basic idea behind the input-output analyses is that a system is forced or driven by a set of final demands Y_i. It is assumed that the demands Y_i can be satisified, and the total output X_i's which satisfy these final demands can be found. The overall result of these transactions may be thought of as "pressures" on the economy. Where the economy is slack, the "pressure" should be a positive factor in stimulating production; and where it is not slack, the "pressure" could create problems by placing demands on factors which are already in short supply [6,16].

The method (model) provides information explicitly on both implied output and induced output. Implied output defined as (in the case of the agricultural sector) values of farm output from the project, purchased input used in farm production, trade and transportation output involved in delivering the farm output to the market, and the output from those industries which purchase the farm output. Induced output covers the interindustry, or intermediate requirements of those industries which supply the farming activity and purchase its output. As such, the model indicates the use and the generation of resources of special importance to economic growth and also the areas where externalities might occur. In this regard, an analysis of the total output and input will identify the "pressure" points and/or needs of the region to satisfy the projected final demands, and as such does provide a degree of comprehensiveness.

The model suffers from some of the similar limitations of the LP technique such as linearity which requires a constant return to scale, and this may not be a correct assumption for the region. Secondly, most LDC's may not be able to afford the extensive and intensive studies required to develop the technological coefficients of the input-output table.

Other limitations of the input-output concept are the difficulties in applying it to a typical transport development project in which a small region is studied. Also, the prediction of the final demands for each sector would be extremely difficult in LDC's with a poor data base. Moreover, although causality is addressed by the model, neither spatial impacts nor the feedback phenomena or constraints are explicitly incorporated.

The technique may be best suited to LDC scenarios that already possess a significant data base and are already using this technique in their planning hierarchy as a guide for transport demands.

2.4 System Dynamics in Perspective

The traditional approach is by and large founded primarily on simplifying statistical relationships between the different variables (activities) that define the behavior of the regional economy. These "simplified" relationships are projected into the future without any serious attempt to quantify time lags (in the case of construction), feedbacks and non-linearity behavior through transient stage and spatial impacts which are invariably evidenced after project implementation. Researchers [10,11] are convinced that transport investments have national impacts and it is equally important that transport is but only one of the many factors which determine economic growth of a nation. Furthermore, the complex interactions and inter-relationships of transport and of the other sectors of the economy need to be understood so that investments in transportation can be more wisely and beneficially utilized.

Moreover, in scenarios plagued with an insufficiency of financial and technical resources and a significant lack of coordination among the different planning agencies, it is important to provide a methodology that addresses explicitly the views of other agencies when it comes to allocating the funds their agencies are seeking.

The system dynamics approach, it is contended, can specifically address the above needs, since it has the capability not only of using realistic statistical relationships (linear or non-linear), but also to incorporate causality and feedbacks explicitly.

A system dynamics operating model can be used to communicate and incorporate the views and opinions of groups not involved in building the model. By experimenting with changes in policies and model parameters (sensitivity analyses) and observing the effects of these changes on behavior, these groups can help or be helped to better understand the dynamic forces at work in the real world system.

Ever since the development of system dynamics by Professor Forrester in 1958 (known then as Industrial Dynamics), the methodology has been increasingly applied to a wide range of socio-economic problems as documented in Roberts, Managerial Applications of System Dynamics [16]. However, except for the work of Drew, et al. [17], very little use has been made of this methodology in the field of transportation planning for poorly accessible regions. In this research, the system dynamics capabilities for explicitly incorporating causality and feedback systems principles will be utilized to evaluate both the direct and spatial impacts of transport and related investments in a developing region.

2.5 An Overview of System Dynamics Methodology

System dynamics, a field which extends from the work begun by Professor J. W. Forrester at the MIT School of Industrial Management, is a methodology for analyzing the behavior of complex dynamic systems. Through simulation techniques, if the conditions are known at one point in time, some logic or policy expressed as equations can be used to compute the conditions at the next point in time. In this way, one can move step-by-step through time producing various patterns based on various technological alternatives, institutional policies, or economic strategies. Professor Forrester's methodology provides the foundation for expressing in mathematical equations the structure of the system upon which policy acts [18,19,20].

In undertaking system dynamics analysis of a problem, the steps involved are: (a) causal loop diagramming; (b) flow diagramming; and (c) the conversion of the flow diagrams into sets of simultaneous difference equations.

2.5.1 Causal Loop Diagramming

The first step is to hypothesize the underlying structure of the system that is causing and maintaining the problem. The causal loop diagrams show the existence of all major cause-and-effect links, indicate the "direction" of each linkage relationship between variables, and denote major feedback loops and their "polarities".

In developing a causal loop diagram, each link is represented by an arrow and given a plus (+) or minus (-) "directional" sign, usually shown near the arrowhead, and is referred to as a positive or negative linkage. A linkage is a cause-and-effect relationship between two variables in which the variable at the tail of the arrow is the cause (independent variable), and the one at the head of the arrow is the effect (dependent variable). A positive linkage means that the independent and dependent variables vary in the same direction (both increasing or decreasing). A negative linkage, on the other hand, implies that the two variables it connects vary in opposite directions (one increasing and the other decreasing).

A feedback loop is formed when two or more linkages are connected in such a way that, beginning with one variable, one can follow the arrows and return to the starting variable. Like linkages, feedback loops are also identified according to their polarities, positive (+) or negative (-). In a positive feedback loop, the loop acts to reinforce variable changes in the same direction as the initial change, contributing to sustained growth or decline of the variables in the loop. In a negative feedback loop, the loop acts to resist or to counter variable changes, thereby pushing towards a direction opposite to change, contributing to fluctuation or to maintaining the equilibrium of the variables in the loop. A simple method of determining loop polarity is to count the negative linkages in the loop. An odd number of negative links indicates a negative feedback loop. Zero or an even number of negative links indicates a positive feedback loop.

Figure 2.1 provides an illustration of the cause and effect and feedback phenomena described above. As described in this figure, one can conceptually think of investment fund and demands for roads influencing the rate of road construction, which in turn increases the miles of road network provided. An increase in network mileage (also represented by road density) should: (a) increase the accessibility of the region; and (b) reduce further demands for roads. Likewise, an increase in accessibility should positively influence land development rate, a main determinant of future area under cultivation. Figure 2.1 provides a succinct description of the above concept using the underlined words as the main variables explaining the behavior of the system.

2.5.2 Flow Diagramming

From a system dynamics perspective, all systems can be represented in terms of variables. A variable is a quantity that changes as time evolves. A variable may be a decision variable, or it may be a quantity that is affected by such a decision, or it may be a changeable input to a decision [20]. When a variable is not affected by other variables inside the system being analyzed, the variable is termed "exogenous" or outside of the system. A variable that is subject to effects of other

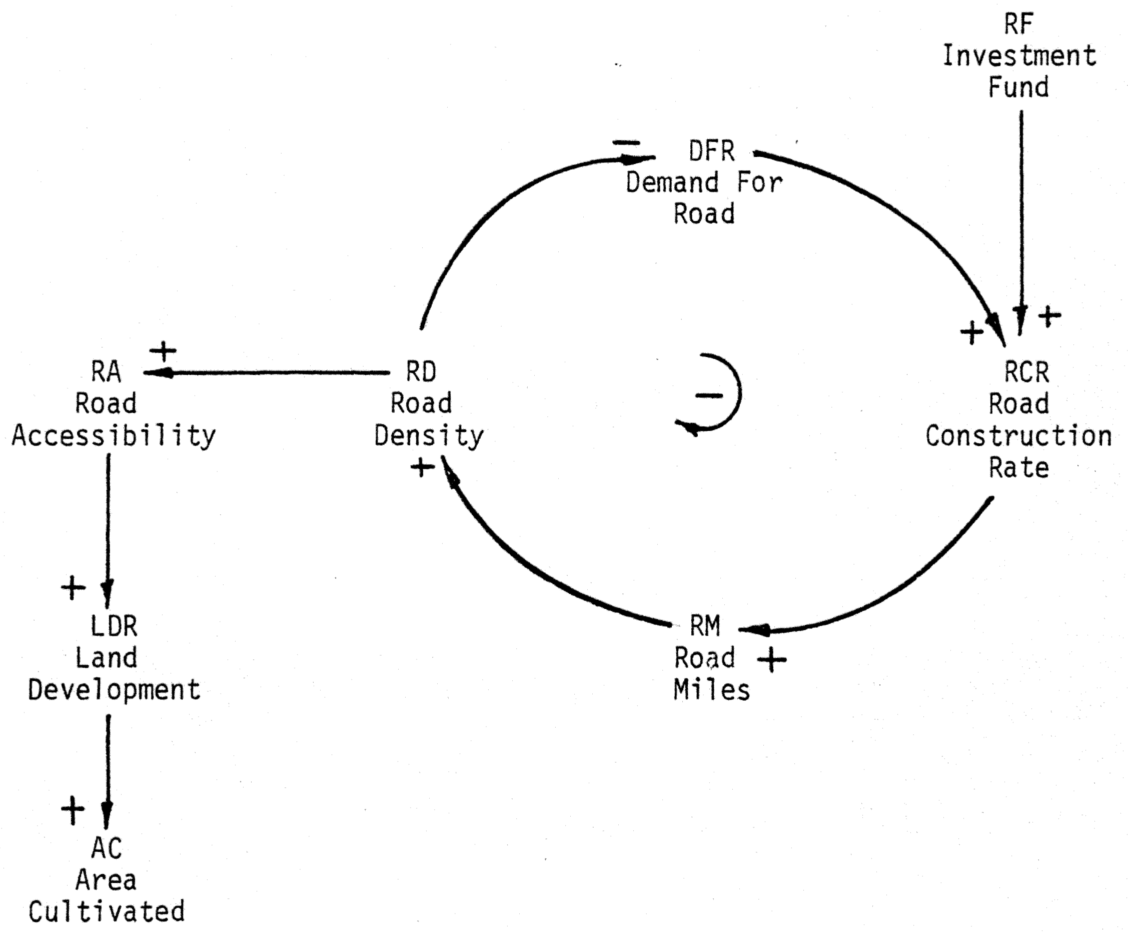


FIGURE 2.1 - An Illustration of a Causal Diagram-Feedback Phenomenon of the Transport Demand/Investment Behavior

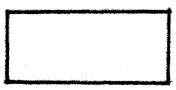
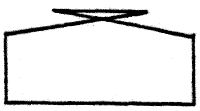
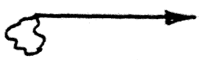
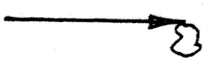
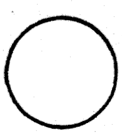
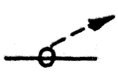
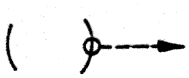
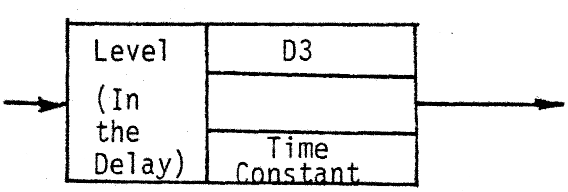
variables in the system is termed "endogenous". In system dynamics there are three types of basic variables: (1) level variable -- which is an accumulation, or integration, over time of flows or changes that come into or go out of the level; (2) rate variable -- a flow, decision, action or behavior that changes over time as a function of the influences acting upon it; and (3) auxiliary variable -- used for clarity or simplicity, which is a combination of information inputs and concepts. In Table 2.2, the flow diagram conventions used in system dynamics are summarized. In visually representing a system dynamics model, causal loop diagrams (typical of Figure 2.1) are generally used for purposes of communication. However, for formal documentation of a model, formal flow diagrams are developed for equation writings. Figure 2.2 provides the formal flow diagramming for the causal diagram of Figure 2.1 from which the system dynamics equations can be developed.

2.5.3 DYNAMO Equations

Equations permit expressing model relationships in explicit quantitative terms that can be simulated manually or by a computer. In system dynamics modeling, each variable in each equation must indicate the specific point in time or time period to which it refers. Time instants are denoted by using time postscripts. The postscript conventions are:

- .J Refers to the previous point in time.
- .K Refers to the current point in time.
- .L Represents the next point in time.
- .JK Represents the most recent time interval.
- .KL Represents the next time interval.

TABLE 2.2 - System Dynamic Flow Diagram Conventions

SYMBOL	MEANING
	Level Variable
	Rate Variable
	Source
	Sink
	Auxiliary Variable
	Constant
	Variable on Other Diagram
	Variable Being Influenced on Other Diagram
	Physical Flow (solid line)
	Information Flow (dashed line)
	Third Order Delay. It transforms an input rate at a moment in time into an output rate distributed over an extended period of time.

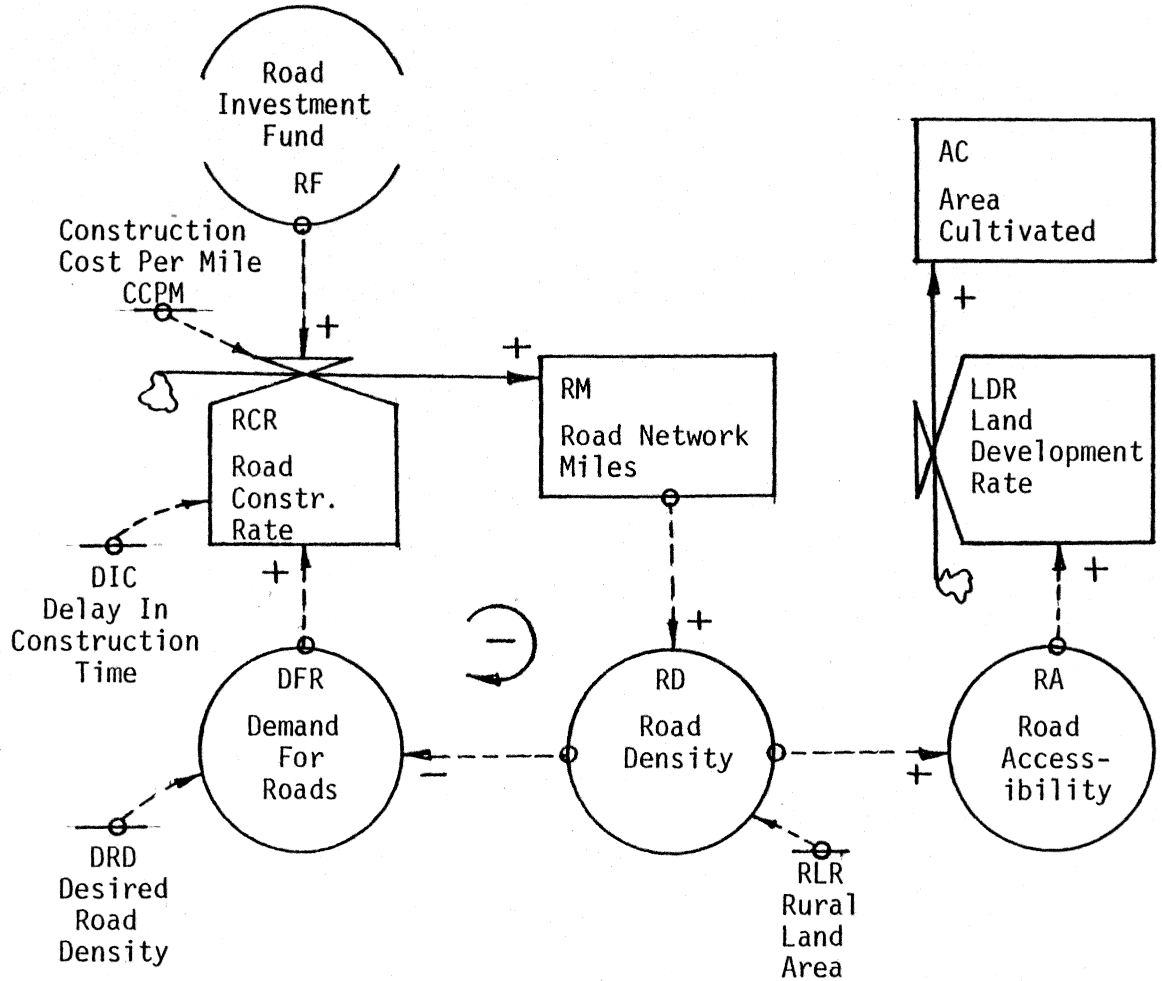


FIGURE 2.2 - An Illustration of Flow Diagramming for Transport Demand/Investment Behavior and the Use of System Dynamics Symbols

Graphically, the implications of the time postscrips are shown in Figure 2.3 with DT being the increment in time -- a predetermined time interval by which solutions are sought.

The development of a formal set of equations for the level variable RM (Road Miles) and the rate variable RCR (Road Construction Rate) in Figure 2.2 are presented as follows:

L	RM.K=RM.J+(DT)(RCR.JK)	(1)
N	RM=100	(1.1)
R	RCR.KL=MIN(DFR.K,(RF.K/CCPM)/DIC)	(2)
C	CCPM=200000	(2.1)
C	DIC=5	(2.2)

where:

Equation (1) provides the total number of miles in the road network at a given point in time; Equation (1.1) is the initial value of road miles at the beginning of the simulation; Equation (2) provides the rate at which road is constructed in the future for any given time increment (DT); Equation (2.1), a constant, is the assumed cost of construction per mile of road; and Equation (2.2) incorporates the delay envisaged between the starting and completion of construction. The postscripts and variable names are as previously defined.

The simulation is executed by performing a sequential solution to all equations. The sequence is as follows:

1. Compute all values at time K based on all values given at time J and the rates during time JK.

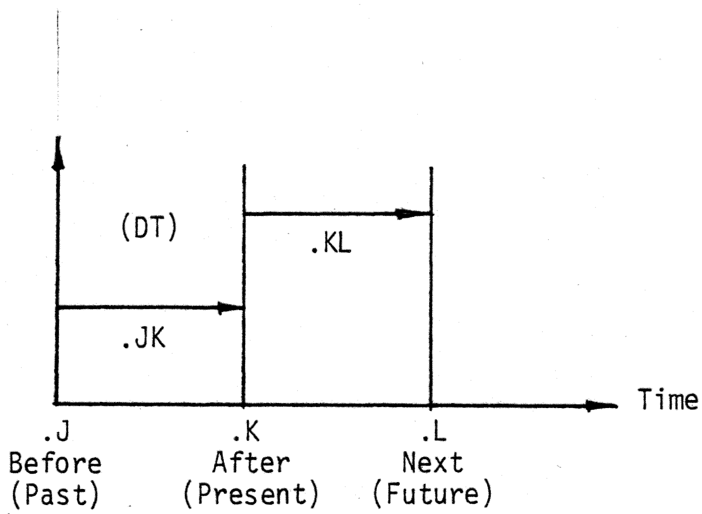


FIGURE 2.3 - The Graphical Representation of Time Postscripts

2. Compute the new rates over KL from the values of the levels at time K.
3. Compute output variables and place them in an output file.
4. Shift J, K and L ahead one increment DT for the next cycle of computation.

More detailed information on system dynamics and DYNAMO simulation language can be obtained from Forrester [20] and Pugh-Roberts [21].

CHAPTER 3

THE UNDERLYING STRUCTURE AND CONCEPTUAL CAUSAL MODEL

As evidenced by the literature search, it is quite clear that investment in transportation, in poorly accessible regions, results in significant regional and national impacts which are often more important than the traditional road users' costs and benefits generally used for the evaluation of the investment. Furthermore, these impacts are the results of the complex interactions between the socio-economic factors that define the regions' performance. Thus, it is necessary to identify the extensiveness and intensiveness of these impacts through the structural inter-relationships, the causal and feedback phenomena of and between the main regional socio-economic factors, if a meaningful development plan of the region is to be provided. Further, it is contended that System Dynamics methodology can specifically address the above needs since it is capable of explicitly incorporating and validating the hypothesized behavior and, through the technique of computer simulation, tracing the hypothesized behavior through transient state to steady or equilibrium state. In this chapter the fundamental characteristics underlying system dynamic methodology and the conceptual model will be illustrated.

In Section 3.1 the main underlying features -- (1) hypotheses or assumptions and mathematical formulation; (2) simulation; (3) transient state; and (4) equilibrium state -- referred to earlier are discussed. Section 3.2 outlines the phases of the proposed methodology. In Section

3.3 the dominant feedback loops of the main sector of the economy and a generalized conceptual causal model to be used for the evaluation of transport and related investments are developed.

3.1 The Underlying Concepts of System Dynamics

Since it is very often too costly and impractical to experiment with the real world problems, one resorts to modeling. Model building inevitably involves assumptions about the real world behavior, and therefore results in limitations in the utilization of the model's output. Since system dynamics is a modeling approach, the above problems are also true for its output. The question that obviously arises is: how significant are these limitations for the outputs of the proposed system dynamics methodology? This question is best addressed by an examination of the main concepts that constitute system dynamics methodology. These concepts are:

1) Hypotheses and mathematical formulation of the behavior;
2) The use of aggregation; and
3) Simulation.

A brief overview of these concepts is necessary as a prelude to the model development process, since the confidence with which the model's outputs are regarded depends strongly on the concepts used.

3.1.1 Hypotheses in System Dynamics Methodology

It is clear that the number of variables or "facts" of all but the simplest (and probably trivial) problem associated with economic growth is so large that the selection of the "facts" to be studied must be considered. But on what basis would the observer choose from the infinite complexity of reality a manageable subset of "facts" or variables to study? It seems clear that selection would depend on some hypotheses of the causes and consequences of economic growth [22].

Too often we approach the problems only at the level of symptoms forearmed with a mathematical model that the problems or symptoms must fit. This lack of understanding of the structure of the underlying system often leads us to wrong conclusions regarding the problem [18]. The use of hypotheses or assumptions in system dynamics approach affords us a useful way to deal with problems involving many considerations, interrelationships and feedback phenomena. Assumptions of the relationships of the forces or "facts" that have created and continue to sustain the problem are made. Relevant data are then gathered and compared to the hypothesized behavior. This process is continued in an iterative manner until the behavior is acceptably replicated. Thus, through the use of hypotheses, a "more realistic" model is developed in system dynamics methodology.

3.1.2 Aggregation in System Dynamics Methodology

In the development of any model of socio-economic growth, some degree of aggregation is necessary. What is important is that care should be taken not to make the simplification in such a manner that the model falls to pieces when the variables are disaggregated or removed.

The purpose of the developed model is to provide comprehensive (social factor included) analyses of proposed investment policies. Comprehensiveness suggests breadth (i.e., macro approach), and economic quantification suggests depth (i.e., detailed or disaggregated treatment). Budgetary limitations demand a compromise; however, the compromise provided by aggregation must be representative (i.e., not oversimplified), if the model is to be useful. System dynamics methodology provides for checks for representativeness through the technique of sensitivity analyses on the main aggregated variables. Where such disaggregation is warranted (as indicated by sensitivity analyses) and the cost of modeling is affordable, such disaggregative inputs would strengthen rather than destroy the output of the model.

For example, the labor force may be aggregated in the model as a fraction of the entire population. This assumption implies that in the case of a growing economy, the labor force grows at a constant exogenous rate, and no element of the model under consideration can affect the overall labor force growth. Since real growing economies are often constrained by particular kinds of skilled labor, the constant exogenous growth rate of labor might be considered a drastic oversimplification. If, however, it is conceived that a particular skill, or for that matter, age group is constraining growth, then the disaggregation can be incorporated without any apparent "modeling" problem. Thus, cost and/or time rather than modeling capabilities are the true constraints in system dynamics.

3.1.3 Simulation in System Dynamics

In any economy, there are forces that "drive" the economy, and it is necessary to identify whether these forces and feedback phenomena tend towards steady state behavior or continue to produce growth or decline (i.e., transient state behavior). This process is often referred to as the stability problem of the region.

The concepts of both equilibrium and transient states are important characteristics in growth models of economic development. Equilibrium state is used as a bench mark for the study of the system; in general, it is taken as that configuration of the economy from which there is no tendency to change. Thus, the factors that constrain further growth can be identified and possibly purturbed (through policy changes) to induce growth. Transient state provides information on the trace of the behavior of the system through time, thereby providing for "more accurate" economic evaluation of receipts and disbursement of the impacts of a given policy. Furthermore, an economy in transient state may be more easily manipulated if explicit knowledge of the factors that induce the changes is provided.

System dynamics methodology, unlike the main models reviewed in Chapter 2, makes use of the tool of simulation, thereby explicitly providing a trace through time of the impacts of a given investment strategy. Furthermore, through sensitivity analyses and trace of the behavior, the variables or "forces" that "drive" the economy may be better understood to allow for timely modification.

The review of the underlying structure of the proposed methodology -- system dynamics -- shows that even though the model is based on hypotheses and aggregation, the outputs can be utilized with confidence.

The model development process is dynamic because of the iterative process of mathematical formulation and calibration to the desired replication of the perceived behavior. It is also flexible enough to allow for disaggregation, where such disaggregative efforts will lead to improved reliability of the outputs, without destroying the overall structure and usefulness of the developed model.

3.2 Outline of Method of Approach

Figure 3.1 shows a flow diagram of the twelve steps involved for the provision of the model, analyses, and recommendation for the development of a potentially viable rural region. Only a brief outline of each step is offered at this stage as a quick synopsis of the research. The detailed development of each step or phase is the purpose of Chapter 4.

3.2.1 System Boundary

Identification of the limits of the impacts of a development strategy is crucial to the overall evaluation of the proposed strategy's benefits or disbenefits.

Most transport investment models delimit the impacted region as a zone extending a given number of miles along the proposed routes. The hypothesis of this research is that the zone of influence extends beyond the immediate region of the investment and that such spatial impacts are experienced through population movements; therefore, the "true boundary" of the impacts should include the spatially impacted region.

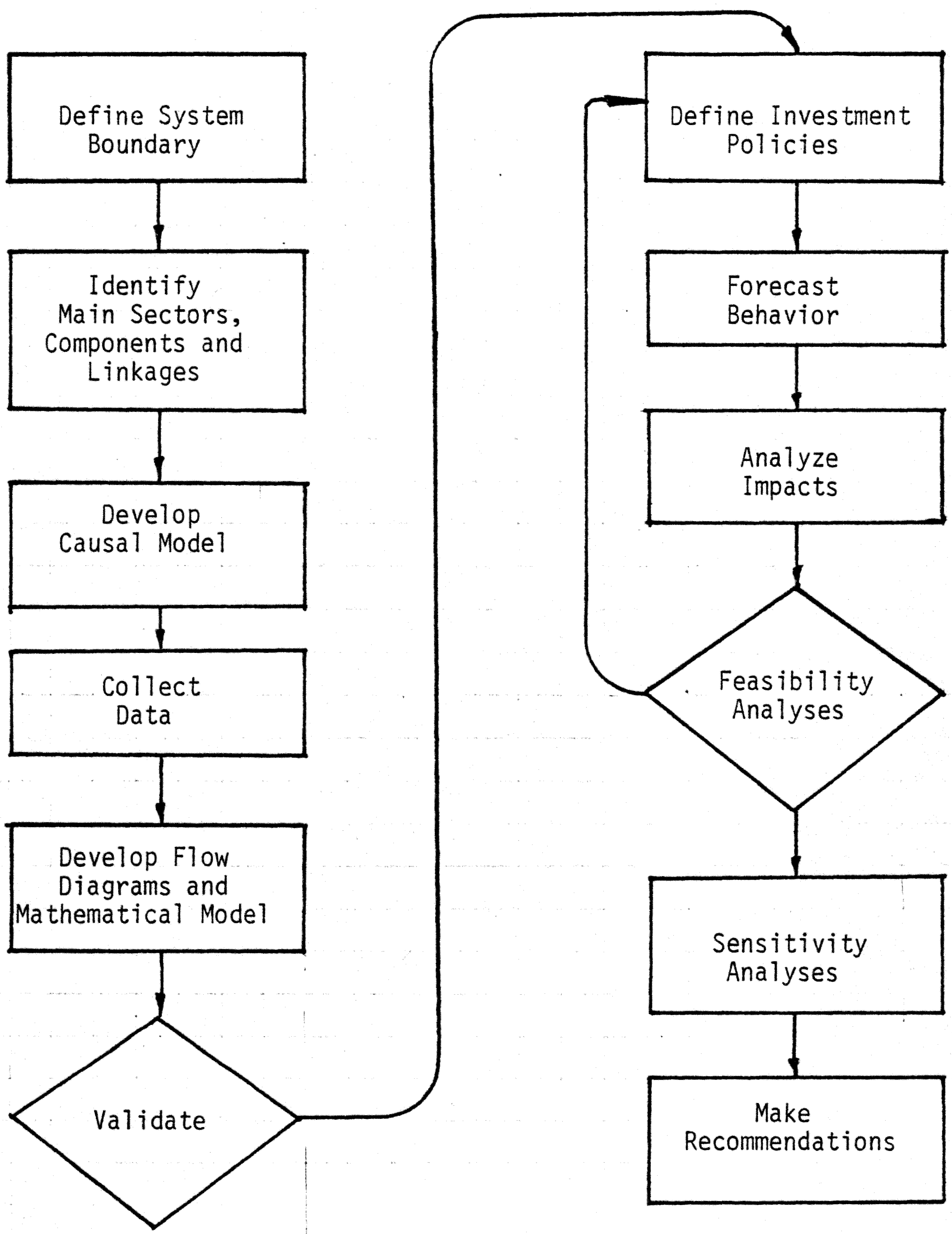


FIGURE 3.1 - Flow Diagram of Method of Approach

3.2.2 Main Socio-Economic Factors

The behavior or economic performance of any region is the outcome of the dynamic interactions among the socio-economic endowments of that region. The improvement of the region through investments begins with an identification of the main socio-economic factors and how they impact one another to produce the regional performance. The main sectors and linkages are at least determined at this stage.

3.2.3 The Causal Model

The hypotheses of the behavior of a region is formalized through the development of signed di-graphs. The directions of the impacts -- positive (+) or negative (-) -- and feedback structures for the main variables of the dominant sectors of the economy are graphically illustrated. The grasp of the complex phenomenon of economic growth is indeed overwhelming when viewed totally. Thus, the causal diagram phase should show the subdivision of the total problem into subsectors and components so that the forces that produce sectoral behavior can be examined. Then, from an understanding of the sectoral performances, linkages among sectors are identified to produce the total causal model.

3.2.4 Data Base

In most LDCs the complaints of inadequacies of data are quite vocal, but very often little is said about what data are needed or in what manner they should be collected and structured for socio-economic planning. As evidenced by the position of the data step in the method of approach after the development of the causal diagram, one begins to appreciate what type of data are critical for an effective analysis of the region's performance. The data base is of course fundamental to the analysis, and therefore needs to be collected and utilized in an effective manner.

3.2.5 Flow Diagrams and Mathematical Model

The ultimate objective of the development of the model is to be able to quantitatively evaluate the impacts of a proposed investment. The causal diagram, even though very useful, is inadequate for this task. However, as soon as feasible (i.e., all the defining variables are present in the causal diagram), the signed di-graphs are converted into flow diagrams from which mathematical equations are developed, as explained in Chapter 2.

3.2.6 Model Calibration

The mathematical model is then tested for significance (i.e., the ability to replicate past performance). Or, where an interdisciplinary group is involved in the development process, the model is opened to criticisms and inputs from such group. Calibration is an interative process (i.e., formulations and simulation) and continues until the structure and output of the model is proved useful.

3.2.7 Definition of Policies

Investment strategies in LDCs for poorly accessible rural regions vary from a piecemeal approach to a comprehensive, well-planned and funded project -- especially when these projects are foreign financed. These approaches are rationalized into three main investment strategies -- (1) Do Nothing; (2) Investment in Roads Only; and (3) Investment in

Roads, Drainage and Irrigation, which are analyzed for their impacts on the study region.

3.2.8 Forecast Behavior

The impacts of each investment strategy is then traced to equilibrium (i.e., to the time at which no further growth in production results from that policy), through the technique of simulation. Simulation technique provides explicit information on the timing of the impacts, a characteristic that is not found in any of the traditional approaches.

3.2.9 Analyses of Impacts

The traditional net present worth method will be used to determine the economic (i.e., quantifiable monetary) impacts of the tested policies over the "viable life" of the infrastructure provided. In addition to the economic analyses, the impacts on income, demography, etc., will be evaluated in order to determine that strategy or policy with the least negative benefit to the nation.

3.2.10 Feasibility Analyses

All policies must satisfy the economic criteria of a benefit/cost ratio of one or greater and a positive net return on investments over the analysis period (i.e., the viable life of the project), in order to be considered feasible. This condition is placed, since for all intents and purposes it is the one condition that almost all financiers or decisionmakers insist on before funding is even considered.

3.2.11 Sensitivity Analyses

Feasibility of investment strategies are based on economic analyses and socio-economic indicators (i.e., benefit/cost ratio, income per capita, etc.); but these indicators are the outcome of the hypotheses and estimates of the behavior and costs of the real activities. Even though every effort is made to calibrate past behavior, changes in behavior and costs in the future may significantly influence impacts, and therefore feasibility.

Sensitivity analyses provide a measure of understanding of the severity of these future impacts, given changes in key socio-economic factors. For that reason, sensitivity analyses are performed to identify the variables that need to be monitored more closely during and after planning and implementation.

3.2.12 Conclusions and Recommendations

Finally, the main characteristics of the research will be highlighted. Recommendations of an investment strategy will be based on a combination of economic feasibility and the strategy that provides the least negative national and regional impacts.

3.3 Development of the Causal Model

3.3.1 The Main Hypotheses

The hypothesis of the model formulation is that investment is not spatially neutral; that is, decisions taken in any of the regions (developed or undeveloped) will eventually impact other regions of the country. The question is how far-reaching and diffused would the impacts be? The degree of the spatial impacts will depend on the baseline socio-economic characteristics of the specific country under consideration. That is, in countries where there are significant regional disparities (in terms of job opportunities and income), there is a greater likelihood for shifts in population than in countries with more "equitable" distribution of development. However, most LDCs can be typified as agriculturally based or rural economies, in which there are a few or even only a single well developed urban center (generally the capital region), and the remainder of the nation experiencing different levels of development as measured by population density and socio-economic infrastructure such as schools, electricity, transportation, drainage and irrigation, etc. Furthermore, the urbanized centers are generally the attractors of population because of their relatively higher income per capita, better social infrastructure, and perceived greater job prospects, as evidenced by time-series demographic data of most LDCs.

Thus, the boundary of influence of the investment may be defined as the immediate region in which the investment is made and the regions that will possibly be affected by in- or out-migration as a result of the impacts of such investments. This boundary and the hypothesized socio-economic characteristics and interactions of the impacted regions are schematically illustrated in Figure 3.2.

The hypothesis of Figure 3.2 is that a poorly developed region (as measured by production level, income per capita, unemployment rate and accessibility) will lose population to more developed regions of the

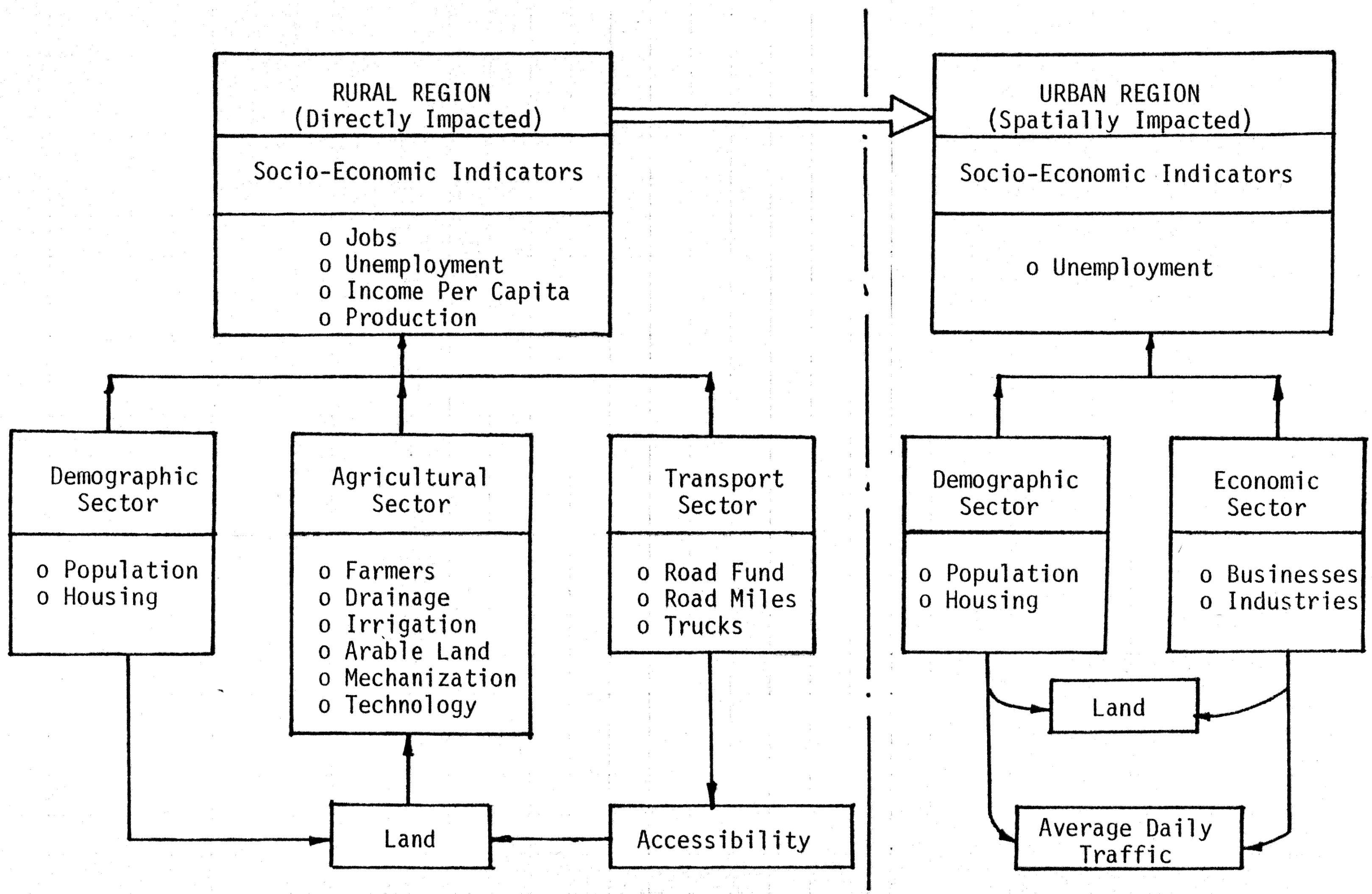


FIGURE 3.2 - <u>Simplified Block Diagram Showing Linkages of the Main Sectors of the Economy</u>

country, and this migration to urban centers defines the impacted system boundary.

The simplified block diagram in Figure 3.2 shows the subdivision and main variables of the sectors of the impacted regions that dynamically interact to produce the regional socio-economic characteristics of unemployment rate, jobs, income per capita and production rate. It also implies that, if nothing else, land availability will eventually constrain regional growth and output.

The rural region (i.e., the region directly impacted through investments) is conceptualized as having three main sectors, as shown in Figure 3.2. The demographic sector -- whose main components are population and housing -- impacts unemployment (through labor force) and land availability, respectively. The agricultural sector -- whose main components are farmers, drainage and irrigation, arable land, mechanization and agricultural technical inputs -- impacts production rate, yield per acre, job opportunities and profitability. Finally, the transport sector -- whose main variables are road funds, road network miles and trucks -- impacts regional accessibility and after production loss.

Now, recall that the objective of the developed model is to investigate a strategy in transport and related investments in rural regions that provide the most beneficial direct and spatial impacts. Furthermore, spatial impacts were defined as the shift in population due to differences in regional socio-economic characteristics measured primarily by differences in unemployment rates. Therefore, the main interest in the urban region (i.e., zones to which population are attracted) is its perceived employment characteristics. As such, the urban region is aggregated into only the demographic and economic sectors -- the main determinants of unemployment rates. The demographic sector, whose main components are population and housing, determines the labor force and housing stock of the region. The economic sector, whose main components are business and services, determines the job opportunities of the region. Both sectors impact land availability and traffic generated.

3.3.2 The Causal Model

Figure 3.2 presented the simplified but definite linkages that exist between the major sectors of an economy. In the following sections, the model is presented in more detail so that the causal relationships between the system elements can be understood. The dynamic structure of the model is illustrated using the di-graph concept (or causal model), since it is more convenient to show the direction and the polarity of impacts among the variables. First, the main feedback loops that underlie the sectoral behavior are developed; then the sectoral loops or submodels are synthesized to form the hypothesized causal model of the impacted region.

The Rural Region: Demographic Sector

The demographic sector is represented by the population and housing components. The regional population level determines the labor, unemployment rate, and income per capita of the region, and exerts a strong influence on the housing component and land conversion from agricultural production to housing use. Figure 3.3 shows that the demogrpahic sector has two main feedback loops underlying its dynamic structure: (1) a

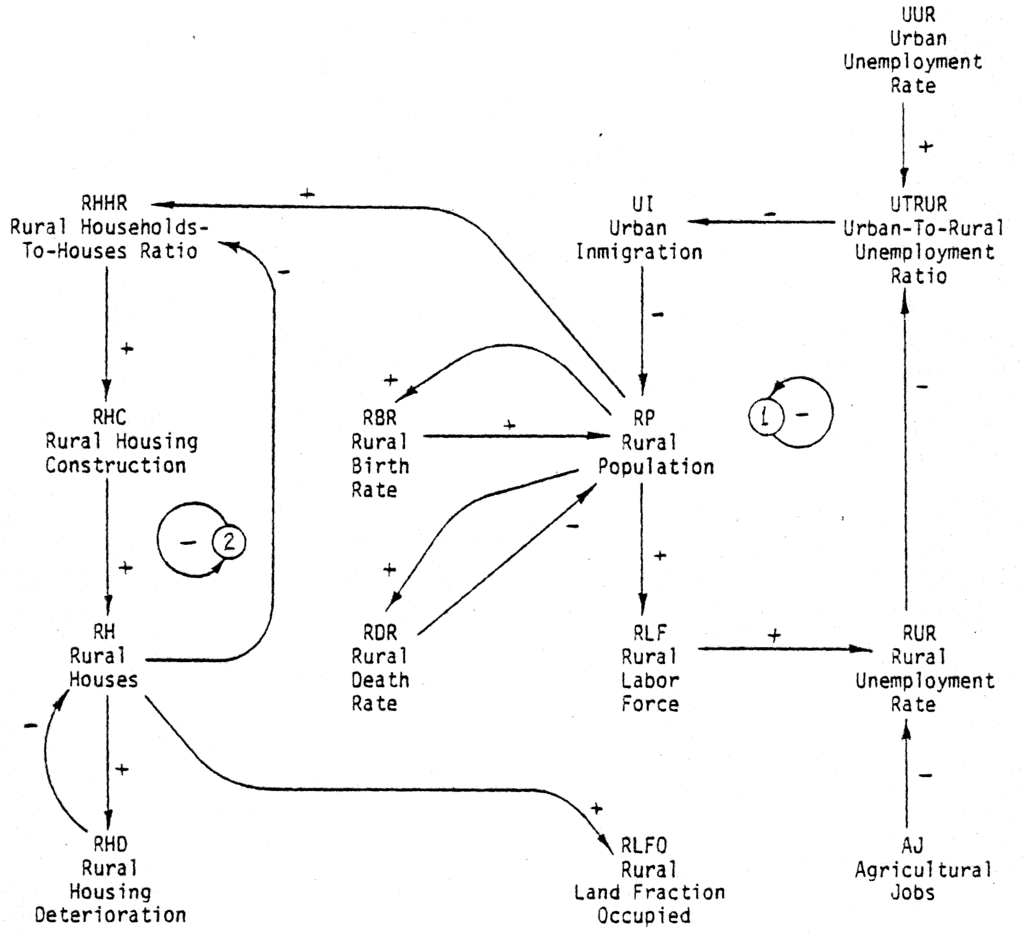


FIGURE 3.3 - The Causal Diagram of the Demographic Sector and Its Two Main Components: Population and Housing

population movement loop (Loop 1); and (2) a housing construction loop (Loop 2).

Loop 1 (Rural Population RP, Rural Labor Force RLF, Rural Unemployment Rate RUR, Urban To Rural Unemployment Ratio UTRUR, and Urban In-migration UI) shows that population movement is governed by the relative unemployment rate (UTRUR) between the rural and urban regions. The forces result in a negative feedback loop, indicating stability in the rural population level in the long run (i.e., urban in-migration will be neutralized when the two unemployment rates are equal, and population growth will be dependent only on birth and death).

Loop 2 (Rural Houses RH, Rural Households to Houses Ratio RHHR, and Rural Housing Construction Rate RHC) shows that the housing level is constrained by the housing demand exerted by the rural population level and the housing stock of the rural region. An outflow of rural population relieves the rural housing needs, thereby reducing the impact of housing on the rural land fraction devoted to housing (i.e., a positive impact for agricultural production). This is also a negative feedback loop, since any increase in construction (due to rural housing need expressed by RHHR) increases the housing stock, and in turn, reduces the demand for housing.

<u>The Rural Region: Agricultural Sector</u>

Production and productivity of the agricultural sector are dependent on the following main factors: (1) farmers; (2) arable land area; (3) drainage and irrigation; (4) mechanization; and (5) agricultural technical inputs and the cost and level of accessibility of transportation (to be discussed in the Trnasport Sector). The rate of growth of this sector is influenced by the rate at which arable land is brought under cultivation, while the land area under cultivation determines the socio-economic performance of the region through the number of "agricultural jobs" and "production rate" variables. Figure 3.4 shows that the dynamic interaction of people, land, machine and economic infrastructure of the agricultural sector results in five main negative feedback loops.

Loop 1 (Farmers F, Rural Land Development Rate RLDR, Agricultural Land Under Cultivation AL, Agricultural Land To Water Ratio RLTWR, Yield Per Acre YPA, Profit Per Acre PPA, and New Farmers NF) shows the impacts of one of the most important economic infrastructures (i.e., drainage and irrigation, represented by the variable Agricultural Land To Water Ratio ALTWR) on the amount of agricultural land cultivated. This is a negative feedback loop which limits the acreage cultivated to a level which can be feasibly irrigated and drained by the available water and drainage infrastructure of the study region. The inference is that roads (probably the most important economic infrastructure) is not the only answer to production expansion. For instance, as the acreage of cultivation increases, the ratio ALTWR increases, implying drainage and irrigation availability per acre drops, and hence negatively impacts yield, profit and the number of people turning to farming. These factors, in turn, negatively impact land development rate, resulting in lower acreage under cultivation.

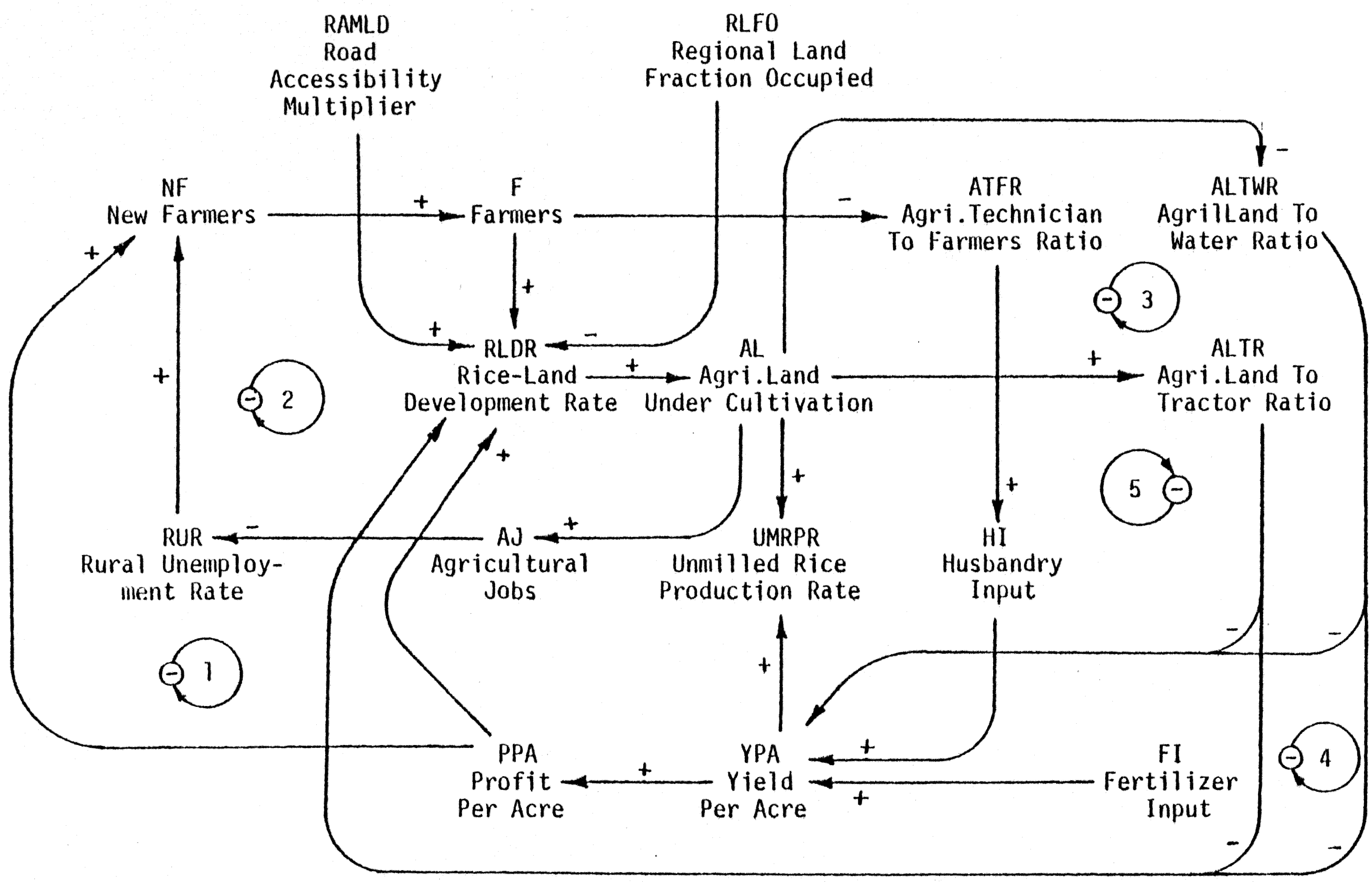


FIGURE 3,4 - Causal Relationships Within the Agricultural Sector

Loop 2 (Farmers F, Agricultural Technicians-To-Farmers Ratio ATFR, Husbandry Inputs HI, Yield Per Acre YPA, Profit Per Acre PPA, and New Farmers FN) shows the impacts of technological inputs or farmers education, as represented by the variable ATFR, on production and productivity.

As technical advice to farmers (represented by the number of agricultural technicians) increases, it is expected that yield will be positively impacted, and therefore the overall production will also increase. This is a negative feedback loop, since an increase in yield means an increase in profits, which positively impacts the number of farmers; and this reduces the agricultural technicians-to-farmers ratio ATFR.

In a similar manner, Loops 3, 4 and 5 show the direct impacts of drainage and irrigation ALTWR, and mechanization ALTR on rural land development rate RLDR; that is, the perceived availability of these services speeds up the rate at which "new" or virgin land is brought under cultivation.

<u>The Transportation Sector</u>

More and more, transportation has come to symbolize road transportation, which is especially the belief in agricultural development projects. This may be so, because every other mode involves intermodal transfers, creating multiple handling, delays and increased costs. In addition, the provision of roads allows for all levels of entrepreneurships (i.e., single operator and/or major firm operating side by side) in the transportation of regional inputs and outputs. Wherever other

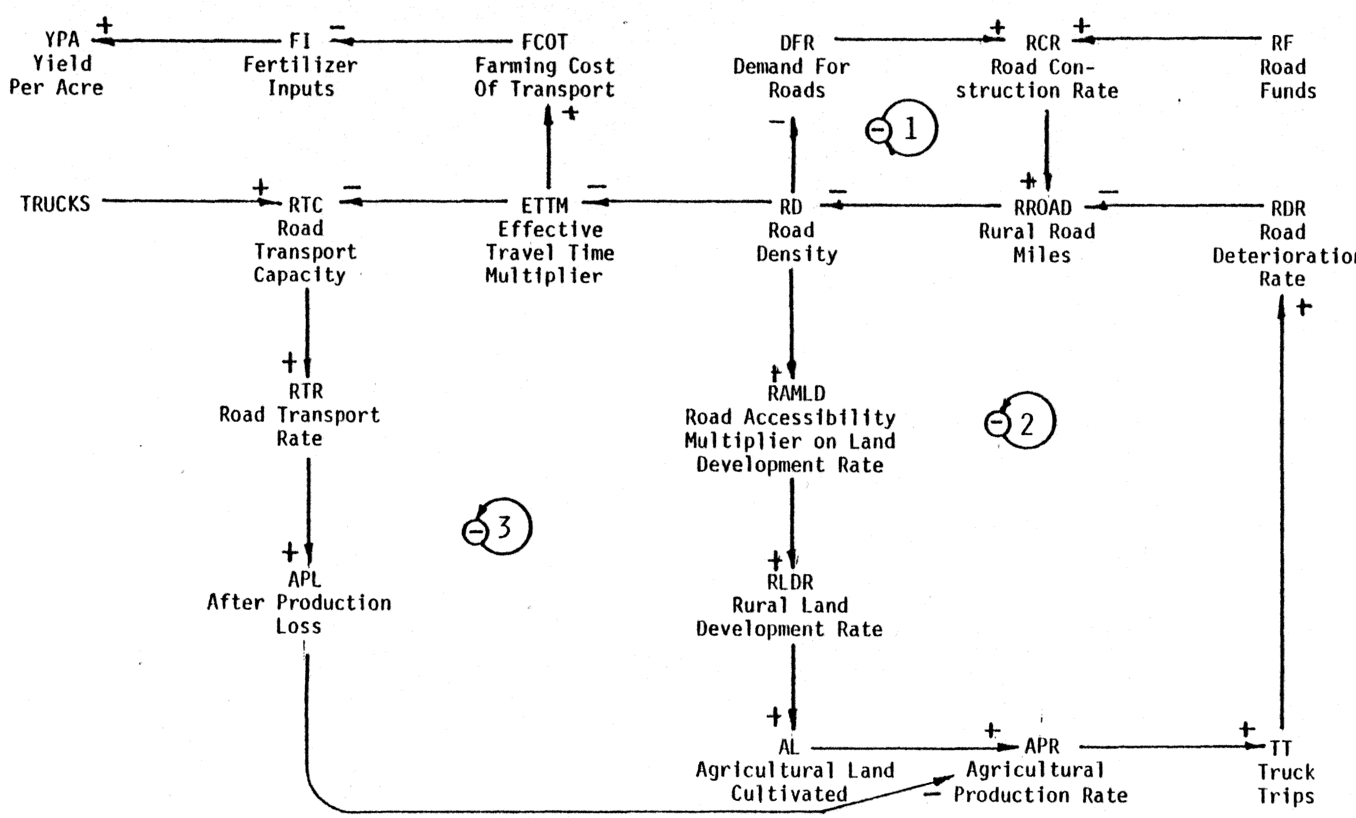


FIGURE 3.5 - Causal Relationships Within the Transport Sector

modes are involved, they are primarily provided to keep pace with the expansion in production due to the increased accessibility and mobility provided by the improved road infrastructure. In the rural scenario, road transportation is generally perceived to be the main constraint to economic growth, and as such it is the focus of the model design. This sector is explicitly represented by the following main components: (1) road fund; (2) total miles of road; and (3) trucks. These components dynamically interact to provide regional accessibility and transport capacity. Figure 3.5 shows that the road transportation sector is defined by three main feedback loops.

Loop 1 (Demand For Road DFR, Road Construction Rate RCR, Rural Road Miles RROAD, and Road Density RD) explicitly incorporates the demand/supply equilibrium concept of roads in the model. Conceptually, the network of roads needed in a given region depends on the crop type being cultivated (or proposed for cultivation); that is, each crop type is best served by a given configuration or network density. As this "ideal" density is reached, further demand for roads ceases, resulting in an equilibrium demand/supply situation, as illustrated by the negative polarity of the feedback loop.

Loop 2 (Road Density RD, Road Accessibility Multiplier on Land Development Rate RAMLD, Rural Land Development Rate RLDR, Agricultural Land Cultivated AL, Agricultural Production Rate APR, Truck Trips TT, Road Deterioration Rate RDR, and Rural Road Miles RROAD) shows the impacts of increased network miles on land development rate on the after production loss. An increase in road density increases the accessibility of the region, which should positively increase the rate at which "new" land is brought under cultivation, and therefore increase the overall output of the region. An increase in regional output without a concomitant increase in transport capacity (i.e., an increase in the mobile stock -- trucking fleet) would result in increased after production losses. Thus, the road infrastructure alone is not the complete answer to overall output rate of the region.

Loop 3 (Road Density RD, Effective Travel Time Multiplier ETTM, Road Transport Capacity RTC, Road Transport Rate RTR, After Production Loss APL, Agricultural Production Rate APR, Truck Trips TT, Road Deterioration Rate RDR, and Rural Road Miles RROAD) shows the impacts of improved road network on road transport capacity and after production losses. Improvements in the road network should reduce the effective travel time of the region, and a reduction in travel time results in an increase in transport capacity of the region due to shorter return trip time. Likewise, an increase in transport capacity reduces after production loss. This is a negative feedback loop, which also indicates that as after production loss reduces, overall regional agricultural production increases; and an increase in production results in an increase in truck trips, which in turn reduces the road network "effective" miles. Furthermore, the significance of a good maintenance policy is also implied in this loop (i.e., it is not enough to only construct an adequate network, but maintenance of the network must also be adequately provided if overall production is to be sustained).

This loop also attests to dynamic interactions between the transport and agricultural sectors -- through the road accessibility multiplier, agricultural production rate and the road deterioration rate variables.

The Urban Region: Demographic Sector

The hypothesis is that spatial impacts are due to shift in regional migration which is caused by the perceived differences in unemployment rates or the ability to secure employment in a given region. At this stage, one possible approach to complete the modeling process is to use the current or projected unemployment rate of the urban region. This approach, however, would remove the dynamic impacts that would result in the socio-economic characteristics of the regions affected by a significant shift in the population. A change in population not only affects the unemployment rate, but also the demand for housing, labor availability, regional income per capita, etc., as shown in the previous submodels developed so far. Thus, it becomes necessary to use a "dynamic" or updated urban unemployment rate, which can only be done by explicitly incorporating the sectors that produce the unemployment rates.

Figure 3.6 shows that the demographic sector has three main feedback loops with the underlying structure similar to that of the rural demographic sector (as it should be, since the population level of any region depends primarily on the same variables -- birth, death and migration rates); the only difference is in the housing construction loop, where land availability in the urban region creates an additional

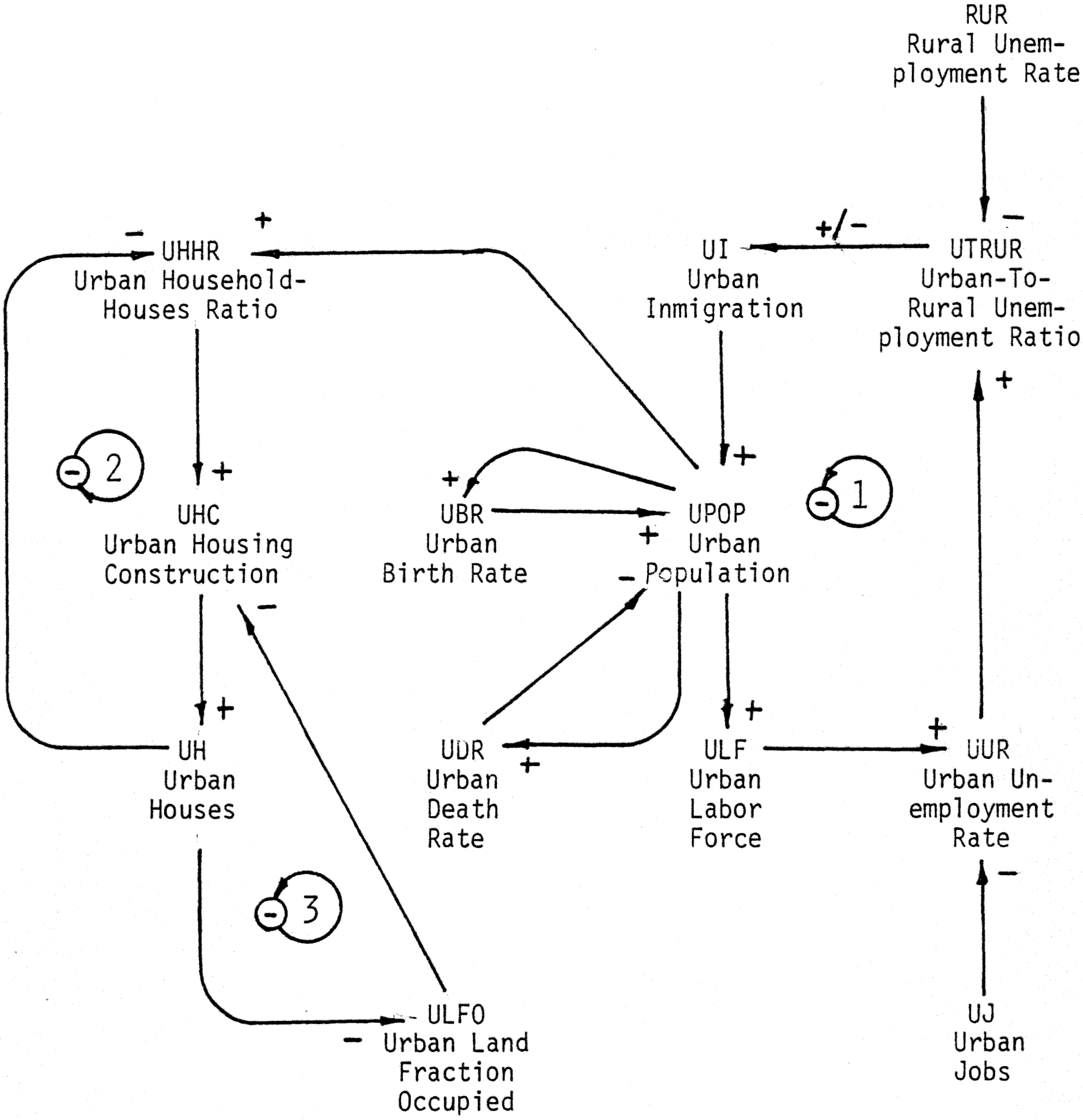


FIGURE 3.6 - The Causal Relationships Within The Demographic Sector

constraint to housing rate of growth not experienced in sparsely populated rural regions. The explanation of the loops is similar to that of the rural region.

The Urban Region: Economic Sector

The socio-economic activities of the urban region create the job opportunities of the region. The degree of disaggregation of the socio-economic activities into manufacturing, service industries, etc., depends on the region being studied and the cost involved for the disaggregative studies. Figure 3.7 shows the main feedback loop (Urban Business Structures UBS, Urban Jobs UJ, Urban Unemployment Rate UUR, Urban Labor Availability Multiplier ULAM, and Urban Business Construction Rate UBCR) underlying the dynamic structure of the sector. Conceptually, as the number of business structures increases, the job opportunities increase, leading to reduced unemployment rate, which in turn reduces the labor force available for further business expansion. This indicates that the feedback loop is negative. Furthermore, the growth of both sectors (the demographic and economic) is governed by land availability.

3.3.3 Synthesis of the Submodels

The premise of the model development is that there are definite linkages, causality and feedback relationships between the major sectors of the economy; and that investments in any of the sectors will impact the other sectors in the long run. Specifically then, the synthesis or linkage of the sectoral submodels explicitly accounts for the causality, feedback and catalytic impacts of investments in transport

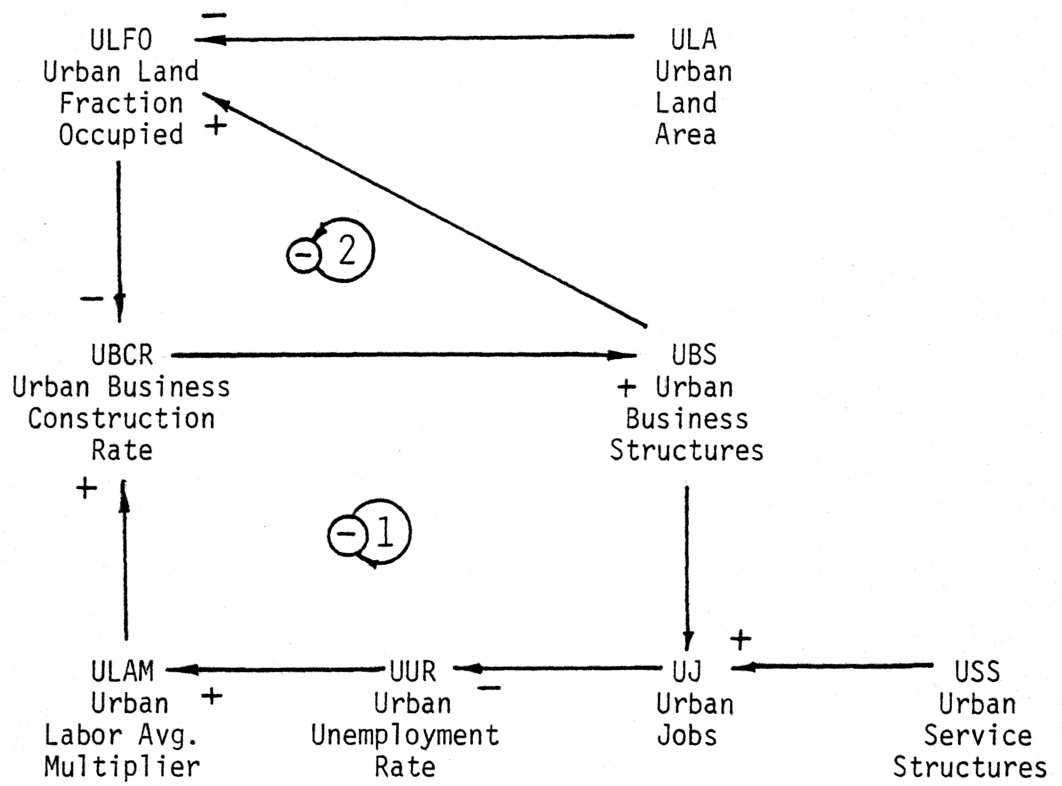


FIGURE 3.7 - The Causal Relationships Within the Economic Sector

and other economic infrastructure on production (i.e., the economic sector) and on shifts in population (i.e., the demographic sector).

Figure 3.8 shows the simplified synthesized causal model of the impacted regions, in which only the main loops that influence inter-sectoral impacts are included. The important inter-sectoral impacts are recognized through the following variables: (1) Agricultural Land Development ALDR: (2) After Production Loss APL; (3) Agricultural Jobs AJ; (4) Urban To Rural Unemployment Ratio UTRUR; and (5) Urban In-Migration UI. The first three variables link the sectors of the investment region, while the last two variables link the rural region with the urban region, thus providing explicitly for the spatial impacts.

The synthesized causal model of the impacted regions provides the framework for the collection of the appropriate data base and the development of the quantitative mathematical model for the economic analyses of a given investment policy.

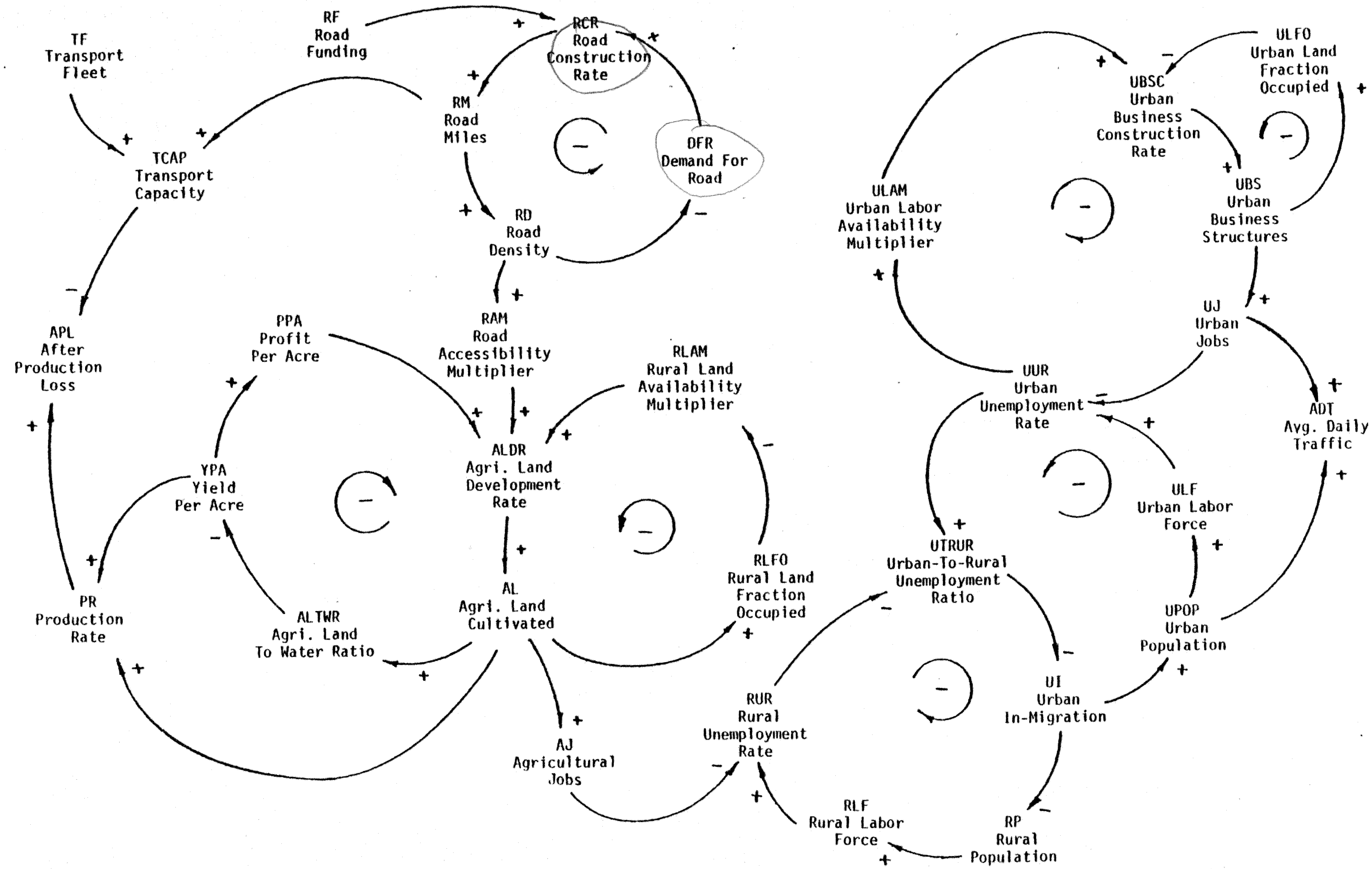


FIGURE 3.8 - The "Comprehensive" Causal Model Showing Main Feedback Loops

CHAPTER 4

CASE STUDY OF GUYANA

The foregoing chapters have presented the rationale and concepts considered necessary for a comprehensive evaluation of rural transportation and related investments in developing and poorly accessible agricultural regions in less developed countries. What remains to be done now is to apply these concepts and techniques in a real world scenario. The nation of Guyana is chosen for the case study because (1) it is typical of LDCs in which accessibility is perceived to be a main constraint to accelerated economic growth and national integration; (2) large sums of money are annually allocated for the expansion of the transportation sector; (3) the nation's professed economic destiny is in the development of its agricultural potentials; and (4) the researcher's own intimate knowledge of the country.

This chapter consists of four sections. Section 4.1 provides a brief background of the geographic, demographic and economic characteristics and also the agricultural objectives of the nation. Section 4.2 provides a detailed discussion of the socio-economic characteristics of the study regions directly impacted by the investments and the region that is assumed to be spatially impacted under any given investment strategy. In Section 4.3, the model's levels, main assumptions and equations are presented and discussed. In Section 4.4, the model calibration is undertaken -- a ten-year period of basic data is used to develop a working model on which policy analyses will be undertaken in Chapter 5.

4.1 Background

4.1.1 Geography: Location

Guyana is located on the northern coast of South America between 1 and 9 degrees North Latitude and 57 and 65 degrees West Longitude. It is bounded on the east by Surinam, on the south by Brazil, on the west by Venezuela, and on the north by the Atlantic Ocean. Figure 4.1 shows the main regions and geographic location of Guyana to its neighbors.

4.1.2 Geography: Land Topography

Guyana consists of three natural regions: (1) a coastal plain; (2) an intermediate peneplain; and (3) the highlands.

The coastal plain, which comprises the coastal and peripheral areas, is rich in alluvial soils, flat and low-lying (four to five feet below the sea-level at high tides), and subject to deluge and drought. Costly sea defense, drainage and irrigation works are pre-requisites for agriculture.

The intermediate peneplain situated immediately to the south of the coastal plain, and constituting a part of the Interior Areas, is a broad east-west plateau of sand and clay, which contains minerals such as bauxite, manganese, laterite and copper. Part of this region is Savannah (the Intermediate or Eastern Savannahs in the Berbice Area), which is subject to leaching, is deficient in minerals, sparsely-covered with grass, and suited only to very extensive farming. The remainder is dense equatorial forests which contain greenheart, purpleheart, mora, crabwood and wallaba (i.e., commercial species of wood).

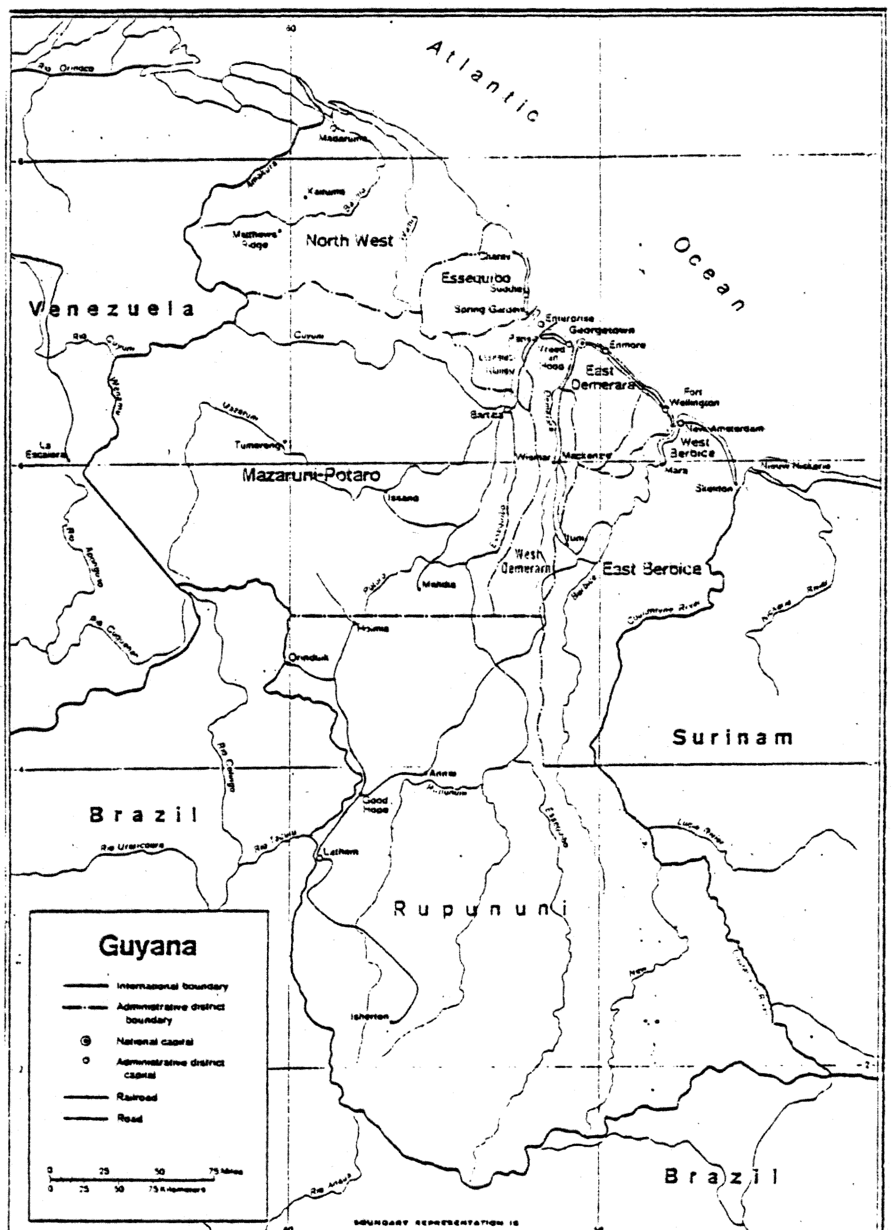


FIGURE 4.1 - Map of Guyana

The highlands, situated immediately to the south of the intermediate peneplain, and constituting the remainder of the Interior Areas, is by far the largest of the three natural regions and is for the most part hilly, mountaineous and intersected by rivers. It is known for its gold and diamonds and spectacular scenery (including the world-famous Keiteur Fall with a sheer drop of 721 feet). It is mostly covered with dense equatorial forests except for a small area (about 4,500 square miles) located in the southwest which is Savannah (the Interior or Ruqununi Savannahs). The Savannahs are sparsely covered with grass and suited only for extensive farming; that is, cattle rearing.

4.1.3 Geography: Rivers

Guyana's land platform is cut by numerous rivers which flow generally in an easterly or northerly direction to the Atlantic Ocean from the highlands, through the intermediate peneplain and the coastal plain.

The four major rivers which all flow in a northerly direction are: the Corentyne, which is located along Guyana's eastern border with Surinam; the Berbice, which is located to the west of the Corentyne and runs generally parallel to it at distances varying from 20 to 60 miles; the Demorara, which is located to the west of the Berbice and runs generally parallel to it at distances varying from 20 to 60 miles; and the Essequibo, which is located about 20 to 30 miles to the west of the Demorara.

The Essequibo is the largest river (approximately 30 miles wide at its mouth). It originates near the Brazilian border, flows a distance of about 400 miles to the Atlantic Ocean and has many large tributaries.

4.1.4 Geography: Climate

Guyana has an equatorial climate with high humidity, a high but variable rainfall, and medium to high temperatures. On the coastal region, the high humidity is tempered by the cool northeast sea breezes. The annual rainfall varies from about 65 to 105 inches. Temperature ranges from 65 to 95 degrees; and there are 11 1/2 to 12 1/2 hours of daylight.

The coastal region has two wet and two dry seasons. The first wet season usually occurs from April to August, and the first dry season from August to mid-November. The second wet season normally occurs from mid-November to January, and the second dry season from January to April.

The forested areas have a more even rainfall throughout the year. The Savannahs have a well-marked dry season from October to February, while the wettest months are from May to August.

The country lies to the south of the hurricane belt and is not affected by the hurricanes that periodically sweep the Caribbean and Central American regions.

4.1.5 Land: Area and Distribution

Guyana's total land area is about 83,000 square miles distributed roughly as follows: 1,000 square miles (1.2%) in the coastal region; 2,000 square miles (2.4%) in the intermediate region; and 80,000 square miles (96.4%) in the interior region.

The coastline is about 270 miles long; the longest east-west airline distance is about 300 miles; and the longest north-south airline distance is about 470 miles.

4.1.6 Economy: Production and Distribution

Production here refers to the number of tons of commodities produced annually that have to be exported or that have to be transported from one geographic area to another within the country. Locally consumed products, to the extent feasible, are included.

Additionally, two types of production are distinguished: (1) gross production; and (2) net production. Gross production includes, whereas net production excludes, sugar cane, rice paddy and bauxite ore. Net production includes products derived from sugar cane, rice paddy and bauxite ore (i.e., sugar, rice, dried bauxite, calcined bauxite, aluminia, etc.).

Existing annual production is estimated to total on the order of 10,000,000 tons gross, or 4,000,000 tons net. The large difference between gross and net production (6,000,000 tons annually) indicates the huge quantities of waste products resulting from processing sugar cane, rice paddy and bauxite ore. Available gross and net production figures by major product groups for the year 1972 are given in Table 4.1 and are as follows.

Bauxite ore and sugar cane dominate gross production. Bauxite ore accounted for 4,988,000 tons (52%) of the 1972 gross production. Sugar cane accounted for 3,145,000 tons (33%) of the 1972 gross production. Rice paddy accounted for 169,000 tons (2%) of the 1972 gross production.

Bauxite products dominate net production. They accounted for 2,593,000 tons (66%) of the 1972 net production. Sugar and related

TABLE 4.1 - Gross and Net Annual Production By Products, 1972[23]

	Gross Production (000's of Tons)	% of Total	Net Production (000's of Tons)	% of Total
Agricultural Fishing and Forestry				
Sugar Cane	3,145	32	--	--
Rice Paddy	169	2	--	--
Other Crops	166	2	166	4
Livestock	7	<1	7	<1
Fishing	17	<1	17	<1
Forestry	182	2	182	5
Mining and Quarrying				
Bauxite Ore	4,988	52	--	--
Other	287	3	287	7
Manufacturing and Processing				
Bauxite and Related	--	--	2,593	66
Sugar and Related	431	4	431	11
Rice and Related	110	1	110	3
Other	165	2	165	4
TOTAL	9,667	100	3,958	100

products accounted for 431,000 tons (11%); rice and related products for 110,000 tons (3%).

These three products -- sugar, rice and bauxite -- accounted for over 8,000,000 tons, almost 90% of 1972 gross production, and over 3,000,000 tons, almost 80% of 1972 net production.

When the geographic distribution of the production areas for sugar cane, rice paddy, bauxite ore and their related products is examined, two items of importance stand out. First, the production areas of all three products are in close proximity to Georgetown (country's capital). Second, the production areas of all three products occupy relatively small areas of land.

Production yields from areas close to and remote from Georgetown ("close" being defined as up to approximately 100 miles from Georgetown, "remote" as beyond 100 miles from Georgetown) are given in Table 4.2, and the cultivated areas occupied by the principal crops in 1972 are given in Table 4.3.

Areas close to Georgetown yielded 9,376,000 tons (97%) of the gross production, or 3,667,000 tons (93%) of the net production. Areas remote from Georgetown yielded 291,000 tons (3%) of the 1972 gross production, 7% of the 1972 net production.

Additional to the total area occupied by the principal crops (Table 4.3, 601 square miles in 1972), substantial areas are occupied by related land uses such as pasture, gardens, dams, canals, roads, houses, factories, mills, schools and community buildings, bauxite mining and processing facilities, and other economic activities. But, even

TABLE 4.2 - Gross and Net Production by Areas, 1972[23]

	Gross Production (000's of Tons)	% of Total	Net Production (000's of Tons)	% of Total
Areas Close to Georgetown				
Coastal Area	4,134	43	823	21
Peripheral Area	254	3	251	6
Linden-Ituni-Kwakwani	4,988	52	2,593	66
SUBTOTAL	9,376	98	3,667	93
Areas Remote From Georgetown				
Other Interior Areas	291	2	291	7
TOTAL	9,667	100	3,958	100

TABLE 4.3 - Cultivated Area of Principal Crops, 1972 [23]

	Acres	Square Miles	% of Total
Sugar Cane	130,421	204	34
Rice and Maize	199,919	312	52
Other Crops	54,615	85	14
TOTAL	384,955	601	100

with all these additional areas, it is clear that only a very small part of the total 83,000 square miles of Guyana is actually developed.

Although exact figures are not available, it seems that a maximum of about 3,000 square miles (3.5%) of the total land area is intensively developed, and about 80,000 square miles (96.5%) is undeveloped -- except for isolated pockets, most of which are developed on an extensive basis. It appears that over 90% of the total gross and net production is obtained from less than 2% of the land, and that almost all of this production takes place on land within a hundred or so miles from Georgetown. Figure 4.2 shows the distribution of the production areas of the primary products (i.e., sugar, rice and bauxite) in Guyana.

4.1.7 Human Resources: Population and Distribution

The geographic distribution of the population corresponds closely with the distribution of production, with some notable exceptions. The Linden-Ituni area, for example, contains less than 5% of the total population, produces over 40% of the total net production and over 50% of the total gross production, an imbalance that reflects the high productivity of the bauxite mining and processing operations. The centers of Georgetown and New Amsterdam (the second important center of the country) on the other hand contain proportionately more population than gross production. With these exceptions, the population generally corresponds closely with production regions, and, as would be seen later on, with accessibility by roads.

The 1970 census shows Guyana's population at about 740,000. About 640,000 persons (86% of the population) live and work in the Coastal

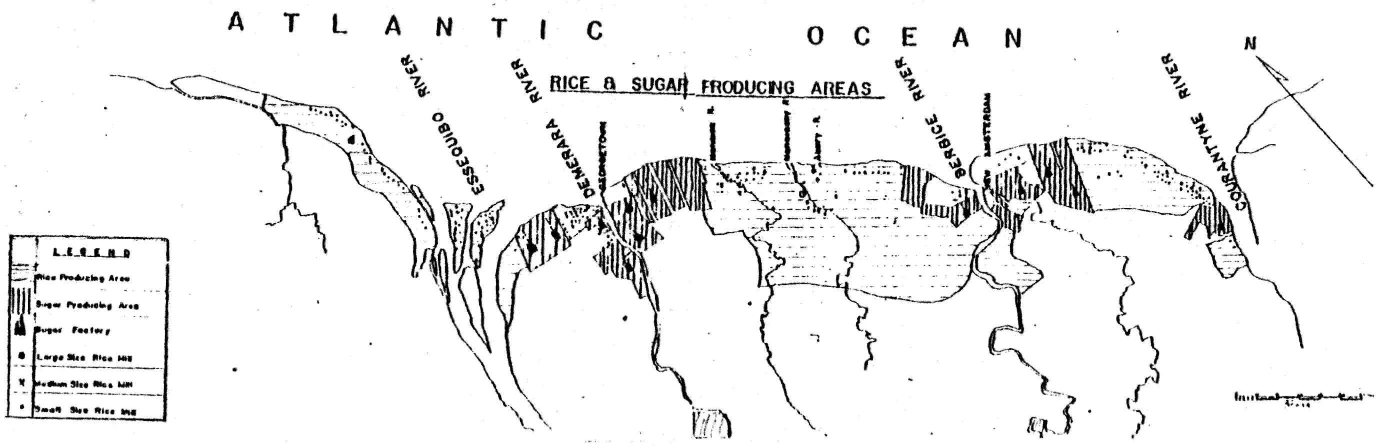


FIGURE 4.2 - Map of Guyana Coastal Region Showing the Distribution of the Main Agricultural Crops

Area, and about 100,000 (14% of the population) live and work in the interior. The metropolitan area of Georgetown, including the vicinity within 25 miles from the center of the city, contains more than 50% of the population. Figure 4.3 shows the distribution of the Coastal Area population, and Table 4.4 gives the breakdown of the Georgetown metropolitan area population.

The population of Guyana in 1945 was 375,000 persons; in 1960, 560,330; and had risen to 740,000 in 1970. This represents an average annual rate of growth of 2.9% over the past decade. Registration data has indicated that birth rate has declined slightly from 42 births per thousand per year in 1960 to 37 per thousand in 1970. This decline has been accompanied by a reduction in the death rate from 9.5 deaths per thousand per year to 8.5 per thousand.

A survey of the manpower requirements and labor conducted by the United Nations in 1965 covered all of Guyana except the very sparsely populated region. At the time of the survey, the labor force was given as 174,772 persons, with participation rates for males 14 years and over of 81.8% and for females of 29.3%. Based on similar participation rates, the labor force for 1970 is given as 225,000 persons in 1970. A similar survey for work places indicates an unemployment rate of over 20% in 1970.

The literacy rate in Guyana is quite high. An estimated 90% of the children receive the basic education, which is eight years of compulsory instruction, including the full primary course, plus two years in all-age school, as a result of the Education Act of 1876.

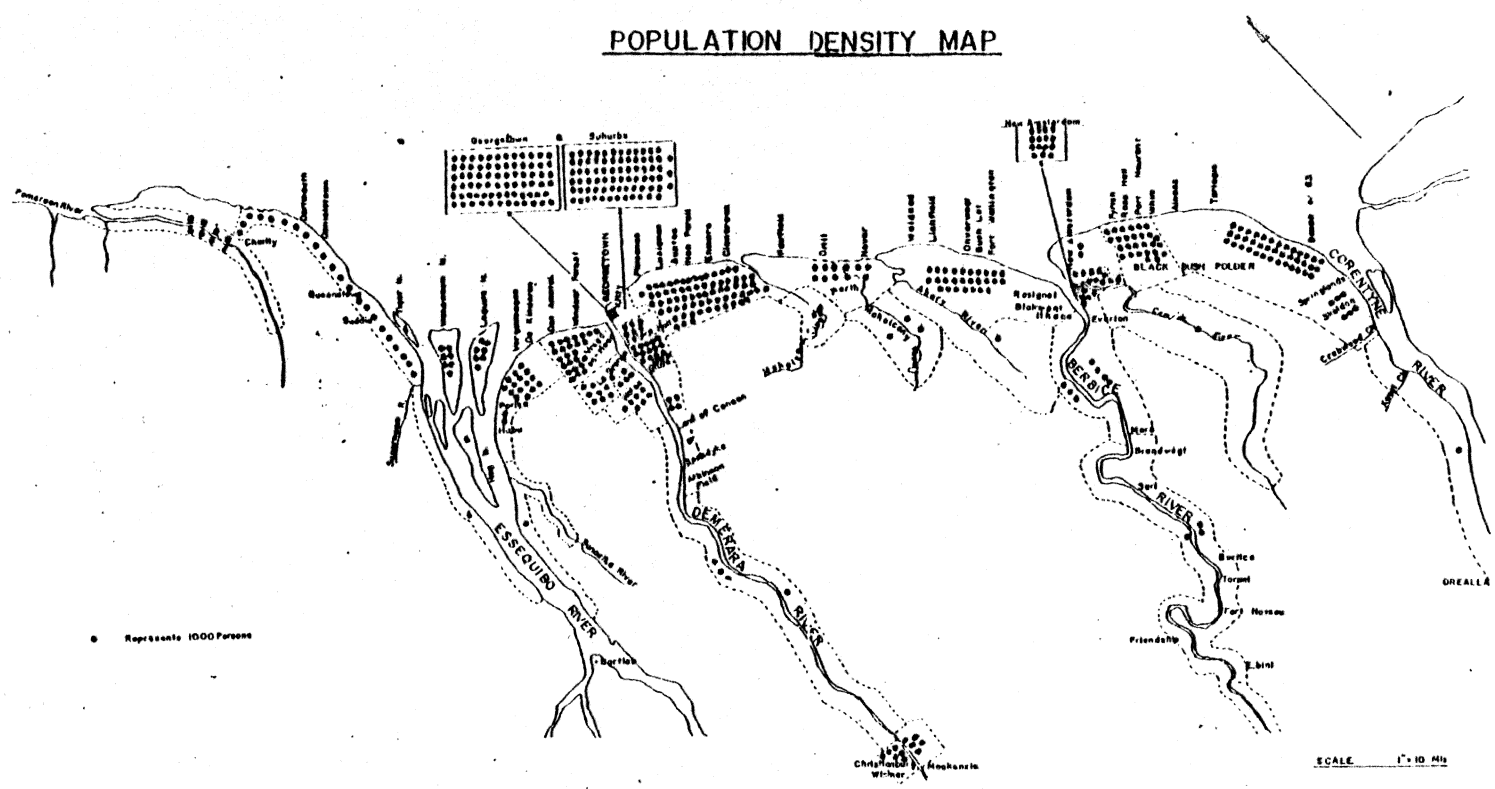


FIGURE 4.3 - Map of the Population Distribution of Guyana

TABLE 4.4 - Population of Georgetown Metropolitan Area, 1970 [24]

	Persons	% of Total Population
Georgetown City	164,000	23.4
Georgetown Environments:		
o East Coast Demerara	92,000	13.1
o East Bank Demerara	36,000	5.1
o West Bank Demerara	25,000	3.6
o West Coast Demerara	53,000	7.6
TOTAL	370,000	52.8

4.1.8 Transportation: Available Modes

The modes of transport available in different geographic areas reflect, and are a reflection of, the geographic distribution of total passenger and freight loads. Figure 4.4 shows the principal means of transport to Georgetown from different parts of the country, divided into six categories as follows:

Category 1: includes areas from which road is the principal means of transport.

Category 2: Includes areas from which road is the principal means of transport, but a ferry must also be used (travel time to Georgetown from these areas is significantly high because of the ferry crossings).

Category 3: Includes areas from which transport via trails is the principal means of transport (vehicular transport from these regions can be accomplished only by 4-wheel drive vehicles; driving is extremely difficult and slow, and in many places is only possible in fair weather).

Category 4: Includes areas from which water transport is the principal means (roads or trails may be used within these areas for transport to a port, but they cannot be used for the total trip to Georgetown).

Cagegory 5: Includes areas from which air transport is the principal means (roads or trails may be used within these areas for transport to an airport, but they cannot be used for the total trip to Georgetown).

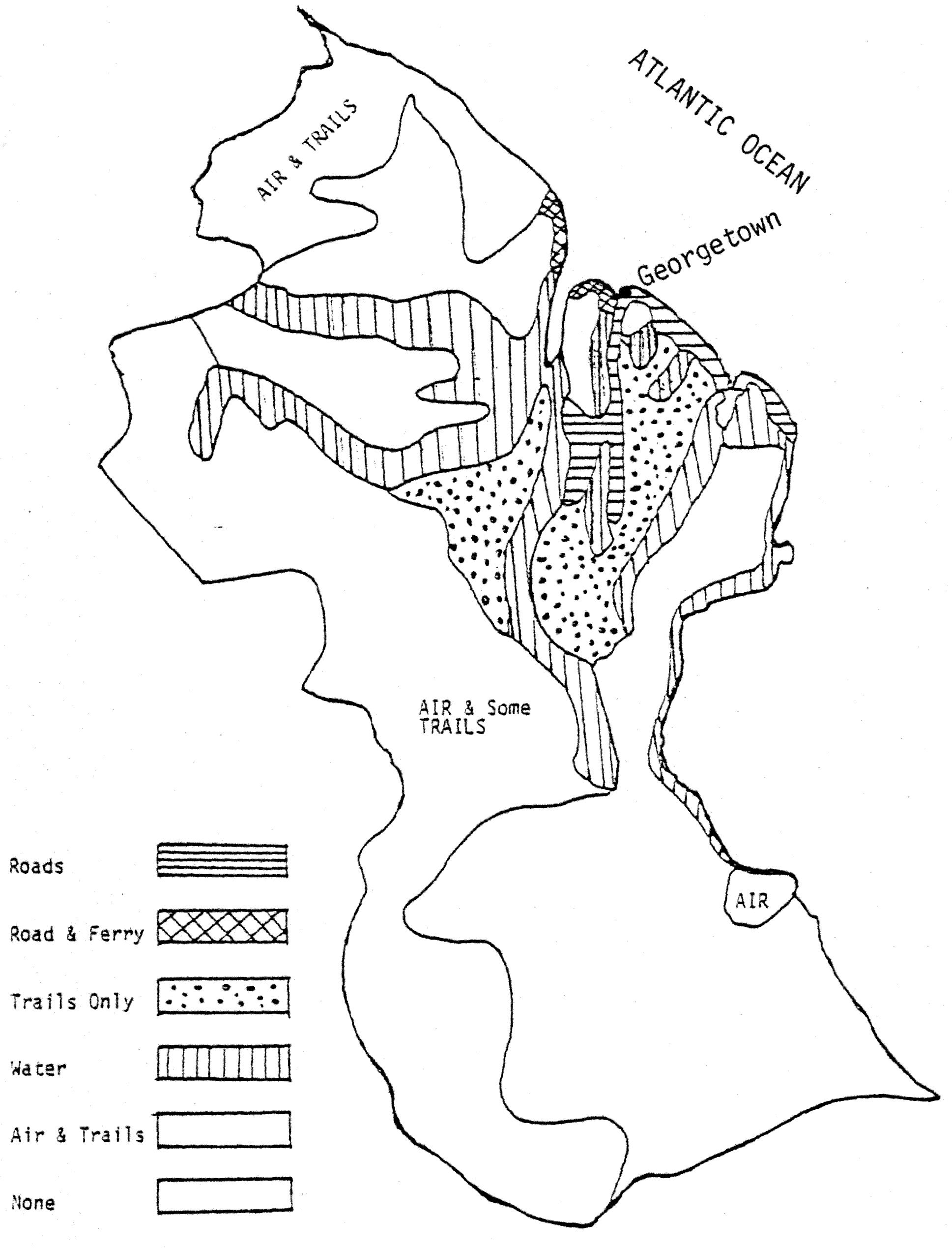


FIGURE 4.4 - Map Showing Principal Modes of Transport to Georgetown

Category 6: Includes areas from which neither road, water nor air transport is available.

With these different modes of transport, one would expect that there would be one single agency responsible for the planning and co-ordination of all aspects of the transport system, intra-modally and inter-modally. However, no such agency exists. The responsibility for each mode of transport is divided and handled by a heterogeneous mix of agencies. Thus, there is a lack of coordination.

Road transport, undoubtedly the most important mode in terms of connectivity and impact on agricultural development, is discussed in some detail. The road subsystem carries almost all of the total passenger load (98% of the estimated 1972 passenger miles), and a substantial proportion of the total freight load (34% of the estimated 1972 ton miles). It carries all of these loads in the Coastal Area and minimal loads in the Interior.

Roads carry passenger and freight loads to and from water and air transport terminals (thus, completing door-to-door trips which involve other transport modes). The national road network which carries these loads consists of about 1,470 miles of paved roads and unpaved trails, as shown in Fiugre 4.5 (urban and other local roads with a total of about 1,600 miles is not included in the figure).

4.1.9 Commodity Flows

The major production flows of sugar, rice and bauxite are fairly concentrated and depend on more or less unique modes of transport, as described below.

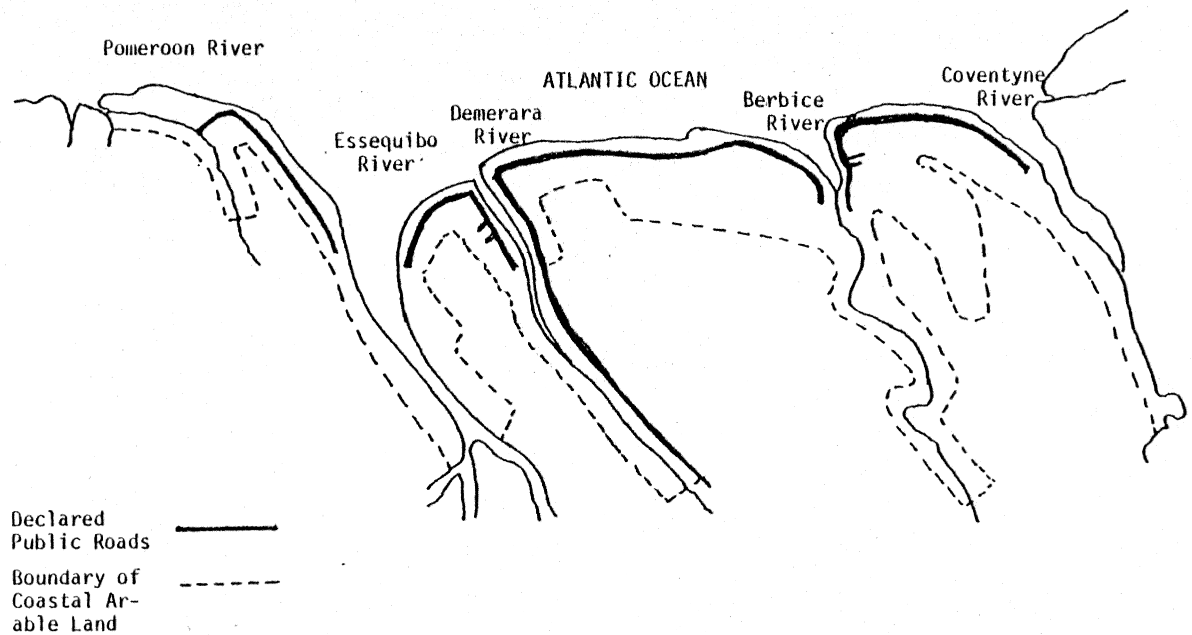


FIGURE 4.5 - Declared Public Road and Limits of Coastal Arable Land

a. Sugar

About 93% of Guyana's sugar cane is produced on eleven large and two small sugar estates; the remaining 7% on a number of small cane farms, all located along the Coastal Area between the Corentyne and Essequibo rivers. The estates run in narrow strips generally southward from the main coastal arterial highway to the swamps at an average depth of about 7 miles south of the highway. The swamps are dammed off to provide a controlled water supply for irrigation and cane transport. The estates range from 1 to 30 square miles in area. The average estate is about 10 square miles, about 7 miles in depth, and about 1.5 miles in width. It has been estimated that the total length of the irrigation-transport canals on all the estates is well over 5,000 miles.

Almost all the sugar cane (3,000,000 to 4,000,000 tons) is transported in small flat-bottomed steel barges, towed by tractors or powered boats, along the canal to one of the eleven estates. Here, the cane is crushed and sugar and molasses extracted.

Most of the processed sugar (300,000 to 400,000 tons annually) is transported from the estate factories by coastal ships or by barges towed by tugs to the port of Georgetown. Factories close to Georgetown use bulk road transporters.

At the port of Georgetown, the sugar is loaded into a 70,000 ton capacity bulk storage-loader facility. About 30,000 tons annually are retained for domestic consumption; the remainder (about 300,000 tons annually) are exported chiefly to the United Kingdom, Canada and the United States.

Molasses (100,000 to 130,000 tons annually) is transported in more or less the same way as sugar.

Water transport is the predominant means used to transport cane, sugar and molasses from estates to factories, from factories to bulk terminals, and from the bulk terminal to overseas markets.

b. Rice

The flows of rice are quite different from those of sugar because of the very large number and small size of rice farms. Sugar estates average about 10 square miles in area; but most rice farms are less than 10 acres, as given in Table 4.5.

While there are 13 sugar estates and a relatively small number of cane farms, it is estimated that the number of rice farms is in excess of 30,000. This means that there are thousands of small flows from rice farms to rice mills; and the estimated annual output from each rice farm is between 3 and 5 tons (a small truckload).

The rice paddy (200,000 to 300,000 tons annually) is moved from the rice farms by truck, boat, or tractor-hauled cart to the rice mills nearby where the husk and rice are separated. Each year, the autumn crop, which is planted between April and May and produces about 80% of the total yield, is harvested during October, November and December. The spring crop is usually planted in December and harvested during March and April.

Some of the processed rice is retained by the producers (35,000 to 45,000 tons annually), but most of it (80,000 to 110,000 tons annually) is transported from the mills to the warehouses of the Guyana Rice

TABLE 4.5 - Acreage of Rice Farms, 1968 [23]

Size of Farms (Acres)	% of Farmers	% of Rice Lands
0 - 9	81	43
10 - 49	17	26
50 - 99	1	7
100 and Over	1	24
TOTAL	100	100

Marketing Board in Georgetown. Nearly all of this is transported by truck except for that from the Essequibo Coast and Islands, which is transported by boat.

The Rice Marketing Board is responsible for storage, remilling, packaging and distribution. It retains a small quantity of the processed rice for local consumption (10,000 to 15,000 tons annually), and exports the balance (70,000 to 100,000 tons annually), mostly to the Carribbean countries.

The basic transport problem of rice farmers is the transport of paddy from farm to mills. Many farmers now have to struggle some distance along muddy dams and tracks before reaching a reasonably well-surfaced road. Moreover, they have virtually no possible way of solving this problem on their own. Provision of the necessary access is the task of Government. This is in strict contrast to the situation of the sugar and bauxite producers. They have virtual control over any transport problem that may arise.

c. Bauxite

The flows of bauxite and related products are fairly simple compared to those of rice and sugar. Almost all of the bauxite ore is mined at three places in the Interior -- Linden, Ituni and Kwakwani -- and transported from there to two processing centers -- Linden and Everton. Products are transported from the processing centers directly to overseas trans-shipment points, and from there to overseas market.

4.1.10 The Relevance of Agricultural Development to Guyana's Economy

Funding of major development projects in LDCs should not only be economically feasible, but in consonnance with the national development policies, if maximum possible benefits are to be achieved from the investments.

The agricultural sector constitutes the largest productive sector in the economy of Guyana. The sector's share of the Gross Domestic Production (GDP) at current factor costs averaged 23%. However, real growth in the agricultural sector has not kept pace with population growth since 1961, resulting in increasing dependence on imported food.

The sluggish growth in agricultural production has been associated with a decline in the proportion of the labor force employed in this sector; that is, from 45% in 1950 to 31% in 1975.

During this period, the share of the population living in the rural areas have remained fairly constant, implying a substantial increase in rural unemployment and underemployment. With limited employment opportunities in the urban areas due to slow growth in light industries and employment saturation in the tertiary sector, there is a strong need for the development of agricultural production for both export and domestic markets.

Guyana's development strategy is directed towards development of the rural sector through an integrated economic and social approach designed to increase food production and rural incomes, while concomitantly providing selective social services to the rural population.

Stressing the emphasis of agricultural development is the Government's Third Development Plan (between 1978 and 1981), which allots fully one-third of all public and private investments to agricultural activities. This amount is more than double the percentage provided to this sector during the previous Five-Year Plan. The rationale for the new plan is that the majority of its resources over the next four years should be devoted to the productive sector, such as agriculture, since it is seen as the only feasible approach open to Guyana to recover from its present economic crisis.

The potential for expansion and diversification of the agricultural sector is not in doubt; all that is needed is the investments to exploit its resources.

Moreover, emphasis on rural oriented project activities are fully in consonnance with policy guidance relating to assisting the most economically deprived areas. The rural per capita income in 1976 was estimated at approximately $200, which is considerably below the national per capita income of $540. Table 4.6 provides the basic socio-economic data on Guyana.

4.2 The Study Regions

In resource-scarce economies, there are no shortages of requests for improved access or other socio-economic infrastructure; the question is generally where to allocate the limited resources in order to obtain the most satisfactory national benefits; or to put it another way, the least negative impacts. Choices are never really clear-cut since there are very often conflicts and trade-offs between national goals and economic returns. However, there are definite socio-economic indicators as to where investments might be "seemingly" justifiable. An examination of the distribution of the population and economic

TABLE 4.6 - Basic Socio-Economic Data on Guyana [23]

Basic Data	
Total Population	832,000 (1978)
Per Capita GNP	$540 (1976)
Average Annual Per Capita Real GNP Growth Rate	- 1% (1970-1975)
Average Annual Rate of Inflation	Not Available
% of National Income Received By Low 20% of Population	4.3% (1960)
Literacy Rate	85% (1972)
Special Data	
Population Growth Rate	2.2% (1967-1977)
% Population in Urban Areas	32% (1970); 40% (1973)
Total Birth Per 1,000 Population	27 (1976)
Total Death Per 1,00 Population	9 (1976)
Foreign Trade	
Major Exports	Alumina, Sugar, Rice (1977)
Major Imports	Machinery, Fuel, Fertilizer, Food (1976)
Main Trading Partners	U.K., U.S.A., Carribean
Transport Capital Expenditure	
Transport Capital Expenditure as a % of Total Capital Expenditure	21.7 (1970); 26.8 (1970)

activities (i.e., industry and agriculture) in relation to the transportation system and classified arable land, as shown in Figures 4.2, 4.3, and 4.5, provides positive indication as to where transportation and agricultural related investments might be feasible. An analysis of the above figures shows quite clearly that the intensity of economic activities is dramatically curtailed at the end of passable roads, even though the soil is classified as arable beyond the end of the passable roads. That is, the quality of the transport services provided influences both the intensity and extensiveness of the region's development. Figure 4.6 shows five such potentially viable regions based on the above socio-economic indicators and soil classifications. However, as previously stressed, no investment is spatially neutral; that is, the impacts of the investment is felt both regionally and nationally, and as such, it becomes necessary to also identify the spatially impacted region.

4.2.1. The Essequibo Coastal Region

The Area of Influence

The Essequibo Coast lies between the Essequibo and Pomeroon rivers, which are 40 miles apart. The entire area is almost flat, with no part rising more than 50 feet above mean sea level. The arable land area is defined by the Atlantic Ocean on the north, the Pomeroon River on the west, and the Essequibo River on the east, and the interface of the clay strip and the pegasse (an inorganic loam-like material) on the south. This boundary is between one and five miles from the coast and encompasses a potential arable land area of 70,000 acres.

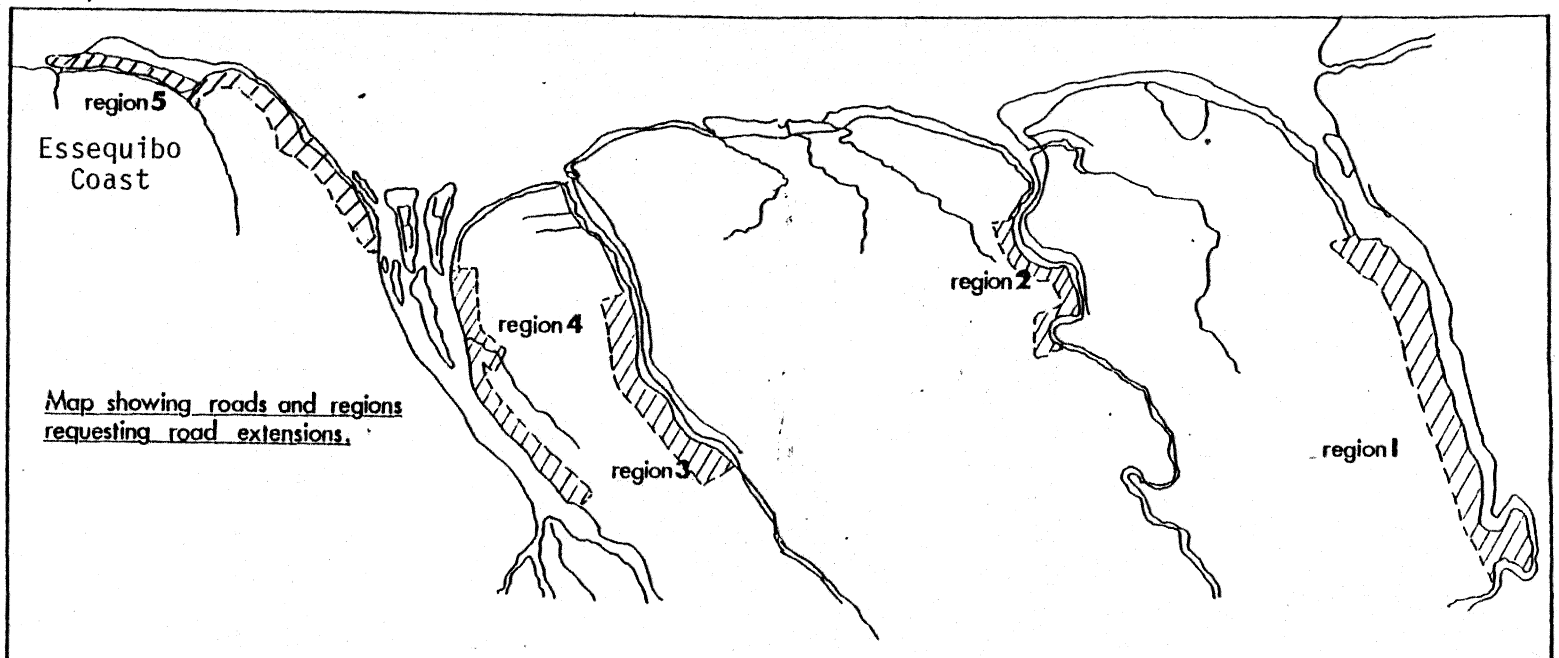


FIGURE 4.6 - Map Showing Regions Requesting Road Transportation

Population Distribution

The bulk of the population lives on the coastal belt, within one-half mile of the Atlantic Ocean. There are two main population centers: Adventure/Suddie and Anna Regina. Ribbon development has occurred along many parts of the existing coastal road, which links the villages of Supenaam on the south and Charity on the Pomeroon River to the north. There are some 40 minor settlements which act as foci for the recreational and commercial activities along the road. The 1970 population is estimated at 35,000 persons.

Economic Activitiy

The prime economic activity in the region is the growing and processing of rice. In 1970 an estimated 29,000 tons of rice were shipped to the Rice Marketing Board in Georgetown. At an average price of G $190 per ton, the base component for the gross regional product was estimated on the order of G $5,551,000. Rice is processed at 33 mills on the coast. The central mill at Anna Regina is government owned, while the others are privately owned. The 1970 acreage under cultivation is 30,000 acres.

Other crops are grown for either local consumption or for sale to the Guyana Marketing Corporation. Other crops cultivated include coconuts (300 acres); citrus (40 acres); plantains (480 acres); ground provisions (450 acres); bananas (300 acres); green vegetables (80 acres); and fruits (150 acres).

Drainage and Irrigation

The area is drained by minor rivers and an extensive drainage and irrigation scheme called the Tapakuma scheme. A pumping station at Dawa lifts water from the Tapakuma River, a tributary of the Pomeroon, and feeds it into Lake Tapakuma. This lake acts as a reservoir for the region and is capable of irrigating 30,000 acres adequately (given that annual rainfall pattern is maintained).

Transportation

The area has three modes of access to the rest of Guyana:

1. Air: An airstrip at Anna Regina serves as a terminal for bi-weekly passenger flights to Georgetown. Light aircraft with a seating capacity of a maximum of 10 passengers may use the strip.
2. Sea: The Transport and Harbours Department has a weekly cargo service connecting the Pomeroon River to Georgetown. In addition, there is a cargo run three times per week between Georgetown and Adventure. All production (primarily rice production) from the coast is transported to Georgetown by these services.
3. Ferry: The Transport and Harbours Department services, totaling 11 runs per week, connects Adventure and the Essequibo Islands with Parika on the west coast of Demerara. This ferry carries primarily passengers, vehicles and some light cargo, and is the link for "land" traffic generated from or going to the Essequibo coast. There is no possibility for a direct road connection to Georgetown in the foreseeable future, since the Essequibo River at this point is approximately 30 miles wide.

On the coast itself, road is the only means of travel between the communities from Supenaam to Charity. The road serves as a vital link for all local traffic, and connects all terminals for alternative modes of access.

The coastal road or main trunk road is approximately 40 miles long, out of which 16 miles can be considered paved, and the remainder "poor to all weather road". There are 110 miles of "dirt" farm roads that serve the current 30,000 acres of rice cultivation. During the wet seasons (twice per year), these roads become impassable and seriously affect the rice production and productivity level. Table 4.7 provides the basic socio-economic data for the Essequibo coast.

Model Economic Growth Potentials

No significant industrial development is foreseen to occur in the Essequibo coast. The one economic area where more rapid growth might be expected to occur is in agriculture. The potential arable land area of the region is estimated at 70,000 acres, out of which only 30,000 are presently cultivated. Rice cultivation is expected to continue as the dominant economic activity of the region, and its growth is dependent on the physical limitation of the road infrastructure and the drainage and irrigation supply of the Tapakuma irrigation scheme. Figure 4.7 shows a map of the Essequibo coast delineating the arable land area, cultivated land area, and the current transport infrastructure.

4.2.2 The Urban or Spatially Impacted Region (Georgetown)

Georgetown's central role in regard to social and economic activities was alluded to in earlier sections. (About 95% of the total annual

TABLE 4.7 - Basic Data of the Essequibo Coast [23]

BASIC DATA	
* Population	30,000-35,000 (1970); 30,000-35,000 (1980)**
Per Capita Income	$260 (1970)
AGRICULTURE	
Total Arable Land Area	70,000 Acres
Cultivated Area (Acres)	30,000 (1970); 33,000 (1975); 35,000 (1980)**
ROAD	
Collector and Farm Roads (Miles)	150 (1970); 175 (1975); 200 (1980)**
Road Expenditure ($)	600,000 (1970); 1,250,000 (1975); 1,500,000 (1980)**

* Population for rural area usually given in ranges because of difficulty to account for everyone in poorly accessible regions.

** Projections for 1980.

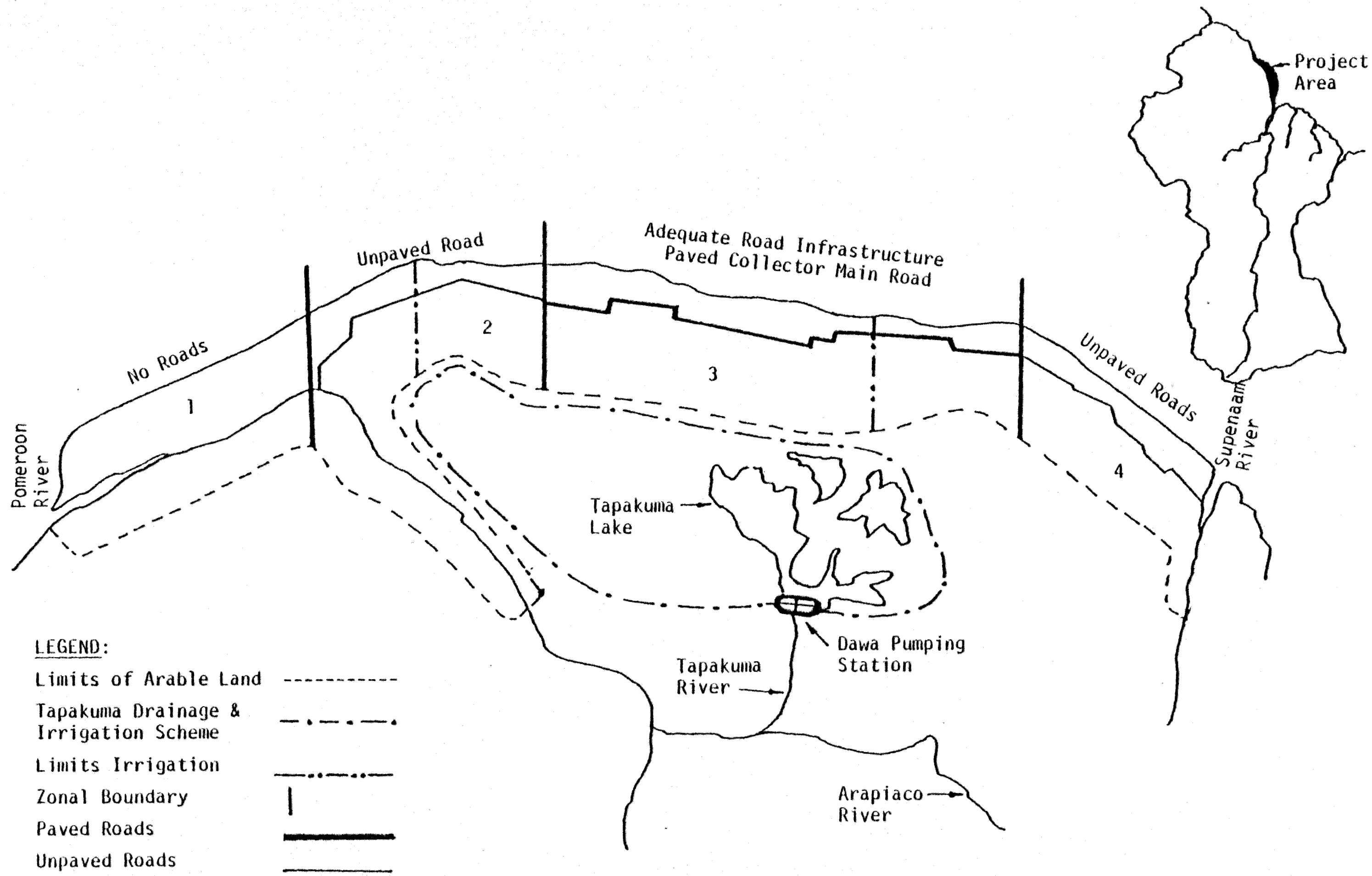


FIGURE 4.7 - Map of Essequibo Coast Showing Limits of Arable Land Area, Roads, Drainage and Irrigation Infrastructure

production and over 90% of the total population are located within a hundred or so miles of Georgetown. Over 50% of the population is located within 25 miles).

There are substantial flows of commodities to and from Georgetown. Those of sugar and rice from the mills to Georgetown and from Georgetown to both local and overseas markets were referred to earlier (see Table 4.3 in Section 4.1.6).

Also, there are substantial daily flows of persons to and from Georgetown, including workers, traders, shoppers, clients, businessmen, civil servants, professionals and others. Additionally, there are smaller, but highly significant, flows caused by less frequent long-distance trips. It appears that the bulk of the country's total daily person trips occurs within the metropolitan area, and that almost all of the country's long-distance trips -- both domestic and international -- either originate in, pass through, or terminate in Georgetown.

Georgetown is Guyana's hub. It holds a commanding position in regard to Guyana's social and economic activities. It holds a parallel position in regard to the total person and goods flows. It is Guyana's political and cultural center, and will undoubtedly remain the main center of activities and flows in the future. Decisions taken in any region will affect Georgetown and its future socio-economic activities.

For the purpose of this study, the urban or spatially impacted region is defined as the region that extends approximately 25 miles from the center of Georgetown (the capital of Guyana) along the Atlantic Coast and the Demerara River. This region accounts for more than 50 percent of the total population and production of the nation (see Tables 4.3 and 4.4). In order to provide a specific advice on the spatial impact due to in-migration to this region, it was considered necessary to subdivide the region into more representative "homogeneous" zones. This subdivision allows for providing explicit advice on population, jobs, housing and highway need for the zones for the planning period. The region is subdivided into four zones, as shown in Figure 4.8. Zone 1 -- Georgetown -- is the defined geographic capital of Guyana, consisting primarily of government services, shopping centers, port facilities and light industries. Zone 2 -- East Bank -- is predominantly sugar cultivation, the country's only international airport, internal shipping and some light industries. Zone 3 -- East Coast -- is predominantly sugar cultivation. Zone 4 -- West Demerara -- is predominantly rice and sugar cultivation. Table 4.8 provides the basic socio-economic data for the four zones of the urban region.

4.3 The System Dynamic Model's Levels, Main Assumptions and Equations

The behavior of a system is the outcome of the feedback loops that underly the structure of the system. Feedback loops govern action and change in the system from the simplest to the most complex. A feedback loop is the closed path that connects an action to its effects on the surrounding conditions, and these resulting conditions in turn come back as "information" to influence further actions [20]. Two kinds of variables dominate a feedback loop -- level and rates. Levels are the accumulation (integrations) and describe the state or condition of a system at any point in time. Rates are flows that cause the level to change

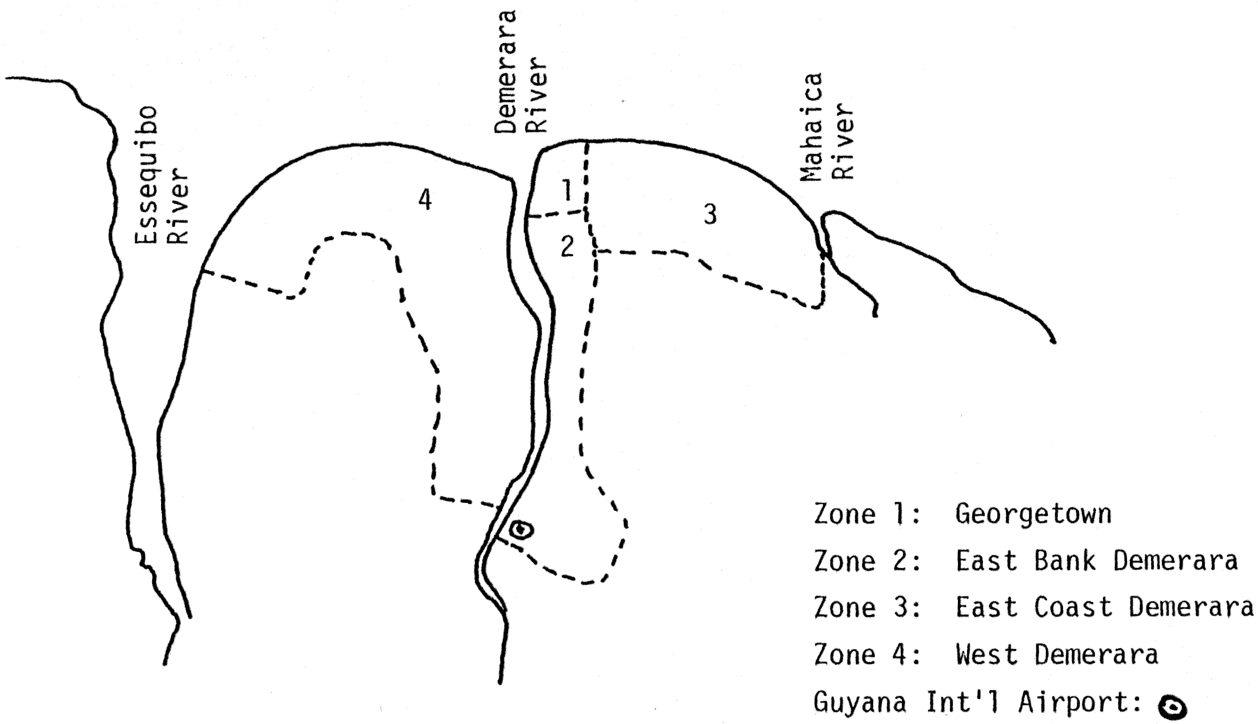


FIGURE 4.8 - Zones of Spatially Impacted Urban Region

TABLE 4.8 - Basic Data of Urban Region[24]

BASIC DATA	ZONE 1 GEORGETOWN	ZONE 2 EAST BANK DEMERARA	ZONE 3 EAST COAST DEMERARA	ZONE 4 WEST DEMERARA
* Population	199,800(1970)	36,600(1970)	78,250(1970)	82,250(1970)
	235,700(1980)	54,600(1980)	122,000(1980)	104,200(1980)
	281,050(1990)	112,200(1990)	180,700(1990)	134,850(1990)
* Jobs	57,400(1970)	9,000(1970)	9,054(1970)	20,060(1970)
	77,930(1980)	15,870(1980)	12,250(1980)	26,970(1980)
	107,700(1990)	27,900(1990)	17,400(1990)	36,250(1990)
Land Area	5,000(acres)	48,000(acres)	70,000(acres)	70,000(acres)

* Values for 1980 and 1990 are projected values.

and are generally associated with policies or decision-making in the system.

In order to understand the behavior of a large complex socio-economic system, it is often necessary to first understand the behavior of components (or main variables) (or smaller sub-system) of the system and then link the components or subsystems to form a "representative" model of the system. Table 4.9 shows the breakdown of the proposed Rural Transportation Planning Model (RURTRAN) in terms of (1) the regions represented; (2) the sectors of regions; (3) the main components or levels that underly the structure and determine the behavior of the region; and (4) the concepts or hypothesized phenomenon represented by the main components or levels.

Figure 4.9 shows a simplified block diagram of the linkage of the main socio-economic sectors and implied shift in population within the study region (i.e., the model's boundary). Investments in the economic infrastructure (i.e., roads and/or drainage and irrigation) in the rural region (Essequibo Coast) impact regional income per capita and unemployment. Furthermore, the perceived differences of these indicators to those of the urban region would result in shifts in population in either direction, as depicted by the double-headed arrow. It should be noted that the urban region in Figure 4.9 is divided into zones, as previously discussed. The major characteristics of each zone relative to those of the nation's capitol are also shown in this figure.

From these main relationships, twelve levels have been chosen to develop the rural region (i.e., the investment region), and five levels

TABLE 4.9 - Rural Transportation Planning Model (RURTRAN): Hierarchical Order of Structure

REGIONS	SECTORS	LEVELS or (Main Components)	CONCEPTS
Rural -- Essequibo Coast. (Directly Impacted Through Investments).	Demographic	Population	Growth depends on births, death, migration, and influences unemployment and housing.
		Housing	Growth depends on population and consumes land area.
	Agricultural	Rice Land Cultivated	Level ultimately depends on available arable land acreage; and determines production and jobs.
		Farmers	Farmer availability determines cultivation level.
		Drainage and Irrigation	Impacts on cultivation intentensity and yield.
Rural -- Essequibo Coast. (Directly Impacted)	Agricultural	Tractors and Harvesters	Impacts of mechanization on cultivation intensity.
		Agricultural Technicians	Influence of farmers education on cultivation intensity and farm productivity.
	Transport	Road Miles	Impacts of accessibility on land development rate.
		Trucks and After Production Loss	Impacts of Transport capacity on amount of after production loss.
		Road Fund	Financial constraint on road construction and maintenance.
Urban Region -- (Spatially Impacted Through Population Movements).	Demographic	Population	Similar as above; also the concept of distribution to the various urban zones.
		Housing	Similar as above; but growth constrained by land availability.
	Economic	Businesses, Services and Wharfs	Impact jobs, unemployment rate and land.

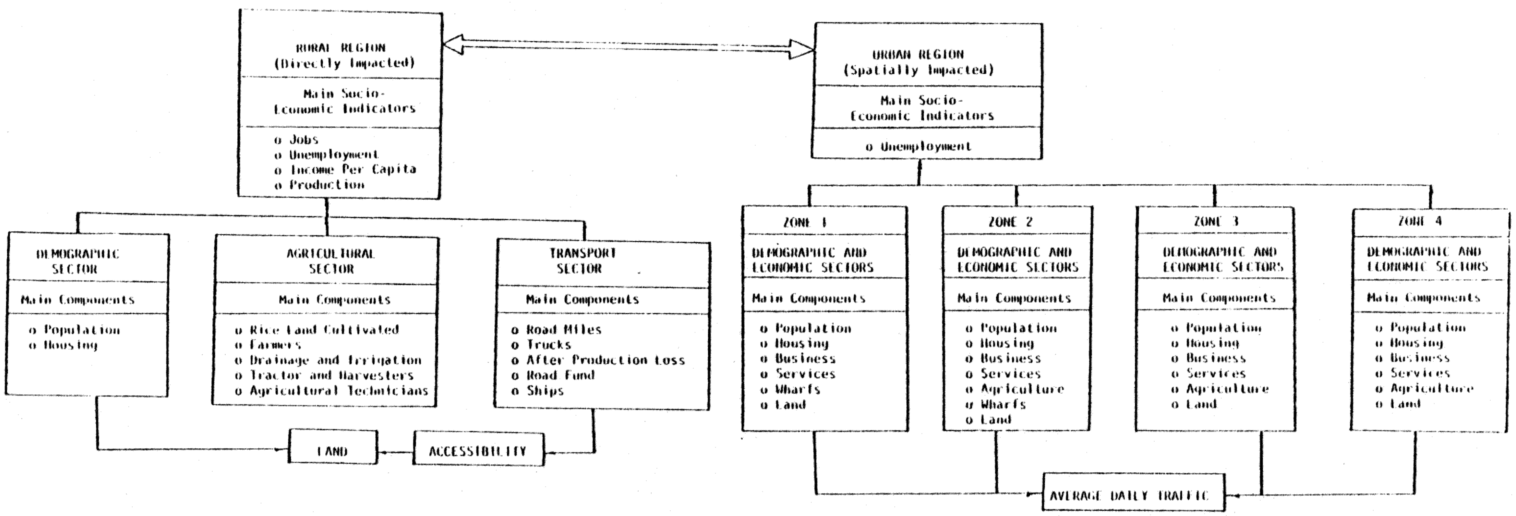


FIGURE 4.9 - Simplified Block Diagram Showing Sectoral Linkages and Interdependence (Continued)

to represent the urban region (i.e., the spatially impacted region). The development of the comprehensive model through the phases of assumptions and/or hypotheses, feedback loops and mathematical equations is next presented in this section.

4.3.1 The Rural Region (Directly Impacted)

The objective of the development is to change the socio-economic characteristics of this region through investments in the economic infrastructure (for example, in transportation and/or drainage and irrigation). The region is represented by three sectors -- demographic, agricultural, and transportation -- that dynamically interact with each other to produce the region's behavior through time.

4.3.1.1 The Rural Demographic Sector

The demographic sector of the model is designed to project the level of population, the supply of labor force, and the housing stock of the region. The trace of these demographic variables through time provides information on unemployment and housing needs of the region.

The Population Level

In most transportation planning models, regional population forecasts have been based mainly on extrapolation of trends or on available forecasts that were adapted for the study. The negative feedback loop in Figure 4.10 exploits the use of causal forces to determine the regional population level.

The population at any point in time is dependent on births, deaths and migrations. However, because of the causality and feedback phenomenon

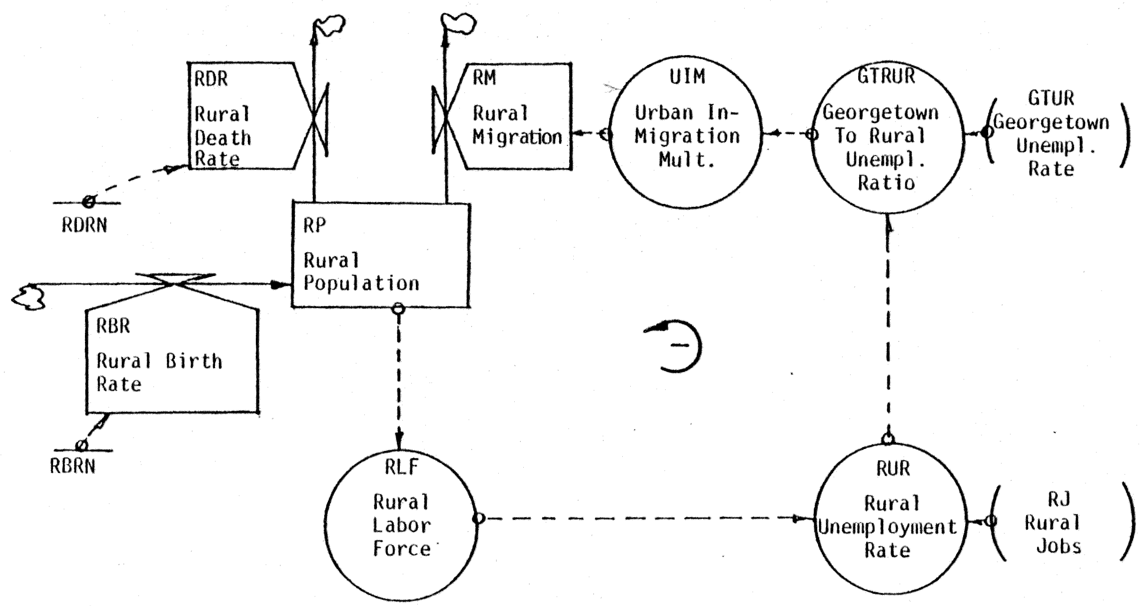


FIGURE 4.10 - Population Level and Assumptions

hypothesized in Figure 4.10, the forecast of the regional population level is significantly different from the values that would be obtained by the traditional extrapolative methodologies, since this approach treats population and employment as an interacting process. These interactions, between population and employment of the impacted regions, are an important part of the dynamics of regional economics and shifts in population, as explained below.

Births and deaths may be relatively "easily" obtained and moreover "dependable" over a planning period. Migration, however, has the greatest potential for fluctuation, especially in the short run. In this study, migration is assumed to depend strongly on the job opportunities between the rural and urban regions, as expressed by the Georgetown-to-Rural-Unemployment Ratio.

The impacts of the relative unemployment on migration is shown in Figure 4.11, in which a hypothesized linear relationship for a given direction of flow between regional unemployment ratio and inter-regional migration is used. The graph is based on the premise that given equal unemployment rates, there will be very little shift to the urban region (achieved through the Urban In-Migration Multiplier, UIM); otherwise, there could be as much as a negative four percentage of shift if the ratio is doubled; and a positive four percentage if the ratio is halved (i.e., implying a greater propensity for urban in-migration). No known study has been conducted in Guyana to justify a linear relationship; however, studies [24,25] conducted in LDCs have found a linear relationship using job opportunities as the independent variable.

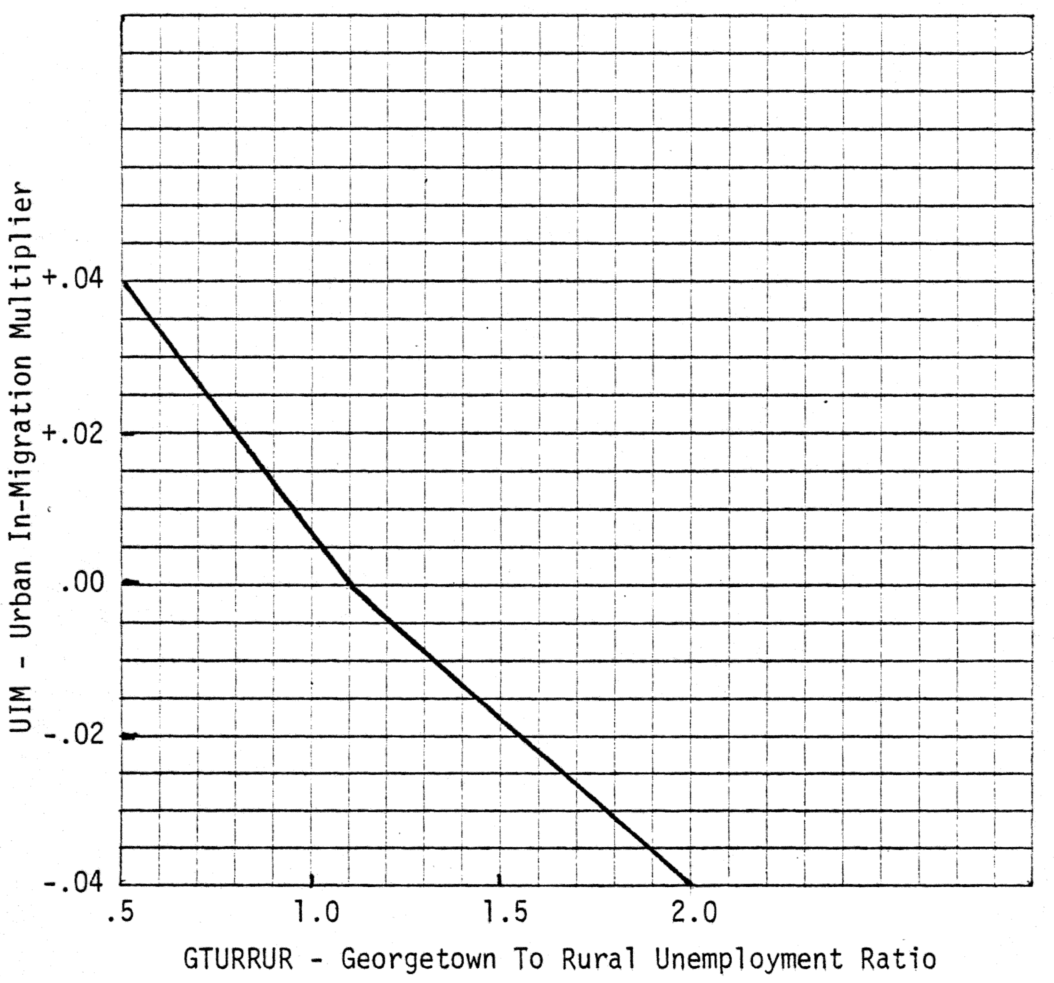


FIGURE 4.11 - <u>Urban In-Migration Multiplier Table UIMT</u>

Equations 1 through 4 define rural population RP, rural birth RBR, rural death RDR and rural migration RM, respectively.

L	RP.K=RP.J+(DT)(RBR.JK-RDR.JK-RM.JK)	1.0
N	RP=35000	1.1
R	RBR.KL=RP.K*RBRN	2.0
C	RBRN=.028	2.1
R	RDR.KL=RP.K*RDRN	3.0
C	RDRN=.006	3.1
R	RM.KL=RP.K*UIM.K	4.0

where:

RP - Rural Population (People)

RBR - Rural Birth Rate (People/Year)

RBRN - Rural Birth Rate Normal (Fraction/Year)

RDR - Rural Death Rate (People/Year)

RDRN - Rural Death Rate Normal (Fraction/Year)

RM - Rural Migration Rate (People/Year)

UIM - Urban In-migration Multiplier (Dimensionless)

Urban In-migration Multiplier, UIM, is an attractiveness multiplier which responds to the changes in the job opportunities existing in the two regions (i.e., urban and rural) and is defined in Equation 5 as a TABLE function. Since the table cannot contain all possible values of GTRUR $(\frac{GTUR}{RUR})$, and the corresponding values for UIM, the table specifies a finite number of points, and the computer assumes that the graph is a straight line between points -- as shown in Figure 4.11.

A UIM.K=TABLE(UIMT,GTRUR.K,.5,2,.1) 5.0

T UIMT=.04/.035/.03/.02/.055/0/-.005/-.009/

-.013/-.017/-.02/-.024/-.028/.032/

.036/-.04 5.1

where:

UIM - Urban In-migration Multiplier (Dimensionless Coefficient)

UIMT - TABLE Function

GTRUR - Ratio of Georgetown Unemployment Rate to Rural Unemployment Rate

The Housing Level

Very rarely, if ever, the housing variable is explicitly dealt with in transportation planning for a rural region, since it may be argued that in sparsely populated regions housing nor land is a constraint to development. This, however, is only a short-term characteristic of the rural scenario. Housing, in its proper perspective, must be viewed as a variable that consumes the prime economic asset of the rural region (i.e. arable land), and in the long run does influence the cultivation level of the region through the land fraction used for housing the rural population. Figure 4.12 shows the causal and feedback phenomenon between the demand for and supply of rural housing. The variables involved are Rural Housing, Rural Households to Houses Ratio, Rural Housing Construction Multiplier, and Rural Housing Construction Rate. These variables form a negative feedback loop which indicates that housing construction is strongly influenced by the housing construction multiplier, which

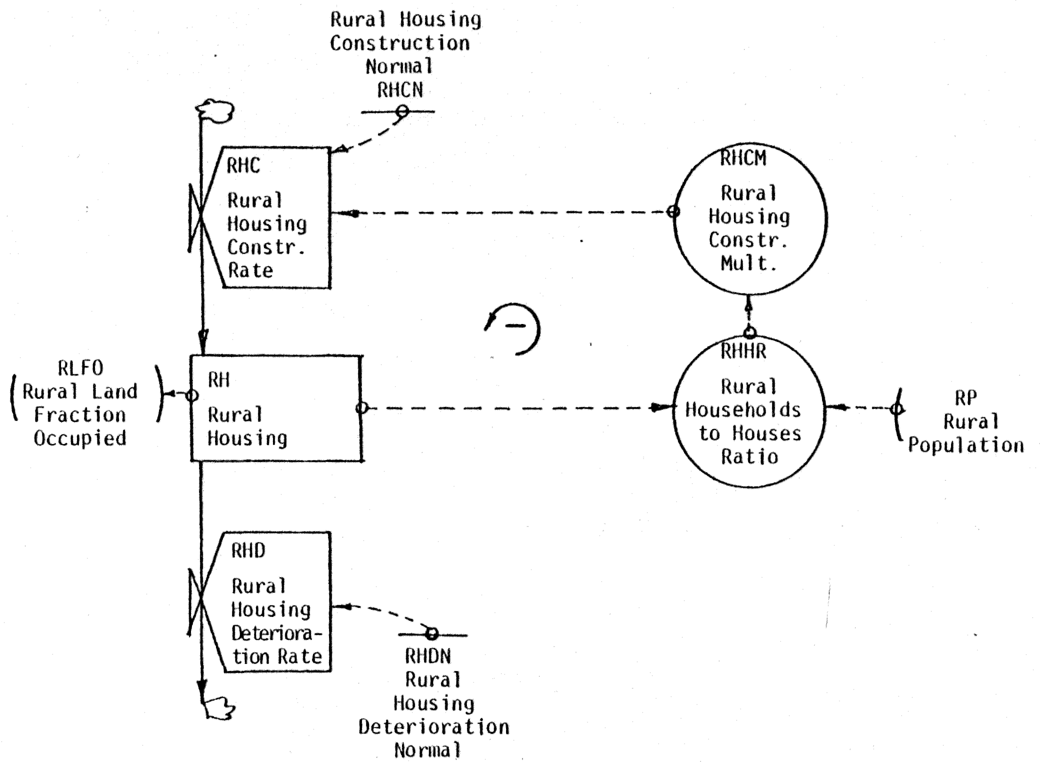


FIGURE 4.12 - The Housing Level and Assumptions

is dependent on the demand for housing relative to its supply, as expressed by the ratio of rural households to the number of houses in the region. Furthermore, the housing stock positively impacts the rural land occupancy.

The housing stock, RH, as shown in Equation 6, is dependent on housing construction rate, RHC, and housing deterioration rate, RHD.

L	RH.K=RH.J+(DT)(RHC.JK-RHD.JK)	6.0
N	RH=3000	6.1

where:

RH - Rural Houses (Housing Units)

RHC - Rural Housing Construction (Housing Units/Year)

RHD - Rural Housing Deterioration (Housing Units/Year)

The Rural Housing Construction Multiplier, RHCM, shown in Figure 4.13, modulates the Rate of Housing Construction, RHC, in response to the demand for housing, as defined by the variable Rural Households to Houses Ratio, RHHR. Figure 4.13 shows the assumed response of this multiplier to demand. The assumption is that given adequate housing, i.e., a ratio of 1, construction will proceed at some normal rate, and the multiplier increases or decreases depending on the demand relative to the supply.

The Housing Construction Rate Multiplier is expressed in a table function as follows:

A	RHCM.K=TABLE(RHCMT,RHHR.K,0,2,.2)	7.0
T	RHCMT=.2/.25/.35/.5/.7/1/1.35/1.6/1.8/1.95/2	7.1

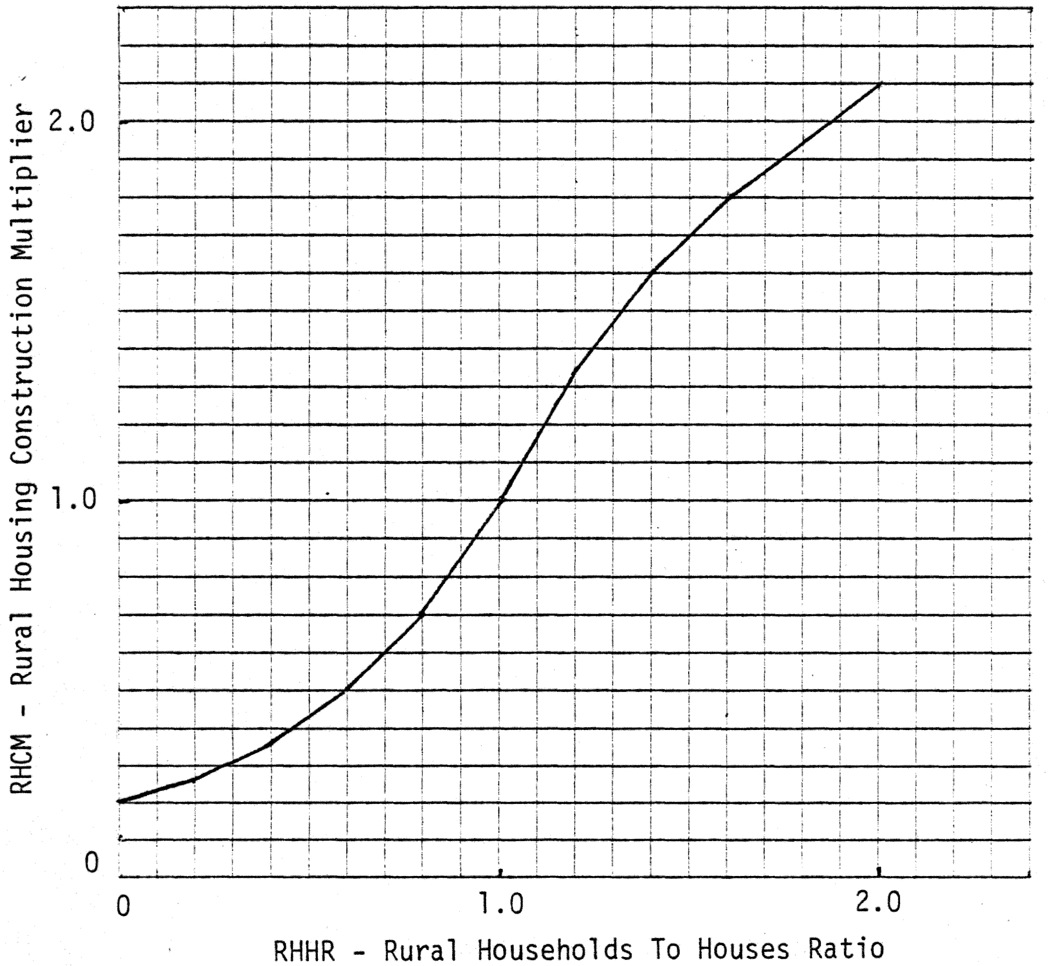


FIGURE 4.13 - Rural Housing Construction Multiplier Table RHCMT

where:

RHCM = Rural Housing Construction Multiplier (Dimensionless)

RHCMT = A TABLE Function

RHHR = Rural Households-To-Houses Ratio (Fraction)

4.3.2 The Agricultural Sector

The economy of the region is determined by the growth of the rice industry. The cultivation level of the rice industry determines the number of jobs provided and the Gross Region Income Per Capita. Further, cultivation and production of the sector depend on the following main components (variables): (1) farmers; (2) arable land area; (3) drainage and irrigation; (4) tractors and harvesters (mechanization); (5) agricultural technicians (agricultural technical inputs); and (6) transportation (as hypothesized and presented in Table 4.9). The causality and feedback phenomena of the sector's main components were illustrated in Figure 3.4, Chapter 3.

Rice Cultivation

Figure 4.14 shows the interdependence and feedback phenomena of the main variables that determine the regional cultivation level. Rice land cultivated RL (Equation 8) is a system level which represents the acreage of land cultivated at any point in time and is calculated as the acreage at the preceding point in time, plus the acreage that has been added by the rice land development rate RLDR, in the intervening interval, minus the acreage that has been converted to other uses by the rice land conversion rate. The initial level of cultivation is 30,000 acres (Equation 8.1).

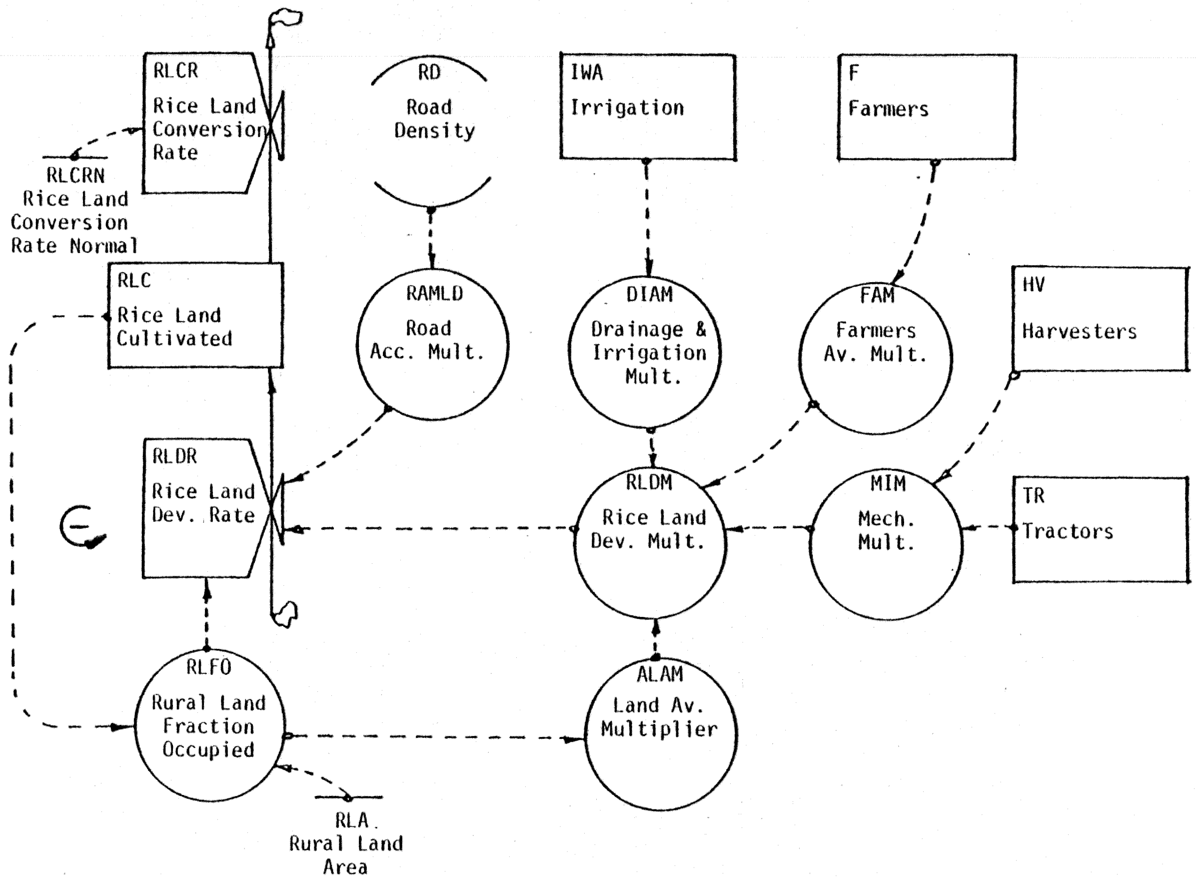


FIGURE 4.14 - <u>The Interrelationships of the Variables that Influence Land Development Rate and Cultivation</u>

L RL.K=RL.J+(DT)(RLDR.JK-RLCR.JK) (8.0)

N RL=30000 (8.1)

where:

RL = Rice Land Cultivated (acres)

RLDR = Rice Land Development Rate (acres/year)

RLCR = Rice Land Conversion Rate (acres/year)

The rice land development rate is part of the negative feedback loop (Figure 4.14). The land development rate depends on the resources of the region, i.e., economic infrastructure (road and drainage and irrigation); natural resources (available arable land); mechanization (tractors and harvesters); and people (farmers). The impacts of the availability of these resources are introduced into the mathematical formulation as "multipliers" that modify the normal or expected growth rate during any intervening interval. Under favorable conditions (i.e., more than adequate provision of resources), the multiplier increases; and under adverse conditions (i.e., lack of resources), the multiplier decreases.

The rice land development rate (Equation 9) in any intervening future interval is the maximum of the difference of the fraction of the rural land area made accessible by the road network, as defined by the road accessibility multiplier on land development rate RAMLD, the rural land fraction occupied, RLFO, at the present time, and zero. Furthermore, the area or acreage that is finally developed depend on the cumulative impacts of the available resources, as defined by the rice land development multiplier RLDM and the time required to bring "virgin" land under cultivation, as defined by delay in land development DILD. Thus, explicitly including the fact that road alone does not expand farming:

R RLDR.KL=MAX(RLDM.K*RLA(RAMLD.K-RLFO.K),0)/DILD (9.0)

where:

RLDR = Rice Land Development Rate (acres/year)

MAX = A Maximum Function Which Prevents Negative Values

RLDM = Rice Land Development Multiplier (a dimensionless variable; is the product of the following multipliers: land availability ALAM, farmer availability FAM, drainage and irrigation availability DIAM, mechanization MIM, and profit from farming PRFM)

RLA = Rural Land Area (acres)

RLFO = Rural Land Fraction Occupied (fraction)

DILD = Delay In Land Development (years)

RAMLD = Road Accessibility Multiplier (the proportion of the rural land area that is made accessible by the road network)

Agricultural Land Availability Multiplier ALAM, an auxiliary variable, reflects the impacts of the stage at which the region is being farmed on land development rate. Figure 4.15 graphs the values of the multiplier versus the land fraction occupied. The assumption is that the rate at which new land is developed depends on the present stage of cultivation. At zero occupancy, the multiplier is 1, and growth is dependent on other factors listed in Equation 9. At full occupancy, the

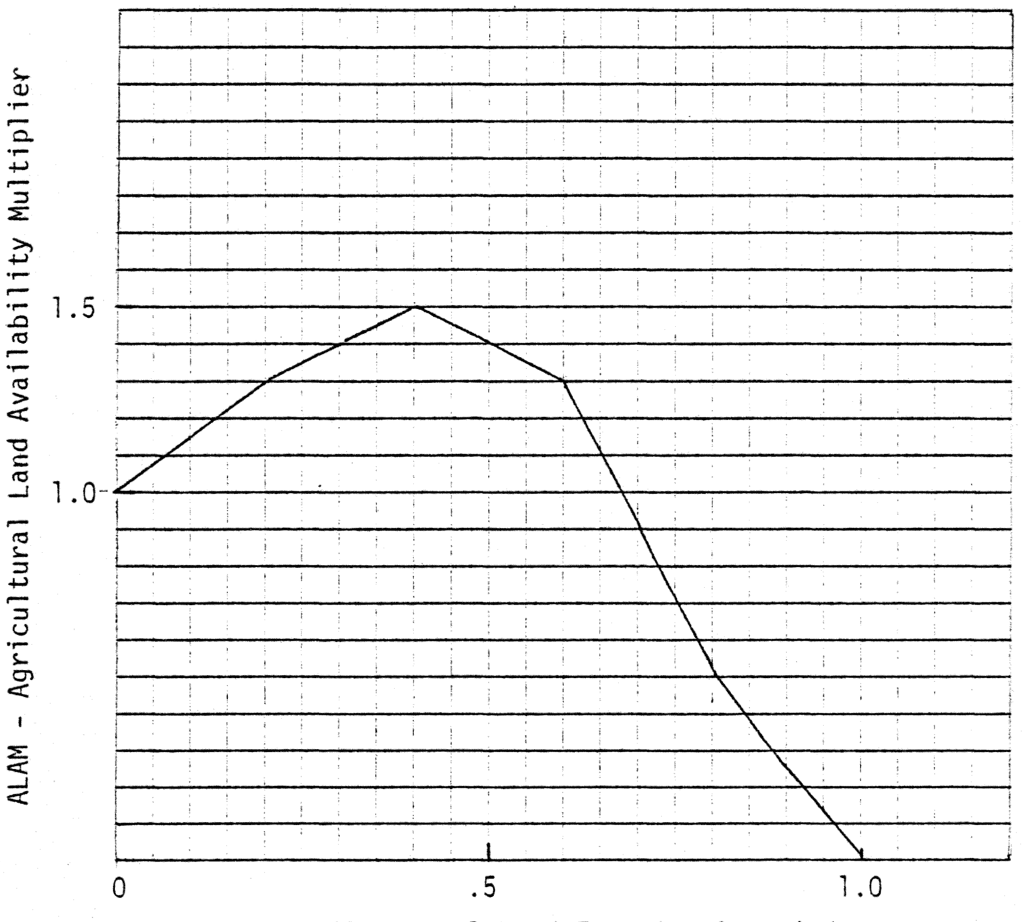


FIGURE 4.15 - Agricultural Land Availability Multiplier
Table ALAMT

multiplier is 0, and the limit to cultivation is reached irrespective of other inputs to the region. Equation 10 quantifies the assumed impact of land availability on land development rate.

A   ALAM.K=TABLE(ALAMT,RLFO.K,0,1,.1)   (10)

T   ALAMT=1/1.5/1.3/1.4/1.5/1.4/1.3/.9/.5/.25/0   (10.1)

where:

ALAM = Agricultural Land Availability Multiplier (dimensionless)

ALAMT = TABLE Function of the Impacts

RLFO.K = Rural Land Fraction Occupied (fraction)

Farmers Availability Multiplier FAM (Equation 11) quantifies the assumed impacts of farmers availability on the riceland development rate. The assumption is that a surplus of farmers (as measured by the ratio of farmers to rice land) positively influence the rate at which new land is brought under cultivation. Figure 4.16 shows the values of the multiplier versus the ratio of farmers to rice land cultivated.

A   FAM.K=TABLE(FAMT,FTLR.K,0,2,.2)   (11)

T   FAMT=.2/.25/.35/.5/.7/1/1.35/1.5/1.8/1.95/2   (11.1)

where:

FAM = Farmers Availability Multiplier (dimensionless)

FAMT = TABLE Function

FTLR = Farmers To Rice Land Ratio (fraction)

Drainage and Irrigation Multiplier DIAM, second to accessibility, is probably the most important infrastructure to both land development

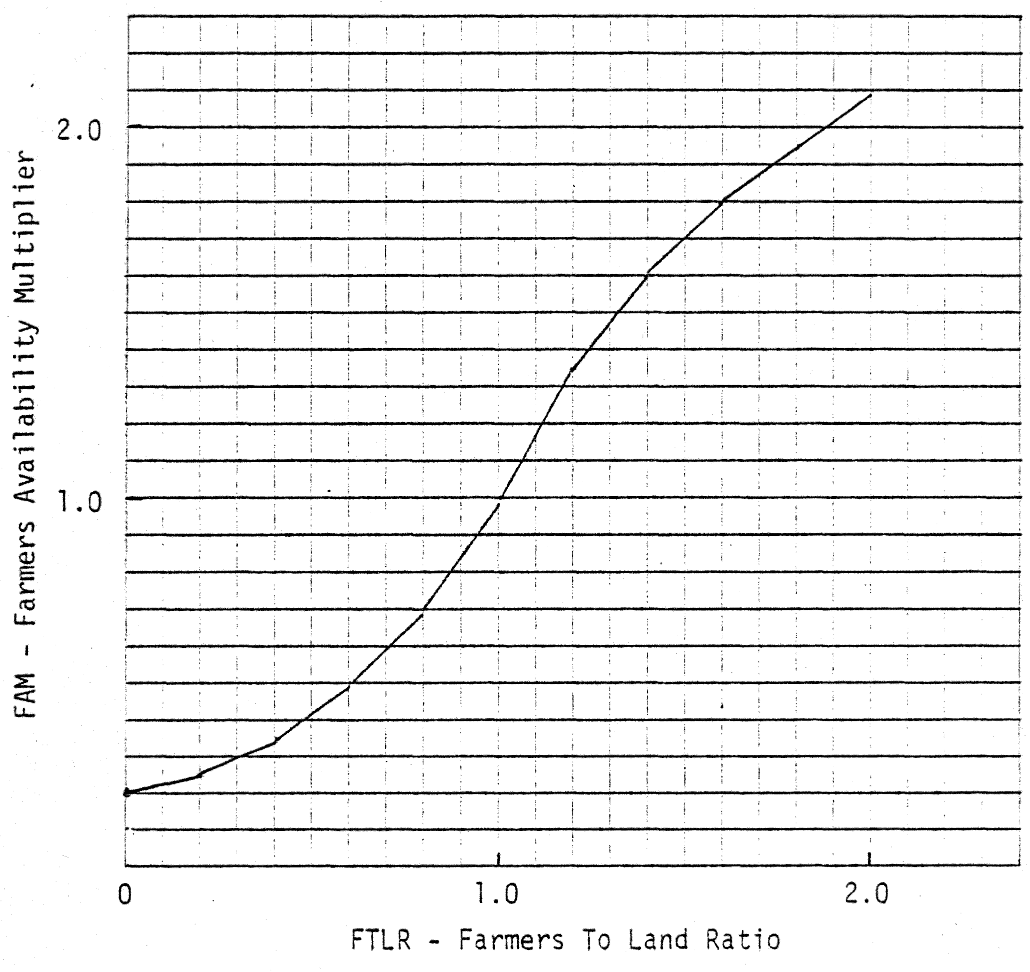


FIGURE 4.16 - <u>Farmers Availability Multiplier Table FAMT</u>

rate and yield per acre. The water availability is measured by the rice land to water ratio. As this ratio increases, land development rate reduces (i.e., as the system of drainage and irrigation becomes inadequate for the area under cultivation, farmers reduce their rate of cultivation). The influence of available drainage and irrigation on land development rate is shown through the drainage and irrigation multiplier. The unwillingness of farmers to expand cultivation under inadequate drainage and irrigation condition is quantitatively expressed in equation 12 and graphically shown in Figure 4.17. It is assumed that if rice land to water ratio is greater than 1.0, land development rate becomes dependent on the regional rainfall characteristics for water supply. In this case, the drainage and irrigation multiplier, DIAM, assumes a constant value of 1.6 (the lowest value in the graph).

```
A    DIAM.K=TABLE(DIAMT,RLTWR.K,0,2,.2)                  (12)
T    DIAMT=2/1.95/1.9/1.85/1.75/1.6/1.6/1.6/1.6/1.6      (12.1)
```

where:

DIAM = Drainage and Irrigation Multiplier (dimensionless)

DIAMT = TABLE Function

RLTWR = Rice Land To Water Ratio (fraction)

Mechanization Multiplier MIM - Ordinarily, land development rate would be restricted by the capability of the individual farmers to the cultivation of a certain acreage through labor intensive means. However, mechanization has greatly enhanced the individual farmer's capabilities to undertake increased cultivation. The mechanization multiplier is defined as the product of two multipliers, tractor availability

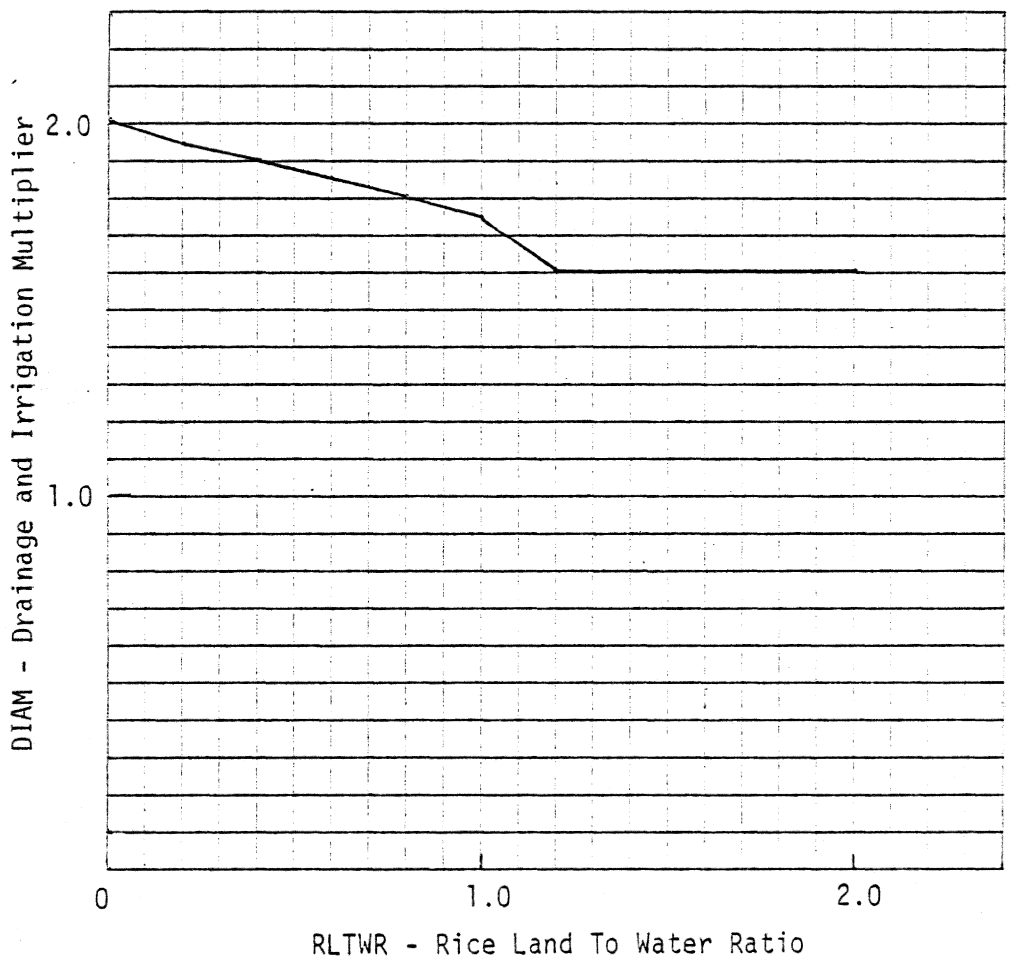


FIGURE 4.17 - Drainage and Irrigation Multiplier Table DIAMIT

multiplier and harvester availability multiplier, as shown in Equation 13. The cultural practices of rice farming are such that these two equipment play unique roles in the phases of rice farming -- tractors in the sowing phase, and harvesters in the reaping phase -- and can independently influence output levels. Figures 4.18 and 4.19 and Equations 14 and 15 indicate the quantitative impacts of the availability of these equipment on land development rate.

```
A    MIM.K=RLHRM.K*RLTRM.K                          (13)
A    RLHRM.K=TABLE(RLHRMT,RLTHR.K,0,1.6,.2)         (14)
T    RLHRMT=1/1/1/1/1/1/.95/.9/.5                   (14.1)
A    RLTRM.K=TABLE(RLTRMT,RLTRM.K,0,1.6,.2)         (15)
T    RLTRMT=1.3/1.2/1.1/1/1/1/.95/.8/.6             (15.1)
```

where:

MIM = Mechanization Multiplier (dimensionless)

RLHRM = Rice Land To Harvester Multiplier (dimensionless)

RLHRMT = TABLE Function

RLTRM = Rice Land To Tractor Multiplier (dimensionless)

RLTRMT = TABLE Function

RLTR = Rice To Tractor Ratio (fraction)

RLTHR = Rice Land To Harvester Ratio (fraction)

Rice Production and Productivity

Production and productivity determine regional income per capita. Figure 4.20 shows the variables that determine the production rate of the region. The production rate during any interval of time is determined by Equation 16, which is simply the product of the acreage culti-

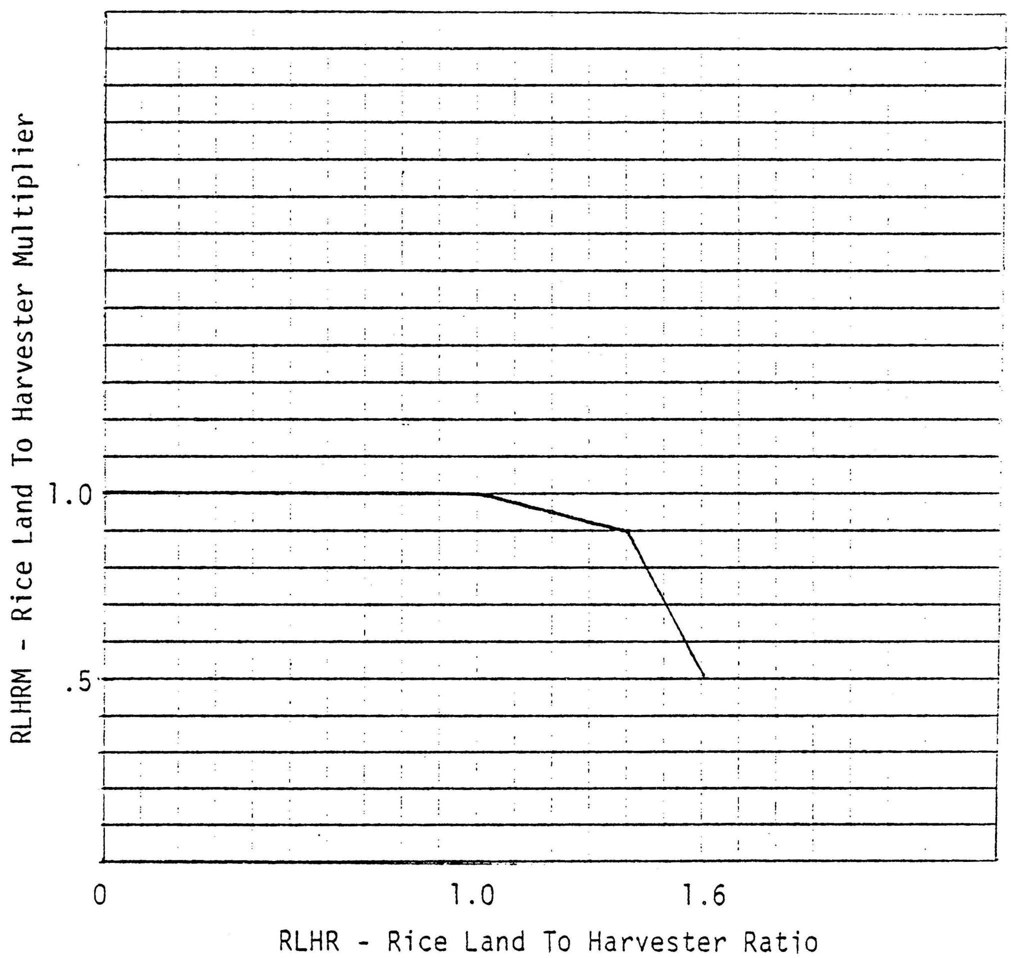


FIGURE 4.18 - Rice Land To Harvester Multiplier Table RLHRMT

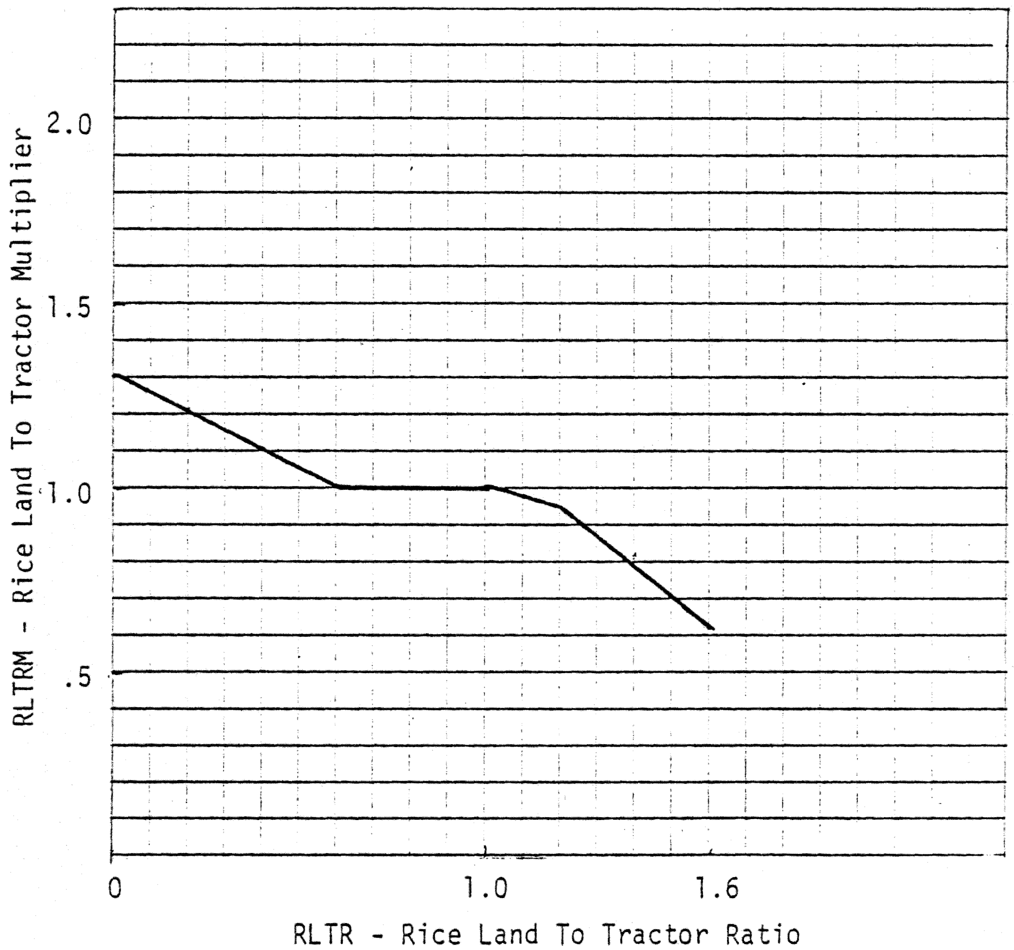


FIGURE 4.19 - <u>Rice Land To Tractor Multiplier Table RLTRMT</u>

vated RL, and the average yield per acre YPA.

R UMRPR.KL=RL.K*YPA.K (16)

where:

UMRPR = Unmilled Rice Production Rate (tons/crop)

RL = Rice Land Cultivated (acres)

YPA = Average Yield Per Acre (tons/acre)

Figure 4.20 shows that yield per acre (or productivity) depends on four major inputs: (1) drainage and irrigation DIAM; (2) mechanization MIM; (3) fertilizer FEAM; and farmers technical input HM. The concepts of drainage and irrigation and mechanization have already been discussed. The variable FEAM (fertilizer input multiplier) will be discussed in the transport sector, since its use is directly dependent on the cost of transportation within the study region. Equation 17 defines the value of yield per acre as follows:

A YPA.K=YPAN*FEAM.K*DIAM.K*MIM.K*HM.K (17)

where:

YPA = Average Yield Per Acre (tons/acre)

YPAN = Normal Yield Per Acre (tons/acre)

FEAM = Fertilizer Availability Multiplier (dimensionless)

DIAM = Drainage and Irrigation Multiplier (dimensionless)

MIM = Mechanization Multiplier (dimensionless)

HM = Husbandry Multiplier (dimensionless)

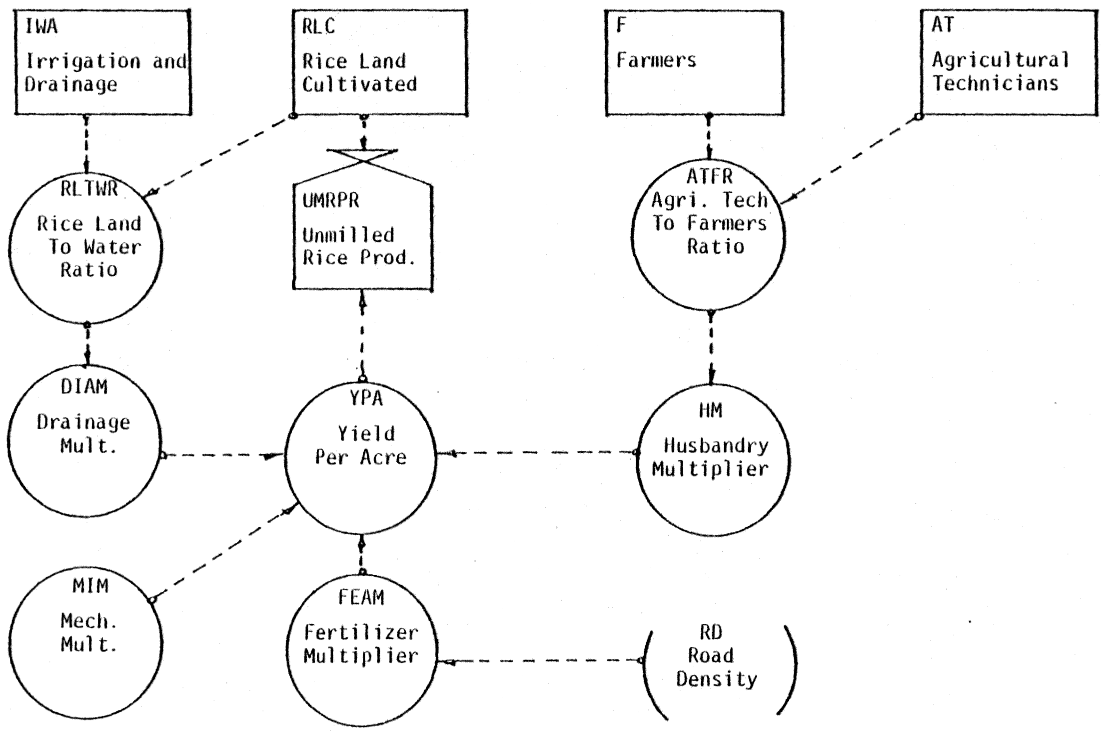


FIGURE 4.20 - <u>The Interrelationships of the Variables (or Resources) That Influence Production and Productivity</u>

Equation 17 quantifies the impacts of the availability of each of the above key resources as a multiplier value. It says that the average normal yield per acre YPAN (a situation where the farmer is operating without assured drainage, irrigation, mechanization, fertilizer and technical advice) will increase, depending on the inputs of the above resources.

The Husbandry Multiplier HM, represents the influence of agricultural extension services in the region as a function of the ratio of the number of trained agricultural technicians to the number of farmers in the region. The assumption here is that as the number of trained personnel increases, the technical input into farming is also increased. Figure 4.21 and Equation 18 show the assumed impact of trained personnel in the region on impact.

```
A     HM.K=TABLE(HMT,ATTFR.K,0,.005,.001)          (18)
T     HMT=1/1.04/1.05/1.08/1.09/1.1                (18.1)
```

where:

HM = Husbandry Multiplier (dimensionless)

HMT = TABLE Function

ATTFR = Agricultural Technicians To Farmers Ratio (fraction)

4.3.3 The Transportation Sector

The transport sector, which is the primary focus of the model's design, is represented by two modes, road and water, with the dominant emphasis on road investment. In this scenario, road accessibility is perceived to be the primary constraint to land development rate; and

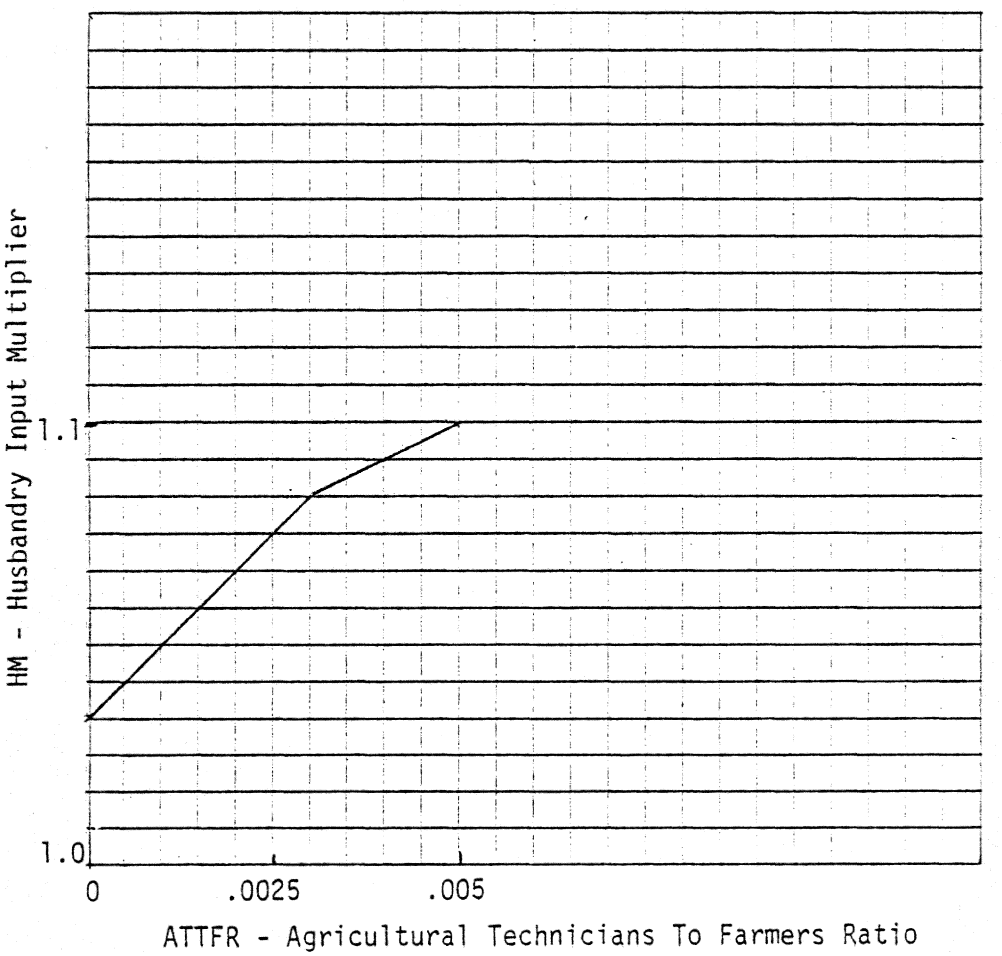


FIGURE 4.21 - Husbandry Multiplier Table HMT

water transportation is incorporated such that the desired water transport capacity keeps pace with the regional production level projected from improved road accessibility. The road transport sector is explicitly represented by three levels -- Road Fund, RF; Rural Road Miles, RROAD; and Trucks, TRUCK -- that dynamically interact to produce the inter-sectoral behavior.

Relationships Between Road Fund and Rural Road Miles

The concept of the demand and supply for road is shown in the negative feedback loop represented by the variables Demand for Road, Road Construction Rate, Rural Road Miles, and Road Density in Figure 4.22. The regional land area and the crop type to be cultivated determine the network mileage needed -- the demand. The road fund provided for new construction determines the road construction rate -- the supply. An increase in road construction rate increases the network mileage; and this, in turn, increases the regional road density, which negatively impacts the demand for roads. Thus, an equilibrium condition is expected when the actual road density reaches the desired road density. Equations 19 and 20, given below, define the level of funding and road mileage at any given point in time. Equations 19.1 and 20.1 give the initial fund and mileage of roads at the beginning of the simulation.

L	RF.K=RF.J+(DT)(RFR.JK)	(19)
N	RM=1000000	(19.1)
L	RROAD.K=RROAD.K+(DT)(RCR.JK-RRDR.JK)	(20)
N	RROAD=150	(20.1)

where:

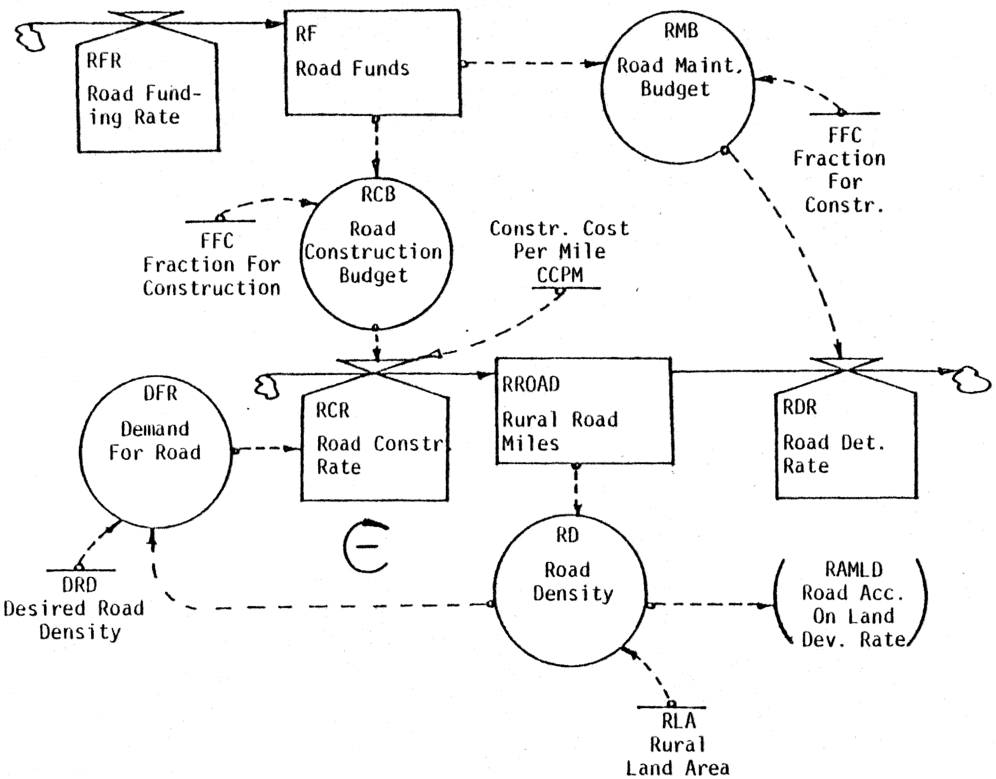


FIGURE 4.22 - <u>Relationships Between Road Fund and Road Miles (The Demand/Supply Concept)</u>

RF = Road Funds ($/year)

RFR = Road Funding Rate ($/year)

RROAD = Rural Road Network (miles)

RCR = Road Construction Rate (miles/year)

RRDR = Rural Road Deterioration Rate (miles/year)

The amount of road to be provided or the desired road density is determined by the crop type to be cultivated, since different crop types require different agricultural infrastructure for full access and drainage and irrigation (dirt roads or dams). In this scenario, the cultivation of rice is best served by the layout shown in Figure 4.23. This layout requires approximately five and one-half miles of road infrastructure with the following characteristics: 0.5 mile of paved collector; 2.5 miles of all-weather sealed road; and 2.5 miles of dirt road to serve approximately 1,000 acres of rice and costs approximately G$550,000 for initial construction and approximately G$17,500 to maintain per year.

Impacts of Rural Road Miles on Accessibility and Transport Capacity

The concepts of road accessibility on land development rate and unmilled rice loss or after-production loss are illustrated in Figure 4.24. An increase in rural roads increases the road density, and an increased road density increases the road accessibility multiplier RAMLD, which positively impacts the rice land development rate and therefore rice land under cultivation.

The road accessibility multiplier, RAMLD, an auxiliary variable, reflects the impacts of rural road density on land development rate.

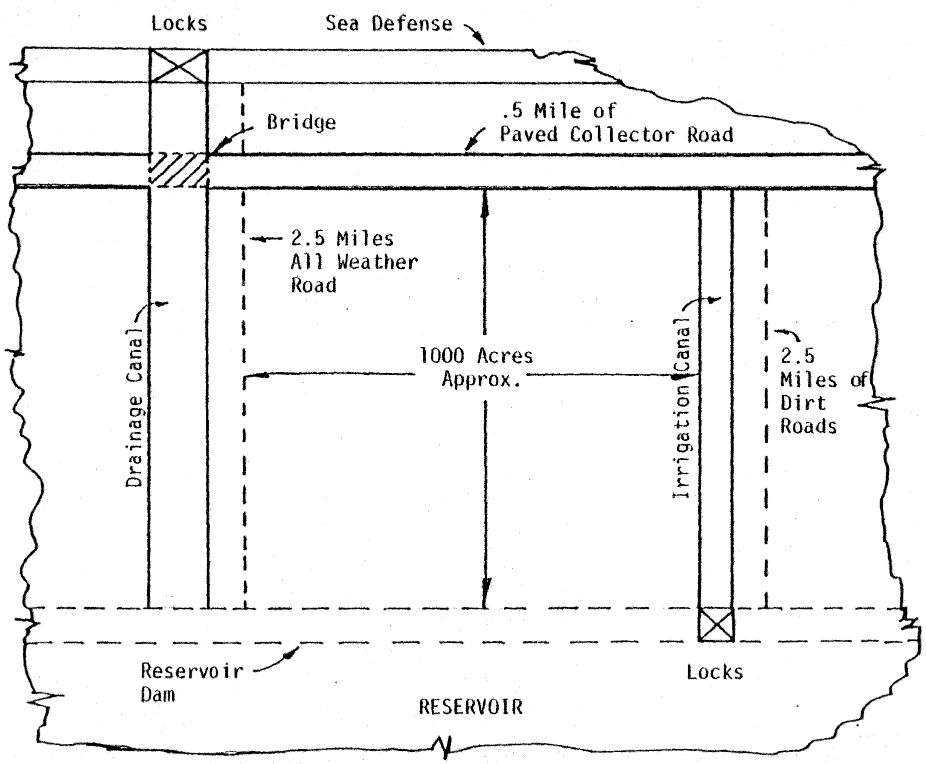


FIGURE 4.23 - Typical Layout Rice Farm Roads and Drainage and Irrigation Infrastructure [25].

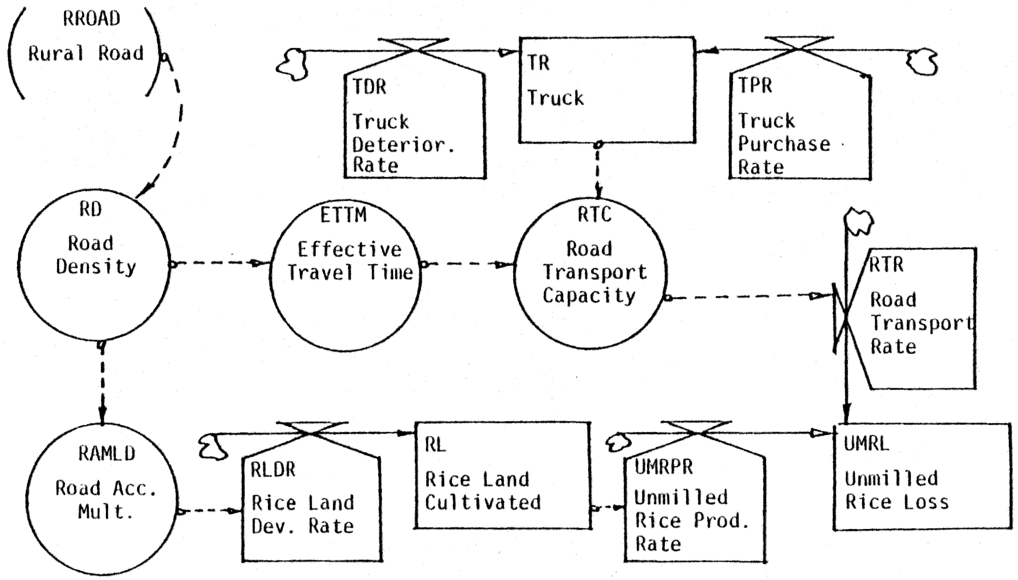


FIGURE 4.24 - <u>The Concept of Accessibility and Transport Capacity on Production Loss</u>

Lack of accessibility by road is often stated as the prime cause for the slow rate of rural development; but equally important is that road expansion per se should not be mistaken for a complete development. The assumed relationship between road density and accessibility is shown in Figure 4.25. In this figure, the assumption is made that at a zero road density (i.e., no roads), rice land development rate is due to factor as defined in Equation 9 for rice land development rate; while at the desired road density, the entire region is assumed to be accessible for cultivation. Equation 21 quantifies the assumed impact of the road accessibility multiplier.

A RAMLD.K=TABLE(RAMLDT,ARD.K/DRD,0,1,.1) (21)

T RAMLDT=.1/.2/.4/.5/.55/.6/.65/.7/.8/.9/1 (21.1)

where:

RAMLD = Road Accessibility Multiplier (dimensionless)

RAMLDT = TABLE Function

ARD = Actual Road Density (fraction)

DRD = Desired Road Density (fraction)

Unmilled rice loss, UMRL, or after-production loss, is the loss that farmers suffer from not being able to transport their produce immediately to the mills due to inadequate transportation capacity. The nature of paddy (i.e., unmilled rice) is such that after reaping, if it is not moved to storage and/or drying locations within a short period of time, the grains are damaged. These damages result in lower prices for the farmers. Thus, the after-production loss is not a physical loss of tonnage -- since the farmers eventually transport their crops

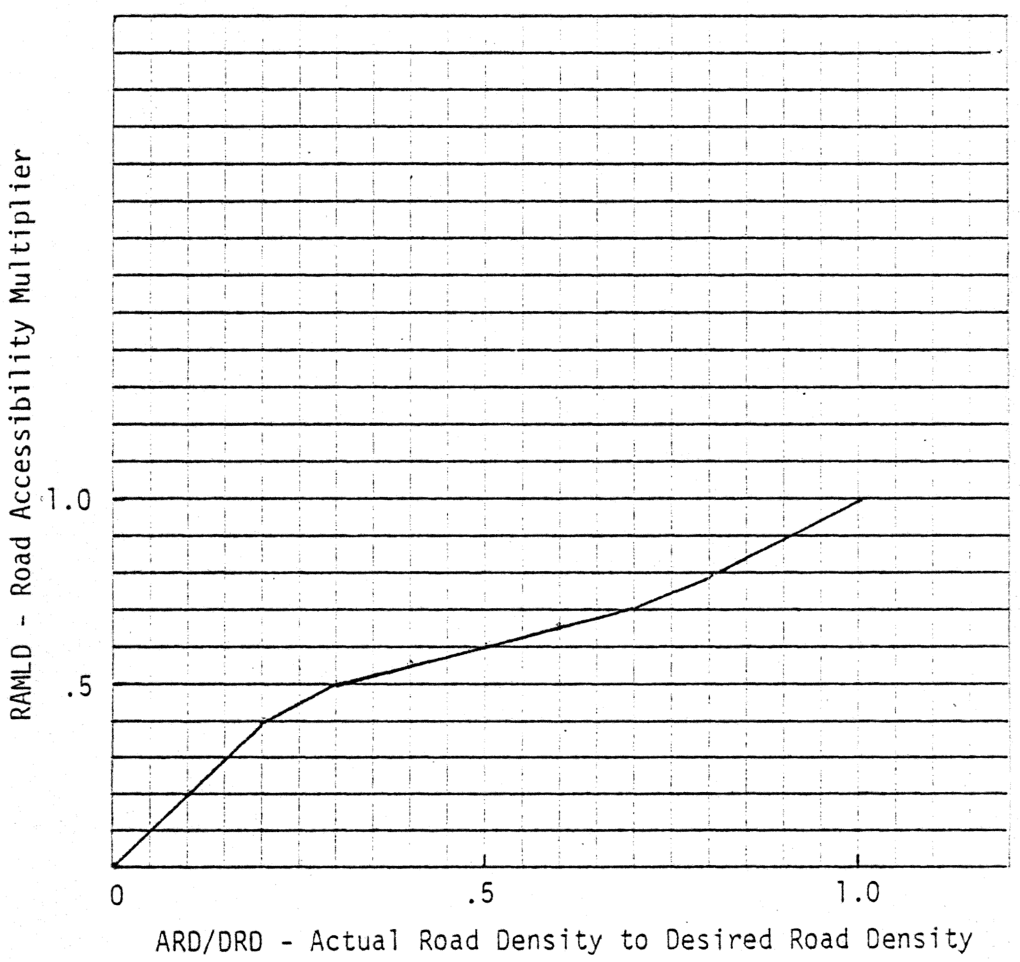


FIGURE 4.25 - Road Accessibility Multiplier on Land Development Rate Table RAMLDT

to the mill -- but a significant financial loss may be incurred to farmers due to inadequate transport capacity. The concept illustrated in Figure 4.24 is the minimization of after production loss by providing matching road transport capacity for the projected rice production rate. Equation 22 quantifies the after-production loss (i.e., unmilled rice loss) as the difference between the unmilled rice production rate and the unmilled rice transport rate as follows:

L UMRL.K=UMRL.J+(DT)(UMRPR.JK-UMRTR.JK) (22)

where:

UMRL = Unmilled Rice Loss (tons/crop)

UMRPR = Unmilled Rice Production Rate (tons/crop)

UMRTR = Unmilled Rice Transport Rate (tons/crop)

Road Transport Capacity, RTC, is assumed to be dependent on the characteristics of the road network, the number of trucks available to the rice industry, and the short period of time over which rice production must be harvested and transported. The road transport capacity is defined in the model as:

A RTC.K=TRUCK.K*TTPD.K*HPP*PLPT (23)

where:

RTC = Road Transport Capacity (tons/crop)

TRUCK = Number of Trucks in the Industry (number)

TTPD = Truck Trips Per Day (average no. of trips/truck/day)

HPP = Harvesting Peak Peak (time in weeks)

PLPT = Pay Load Per Truck (tons/truck)

Impacts of Rural Road Miles on Rice Land Cultivated and Yield

Improved accessibility generally means reduced transport cost, which should be reflected in increased farming inputs -- especially fertilizer and husbandry input. Figure 4.26 illustrates the impacts of improved accessibility through the negative feedback loop defined by Rural Road Miles, Road Density, Actual Road Density Cost Multiplier, Farming Cost of Transport, Fertilizer Inputs, Fertilizer Availability Multiplier, Yield Per Acre, Profit Per Acre, Rice Land Development Rate, Rice Land Cultivated, Unmilled Rice Production Rate, Truck Trips, and Road Deterioration. The loop shows that improved accessibility, defined by the Road Density variable, reduces the actual road density multiplier, which, in turn, reduces the transportation cost. A reduction in transport cost, FCOT, means an increase in fertilizer input, FI, leading to higher yield per acre, YPA. Increased yield means increased production rate, which results in more truck trips and increased road deterioration. The loop implies that road maintenance after construction is equally important if sustained stable agricultural production is to be realized.

The availability of fertilizer, implied by the fertilizer availability multiplier, FEAM, is a function of fertilizer inputs per acre. Increased fertilizer inputs cause yield per acre to increase. Figure 4.27 and Equation 24 show the values of the multiplier for different levels of inputs of fertilizer. The multiplier increases at a decreasing rate, suggesting that after a certain point, additional fertilizer may not be as economical.

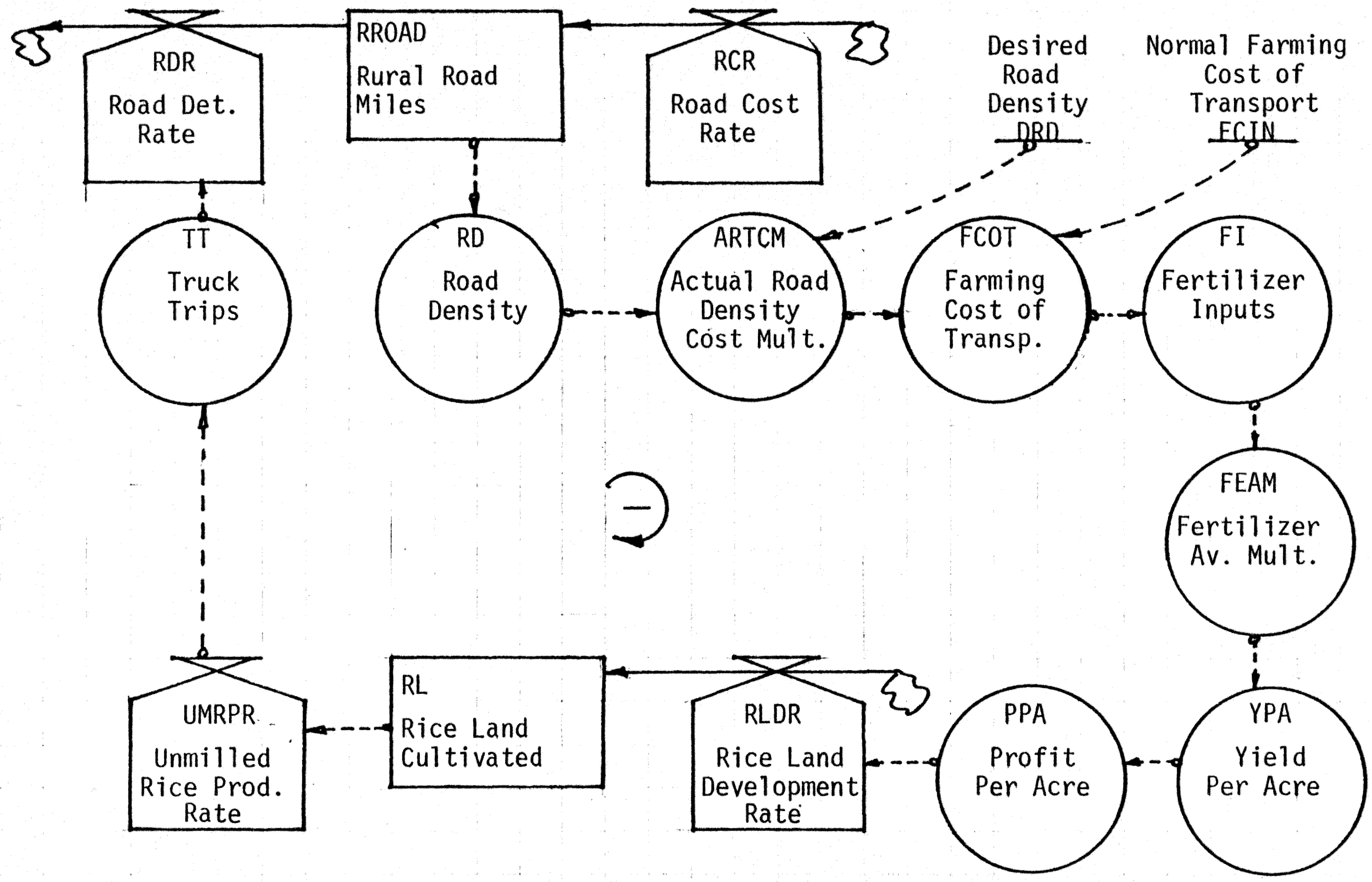


FIGURE 4.26 - The Concept of Improved Access on Fertilizer Inputs Production Rate and Road Deterioration

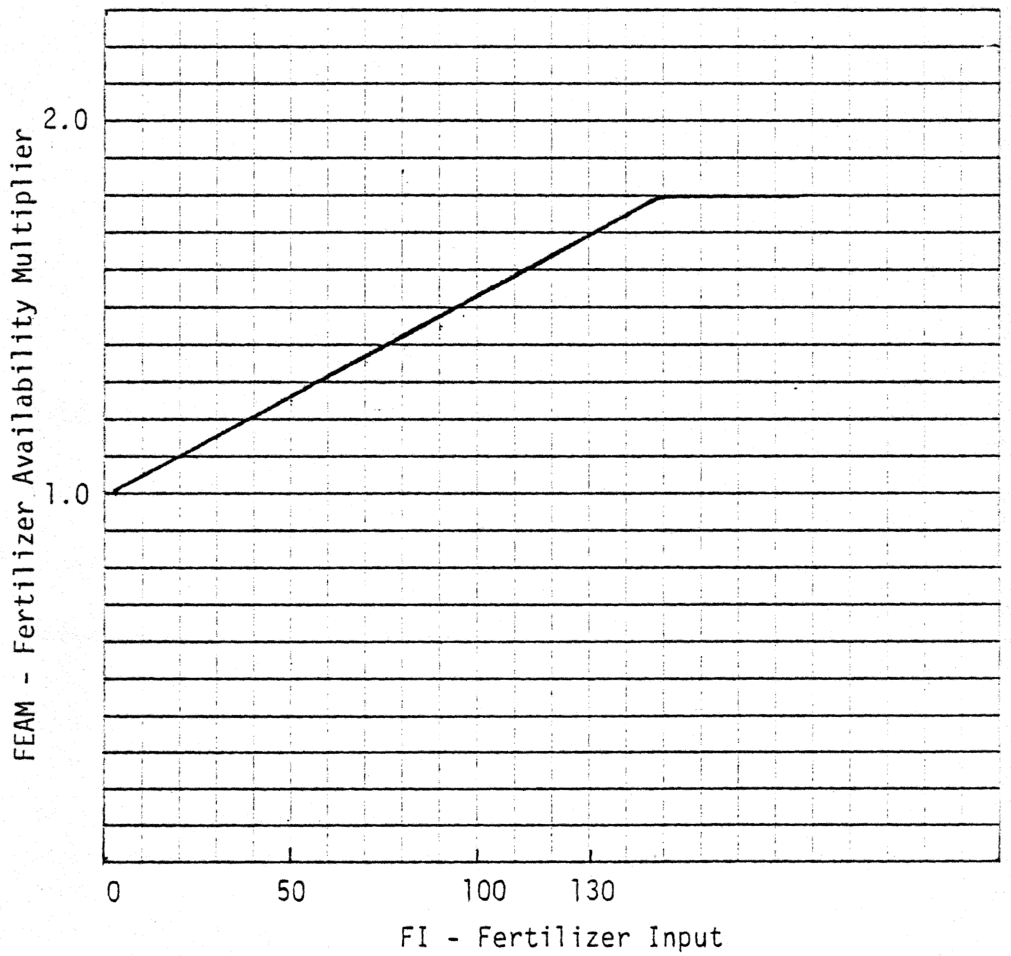


FIGURE 4.27 - Fertilizer Availability Multiplier Table FEAMT

The Actual Road Density Cost Multiplier, ARTCM, as shown in Equation 25, reflects the impact of increasing road density on the farming cost of transportation. As actual road density to the desired road density increases, the multiplier drops, causing a corresponding drop in transportation cost. Figure 4.28 shows the assumed behavior of the multiplier. At zero road access, transport costs are assumed to be one and one-half times higher than that of a region with 70% actual to desired road density.

4.3.4 The Urban Region (Spatially Impacted Region)

The development of a model for the immediate region of influence of the investment would have sufficed in most rural transportation planning approaches; however, an attempt is made here to explicitly incorporate any spatial impacts due to investments in the rural region. In Section 4.2.2, the spatially impacted region has been identified as the capital Georgetown, and a distance of approximately 25 miles along the Atlantic Coast and the Banks of the Demerara River. Furthermore, this region was divided into four "semi-homogeneous" zones in order to provide more explicit understanding of the impacts on the region through zonal behavior. The levels and assumptions of a typical zone are presented; the remainder of the formulation is presented in Appendix 1.1 as part of the comprehensive system dynamics model. Zone 1 -- Georgetown -- is represented by five levels: population, housing, service structures, business structures and wharfs. The dynamic interactions between the levels, their feedback structure and mathematical relationships are presented and discussed in this section.

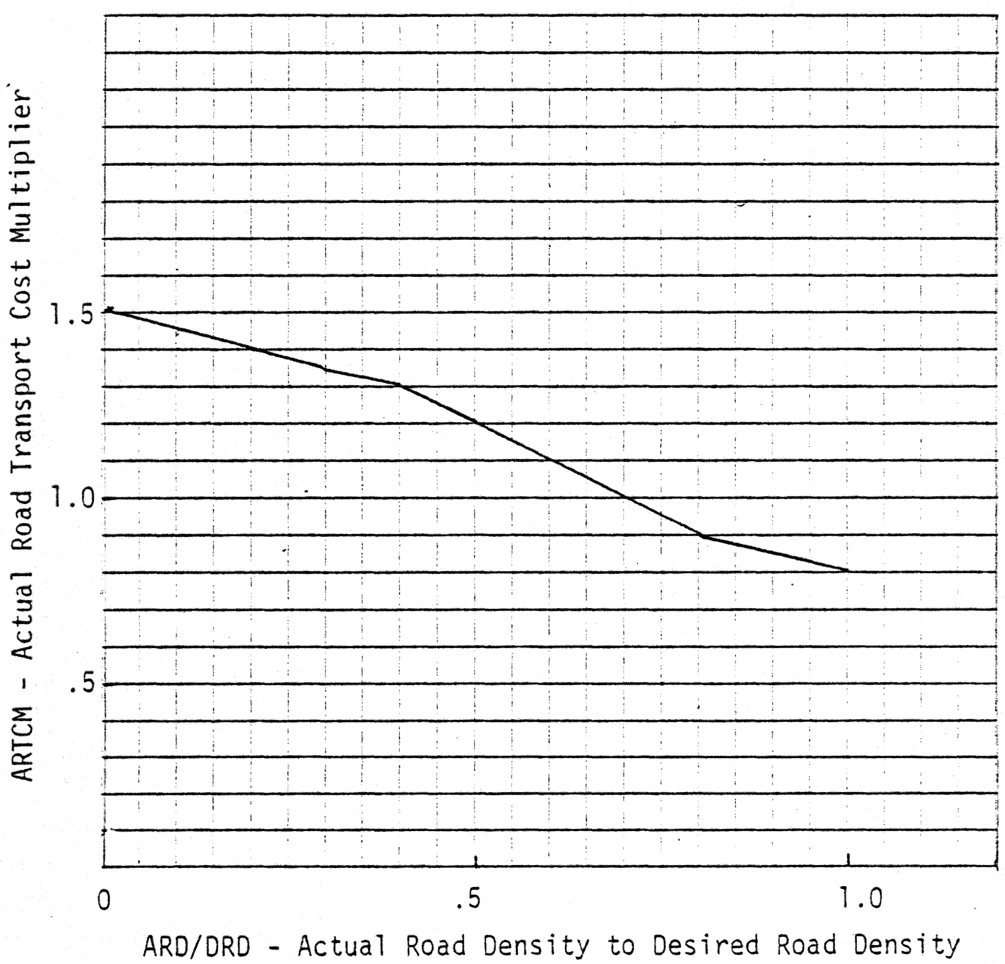


FIGURE 4.28 - Actual Road Transport Cost Multiplier Table ARTCMT

Georgetown Population

Figure 4.29 shows that the underlying structure of the feedback phenomenon of the zonal population level is similar to the structure of the rural population level; and the discussion presented in Section 4.3.1.1 applies here. However, one significant difference in the urban region is the concept of the distribution of the urban immigrants. Equation 26 defines the values of the zonal population at any point in time.

```
L     GTPOP.K=GTPOP.J+(DT)(GTBR.JK+GTI.JK-GTDR.JK
      -GTO.JK)                                          (26)
N     GT=237100                                         (26.1)
```

where:

GTPOP = Georgetown Population (people)

GTBR = Georgetown Birth Rate (people/year)

GTI = Georgetown In-Migration (people/year)

GTO = Georgetown Out-Migration (people/year)

GTDR = Georgetown Death Rate (people/year)

Georgetown In-Migration, GTI, as shown in Equation 27, is expressed as a function of the available civic land area of zones 1, 2 and 3. The concept here is that jobs, first of all, motivated the shift of population from the rural to the urban region; but people will go to where they can find a place to live and travel to work in the urban region. Furthermore, it is assumed that the distribution of the population is based on the proportion of vacant land in the zones identified with

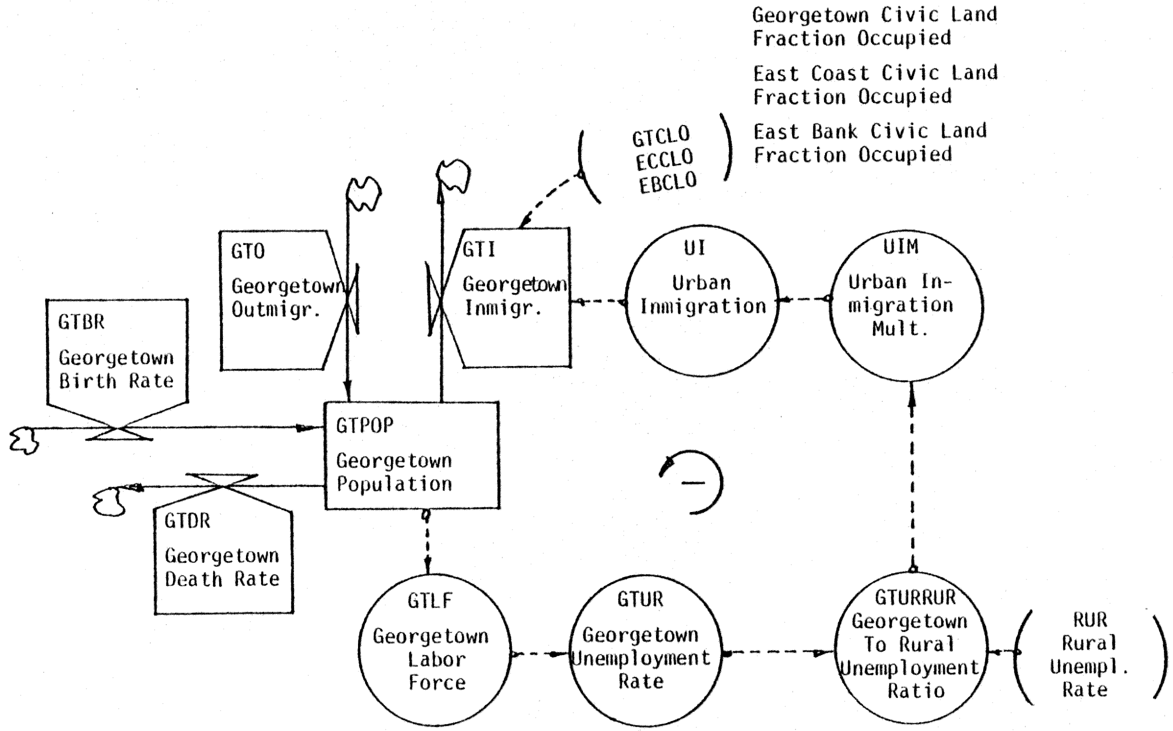


FIGURE 4.29 - Georgetown Population Level and Assumptions

housing land available.

R GTI.KL=(UI.K*(1-GTCLO.K))/((1-GTCLO.K) +

(1-ECCLO.K)+(1-EBCLO.K)) (27)

where:

GTI = Georgetown In-Migration (people/year)

GTCLO = Georgetown Civil Land Fraction Occupied (fraction)

ECCLO = East Coast Civic Land Fraction Occupied (fraction)

EBCLO = East Bank Civil Land Fraction Occupied (fraction)

From Equation 27, the incoming population is distributed only over three zones, while the urban region is divided into four zones. This is because time series data has indicated that zone 4 (West Demerara) is not an attractor or population, which may be due to the fact that it is not directly connected by road to Georgetown, and also that is is relatively more agricultural in its economic potentials (that is, its future expansion is in agriculture rather than light industries and social infrastructure).

The Georgetown Housing

Figure 4.30 shows the housing level is again similar to the rural housing feedback loop of Section 4.3.1.1, with one notable exception; that is, urban housing (zonal housing) is also affected by urban land availability (zonal land area).

Equation 28 defines the level of Georgetown houses at any point in time as follows:

L GTH.K=GTH.J+(DT)(GTHC.JK-GTHDR.JK) (28)

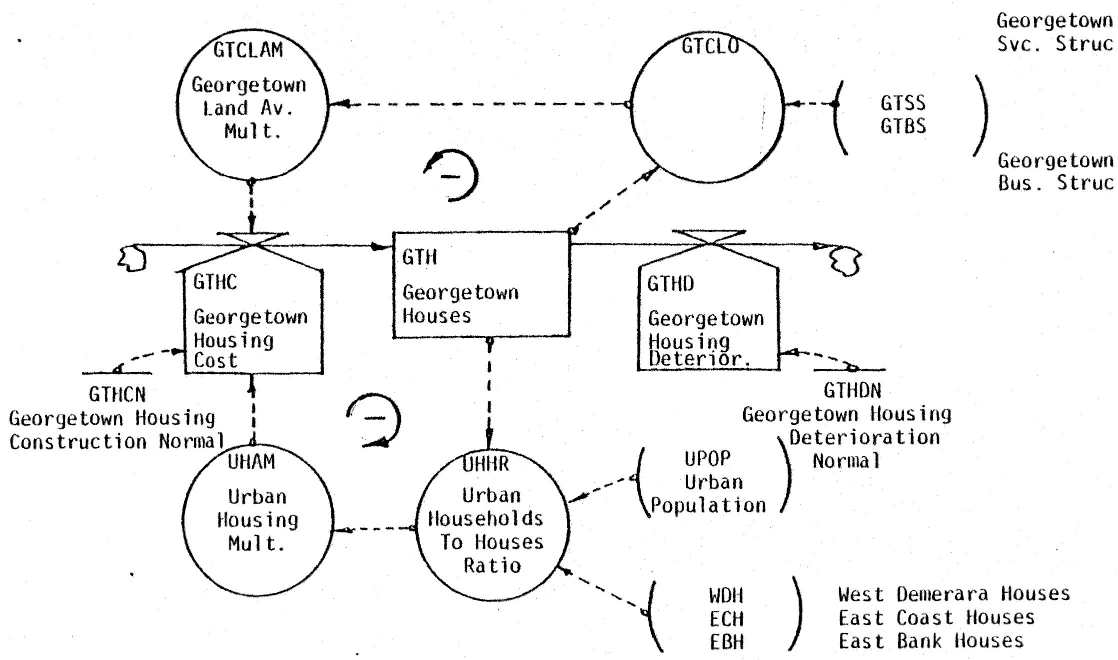


FIGURE 4.30 - Georgetown Housing Level and Assumptions

N GTH=22780 (28.1)

R GTHC.KL=GTH.K*GTHCN*UHAM.K*GTCLAM.K (29)

R GTHDR.KL=GTH.K*GTHDRN (30)

where:

GTH = Georgetown Houses (units of houses)

GTHC = Georgetown Housing Construction Rate (houses/year)

GTHDR = Georgetown Housing Deterioration Rate (houses/year)

GTHCN = Georgetown Housing Construction Normal (houses/year)

GTHDRN = Georgetown Housing Deterioration Normal (houses/year)

UHAM = Urban Housing Availability Multiplier (dimensionless)

GTCLAM = Georgetown Civic Land Availability Multiplier (dimensionless)

Equation 31 below defines the civic land availability multiplier GTCLAM, an auxiliary variable that reflects the influence of available housing land on the housing construction rate. In the urban scenario, land availability is probably the most important factor affecting the growth rate of urban housing. Figure 4.31 graphs the assumed values of the multiplier versus the land fraction occupied. The assumption is that a zero land occupancy construction takes place at some normal rate. However, as the land occupancy increases, construction rate increases significantly, reflecting the pattern that is normally experienced in the housing development of a region. Then, this rate drops significantly as the fraction of land occupied becomes increasingly larger.

A GTCLAM.K=TABLE(GTCLAMT,GTCLO.K,0,1,.1) (31)

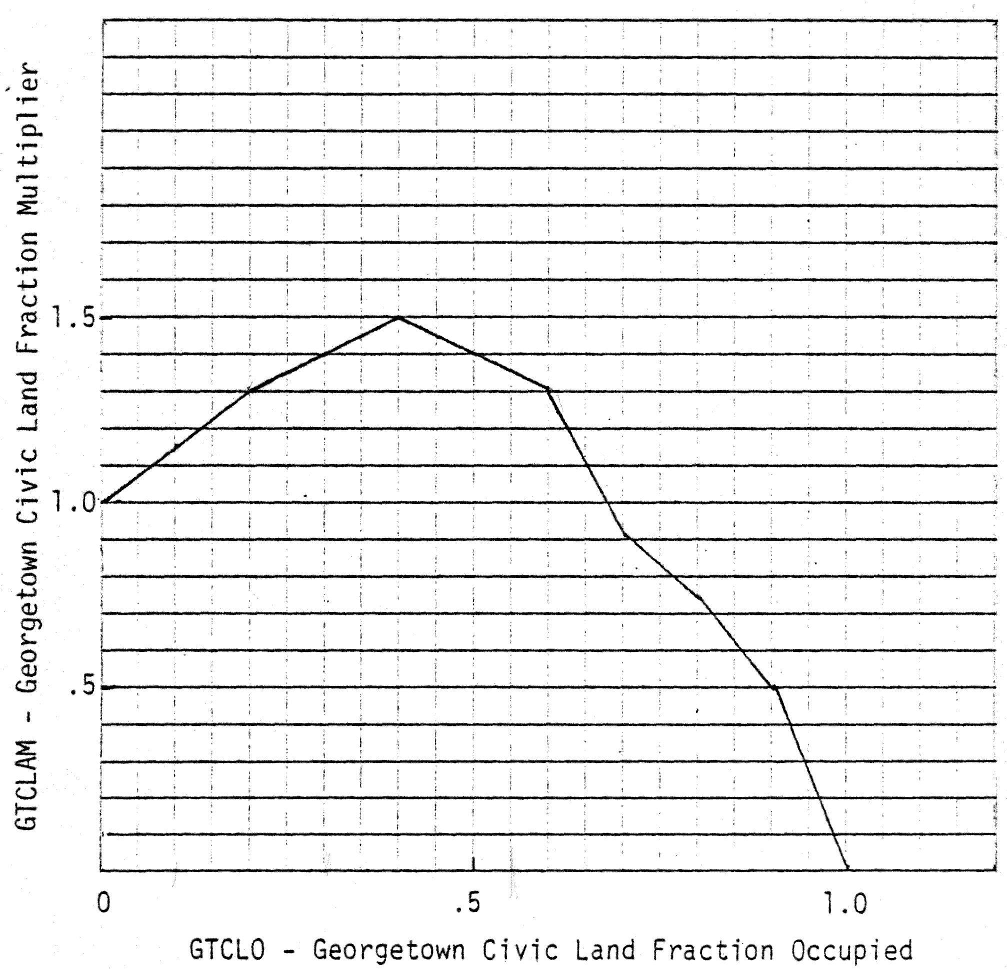


FIGURE 4.31 - Georgetown Civic Land Fraction Multiplier Table GTCLAMT

T GTCLAMT=1/1.15/1.3/1.4/1.5/1.4/1.3/.9/.75/.5/0 (31.1)

where:

GTCLAM = Georgetown Civic Land Availability Multiplier (dimensionless)

GTCLAM = TABLE Function

GTCLO = Georgetown Civic Land Fraction Occupied (fraction)

The Georgetown Business Structures

The economy of the urban region is determined by the growth of its socio-economic activities of the zones that comprise the urban boundary. The economic activities of the zones vary -- for the Georgetown zone, Zone 1, the activities that determine the job level and consumes (or occupies) zonal land area are: (1) businesses; (2) services; and (3) wharfs or docks of Port Georgetown.

In order to incorporate these activities in a quantitative model to determine future job level and area occupied, the zonal activities were divided into three main classes given above. A representative structure was identified for each main class, and this representative structure generated a certain number of jobs and occupied a certain area of land. Given this aggregation for each class of economic activity, the causality and feedback phenomenon of each level were developed.

Figure 4.32 shows that the business structure is influenced by two main feedback loops. Loop 1 (Georgetown Business Structures, Georgetown Civic Land Fraction Occupied, Georgetown Civic Land Fraction Multiplier, Georgetown Business Structures Construction Rate) shows the impact of land availability on business structures growth rate. An increase in

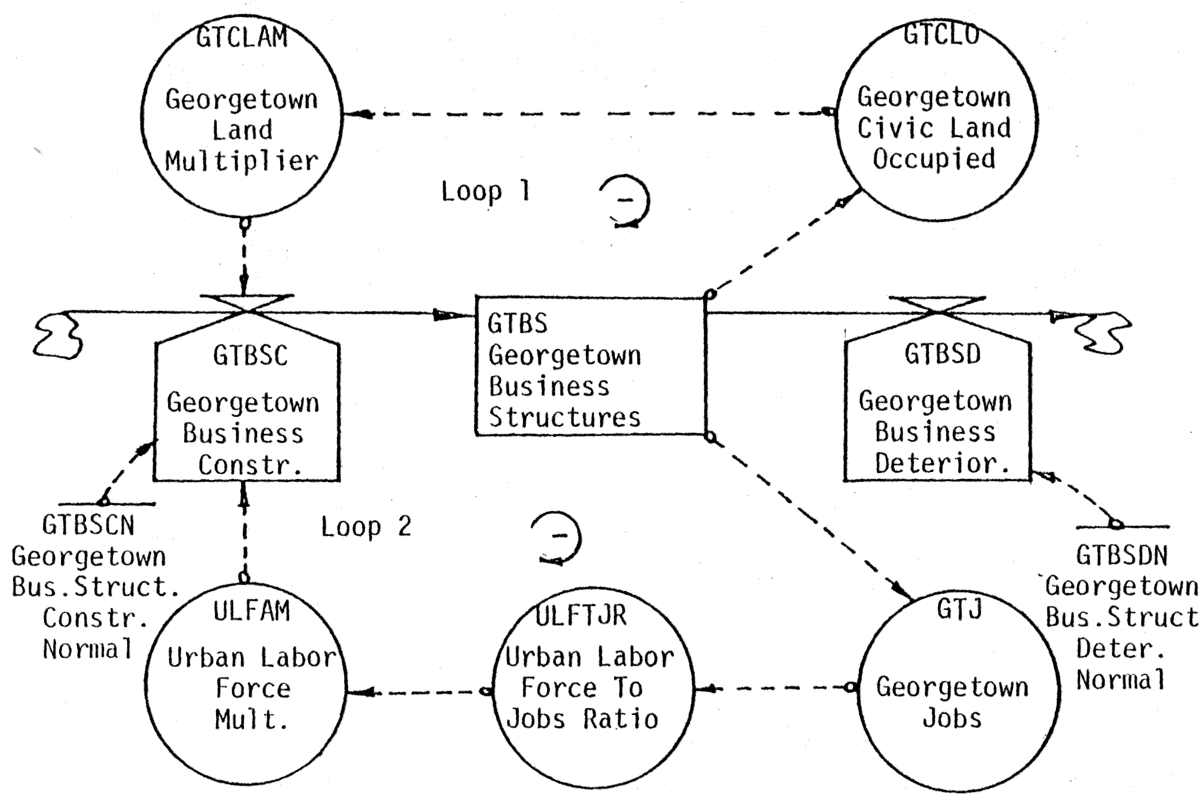


FIGURE 4.32 - Georgetown Business Structures Level and Assumptions

business structures increases the zonal land area occupied, and in turn reduces the rate of expansion of the business sector, due to reduction in available land for expansion. Loop 2 (Georgetown Business Structures, Georgetown Jobs, Urban Labor Force To Jobs Ratio, Urban Labor Force Multiplier, Georgetown Business Structures Construction Rate) shows the impact of labor availability on business expansion. An increase in business increases the jobs available, and this in turn reduces the available labor force. A reduction in the labor slows down the expansion of the business sector.

Equation 32 defines the level of business structures at any point in time.

L GTBS.K=GTBS.J+(DT)(GTBSC.JK-GTBSD.JK) (32)

N GTBS=72 (32.1)

where:

GTBS = Georgetown Business Structures (no. of business structures)

GTBSC = Georgetown Business Structures Construction Rate (business structures/year)

GTBSD = Georgetown Business Structures Deterioration Rate (business structures/year)

Urban Labor Force Availability Multiplier, ULFAM, as shown in Equation 33, defines the impact of labor availability in the urban region on the rate of growth of the business construction. Figure 4.33 graphs the behavior of the multiplier versus the regional unemployment characteristics, as defined by the Urban Labor Force To Jobs Ratio, ULFTJR. The

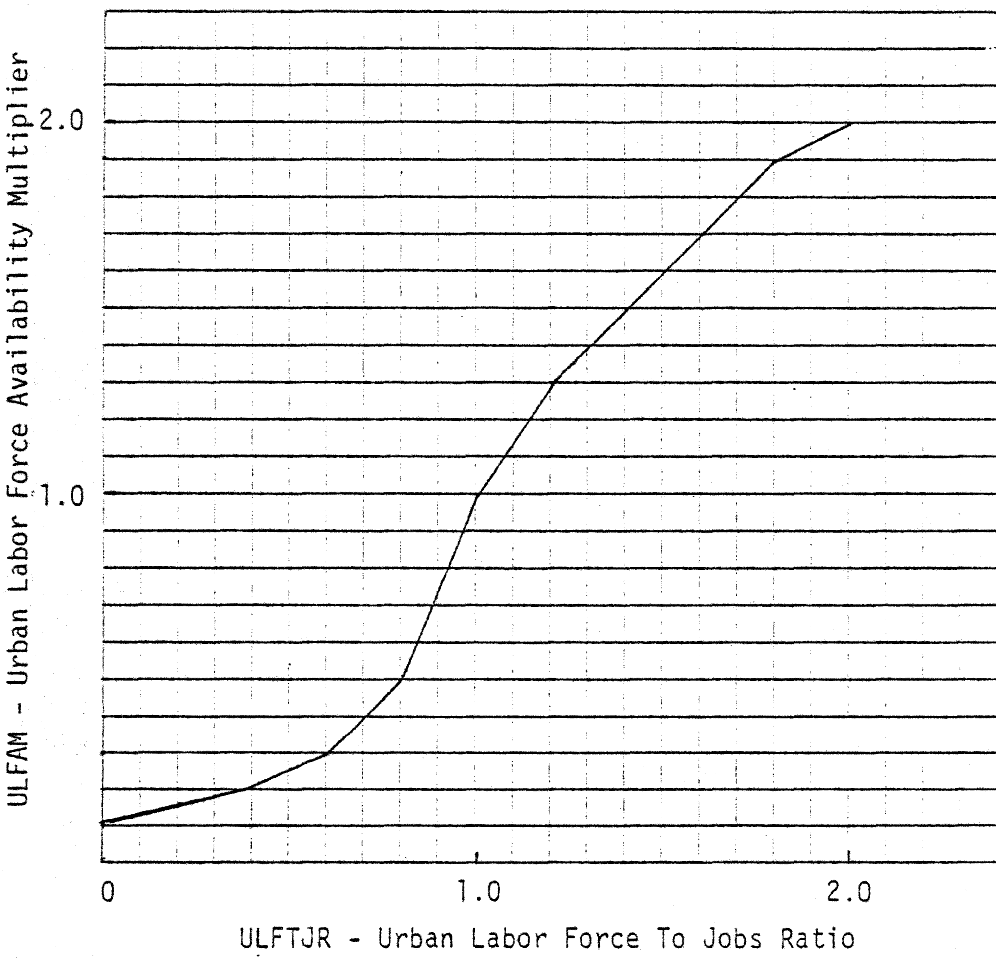


FIGURE 4.33 - Urban Labor Force Multiplier Table ULFAMT

assumption being an excess of labor (i.e., high unemployment), it positively impacts the rate of construction; and the opposite is true in a time of high employment.

Georgetown Service Structures

Figure 4.34 shows the underlying structure and hypotheses of this variable (level). The structure is similar to the Georgetown Business Structures level, and the preceding explanation with respect to the multipliers ULFAM and GTCLAM applies. Equation 34 defines the value of the Georgetown Service Structures at a given point in time.

L GTSS.K=GTSS.J+(DT)(GTSSC.JK-GTSSD.JK) (34)

N GTSS=725 (34.1)

where:

GTSS = Georgetown Service Structures (units of service structures)

GTSSC = Georgetown Service Structures Construction Rate (service structures/year)

GTSSD = Georgetown Service Structures Deterioration Rate (service structures/year)

Georgetown Wharf Level

Figure 4.35 shows the underlying structure and feedback loop for this level. The structure is similar to the service and business structures level, and needs no further explanation. Equation 35 defines the value of the wharf level at any point in time.

L GTWS.K=GTWS.J+(DT)(GTWSC.JK-GTWSD.JK) (35)

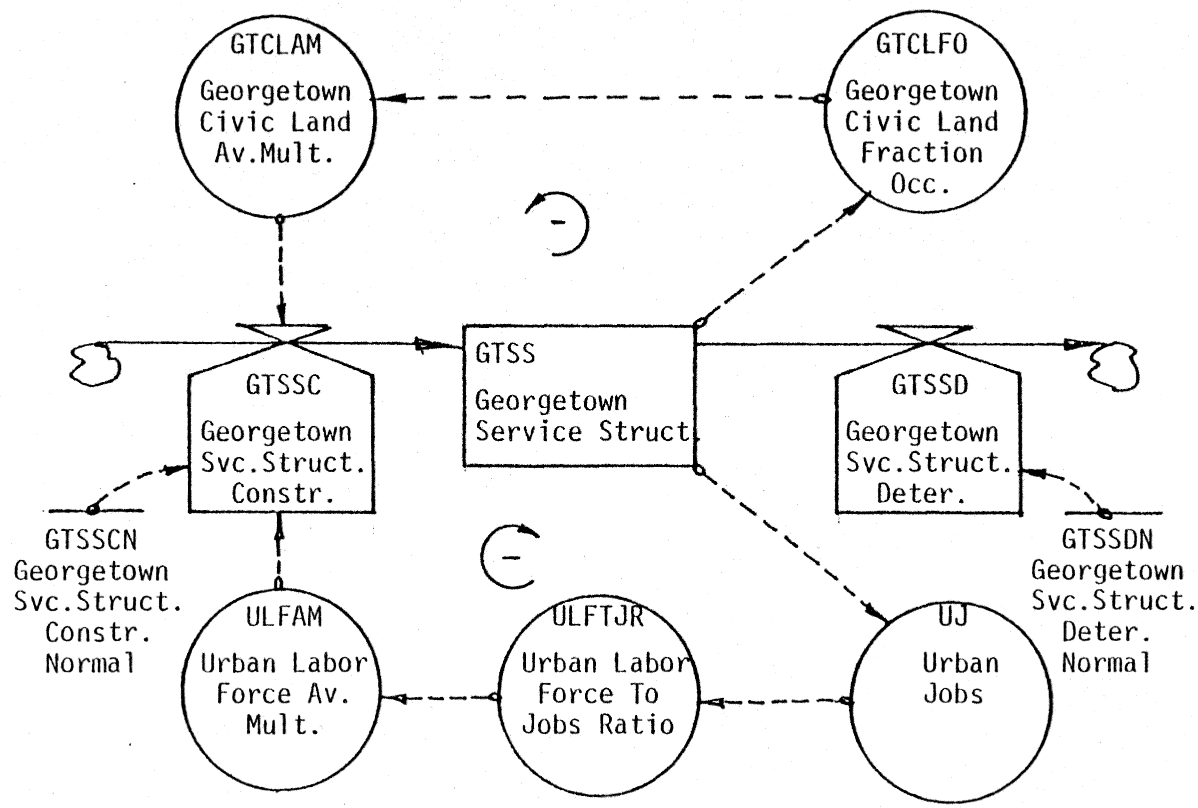


FIGURE 4.34 - Georgetown Service Structures Level and Assumptions

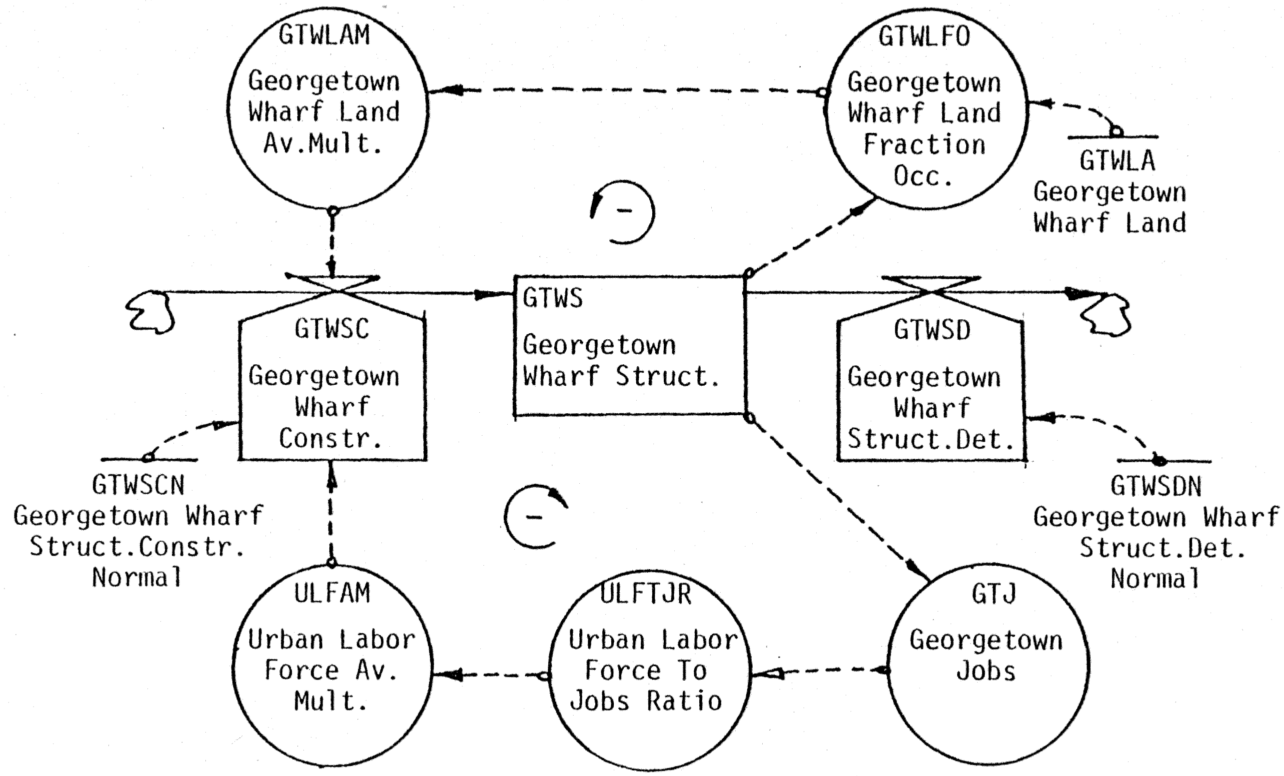


FIGURE 4.35 - Georgetown Wharf Structures Level and Assumptions

N GTW=21 (35.1)

where:

GTWS = Georgetown Wharf Structures (no. of wharfs)

GTWSC = Georgetown Wharf Structures Construction Rate (wharfs/year)

GTWSD = Georgetown Wharf Structures Deterioration Rate (wharfs/year)

4.3.5 <u>The Comprehensive Model</u>

The structure of the comprehensive model -- developed from the main components discussed thus far -- is shown in a simplified form in Figure 4.36. The single hatched variables -- Rural Unemployment Rate RUR, Rural Land Fraction Occupied (RLFO, Rice Land Development Rate RLDR, After Production Loss APL, Truck Purchase Rate TPR, Vessels Purchase Rate VPR, Georgetown Civic Land Fraction Occupied GTLFO, and Urban Labor Force ULF -- are where the main inter-sectoral linkages are.

The double hatched variables -- Georgetown To Rural Unemployment Ratio GTRUR and Urban Inmigration UI -- represent the inter-regional impacts; that is, a difference between the perceived job opportunities of Georgetown and the Rural region results in a shift in population, depending on the perceived differences.

Appendix 1.1 provides the detailed documented system dynamics mathematical model, and Appendix 1.2 provides a key to the variable names.

Table 4.10 provides a summary of the model's main assumptions; that is, the multipliers, the influencing variables that determine the

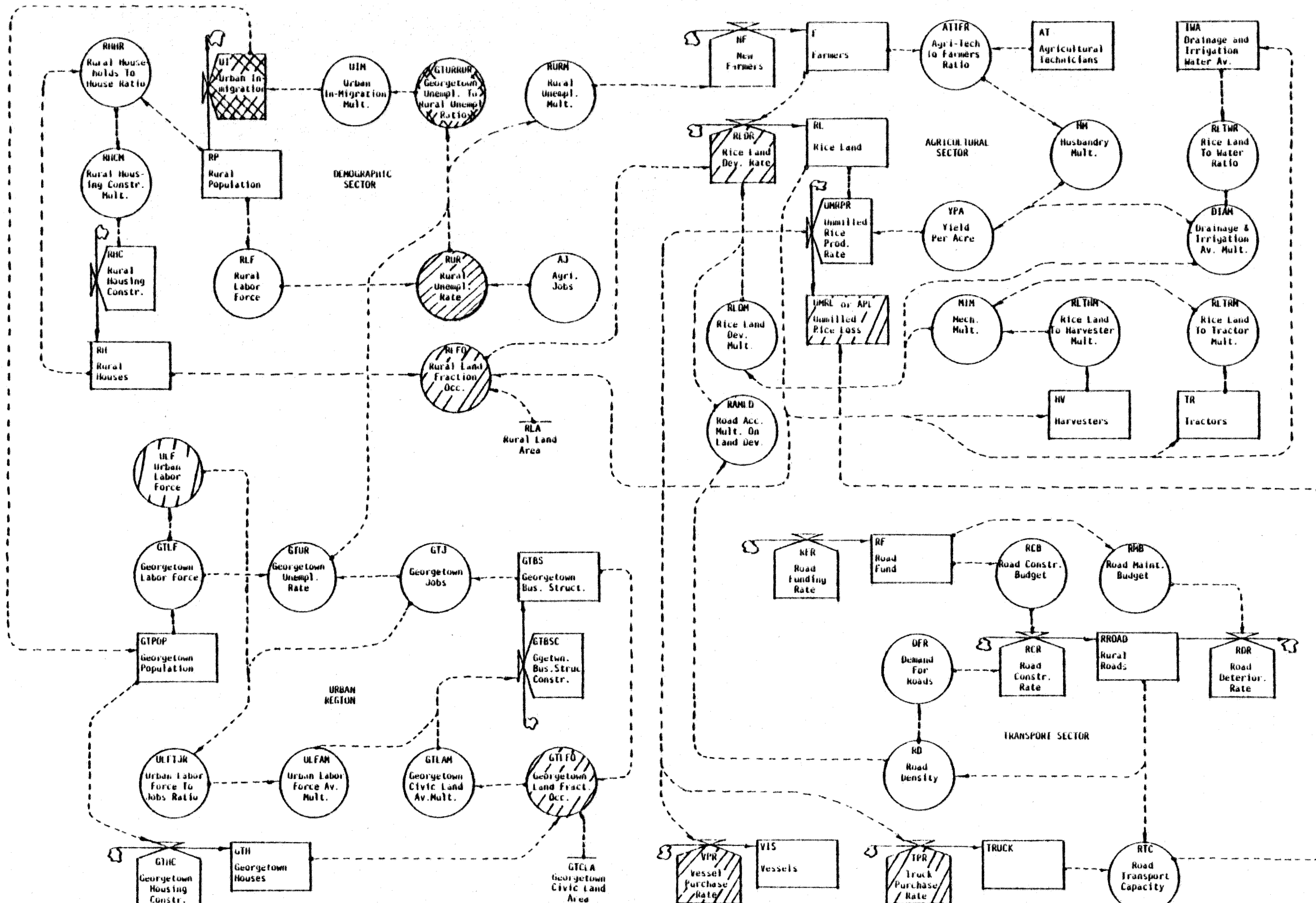


FIGURE 4.36 - A Simplified System Dynamics Flow Diagram Showing Structure of Comprehensive Model

TABLE 4.10 - Summary of Model Main Assumptions

Multipliers	Influencing Variables	Influenced Variables	Direction of Influences
Urban Inmigration - UIM -	Georgetown Unemployment rate/Rural Unemment Rate - GTRUR -	Rural Migration - RM	(+/-)
Rural Housing Construction - RHCM -	Rural Households/House - RHHR -	Rural Housing Construction - RCH	(+)
Agri-Land Availability - ALAM -	Rural Land Fraction Occupied RLFO -	Rice Land Development Rate - RLDR -	(+/-)
Farmers Availability - FAM -	Farmers/Land Areas Cultivated - FTLR -	Rice Land Development Rate - RLDR -	(+)
Drainage and Irrigation - DIAM	Rice Land Cultivated/ Water Available - RLTWR -	Rice Land Development Rate - RLDR -	(-)
		Yield Per Acre - YPA -	(-)
Mechanization - MIM -	Rice Land/Tractor - RLTRM - Rice Land/Harvester - RLHRM -	Rice Land Development Rate - RLDR -	(-)
		Yield Per Acre - YPA -	(-)
Husbandry - HM -	Agri-Technicians/ Farmers - ATTFR -	Yield Per Acre - YPA -	(+)
Road Accessibility - RAMLD -	Actual Road Density/ Desired Road Density - ARD/DRD	Rice Land Development Rate - RLDR	(+)
Actual Road Density Cost - ARCM -	Actual Road Density/ Desired Road Density ARD/DRD	Farming Cost of Transport - FCOT -	(-)
Fertilizer Availability - FEAM	Fertilizer Inputs - FI -	Yield Per Acre - YPA -	(+)
Georgetown Civic Land Availability - GTCLAM -	Georgetown Civic Land Fraction Occupied - GTCLO -	Georgetown Housing Bus Service Structures Constr. - GTHC, GTBSC, GTSSC -	(+/-)
Urban Labor Force - ULFAM -	Labor Force/Jobs - ULFTJR -	%	(+)

multipliers, the variables that are influenced by the multipliers, and the direction of the influence on the impacted variables.

4.4 Model Calibration

It is particularly important, with a model this large and whose formulation is based on observed data, assumptions and concepts drawn from demography, economics, agriculture, transportation and technology, to test its predictive ability over a sample period.

The first step in such a calibration process is to identify a set of endogenous variables whose characteristics or behavior over the observed period more or less determine regional behavior, and whose values (i.e., available data) are "dependable" over the observed period.

The next step is to make several simulation or "calibrating" runs paying special attention to the table functions and the realism of their values over the test period, and to modify their values in an iterative manner, if necessary.

The final step is to compare the values of the predicted endogeneous variables (of the model) with the actual observed values of the same variables.

The above procedure was followed for the model calibration -- for the rural region, the following variables: (1) rural population; (2) the acreage of rice land cultivated; and (3) the rural road miles, were chosen. These variables, it is felt, determine the rural overall performance (i.e., population influences the demographic sector; cultivation level influences the economic sector; while roads determine the accessibility characteristics). In the urban region -- urban population and urban jobs -- it is felt, determine the key variable of unemployment rate, which influences population movements and links the two regions.

Figures 4.37, 4.38 and 4.39 and Table 4.11 show the plots and values for the predicted (model values) and observed values for the rural region's variables.

The data base for the rural region are only estimates (i.e., these values were taken from studies that quoted them as estimates provided by government agencies). An examination of Table 4.11 reveals that the model has a relatively high explanatory power over the sample period (1970-1990), with the model's values being very close to the observed values for the set of endogeneous variables used. The highest differences between predicted and observed values is 8 percent.

Figures 4.40, 4.41 and Table 4.12 show the plots and values for the urban region's variables. Table 4.12 shows population variation is between 8 and 13 percent between model and observed values, with the divergence being highest for the year 1990. These differences are not considered too large for model calibration, especially when the fact that the observed values are also forecasted values and would obviously be different from true values. Similarly, in the case of the job variable, the maximum differences occur in the year 1990 and is only of the order of 9 percent, and therefore considered acceptable.

The listing and definition of variables of the calibrated model are presented in Appendix 1.1 and 1.2. This model will be used in Chapter 5 to determine the rural investment alternative that provides the "most" beneficial national impacts.

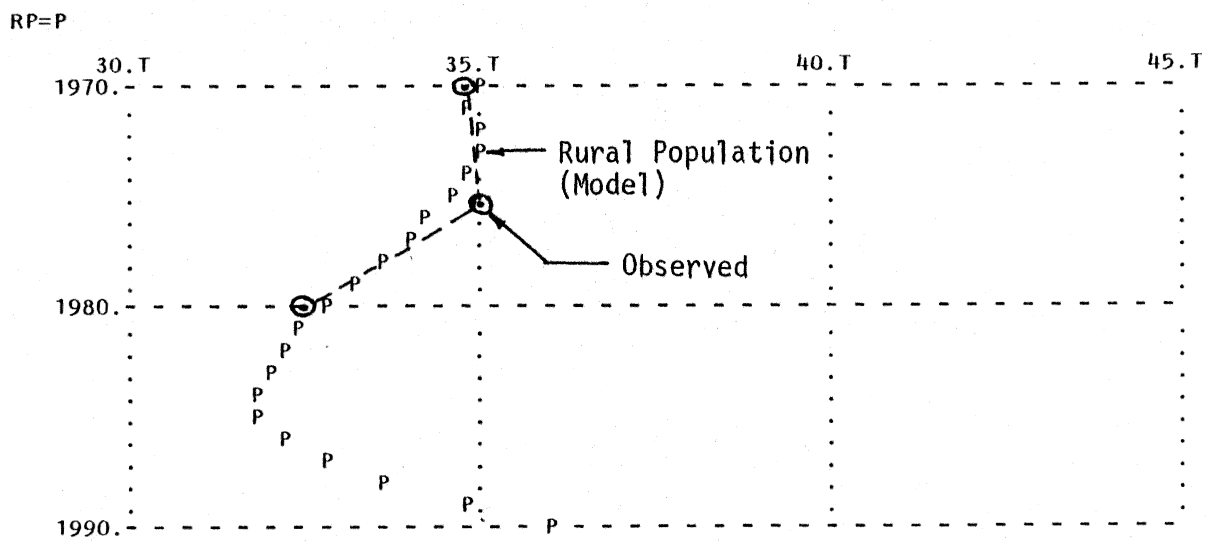


FIGURE 4.37 - The Plots of Observed and Model Values for Rural Population

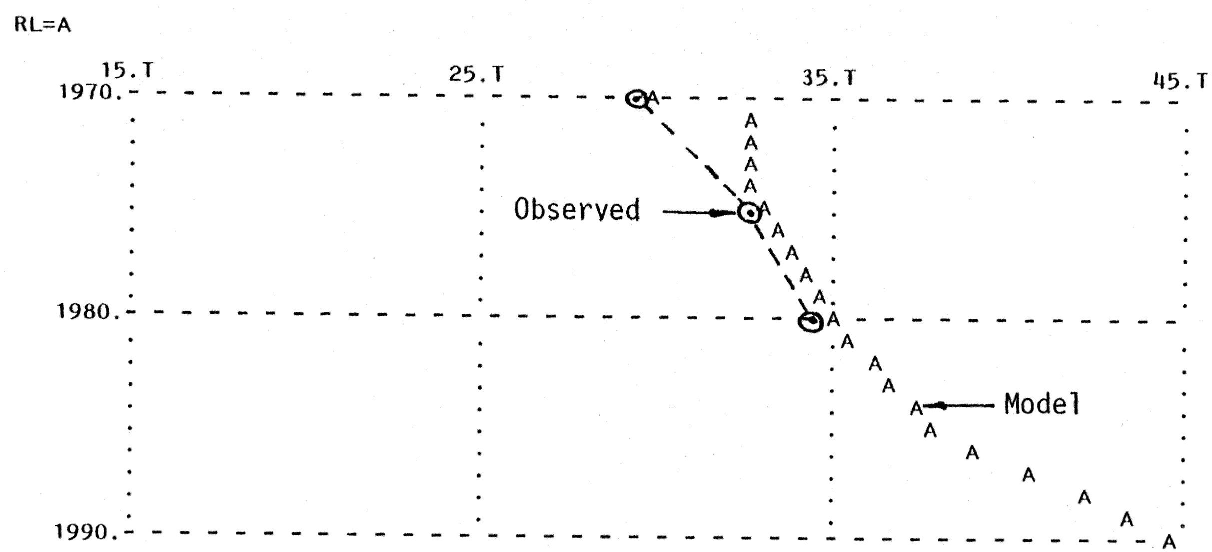


FIGURE 4.38 - The Plots of Observed and Model Values for Agricultural Cultivation

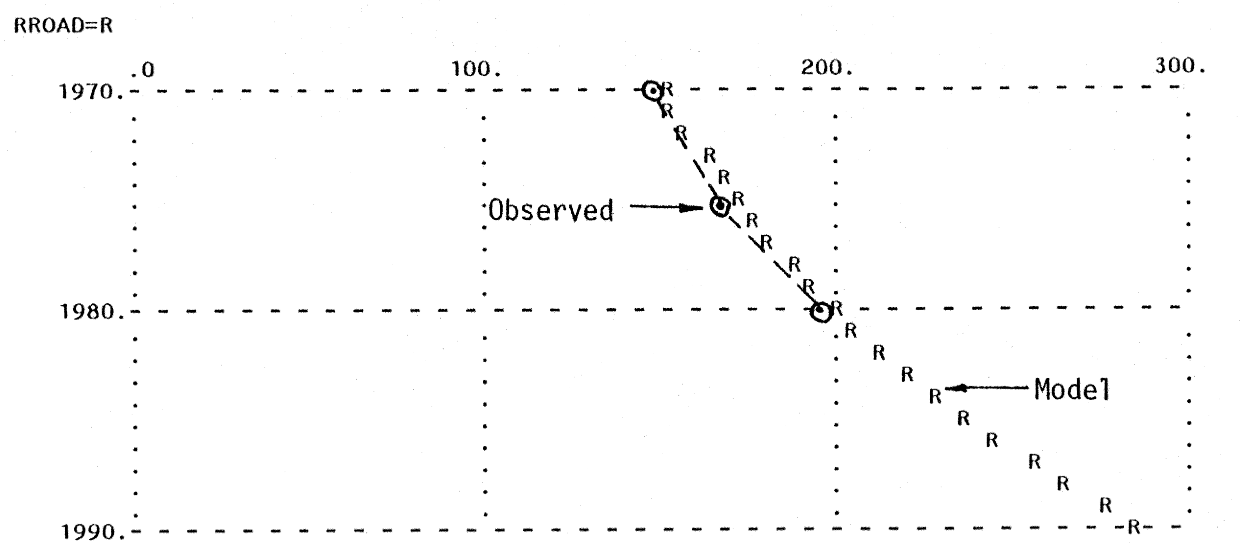


FIGURE 4.39 - The Plots of Observed and Model Values for Rural Road Miles

TABLE 4.11 - Predicted (Model) and Observed Values of Rural Population, Cultivations and Roads

Variables	Time -- Year 1970	1975	1980	1990
Population (Persons)				
- Model	35,000	34,500	32,800	36,000
- Observed	35,000	35,000	30,000-35,000[b]	N.A.
- Percent Difference	0.00[a]	1.5%	6-8%	--
Cultivation (Acres)				
- Model	30,000	33,100	35,000	44,800
- Observed	30,000	33,000	35,000[b]	N.A.
- Percent Difference	0.00[a]	<1%	0.00	--
Roads (Miles)				
- Model	150	171	198	284
- Observed	150	175	200[b]	N.A.
- Percent Difference	0.00[a]	<1%	<1%	--

a. Beginning of simulation.

b. Forecasted values.

N.A. Not Available

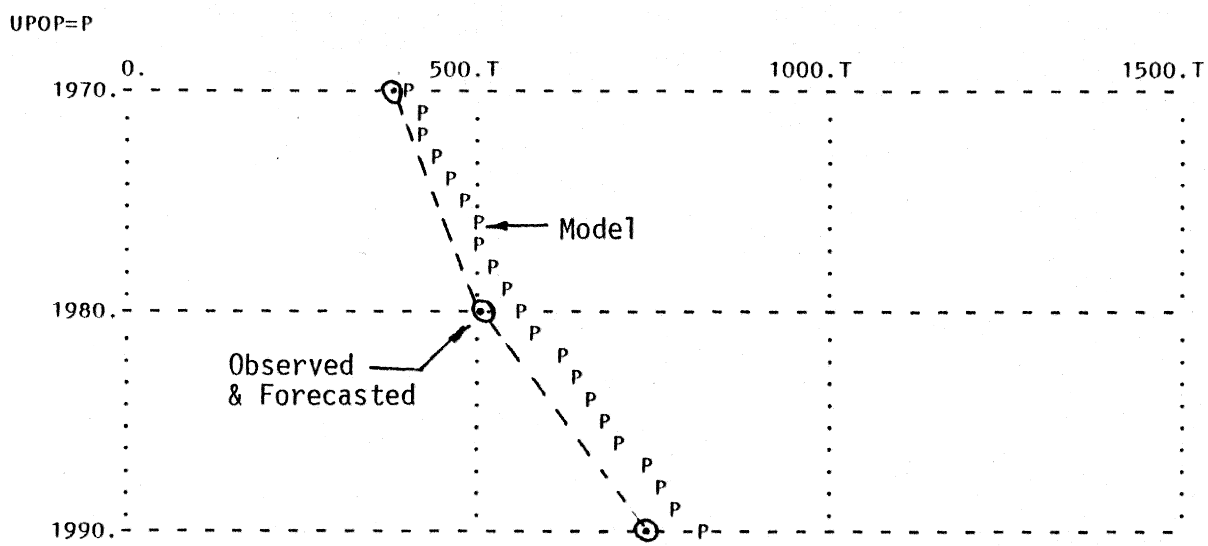


FIGURE 4.40 - The Plots of Observed and Model Values for Urban Population

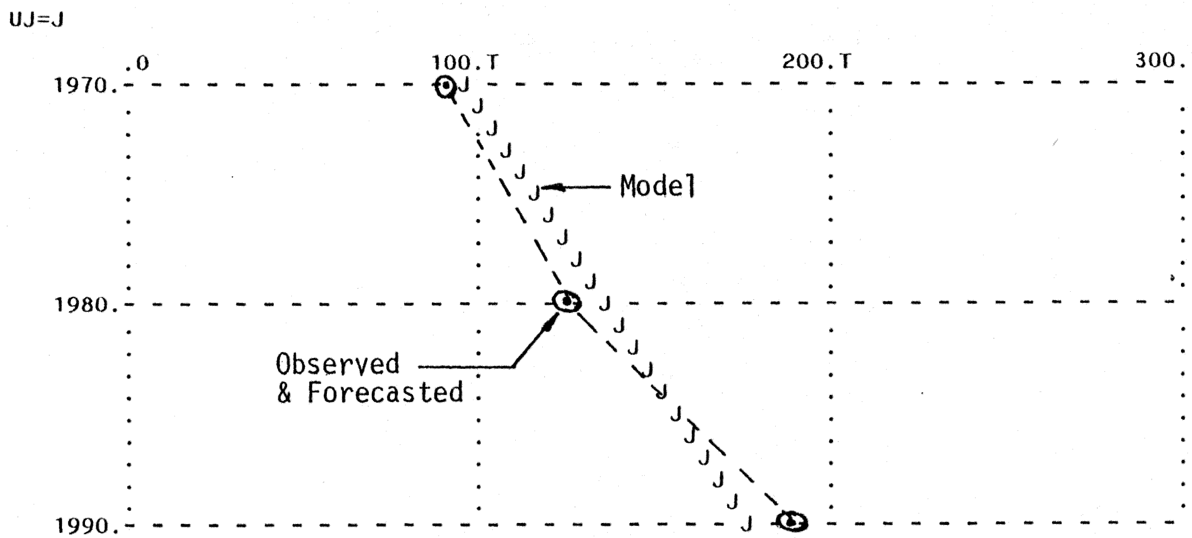


FIGURE 4.41 - <u>The Plots of Observed and Model Values for Urban Jobs</u>

TABLE 4.12 - Predicted (Model) and Observed Values of Urban Population and Urban Jobs

Variables	Time -- Year 1970	1975	1980	1990
Population				
- Model	396,900	473,100	567,400	814,500
- Observed	396,900	N.A.	516,500[b]	708,800[b]
- Percent Difference	0.00[a]	--	8%	13%
Jobs				
- Model	96,050	116,320	136,930	174,050
- Observed	95,518	N.A.	133,020[b]	189,250[b]
- Percent Difference	<1%		3%	9%

a. Beginning of simulation.

b. Forecasted values.

N.A. Not Available.

CHAPTER 5

ANALYSES OF ALTERNATIVE INVESTMENT STRATEGIES

If a road network is built to stimulate economic growth, then a much more satisfactory basis for estimating the benefits would seem to be one which measures the increases in production and changes in other socio-economic factors. This can be done directly without reference to traffic volume, except for the structural design of the roadway.

Likewise, it is important to recognize that the estimates of output are not based on only marginal reduction in transport costs. The development project, which embodies a variety of factors, should instead be considered as removing a bottleneck to production so that discrete rather than marginal changes to production can occur. Thus, instead of a single numerical indicator for the value of a project, a set of socio-economic characteristics should be used in the evaluation process. It is for these reasons that the practices in highway economics offer only limited insight into the overall impacts of the investments.

In this study the traditional practices -- Benefit Costs (B/C) and Net Present Worth (NPW) -- analyses will be undertaken, since for all intent and purpose, quantification in monetary terms is still the single-most desirable and utilized indicator of the impacts of the investments; but benefits for production instead of traffic flows will be evaluated for the given outlay. However, final recommendations will be based also on analyses of the behavior of the following set of socio-economic characteristics through time (i.e., the anticipated life of the investments): (1) impacts on production and productivity; (2) impacts on population, migration, jobs, unemployment and gross regional income per capita; and (3) spatial impacts of each investment strategy.

Approaches to rural development (i.e., investment strategies) in LDCs vary from a piecemeal, uncoordinated investment in roads and other infrastructure to a comprehensive, detailed, planned, funded and executed project. For convenience, this continuum of investment approaches is divided into three main alternatives: (1) Do Nothing, (2) Investments In Roads Only, and (3) Investments in Road, Drainage and Irrigation, for simulation by the "calibrated" model developed in Chapter 4. Section 5.1 will deal with analyses of the socio-economic impacts of the "Do Nothing" strategy; Section 5.2, the "Road Investment Only" strategy; Section 5.3 the "Comprehensive" investment strategy of "Road, Drainage and Irrigation." In Section 5.4, the differences of the three alternatives will be discussed with specific emphasis on the spatial impacts and timing of receipts.

5.1 "Do Nothing" Alternative

In a real world scenario, nations never really completely neglect their rural regions, except for those areas which are labeled "jungle" with zero output and population. Whereas the desired level of investment is not forthcoming (in many cases because of traffic demand evaluation techniques and prioritization), cognizance is taken of the contribution of these rural regions to the national economy. In addition, funds are allocated to at least maintain the status quo and in some cases to also provide a minimum of funding for expansion of the economic infrastructure.

As such, the "Do Nothing" alternative is a pseudonym for the continuation of the status quo of the region (i.e., whatever has been the history of the funding and performance of the region is assumed to continue into the future.

The Essequibo Region falls in this category of "Do Nothing" strategy, since feasibility studies conducted between the period 1970-1973 for the Essequibo Region, based primarily on traffic demand concept, recommended no major investment in the region (i.e., the expansion of the road network was found to be infeasible at a five percent interest rate). However, funds for the region did not totally "dry up"; and as shown in Chapter 4, Table 4.7, funding continued at an average rate of approximately one million dollars per year, with fluctuation as shown in the table. For the "Do Nothing" alternative, this strategy of funding is assumed to continue in the foreseeable future with annual increases of approximately ten percent to take care of price increases in labor, materials, etc.

Thus, from a modeling point of view, no modification is made to the "calibrated" model developed in Chapter 4 for the socio-economic analyses of the region. The developed model is simply "projected" or simulated for another twenty years, to the year 2000, and the analyses of the socio-economic behavior of the region over the period is considered as the "Do Nothing" alternative.

5.1.1 Economic Analyses

The economic characteristics of any investment includes information about the nature, amounts and timing of receipts and expenditures. Also, in addition to receipts and expenditures, the following assumptions are made in order to keep the concept of the economic analyses clear. First, whatever the production rate reaches, it can be marketed (i.e., there is no market constraint). This is so in reality, in Guyana as for now; there is no projected market limitation in the foreseeable future for Guyana's rice. In fact, the demand is growing faster than Guyana's current rice production growth rate. Secondly, both the input costs for production and the selling price for paddy (i.e., unmilled rice) are kept constant over the analysis period. Because of the uncertainties of input prices and future negotiated selling prices to importers of Guyana's rice, this approach is taken. However, sensitivity analyses can be applied to any key input factors or changes in selling price over the planning period.

Table 5.1 provides a direct computer printout of the values for the variables that are used in the economic anlayses of the "Do Nothing" alternative. These variables are Rice Land cultivated in acres (RL), Farming Cost per Acre in dollars (FCA), Rural Road in miles (RROAD), Road Construction Expenses in dollars (RCE), Road Maintenance Expenses in dollars (RME), Total Road Expenses in dollars (RER), and Unmilled Rice Production Rate (UMRPR) in tons.

The economic analyses of benefits and costs involve primarily the comparison of the discounted receipts and costs over the planning period

TABLE 5.1 - The Computer Printout of the Values of the Main Variables Used in the Economic Analysis

TIME E+00	RL E+03	CFA E+00	RROAD E+00	RCE E+03	RME E+03	RER E+03	UMRPR E+03
1970.	30.000	229.89	150.00	376.78	231.1	607.8	47.734
1971.	32.722	231.83	153.77	376.78	287.2	664.0	53.553
1972.	32.692	230.65	157.77	400.08	349.5	749.6	50.714
1973.	32.654	230.72	162.03	425.65	419.0	844.7	51.126
1974.	32.618	230.68	166.56	453.44	536.1	989.6	51.256
1975.	33.084	230.79	171.20	463.93	656.4	1120.3	51.942
1976.	33.362	230.68	176.00	479.65	785.0	1264.6	51.975
1977.	33.783	230.68	180.98	498.82	895.4	1394.2	52.379
1978.	34.138	230.61	186.34	535.72	931.7	1467.4	52.577
1979.	34.576	230.57	192.15	580.93	960.7	1541.7	52.945
1980.	35.023	230.51	198.45	630.10	992.3	1622.4	53.256
1981.	35.518	230.45	205.28	682.83	1026.4	1709.2	53.630
1982.	36.047	230.37	212.55	727.35	1062.8	1790.1	54.044
1983.	36.606	230.29	220.26	771.02	1101.3	1872.3	54.861
1984.	37.215	230.20	228.40	813.66	1142.0	1955.7	55.756
1985.	37.851	230.15	236.96	856.46	1184.8	2041.3	56.845
1986.	39.152	230.24	245.95	898.85	1229.8	2128.6	59.203
1987.	40.636	230.18	255.35	939.84	1276.8	2216.6	61.343
1988.	42.033	230.07	265.10	975.20	1325.5	2300.7	63.240
1989.	43.437	230.02	274.95	984.79	1374.8	2359.5	64.984
1990.	44.782	229.95	283.67	872.09	1418.4	2290.4	66.570
1991.	46.034	229.87	291.19	751.91	1456.0	2207.9	68.007
1992.	47.136	229.80	297.52	632.73	1487.6	2120.3	69.205
1993.	48.081	229.73	302.75	523.46	1513.8	2037.2	70.201
1994.	48.878	229.67	307.37	462.04	1536.9	1998.9	71.033
1995.	49.568	229.61	311.39	401.48	1556.9	1958.4	71.767
1996.	50.166	229.57	314.82	343.24	1574.1	1917.3	72.402
1997.	50.681	229.52	317.77	295.36	1588.9	1884.2	72.947
1998.	51.125	229.49	320.31	253.74	1601.6	1855.3	73.416
1999.	51.506	229.46	322.44	213.34	1612.2	1825.6	73.816
2000.	51.831	229.43	324.20	175.84	1621.0	1796.9	74.153

Legend:

RL = Rice Land (acres)

CFA = Cost of Farming Per Acre ($)

RROAD = Rural Road (miles)

RCE = Road Construction Expenses ($)

RME = Road Maintenance Expenses ($)

RER = Total Road Expenses ($)

UMRPR = Unmilled Rice Production (tons)

or the useful life of the infrastructure provided. The general form of the economic efficiency criterion for measuring the direct consequences of the project follows the concept of "shadow prices". It says that all projects should be accepted whose net present worth is positive where:

$$\text{Net Present Worth} = \sum_{j=0}^{n} [(B_j - C_j) \div (1 + i)^j]$$

and,

j = the year in which benefits and costs occur.

n = the period of the analysis.

B_j = the value of benefits in the j^{th} year.

C_j = the value of costs in the j^{th} year.

i = the interest rate used for discounting, which is also the shadow price of capital [6].

$(1+i)^j$ = the discounting factor required to place the benefits and costs which occur in different years on a directly comparable basis.

Alternatively, the concept of a benefit/cost ratio of 1 or greater is used for accepting a project -- where the ratio is simply the net present worth of all receipts divided by the net present worth of all costs for a stated period.

In this case study, annual receipts or benefits are those accruing from the sale of its agricultural produce (i.e., rice); and annual expenses are those accruing from farming and roads and/or investment on other infrastructure.

Farming Cost Per Annum = RL x CFA

where:

RL = Rice Land cultivated per year (acres).

CFA = Farming Cost per Acre (dollars).

and,

Total Road Expenses per annum (RER) = RCE + RME

where:

RCE = Road Construction Expenses per year (dollars).

RME = Road Maintenance Expenses per year (dollars).

and,

Receipts or Benefits per annum = UMRPR x SPT

where:

UMRPR = Unmilled Rice Production Rate per year (in tons).

SPT = Selling Price of unmilled rice per Ton (in dollars)

= 200

The "Do Nothing" policy (Table 5.1) evaluated at ten percent (10%) interest rate for the analyses period from year 1978 to 2000 results in a net present worth of the road expenditure of approximately $15,900,000 and the net present worth of the receipts of approximately $23,700,000. These flows result in a benefit/cost ratio of 1.49 and a net present worth of $7,767,000.

5.1.2 Analyses of Other Socio-Economic Regional Indicators

The "Do Nothing" alternative satisfies both the benefit/cost ratio and the net present benefit criteria and is therefore a potential viable candidate for recommendation. However, as earlier contended, development strategies should be based not only on a ratio greater than one nor positive cash flows, but on the overall improvement and the least negative impact to the region or nation, as measured by the main regional socio-economic indicators.

5.1.2.1 Impact on Production Level and Productivity

Figure 5.1 shows the computer plot for cultivation, production and road. The rice industry (acres cultivated) grows at a decreasing rate and does not reach its true potential in terms of acres cultivated until the year 2000 (Table 5.1). Cultivation follows the expansion of the road network; thus,accessibility by road is undoubtedly one of the major constraints to the expansion of the rice industry. A close examination of production rate and cultivation level (UMRPR/RL) shows that productivity (yield per acre) has remained constant at approximately one and one-half ton per acre throughout the analysis period. Thus, the "Do Nothing" alternative constrains growth and productivity in the rice industry; and as such, the expansion of the regional economy, since rice production is the mainstay of the economy of the region.

5.1.2.2 Impacts on Population and Income Per Capita

Rural population is determined by birth, death and migration rates; and further, migration is determined by the relative job opportunities in the investment region and the urban region. Figures 5.2 and 5.3 and Table 5.2 show the plots and printout of the main variables (Agricultural Jobs, Rural Unemployment, Rural Population and Rural Migration) that

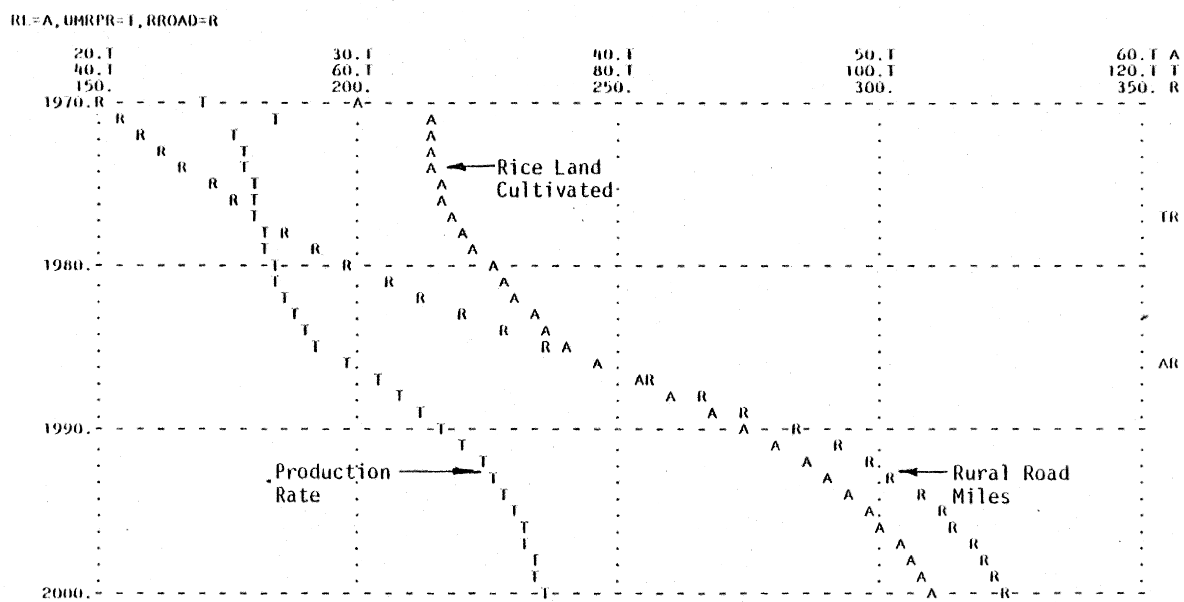


FIGURE 5.1 - <u>The Computer Plot of Main Economic Variables (Roads, Cultivation and Production)</u>

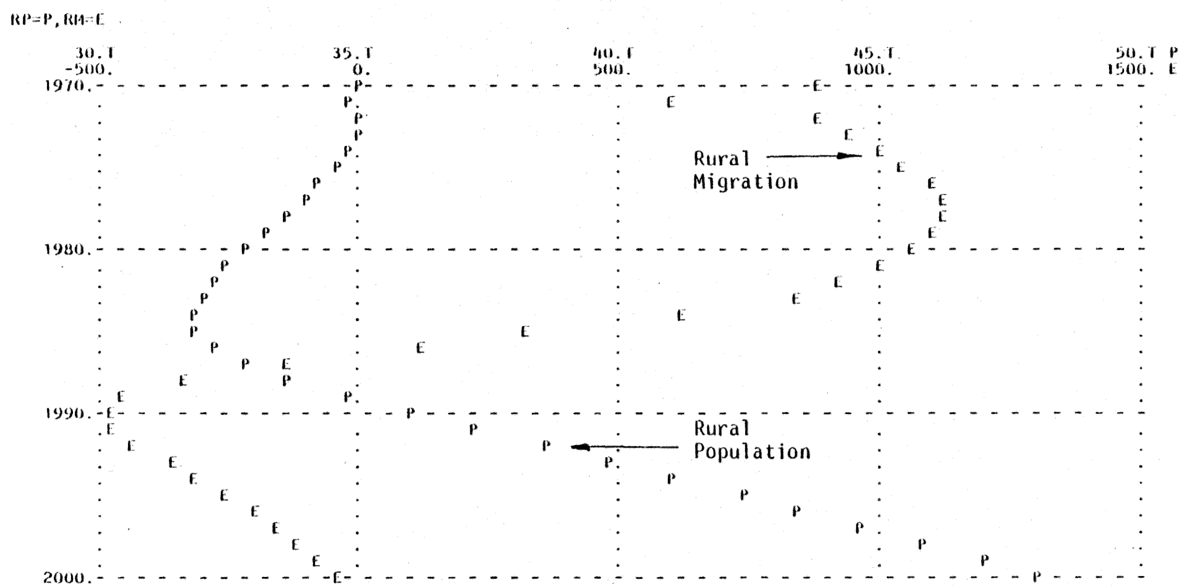


FIGURE 5.2 - <u>Computer Plot of Rural Population and Migration</u>

TABLE 5.2 - Computer Printout of the Main Socio-Economic Variables

TIME E+00	AJ E+03	RUR E+00	RP E+03	RM E+00	UMRL E+03	UMRTR E+03	RTC E+03
1970.	9.000	.40474	35.000	887.1	.00	47.734	98.438
1971.	9.817	.35025	34.883	602.5	.00	47.734	84.108
1972.	9.808	.35306	35.048	879.8	5.82	53.553	72.003
1973.	9.796	.35091	34.939	949.1	2.98	50.714	61.690
1974.	9.785	.34731	34.759	1008.8	3.39	49.745	49.745
1975.	9.925	.33295	34.515	1031.2	4.90	40.943	40.943
1976.	10.009	.32140	34.243	1093.0	15.90	38.159	38.159
1977.	10.135	.30543	33.903	1117.7	29.72	38.368	38.368
1978.	10.241	.28946	33.531	1128.6	43.73	38.632	38.632
1979.	10.373	.27089	33.140	1106.8	57.68	38.895	38.895
1980.	10.507	.25187	32.762	1064.3	71.73	39.057	39.057
1981.	10.655	.23210	32.419	995.3	85.92	39.274	39.274
1982.	10.814	.21277	32.137	929.1	100.28	39.476	39.476
1983.	10.982	.19392	31.915	848.7	114.85	39.705	39.705
1984.	11.164	.17569	31.768	627.6	130.00	39.961	39.961
1985.	11.355	.16242	31.839	311.5	145.80	40.427	40.427
1986.	11.746	.14380	32.228	111.8	162.22	41.001	41.001
1987.	12.191	.12741	32.826	-141.8	180.42	41.739	41.739
1988.	12.610	.12038	33.689	-333.4	200.02	43.228	43.228
1989.	13.031	.11927	34.764	-462.6	220.04	44.755	44.755
1990.	13.434	.12472	35.991	-489.7	240.26	46.107	46.107
1991.	13.810	.13294	37.273	-476.8	260.73	47.310	47.310
1992.	14.141	.14369	38.570	-430.4	281.42	48.378	48.378
1993.	14.424	.15601	39.849	-369.9	302.25	49.324	49.324
1994.	14.664	.16883	41.095	-312.0	323.13	50.125	50.125
1995.	14.870	.18207	42.311	-256.9	344.03	50.775	50.775
1996.	15.050	.19549	43.499	-206.3	365.03	51.295	51.295
1997.	15.204	.20893	44.662	-160.7	386.13	51.729	51.729
1998.	15.338	.22237	45.806	-119.5	407.35	52.088	52.088
1999.	15.452	.23581	46.933	-81.4	428.68	52.379	52.379
2000.	15.549	.24920	48.047	-46.2	450.12	52.614	52.614

Legend:

- AJ = Agriculture Jobs
- RUR = Rural Unemployment Rate
- RP = Rural Population
- RM = Rural Migration
- UMRL = Unmilled Rice Production Loss
- UMRTR = Unmilled Rice Transportation Rate
- RTC = Unmilled Rice Transport Capacity

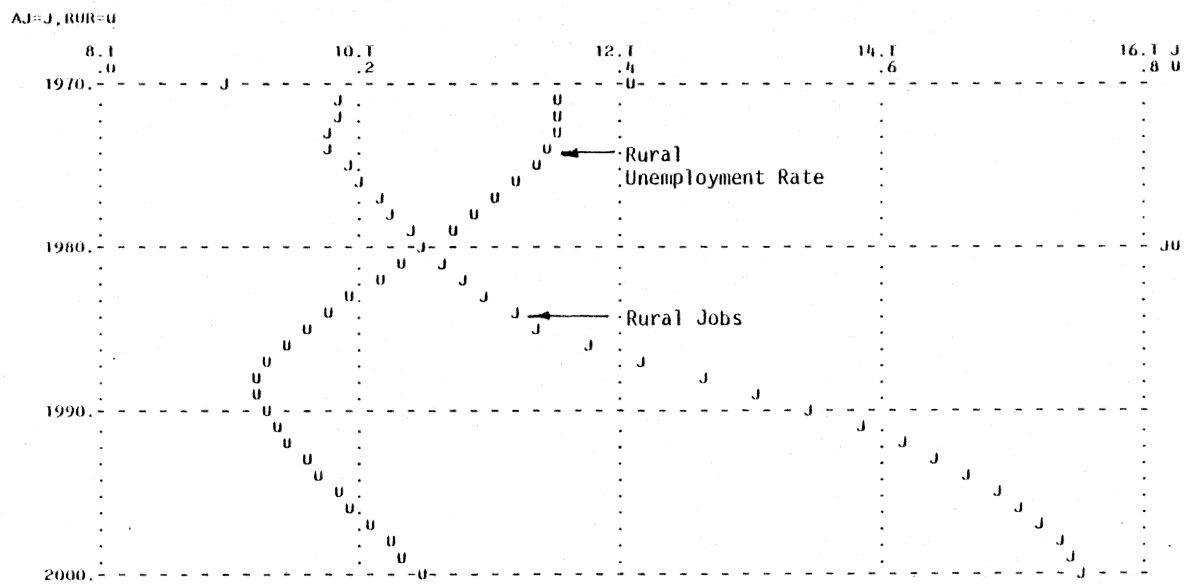


FIGURE 5.3 - Computer Plot of Rural Jobs and Unemployment Rate

influence population level. Jobs for the first fifteen years (1970-1975) increase very slowly (almost static to an average growth of one percent); and from 1985-1995, there is a greater growth, reaching approximately four and one-half percentage. This change is due to the cummulative impact of the improved accessibility over the past fifteen years (1970-1985). From 1995-2000, the growth rate falls to less than one percentage and is likely to remain there since the potential arable land area is now more or less occupied, and any new jobs created must be from other sources.

However, an interesting feature of the region during this low generation of job opportunities under the "Do Nothing" strategy is that the unemployment rate is falling (the converse of what should be expected). This fall in unemployment rate is due primarily to the heavy outmigration, as shown in Table 5.3 and Figure 5.4, reaching a high point of approximately 1,100 persons in 1978 and gradually decreasing to a positive inflow in 1987. Migration produces the most significant impact on the rural population level. An outflow of population is experienced between 1979-1987, and the region (with an initial population of approximately 35,000) finally stabilizes at a population of approximately 48,000 persons in the year 2000.

Gross regional income per capita at the beginning of the analysis (i.e., in the year 1970, the population is 35,000 persons; production is 47,000 tons) results in an approximate income per capita of $268 per annum. Gross income per capita at stability or at the time when the potential of the region has been reached (i.e., in the year 2000, the

TABLE 5.3 - The Computer Printout of the Main Spatially Impacted Variables

TIME E+00	UPOP E+03	UI E+03	RM E+00	ECADT E+03	EBADT E+03
1970.	396.9	5.458	887.1	13.723	9.209
1971.	411.1	5.319	602.5	14.832	9.946
1972.	425.4	5.743	879.8	15.963	10.688
1973.	440.6	5.968	949.1	17.173	11.480
1974.	456.5	6.189	1008.8	18.443	12.302
1975.	473.1	6.380	1031.2	19.773	13.152
1976.	490.4	6.616	1093.0	21.160	14.024
1977.	508.5	6.823	1117.7	22.600	14.912
1978.	527.3	7.022	1128.6	24.093	15.811
1979.	547.0	7.196	1106.8	25.640	16.715
1980.	567.4	7.356	1064.3	27.238	17.618
1981.	588.6	7.497	995.3	28.886	18.516
1982.	610.6	7.649	929.1	30.561	19.394
1983.	633.5	7.793	848.7	32.241	20.243
1984.	657.2	7.805	627.6	33.923	21.059
1985.	681.6	7.727	311.5	35.596	21.827
1986.	706.6	7.772	111.8	37.253	22.537
1987.	732.3	7.769	-141.8	38.916	23.199
1988.	758.7	7.835	-333.4	40.587	23.799
1989.	786.1	7.972	-462.6	42.280	24.340
1990.	814.5	8.221	-489.7	44.015	24.822
1991.	844.4	8.522	-476.8	45.819	25.247
1992.	875.8	8.872	-430.4	47.716	25.607
1993.	909.1	9.253	-369.9	49.731	25.890
1994.	944.6	9.651	-312.0	51.898	26.098
1995.	982.7	10.070	-256.9	54.251	26.259
1996.	1023.9	10.513	-206.3	56.841	26.369
1997.	1068.7	10.984	-160.7	59.740	26.425
1998.	1118.4	11.494	-119.5	63.051	26.423
1999.	1174.3	12.058	-81.4	66.903	26.568
2000.	1238.4	12.692	-46.2	71.432	26.900

Legend:

UPOP = Urban Population

UI = Urban Inmigration

RM = Rural Migration

ECADT = East Coast Average Daily Traffic (passenger car units)

EBADT = East Bank Average Daily Traffic (passenger car units)

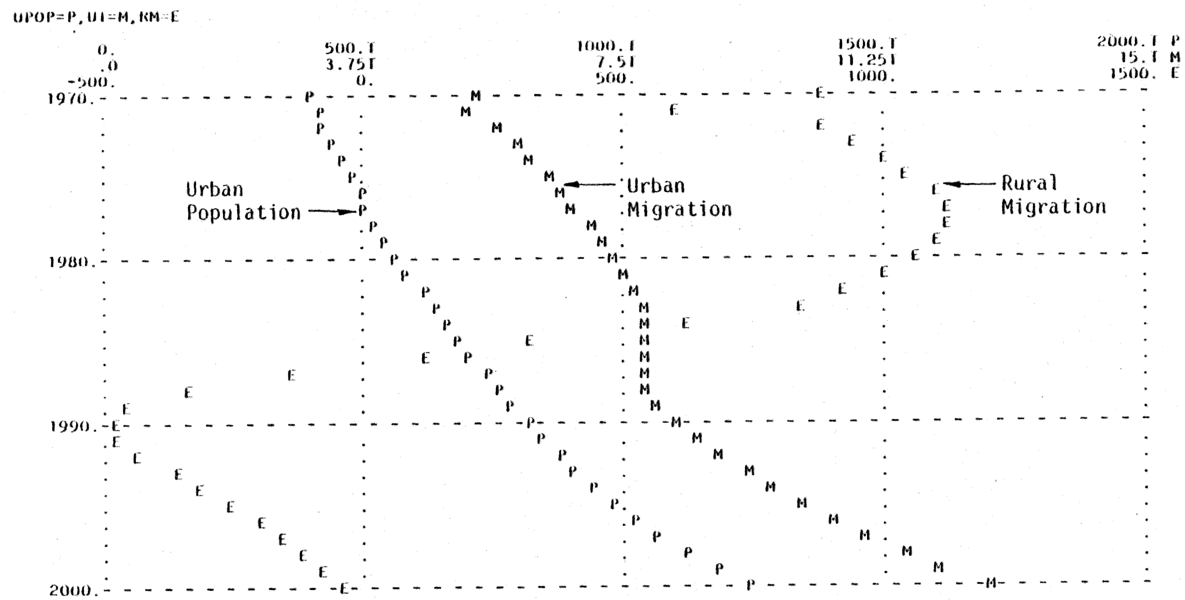


FIGURE 5.4 - The Computer Plot of Main Spatially Impacted Variables

population is 48,000 persons; production is 74,000 tons) is approximately $308 per annum. Both incomes per capita are based on a selling price of $200 per ton for unmilled rice.

Thus, the "Do Nothing" strategy has resulted in heavy urban inmigration and no major changes in the rural region's income per capita in the long run.

5.1.2.3 <u>Impacts on the Urban Region (Spatial Impacts)</u>

Spatial impacts, as hypothesized in this study, is due primarily to population movements. The influx of people from the rural region increases the urban population, labor force and unemployment rate and creates additional stresses on the urban socio-economic infrastructure of housing and transport among others. Furthermore, the urban region was subdivided into four zones in order to be able to explicitly evaluate zonal impacts of inmigration on transportation per se. The spatial impacts as measured by: (a) urban population, and (b) traffic on the road approaches to Georgetown (i.e., East Coast and East Bank Demerara -- the only zones with direct road connection into the capital Georgetown) are traced and discussed.

Table 5.3 and Figure 5.4 show that the urban population has increased from 396,900 persons (in the year 1970) to 1,238,400 persons (in the year 2000); and during the same period, overall inmigration has jumped from approximately 5,500 persons per year in 1970 to approximately 12,700 persons per year in 2000. Of importance, however, is that the "Do Nothing" policy in the Essequibo Region has contributed significantly to the overall urban migration (as much as 15%) between the years

1970 to 1985; and not until 1986, when the cumulative impact of the road investment is felt, does this outmigration trend cease. Thus, the "Do Nothing" policy has resulted in "premature" growth in urban population and traffic on the East Coast and East Bank approach roads. The traffic increases are assumed to be directly proportional to the population increase (i.e., each "new resident" generates his share of social and economic trips). Both approaches to Georgetown are served by a two-lane urban highway (i.e., 12-foot wide lanes and 0-6-foot wide shoulder), resulting in an average capacity of 2000 passenger cars per hour. Further, the peak hour traffic on both approaches is between 8 and 12 percent. Figure 5.5 shows a plot of the approach roads traffic; the East Coast route has reached its peak hour capacity in 1976 and continues to grow to almost triple the value by year 2000. The East Bank route is even worse. It has reached its capacity in 1971, but stabilizes by 1990 to approximately 2.5 times its 1970 value. The equilibrium is due primarily to the land constraint of the zone.

The results of this policy run clearly show that the traffic problem of the approach roads to Georgetown is one of the impacts of rural policies. It is contended that unwarranted inmigration contributed to a deteriorating traffic problem of Georgetown. Today, the approach roads to Georgetown are being improved to 4 lanes to cope with the traffic growth.

5.2 Investment in Roads Alternative

The fact that roads influence the intensiveness and extensiveness of socio-economic activities in Guyana was clearly illustrated in

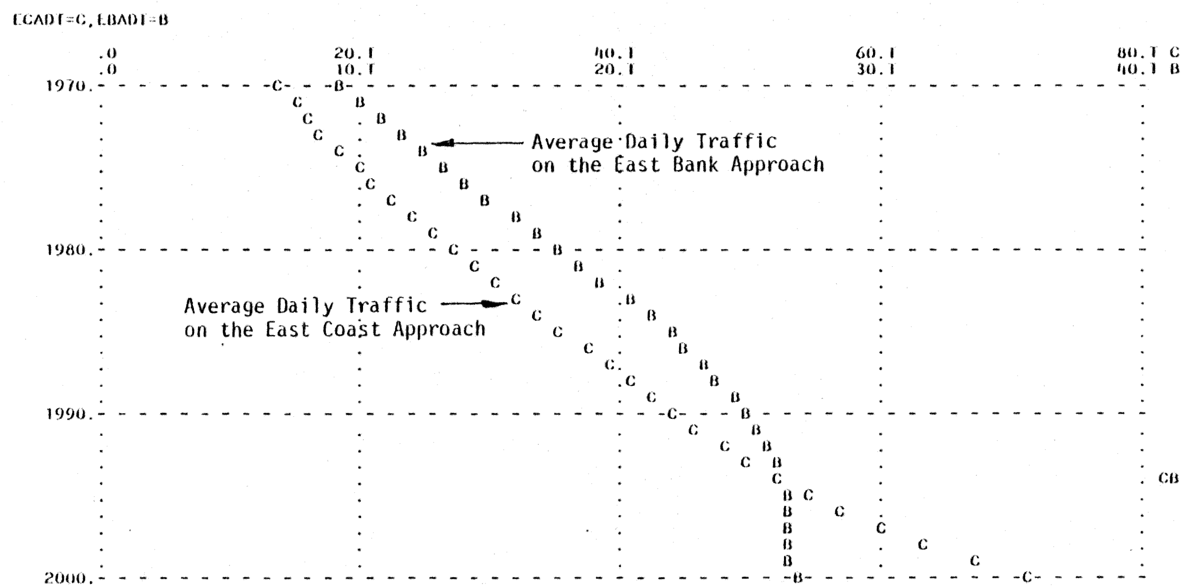


FIGURE 5.5 - The Computer Plot of the Traffic on the Approaches to Georgetown

Chapter 4. Figures 4.2, 4.3 and 4.5 showed that population distribution and cultivation followed very closely the road infrastructure. This national behavior is also evidenced in the study region, which has a potential arable area of 70,000 acres, but is cultivated at only just over 30,000 acres for the past ten years (1970-1980) because of an "inadequate" road network.

Accessibility by road is therefore unquestionably the main perceived bottleneck to the expansion of the agricultural base of the region. The question to be addressed is whether it is feasible to expand the road network and take advantage of the agricultural potential of the region. The remainder of this section addresses the feasibility of investment in "Roads Only".

From a modeling point of view, the only modification required to the "calibrated" model developed in Chapter 4 is the removal of the budgetary or funding constraint, as was the case in the "Do Nothing" alternative. This was done by simply re-initializing the model in the year 1980 and providing an input of $20,000,000 for road expenditure in 1980. Thus, the expansion of the road network from the year 1980 and onward is dependent only on the construction capabilities of the system (i.e., the contractor or government and problems of right-of-way access), and no longer on funding. This time lag between funding and the expansion of the road network is reflected in the model by the equation for Road Construction Rate per year as follows:

RCR.KL = MIN(DFR.K,RCB.K/CCPM)*RRLAM.K/RCT

where:

RCE = Road Construction Rate (miles of road per year).

MIN = Minimum function (i.e., number of miles constructed per year is equal to the minimum required or that the budget would permit).

DFR = Demand For Road (miles).

RCB = Road Construction Budget (in dollars).

CCPM = Construction Cost Per Mile (in dollars).

RRLAM = Rural Road Land Availability Multiplier (Dimensionless).

RCT = Road Construction Time (years)(i.e., the time lag between funding and completion).

The behavior was then simulated for another twenty years to the year 2000. The analyses of the behavior of the region over this period is considered as the "Roads Only" investment strategy.

5.2.1 Economic Analyses

Table 5.4 provides the direct computer printout of the main variables needed for the economic analysis. The names and definitions of the variables are similar to those of the "Do Nothing" alternative. The evaluation of Table 5.4 for the "Road Only" alternative at ten percent (10%) interest rate for the analyses period from year 1980 to 2000 results in a net present worth of road expenditure of approximately $23,739,000, and the net present worth of receipts from farming of approximately $26,454,000. These cash flows provide a benefit/cost ratio of 1.12 and a net present benefit of approximately $2,714,000.

TABLE 5.4 - The Computer Printout of the Main Variables Used in the Economic Analysis

TIME E+00	RL E+03	CFA E+00	RROAD E+00	RER E+03	RCE E+03	RME E+03	UMRPR E+03
1980.	33.000	230.47	198.00	6019.3	5326.3	693.0	52.787
1981.	37.192	230.91	251.26	6205.8	5326.3	879.4	59.996
1982.	42.984	230.75	293.35	5235.4	4208.6	1026.7	68.528
1983.	47.255	230.19	313.06	3066.5	1970.8	1095.7	71.948
1984.	49.345	229.76	321.90	2011.2	884.6	1126.7	72.717
1985.	50.594	229.62	326.05	1556.1	414.9	1141.2	73.620
1986.	51.416	229.53	328.09	1351.8	203.5	1148.3	74.206
1987.	51.985	229.47	329.09	1252.3	100.5	1151.8	74.610
1988.	52.392	229.43	329.58	1202.3	48.7	1153.5	74.894
1989.	52.691	229.40	329.81	1177.3	23.0	1154.3	75.093
1990.	52.913	229.37	329.91	1165.2	10.5	1154.7	75.236
1991.	53.081	229.35	329.96	1159.6	4.8	1154.9	75.350
1992.	53.210	229.34	329.98	1157.1	2.1	1154.9	75.442
1993.	53.311	229.33	329.99	1155.9	1.0	1155.0	75.516
1994.	53.390	229.32	330.00	1155.4	.4	1155.0	75.578
1995.	53.452	229.31	330.00	1155.2	.2	1155.0	75.629
1996.	53.501	229.30	330.00	1155.1	.1	1155.0	75.673
1997.	53.538	229.30	330.00	1155.1	.1	1155.0	75.711
1998.	53.567	229.29	330.00	1155.0	.0	1155.0	75.743
1999.	53.589	229.29	330.00	1155.0	.0	1155.0	75.772
2000.	53.605	229.28	330.00	1155.0	.0	1155.0	75.797

Legend:

RL = Rice Land Cultivated

CFA = Cost of Farming Per Acre

RROAD = Road Miles

RER = Total Road Expenses

RCE = Road Construction Expenses

RME = Road Maintenance Expenses

UMRPR = Unmilled Rice Production Rate

5.2.2 Analyses of Other Socio-Economic Regional Indicators

Rarely, if ever, transportation planners would recommend an investment alternative based only on non-quantifiable socio-economic characteristics. However, the premise of this study is that an awareness of the overall socio-economic impact of any investment approach is as equally important as the economic analysis and should be undertaken before final recommendations are made, especially if the economic test is a borderline case. Moreover, when all alternatives are feasible, then the socio-economic analyses become even more relevant if negative impacts are to be minimized. The "Road Only" alternative satisfies the feasibility criteria of benefit/cost and net present benefit, and is therefore a viable candidate for overall impact analyses and final consideration.

5.2.2.1 Impact on Production and Productivity

Figure 5.6 traces the level of road, cultivation and production for the investment in the "Roads Only" policy. Within six years (1980 to 1985), the road network is almost completed. Cultivation reaches its full potential in 1990, increasing from 33,000 acres in 1980 to 53,000 acres in 1990. The delays between funding (in 1980) and accessibility (completion of network in 1985) and full cultivation (in 1990) are due to the time required for road construction and land development.

Expansion of the road network has resulted in approximately fifty percent (50%) increase in production (from 53,000 tons to 75,000 tons) within ten years (from 1980 to 1990). From Table 5.4, productivity (UMRPR/RL) (i.e., yield per acre) has remained constant over the analysis

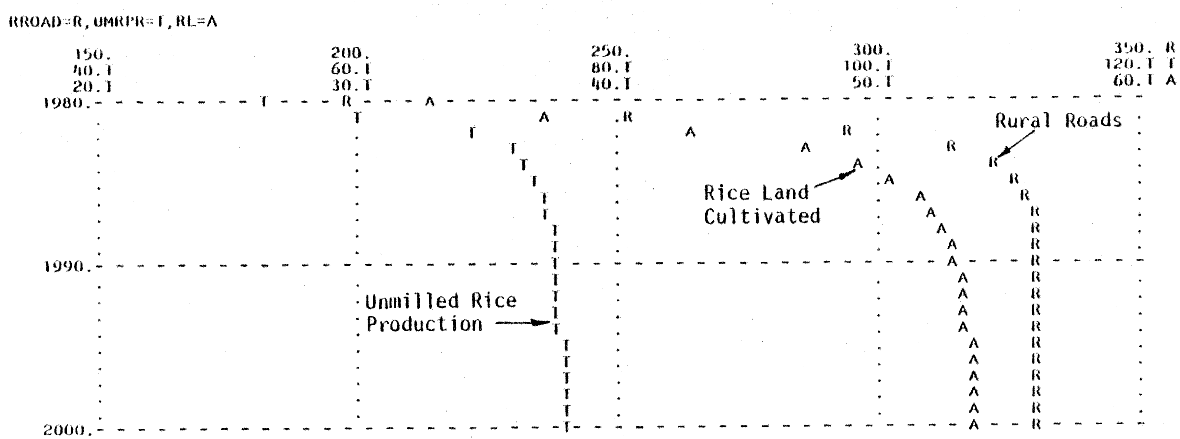


FIGURE 5.6 - <u>The Computer Plot for the Main Economic Variables (Roads, Cultivation and Production)</u>

period at approximately one and one-half ton per acre. This is not surprising, since yield per acre is determined by several factors including drainage and irrigation availability. The "Roads Only" investment strategy in no way improves the drainage and irrigation level. If any, the increased acreage has effectively reduced the water availability per acre cultivated. However, the expansion of the network has significantly impacted the timing of the receipts from agricultural expansion.

5.2.2.2 Impact on Population and Income Per Capita

Jobs influence migration and migration has the most significant impact on rural population level. The expansion of the rural road network has resulted in increased cultivation; within five years (1980-1985), job opportunities jumped from 10,000 to 15,000 -- a fifty percent (50%) increase (see Table 5.5 and Figure 5.7). Outmigration ceased in 1981 with "heavy" inmigration between the years 1981 and 1986 due to a combination of the impacts from road construction and agricultural cultivation. In the same period (1981-1986), rural population increased to 40,000 from 32,000 persons, indicating the potential of the region to provide a livelihood for its population; also, unemployment reached its lowest level of approximately four percent (4%) in 1983. Gross regional income per capita rose to $373 based on production and population levels in 1986 (i.e., 74,600 tons and 40,000 persons). Thus, the socio-economic characteristics of the rural region have been propitiously impacted.

TABLE 5.5 - The Computer Printout of the Main Variables Used in the Analysis

TIME E+00	RP E+03	RM E+00	AJ E+03	RUR E+00	UPOP E+03	UI E+03	EBADT E+03	ECADT E+03
1980.	32.500	871.2	9.900	.22045	567.3	7.163	17.769	27.245
1981.	32.344	-206.5	11.158	.12268	588.2	6.292	18.637	28.856
1982.	33.262	-1164.2	13.030	.03525	608.3	5.534	19.390	30.384
1983.	35.158	-1230.5	14.185	.03954	627.7	5.661	20.026	31.806
1984.	37.162	-1196.1	14.810	.06560	647.8	5.895	20.626	33.223
1985.	39.175	-635.6	15.183	.09714	668.8	6.664	21.201	34.655
1986.	40.673	-215.9	15.428	.11902	691.7	7.308	21.803	36.175
1987.	41.784	-27.9	15.598	.13439	716.4	7.738	22.416	37.776
1988.	42.731	83.7	15.719	.14774	742.5	8.104	23.010	39.442
1989.	43.587	155.9	15.808	.16017	770.0	8.443	23.571	41.172
1990.	44.390	204.1	15.875	.17216	799.0	8.772	24.091	42.974
1991.	45.163	236.9	15.925	.18390	829.5	9.100	24.561	44.858
1992.	45.919	259.4	15.964	.19550	861.8	9.434	24.966	46.841
1993.	46.670	275.1	15.994	.20702	896.0	9.777	25.291	48.944
1994.	47.422	286.2	16.017	.21848	932.3	10.137	25.534	51.195
1995.	48.179	294.3	16.036	.22991	971.2	10.516	25.723	53.631
1996.	48.945	300.4	16.050	.24130	1013.1	10.920	25.855	56.302
1997.	49.721	305.1	16.062	.25264	1058.7	11.357	25.926	59.279
1998.	50.510	308.9	16.070	.26393	1109.0	11.837	25.932	62.667
1999.	51.312	312.2	16.077	.27515	1165.7	12.372	26.074	66.593
2000.	52.129	315.0	16.082	.28631	1230.4	12.980	26.401	71.196

Legend:

RP = Rural Population

RM = Rural Migration

AJ = Agricultural Jobs

RUR = Rural Unemployment Rate

UPOP = Urban Population

UI = Urban In-Migration

EBADT = East Bank Average Daily Traffic

ECADT = East Coast Average Daily Traffic

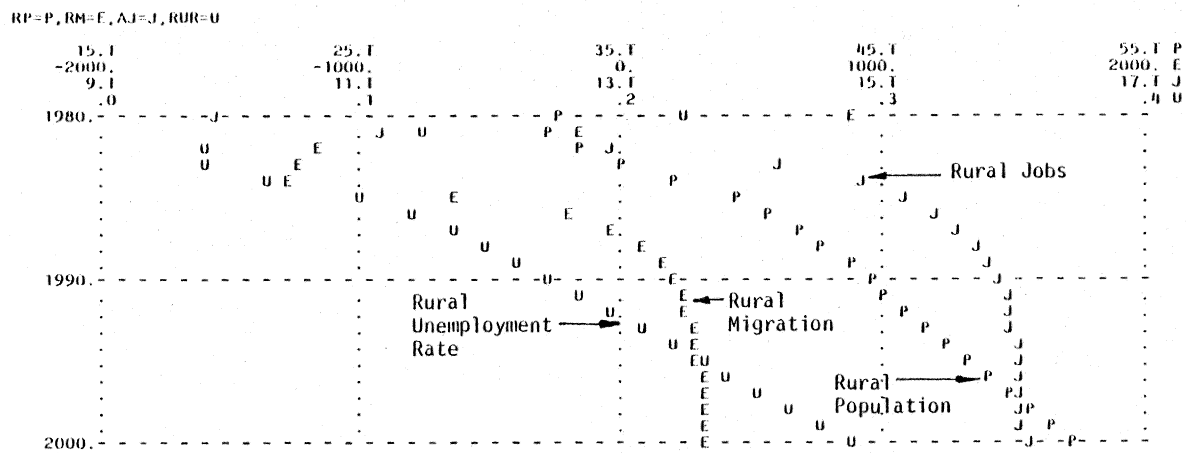


FIGURE 5.7 - The Computer Plot of the Main Socio-Economic Variables

5.2.2.3 Impacts on the Urban Region (Spatial Impacts)

Table 5.5 and Figure 5.8 show that overall urban inmigration rose from approximately 7,000 persons in 1980 to approximately 13,000 persons in the year 2000; but of real significance here is that the Essequibo Region has contributed to less than three percent (3%), as opposed to as much as fifteen percent (15%) in the "Do Nothing" alternative. In fact, during the period 1981-1986, the investment in road strategy has relieved the "population pressure" on the urban region through rural inmigration. Again, the impact on the approach roads traffic is proportionately reduced due to a reduction in urban inmigration. Figure 5.9 shows that the East Bank Road Approach reaches stability in the year 1995, five years later than the "Do Nothing" strategy; while a similar (or portionate) reduction is observed on the East Coast Road Approach.

5.3 Investments in Roads, Drainage and Irrigation Alternative

Because of the positive impacts (attested to from empirical evidence), resulting from road investment in many poorly accessible regions of LDCs, there is the belief that road or transportation per se is the answer to the development problem. The concept that road equals development is especially misleading in agricultural expansion schemes. There is no doubt that road is the main catalyst to the initial expansion, but sustained and continued growth and productivity depend on other inputs of which "dependable" drainage and irrigation may be as equally important as roads. Roads provide primarily access and reduction in the cost of transportation of inputs and outputs to and from

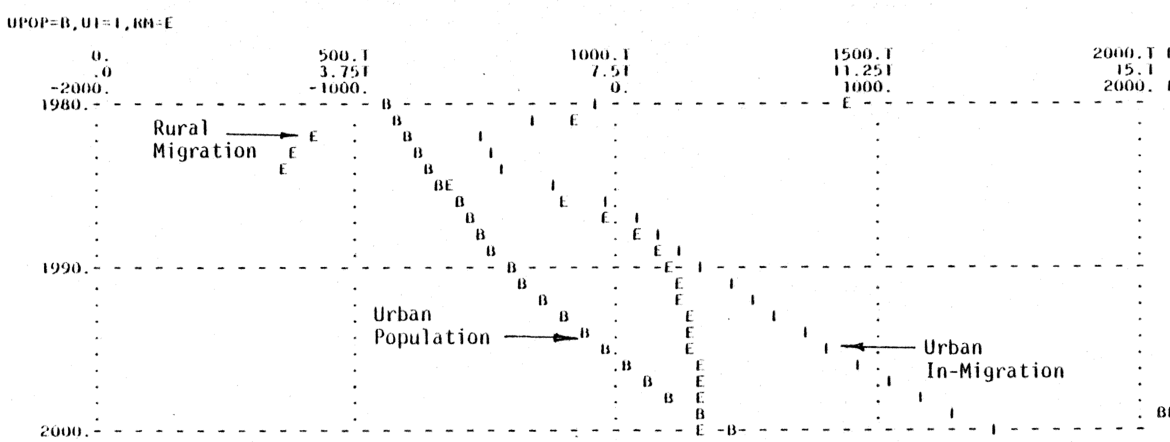


FIGURE 5.8 - The Computer Plot of the Main Spatially Impacted Variables

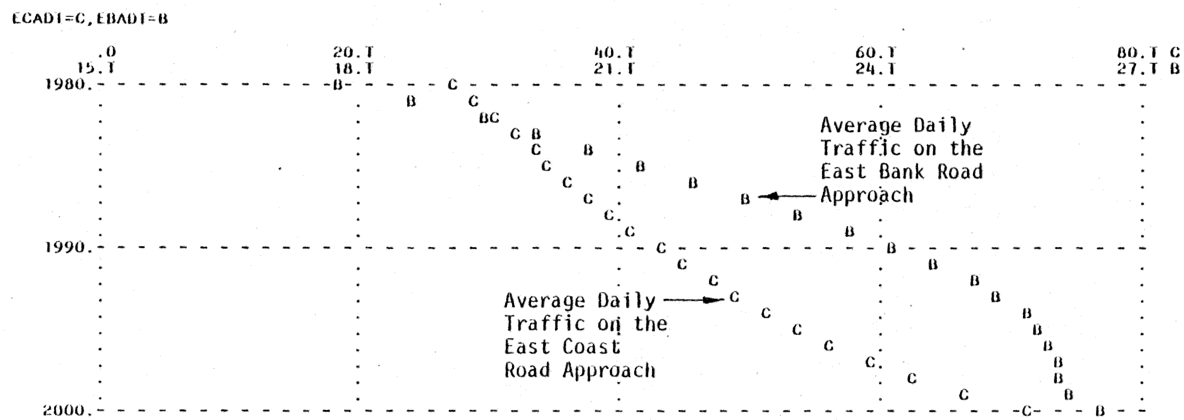


FIGURE 5.9 - The Computer Plot of the Traffic Flow on the Georgetown Approaches

the farm. However, the rate at which inputs (such as fertilization, mechanization, husbandry, etc.) are introduced to farming depends on the farmers' perception of their crops, free from the threat of droughts or floods (i.e., drainage and irrigation) of the region. Simply put, "dependable" drainage and irrigation not only compliment the farming infrastructure, but maximize the benefits derived from lowered transportation costs due to road investments.

Again, from a modeling point of view, the only modification needed to the "Roads Only" alternative model is the removal of the drainage and irrigation constraint and incorporate the time lag needed to construct the increased drainage and irrigation capacity. This is done by changing the rate equation for drainage and irrigation inputs from:

R IWAR.KL = 0

to:

R IWAR.KL = STEP(156000, 1987) - STEP(156000, 1988)

where:

IWAR = Drainage and Irrigation Rate (acre feet/year)

STEP = This is a function that explicitly incorporates a change in the reservoir capacity by 156000 acre feet in 1987 and maintains a zero growth rate after 1987. (Thus, the new drainage and irrigation capacity after 1987 is equal to the initial capacity of 156000 acre feet plus the expansion of 156000 acre feet between 1980 to 1987).

The modified model was then simulated to the year 2000, and the analyses of the performance of the region over this period is considered as the impacts of the "comprehensive" investment strategy. The disbursement for drainage and irrigation, as shown in Table 5.6, is over a seven-year period (funding for drainage and irrigation was not explicitly incorporated in the model).

5.3.1 Economic Analyses

Tables 5.6 and 5.7 provide the data and summary of the calculation and values of the benefit/cost ratio and net present benefits for the "Roads, Drainage and Irrigation" alternative. These cash flows of a net present worth of expenditure of approximately $41,608,000 in roads and drainage and irrigation infrastructure, and a net present worth receipts from farming of $55,122,000, result in a benefit/cost ratio of 1.32 and a net present benefit of $13,514,000.

5.3.1.1 Impacts on Production and Productivity

Figure 5.10 and Table 5.6 trace the growth of road, cultivation and production between the period 1980-2000. Within ten years, cultivation reached its total potential from 54,000 tons to 100,000 tons, resulting in an average yield of 1.89 tons per acre. "Dependable" drainage and irrigation have produced a decided impact on productivity of the region -- from an average of 1.5 tons per acre to approximately 2 tons per acre.

5.3.1.2 Impacts on Population and Income Per Capita

The hypothesis is that job availability depends on the expansion of the agricultural base (i.e., the rice industry). Furthermore, the

TABLE 5.6 - The Computer Printout of the Main Economic Variables Used in the Analysis

TIME E+00	RL E+03	CFA E+00	RROAD E+00	RER E+03	RCE E+03	RME E+03	UMRPR E+03
1980.	33.000	230.47	198.00	6019.3	5326.3	693.0	54.79
1981.	37.192	230.91	251.26	6205.8	5326.3	879.4	64.69
1982.	42.984	230.75	293.35	5235.4	4208.6	1026.7	77.28
1983.	47.255	230.19	313.06	3066.5	1970.8	1095.7	83.36
1984.	49.345	229.76	321.90	2011.2	884.6	1126.7	85.25
1985.	50.594	229.62	326.05	1556.1	414.9	1141.2	86.88
1986.	51.416	229.53	328.09	1351.8	203.5	1148.3	87.94
1987.	51.985	229.47	329.09	1252.3	100.5	1151.8	88.67
1988.	52.392	229.43	329.58	1202.3	48.7	1153.5	99.32
1989.	52.751	229.41	329.81	1177.3	23.0	1154.3	99.80
1990.	53.009	229.38	329.91	1165.2	10.5	1154.7	100.06
1991.	53.200	229.37	329.96	1159.6	4.8	1154.9	100.28
1992.	53.346	229.35	329.98	1157.1	2.1	1154.9	100.44
1993.	53.459	229.35	329.99	1155.9	1.0	1155.0	100.58
1994.	53.547	229.34	330.00	1155.4	.4	1155.0	100.69
1995.	53.617	229.34	330.00	1155.2	.2	1155.0	100.78
1996.	53.673	229.34	330.00	1155.1	.1	1155.0	100.85
1997.	53.717	229.34	330.00	1155.1	.1	1155.0	100.92
1998.	53.752	229.34	330.00	1155.0	.0	1155.0	100.98
1999.	53.780	229.34	330.00	1155.0	.0	1155.0	101.02
2000.	53.802	229.34	330.00	1155.0	.0	1155.0	101.07

Legend:

RL = Rice Cultivation

CFA = Cost of Farming Per Acre

RROAD = Road Miles

RER = Total Road Expenses

RCE = Road Construction Expenses

RME = Road Maintenance Expenses

UMRPR = Unmilled Rice Production

TABLE 5.7 - Summary of Calculation for Economic Analysis of Road, Drainage and Irrigation Alternative

Drainage Irrigation Cash Flow (D and I)	Present Worth of D and I	Present Worth of Road Expenses	Present Worth of Net Farm Income
$2 Million (1980)			
$5 Million (1981)	$17,868,400	$23,739,390	$55,121,500
$5 Million (1982)			
$5 Million (1983)			
$5 Million (1984)			
$2 Million (1985)			
$1 Million (1986)			

Benefit/Cost (B/C) = 1.32

Net Present Worth (NPW) = $13,514,000

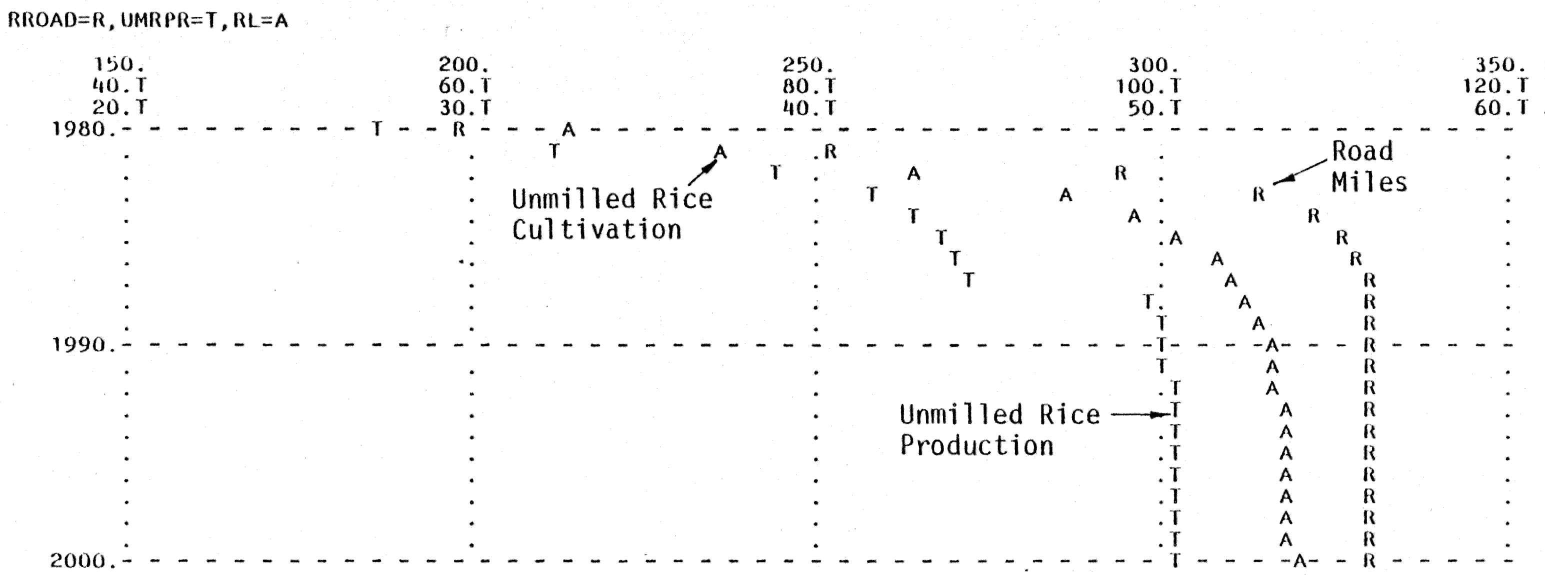


FIGURE 5.10 - <u>The Computer Plot of the Main Economic Variables (Road, Cultivation and Production)</u>

expansion of the rice industry depends primarily on accessibility (i.e., the road network); and since this alternative involves the expansion of the road network, then it would be expected that population growth would be similar to the "Roads Only" strategy. Production and productivity, however, depend strongly on drainage and irrigation. Table 5.6 and Figures 5.10 and 5.11 show that production of rice has jumped from approximately 55,000 tons in 1980 to approximately 100,000 tons in 1990, an almost fifty percent (50%) increase. The population during the same period rose to 44,000 persons in 1990, resulting in a gross regional income per capita of approximately $455. Thus, the combined investment strategy shows significant benefits to rural household income.

5.3.1.3 Impacts on the Urban Region (Spatial Impacts)

Again, the hypothesis is that population movements determine spatial impacts, and since the growth trend of the population of the "Roads, Drainage and Irrigation" alternative is similar to the "Roads Only" policy, then the discussion of the spatial impacts of the "Roads Only" policy applies here. Table 5.8 and Figures 5.12 and 5.13 support this point of view (i.e., socio-economic spatial impacts are similar).

5.4 Comparison of Impacts of Alternative Investment Strategies

The ultimate objective of transportation planning and modeling is to provide decision makers with information that would help in determining future investments in transportation and related economic infrastructure. Thus, it would seem obvious that such an information base should contain some advice on the overall impacts (social and economic)

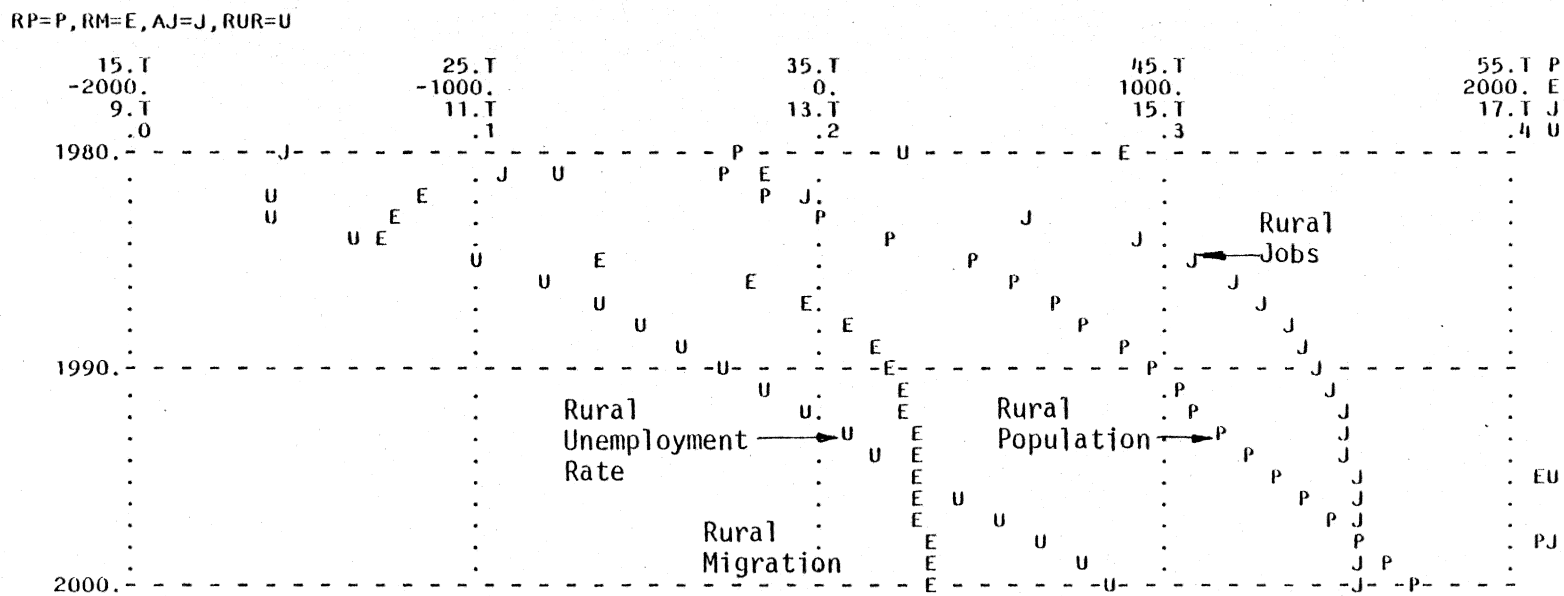


FIGURE 5.11 - The Computer Plot of the Main Socio-Economic Variables

TABLE 5.8 - The Computer Printout of the Main Socio-Economic Variables

TIME E+00	RP E+03	RM E+00	AJ E+03	RUR E+00	UPOP E+03	UI E+03	EBADT E+03	ECADT E+03
1980.	32.500	884.3	9.900	.22316	567.3	7.176	17.741	27.177
1981.	32.331	-172.1	11.158	.12532	588.2	6.327	18.626	28.807
1982.	33.214	-1162.5	12.895	.04167	608.4	5.536	19.395	30.350
1983.	35.107	-1228.8	14.176	.03808	627.8	5.663	20.040	31.780
1984.	37.108	-1285.8	14.804	.06434	647.9	5.806	20.649	33.203
1985.	39.211	-624.4	15.178	.09813	668.8	6.674	21.224	34.627
1986.	40.698	-215.4	15.425	.11971	691.7	7.308	21.834	36.151
1987.	41.808	-29.1	15.595	.13501	716.3	7.736	22.453	37.754
1988.	42.757	82.5	15.718	.14834	742.4	8.102	23.055	39.419
1989.	43.615	143.4	15.825	.15985	769.9	8.430	23.622	41.149
1990.	44.432	189.5	15.903	.17153	798.8	8.756	24.148	42.946
1991.	45.220	222.9	15.960	.18320	829.3	9.084	24.622	44.824
1992.	45.991	246.9	16.004	.19482	861.5	9.419	25.034	46.800
1993.	46.756	264.2	16.038	.20639	895.6	9.763	25.368	48.894
1994.	47.521	276.8	16.064	.21793	931.8	10.123	25.617	51.135
1995.	48.290	286.1	16.085	.22941	970.6	10.502	25.813	53.559
1996.	49.066	293.2	16.102	.24085	1012.3	10.907	25.954	56.214
1997.	49.852	298.8	16.115	.25222	1057.8	11.343	26.033	59.172
1998.	50.650	303.2	16.126	.26354	1107.9	11.820	26.050	62.533
1999.	51.461	307.0	16.134	.27479	1164.1	12.353	26.186	66.423
2000.	52.286	310.3	16.141	.28596	1228.4	12.957	26.506	70.982

Legend:

- RP = Rural Population
- RM = Rural Migration
- AJ = Rural Jobs
- RUR = Rural Unemployment Rate
- UPOP = Urban Population
- UI = Urban In-Migration
- EBADT = Average Daily Traffic on East Bank Road Approach
- ECADT = Average Daily Traffic on East Coast Road Approach

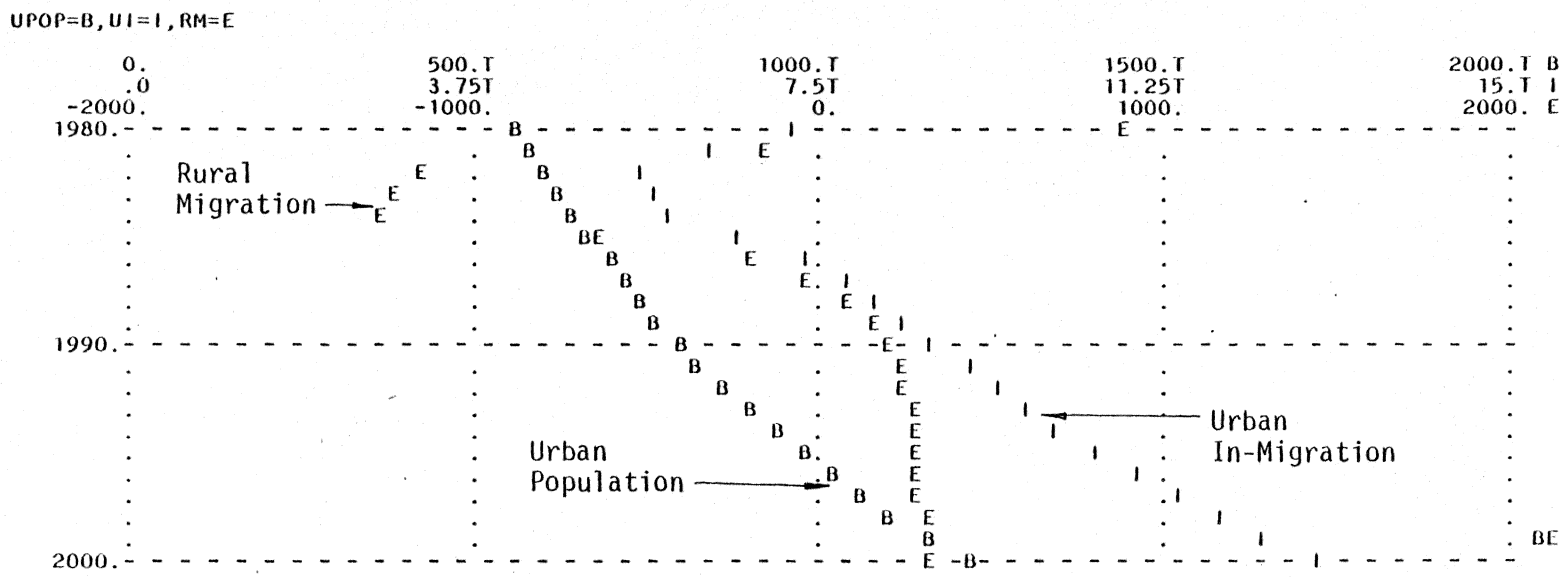


FIGURE 5.12 - <u>The Computer Plot of the Main Spatially Impacted Variables</u>

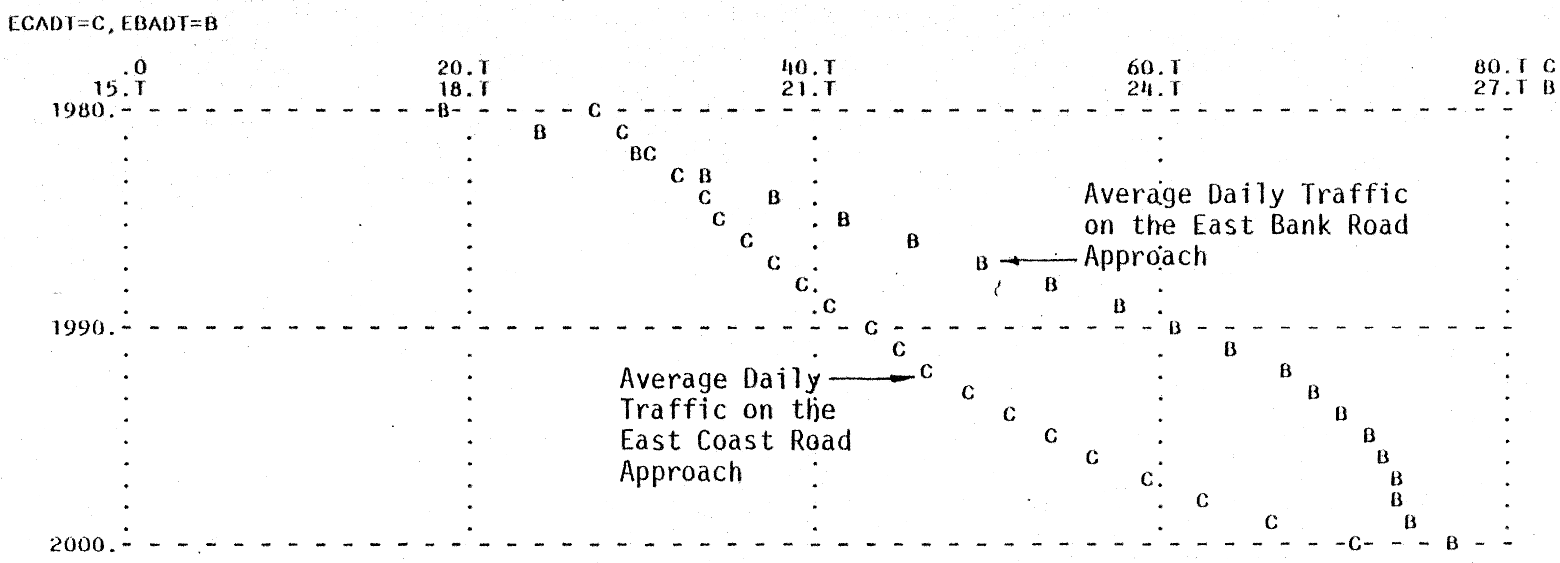


FIGURE 5.13 - <u>The Computer Plot of the Traffic Flows on the Road Approaches to Georgetown</u>

of a particular policy on the region and the nation as a whole. Yet, it is not done; and almost invariably, decisions are based on the monetary impacts of a given strategy of investments, which very often result in severe adverse national impacts.

Table 5.9 provides the results of the economic analyses of the three investment policies for the rural region for a 20-year period at ten percent (10%) annual interest rate. All three policies satisfy the minimum criteria of net present worth and benefit/cost ratio required for project acceptance. The "Do Nothing" alternative has the highest benefit/cost ratio, and a significant net present worth. In a situation of "financial difficulties", it would seem to be the obvious choice. Furthermore, it might be reasonable to conclude that if only the information provided in Table 5.9 were to be presented to a decision maker (in a scenario of limited resources, as characterized by most LDCs), it is more than likely that the "Do Nothing" alternative would be selected for the next twenty years. For sure, in most traditional techniques, the information provided in Table 5.9 is all that would be available to decision makers.

The use of System Dynamics Methodology provides not only the information concerning the traditional economic analyses, as is the case in Table 5.9, but also a time series information on the pertinent socio-economic factors that influence both regional and national performance (e.g., standard of living and utilization of resources).

Table 5.10 provides the information on the main regional socio-economic indicators at steady state (i.e., that point in time when the

TABLE 5.9 - Results of the Economic Analyses of Three Strategies[a]

	Present Worth -G $				
	Costs -G $				
Strategies	Roads	Drainage & Irrigation	Benefits -G $	Net Present Worth -G $	Benefit/Cost Ratio
Do Nothing	15,925,400	--	23,692,400	7,767,000	1.49
Roads Only	23,739,400	--	26,453,700	2,714,300	1.12
Roads, Drainage & Irrigation	23,739,400	17,868,400	55,121,500	13,513,700[b]	1.32[b]

a. Results based on 20-year simulation at 10% annual interest rate and one crop per year.

b. Given guaranteed drainage and irrigation, double cropping per year will result in increased benefits (by a factor of 1.6 to 2).

TABLE 5.10 - Steady State Values for the Main Socio-Economic Indicators

INDICATORS	STRATEGIES: Do Nothing	Roads	Roads, Drainage & Irrigation
Rural Roads (Miles)	324	330	330
Rice Land Cultivated Acres	51,800	53,300	53,000
Unmilled Rice Production (tons)	74,000	75,500	100,000
Gross Regional Income (G$)	14,800,000	15,100,000	20,000,000
Population	48,000	52,300	52,300
Gross Regional Income/Capita (G$)	308	288	382
Jobs	15,500	16,100	16,100
Unemployment Rate (%)	25	29	29
Out Migration (Persons/Year)	-46	310	310
Equilibrium Time (Year)	2000 or in 20 years	1993 or in 13 years	1990 or in 10 years
Out Migration[a] (1985)	311	-624	-624
Gross Regional Income/Capita (1985)	357	375	443

a. Transient state values for 1985.

regional output stabilizes, or further growth in production depends on inputs other than land area farmed or such economic infrastructure as roads, drainage and irrigation). Once again, the "Do Nothing" alternative performance is impressive at "steady state". The main socio-economic indicators of income per capita, regional unemployment rate, and jobs provided suggest that decision makers should leave things as they are (i.e., continue with the status quo). This is, unfortunately, the very type of conclusion that is usually drawn when using "horizon year" projections for developmental projects. In twenty years, there is an obvious convergence of behavior that makes investments in economic infrastructure in poorly accessible regions "seem" infeasible or less attractive than the continuation of the status quo or "Do Nothing" policy.

This is an excellent example of where aggregation (i.e., averaging of impacts to a horizon for economic evaluation) in the traditional evaluation techniques give misleading conclusions; and furthermore, when the aggregation is removed, the results or conclusions of such evaluation techniques fall to pieces.

Also included in Table 5.10 are values for two key socio-economic indicators (outmigration and gross region income per capita for the year 1985), which illustrate quite clearly the superiority of both the "Roads Only" and "Roads, Drainage and Irrigation" policies. In 1985, the "Do Nothing" policy has the least income per capita and a positive outmigration. Further, the high income per capita and low unemployment rate are outcomes of the heavy rural outmigration under this strategy.

Both capital intensive investment strategies provide the least negative national and regional impacts; and the comprehensive investment alternative (Roads, Drainage and Irrigation) is undoubtedly the most beneficial (i.e., making full use of the regional potential; reversing the adverse national spatial impacts, and doubling regional output in less than 10 years of implementation).

CHAPTER 6

SHADOW PRICES, SENSITIVITY ANALYSES AND DATA BASE

In scenarios of high unemployment, rapid inflation and poor data base (characteristics of most LDCs), the values (data) or prices (costs) used in the economic analyses of capital intensive projects are often modified to reflect "true social" costs, benefits and risks. The concepts of "shadow prices" and "sensitivity analyses" are two such techniques used to adjust the profitability of developmental projects. Section 6.1 will briefly discuss the concept of "shadow prices" and its relevance to this study. In Section 6.2, extensive sensitivity analyses will be undertaken on the main hypotheses used for the developed model. Those variables on which the model's output sensitivity depends would form the core of the data base and be recommended for further pre- and post-project implementation, investigation and analyses.

6.1 Shadow Prices

The underlying concept of shadow prices is fundamental to economics. They are the prices at which supply is just sufficient to satisfy demand [26]. Under conditions frequently encountered in the advanced competitive economies, shadow prices are for the most part similar to market prices, and adjustments are seldom made. But, in a number of underdeveloped countries, the market price structure is not a correct guide for taking decisions. The shadow price of a factor is therefore a measure of its opportunity cost or its marginal product. The literature reveals that shadow prices have been used at two distinct levels of analyses. One is involved with theoretical concepts which have strict mathematical and economic meaning; and the other is intuitive and applied [6,26].

The Theoretical Approach

Theoretically, shadow prices can be determined if a continuous production function of the Cobb-Douglas [22,27] form is assumed and an optimal technology is found. The form of the production function is as follows:

$$Y = K^{\alpha}L^{\beta}$$

This equation states that the aggregate output Y is a function of the amount of capital, K, and Labor, L, in the economy and α and β are empirically determined constants.

The optimal technology is one which would:

> ". . . absorb the factors in proportion in which they are available. And by increasing the level of production, we can reach the point where all the factors are fully utilized and yield the maximum values of output." [28]

Qayum [28] suggests the use of partial differentiation to determine the shadow prices of wages and capital as follows:

Let R be the net return which is to be maximized; C the costs; p the value of outputs; and $\alpha + \beta = 1$. Then, using the Cobb-Douglas function, we have:

$$R = pY - C = pL^{\alpha}K^{1-\alpha} - C$$

then, the partial derivative of R with respect to L:

$$\frac{\partial R}{\partial L} = p\alpha(\frac{L}{R})^{\alpha-1} \quad \text{(is the shadow price of labor)}$$

and the corresponding shadow costs of capital is the partial derivative of R with respect to K:

$$\frac{\partial R}{\partial K} = p(1 - \alpha)(\frac{L}{K})^{\alpha}$$

Another approach for determining shadow prices is through the use of linear programming. Given the optimal technology, alternative methods of production, resources and constraints, the economy can be formulated into a linear programming model; and the solution to the "dual" problem provides the respective shadow values.

Intuitive or Empirical Approach

The above stringent theoretical approaches and their concomitant limitations (i.e., the uses of (1) the abstract-continuous production function; and (2) fixed coefficients) have resulted in most analysts resorting to intuitive and/or empirical approaches. One of the most widely used techniques for adjusting project values to reflect "social" costs and benefits is sensitivity analysis -- the subject of the next section.

6.2 Sensitivity Analyses

Grant and Ireson [29] define sensitivity analysis as follows:

> "Sensitivity refers to the relative magnitude of the change in one or more element of an engineering economy problem that will reverse a decision among alternatives."

and further recommend the use of sensitivity analysis by saying:

> ". . . Since all estimates are subject to some amount of uncertainty, the sensitivity approach may be very helpful in analyzing a proposal or set of proposals. The application of the sensitivity concept becomes an intermediate step between the numerical analysis based on the best estimates for the various elements and the final decision. Each element can be tested to see how sensitive the decision is to variations from the best estimate, and the results used in the final decision-making process."

Even though these statements are made with regard to decision among alternatives [6], it is felt that the concept can be used to test the validity of data and assumptions made within a single model, and also to identify those factors on which regional performance most sensitively depends.

6.2.1 The Use of Sensitivity Analysis in This Study

The traditional use of sensitivity analysis to adjust for the "true" or "marginal cost" of labor (i.e., wages) and capital (i.e., interest rate) is not specifically undertaken in this study for the following main reasons.

First, in the case of labor, it is difficult to identify an appropriate adjustment factor for wages in scenarios of high unemployment, as is the situation in the case study -- since by definition "the social opportunity cost of labor", the term used in project evaluation, is equivalent to cost of production, foregone in another sector by the use of the labor in the proposed project. Defined this way, the opportunity cost of labor will be positive when there is full employment, but if there is unemployment, it should be possible to employ labor on the project without having to withdraw it from elsewhere. Thus, the opportunity cost of labor may well be zero in an economy with unemployment [30]. Does this mean that employment of labor is costless in an economy with unemployment? The actual wages paid is the true financial cost that must be ultimately funded by the nation irrespective of the factor used for shadow prices analyses; and therefore, the actual costs should be used for project evaluation.

Secondly, in the case of capital, the choice of 10 percent is considered representative of the interest rate that is likely to be charged for developmental projects in LDCs (if anything else, it is likely to be lower rather than higher).

Thirdly, and probably most important, it is felt that no amount of rigorous sensitivity analyses (i.e., in terms of shadow prices for wages and capital) performed on essentially "suspect" output due to poor data base (as again the case of LDCs) would "improve" the economic benefits of an investment strategy. Such "economic analyses" are after the "fact" (i.e., output or production is unchanged); and mathematics is then used to justify marginal investment strategies.

A case is not made here against the overall use of shadow pricing. On the contrary, in cases where projects' economic feasibility is strongly influenced by cost of capital and labor, shadow prices analyses are recommended and should be undertaken, since these analyses provide insights into the "true" cost of the projects and a further guide to improved decision-making.

Instead, the concept of sensitivity analysis is used to: (a) test the significance of the model's hypotheses (i.e., interactive structural formulation); and (b) identify the data base that is most pertinent to the socio-economic analyses of rural investment policies in transportation and related infrastructure.

The premise of this study is as follows: (1) the impacts from the investment strategies is not strongly based on the marginal costs from transportation per se; but more on the removal of "bottlenecks" to the expansion of production and productivity of the region; (2) transportation is but only one of the main resources needed for increased regional production; and (3) there is significant movement of population between relatively developed regions in LDCs.

The hypotheses were as follows: (1) roads accessibility; (2) drainage and irrigation; (3) fertilizer; (4) mechanization and technology which dynamically interact to influence production and productivity; and (5) relative regional unemployment rate influences population shifts. The impacts of not explicitly (i.e., dynamic modeling) considering the availability of the above resources and the unemployment characteristics of the regions are investigated through sensitivity analyses.

6.2.2 The Sensitivity Tests and Their Results

The sensitivity test procedure is as follows: (1) the investment strategy in "roads, Drainage and Irrigation" is used as the base scenario against which the availability (i.e., the inclusion or exclusion) of the other main resources are tested for their impacts on production; and (2) the linkage of the two regions (rural and urban) is removed, and the impacts on rural unemployment rates are analyzed for representativeness.

Test No. 1 -- drainage and irrigation not available -- was done in the model by simply removing the investment in drainage and irrigation. Table 6.1 shows that production drops by as much as 25 percent from 101,000 tons to 75,800 tons per crop for approximately the same cultivation level. This unquestionably indicates that drainage and irrigation are bottlenecks to increased production and productivity.

Test No. 2 -- limited mechanization (i.e., not readily available) -- was done in the model by holding the mechanization multiplier constant at a value of 1. Table 6.1 shows that even with drainage, irrigation, roads and husbandry, production drops by as much as 26 percent, reflecting the unique roles of machinery (i.e., tractors and harvesters) on overall production.

Test No. 3 -- limited fertilizer -- was performed under two scenarios: (a) fertilizer available at pre-project expansion rate only (i.e., the fertilizer availability multiplier FEAMT = 1); and (b) at one and one-half times the pre-project expansion rate (i.e., FEAMT = 1.5). Table 6.1 shows that for case (a), production drops by a staggering 59 percent; in case (b), production drops only approximately 20 percent. Both scenarios indicate the dramatic significance of fertilizer inputs to farming.

The results of Test No. 4 -- the restriction of drainage, irrigation, fertilizer, mechanization and technology (i.e., only roads investments provided) -- in Table 6.1 show that production dropped dramatically from 101,000 tons to 35,200 tons, a 65 percent reduction; and cultivation reached only 40,600 acres by year 2000. This test proved quite

TABLE 6.1 - The Impacts on Production Under Various Assumed Resource Availability in the Region

TESTS	IMPACTS AT END OF SIMULATION - YEAR 2000		
	AREA CULTIVATED (Acres)	PRODUCTION RATE (Tons)	PERCENT CHANGE (%)
Base Scenario (All Resources Available)	53,800	101,000	---
Test (1) - No Drainage & Irrigation	53,600	75,000	-25
Test (2) - Mechanization	52,700	75,400	-26
Test (3) - Limited Fertilizer:			
(a)	40,700	41,700	-59
(b)	53,200	81,800	-19
Test (4) - No Drainage, Irrigation, Mechanization or Fertilizer	40,600	35,200	-65

conclusively the need for the explicit incorporation of the main resources. A tacit allowance for the availability of these resources overstates the impacts of road investments on rural cultivation and production rate.

The idea of Test No. 5 -- the significance of trucking availability on after-production loss as measured by the variable Unmilled Rice Loss (UMRL) -- is that very often, transportation planners are concerned with the need of the physical infrastructure (i.e., in this case, the miles of roads needed); and the concomitant rolling stock (i.e., trucks, etc.) would be provided. Figure 6.1 shows the plots of the possible impacts of the three investment strategies on after-production losses if the adequate truck fleet is not provided. (Recall, as previously stated, this is not a total loss of tonnage of production; but the amount of production that will not have transportation at the right time and is likely to suffer from spoilages of as much as 10 percent).

The initial trucking fleet of 12 trucks is incapable of meeting the transport demand for the cumulative impacts of the three investment strategies. The comprehensive investment strategy shows the highest loss (approximately 22,000 tons in the year 1990 and thereafter). To avoid these losses, the trucking fleet should be increased by 3, 5 and 10 trucks respectively for the "Do Nothing", "Roads Only" and "Roads, Drainage and Irrigation" investment strategies by the year 1985.

In Test No. 6 -- the road network adequacy for crop exploitation -- 5.5 miles of road infrastructure was assumed to be the required need for the development of 1,000 acres of rice land. What would happen if the

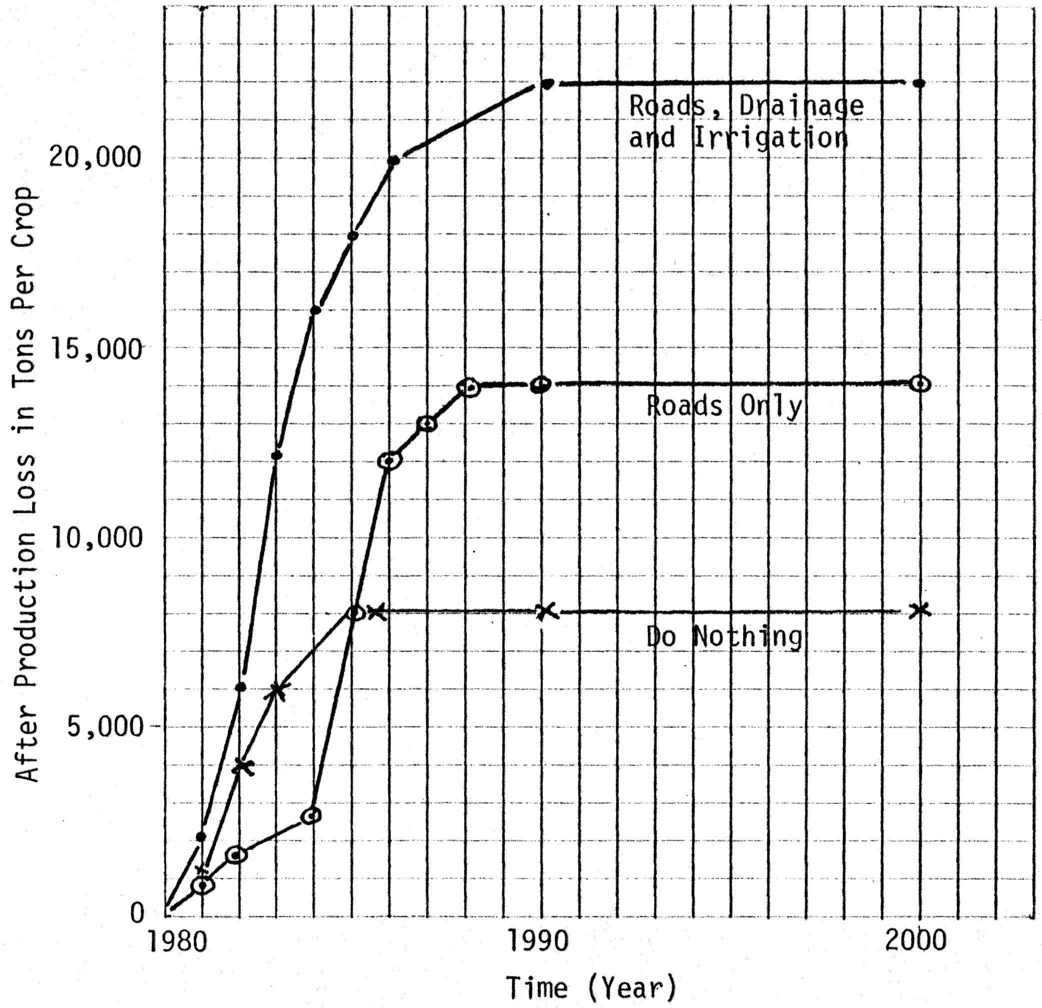


FIGURE 6.1 - Plot of After Production Loss For Three Investment Strategies

need is more or less than the postulated 5.5 miles? Table 6.2 shows the impacts on costs and benefits for two scenarios: (1) 5.0 miles per 1,000 acres; and (2) 6 miles per 1,000 acres for the "Road, Drainage and Irrigation" investment alternative. Both cases (1) and (2) are still feasible. However, in case (2) the feasibility as measured by the benefit/cost ratio is very marginal.

This test proves the need for inter-disciplinary approach to rural road development. The road infrastructure network should be decided by agriculturalist for the crop type to be farmed, and not by traffic volume per se, which determines primarily geometric and structural designs. Project feasibility, and therefore decision to implement, can be significantly affected if the inappropriate network is chosen for rural development.

In Test No. 7, the significance of explicitly accounting for spatial impacts (i.e., population movements) was examined. The impacts on rural unemployment is considered for two investment scenarios (i.e., the "Do Nothing" and "Investments in Roads Only"), without explicitly accounting for shifts in population due to relative regional unemployment rates. This was done in the model by holding the Urban In-migration Mutliplier at a constant value of zero.

Table 6.3 shows the impacts on rural unemployment for the two scenarios. In the case of the "Do Nothing" strategy, rural unemployment progressively increases from 43 percent in the year 1980 to 46 percent in the year 2000. In the case of the "Roads Only" investment alternative (assuming normal population movement is going on as expected in any

TABLE 6.2 - <u>The Impacts on Costs and Benefits Due to Different Road Infrastructure (Accessibility) Needs</u>

TESTS	PRESENT WORTH OF COSTS ($)	PRESENT WORTH OF BENEFITS	NET PRESENT WORTH OF BENEFITS ($)	BENEFITS/COSTS RATIO (B/C)
Base Scenario 5 1/2 Miles/ 1,000 Acres	41,607,800	55,121,500	13,513,700	1.32
Case (1) 5 Miles/ 1,000 Acres	33,142,200	55,121,500	21,979,300	1.67
Case (2) 6 Miles/ 1,000 Acres	46,307,200	55,121,500	8,814,300	1.19

TABLE 6.3 - The Impacts on Rural Unemployment Rate Due to Lack of Consideration of Inter-Regional Migration

	POLICIES	
YEAR	DO NOTHING UNEMPLOYMENT RATE (%)	ROADS ONLY UNEMPLOYMENT RATE (%)
1980	43	22
1981	44	14
1982	44	5
1983	45	3
1984	45	2
1985	45	2
1986	45	3
1987	44	4
1988	43	6
1989	44	7
1990	42	9
1991	43	11
1992	43	12
1993	42	14
1994	42	16
1995	42	18
1996	43	19
1997	43	21
1998	44	23
1999	45	24
2000	46	26

country, and the transportation planner neglected to account for the typical population movement), rural unemployment drops from 22 percent in the year 1980 (because of the investment) to a low of 2 percent in the year 1984, and then rises to 26 percent in the year 2000.

It is contended that these unemployment characteristics would not occur in a country that has "freedom of movement" (i.e., people will react to the perceived job opportunities in the different parts of the country). Also, in- and out-migration would tend to equalize the regional unemployment rates and curtail further movement. Furthermore, empirical evidence does attest to the above fact through the rapid growth rates of urban regions -- usually the main generators of new jobs.

The above tests point quite conclusively to the need for the explicit incorporation and analyses of the main socio-economic factors in a model that purports to deal with economic growth. Tests 1 through 5 show that an implicit assumption of the availability of drainage, irrigation, mechanization, fertilizer and trucking fleet can seriously overstate the impacts of investments in roads if these key resources are limited or not available. Test 7 reinforces the need for explicit consideration of spatial impacts, since the rural demographic (as measured by unemployment rate) and economic (as measured by income per capita) characteristics would be misleading without any explicit accounting of population movement. Finally, Test 6 indicates the need for appropriate advice on the network characteristics (layout) to be constructed, since both financial and economic feasibilities strongly depend on the choice of the desired road needs.

The following factors (variables) and their impacts on production and productivity are recommended for further pre- and post-project implementation analyses: (a) the response of farmers to increase land development rate, given increased drainage and irrigation, fertilizer, mechanization and technical advice; (b) the migration pattern that depends on job opportunities as measured by the relative regional unemployment characteristics; and (c) the road network characteristics that allow for the optimal exploitation (i.e., accessibility) of new agricultural lands.

CHAPTER 7

SUMMARY AND CONCLUSIONS

The basic theme of this dissertation has been that the analyses of investments in transportation and related agricultural economic infrastructure in less developed countries should be conducted in the light of their own characteristics, needs and objectives. In support of this point of view, the principal planning methodologies were reviewed, and their limitations and strengths discussed. A conceptual model of the proposed methodology was then developed and applied to a poorly accessible agricultural region in a less developed country -- Guyana -- in order to illustrate the characteristics and potentials of the technique.

The following is a summary of the dissertation, an indication of its usefulness and possible future research efforts that should be undertaken for the analyses of investments in the economic infrastructure of potentially viable agricultural regions of less developed countries.

7.1 Summary

Chapter 1, by way of introduction, highlighted the role, problems and needs of less developed countries, with respect to transportation as follows.

Transportation is not simply a derived demand of the other socio-economic activities of a region, but a determinant of new production possibilities and the expansion of the economic base of a region.

Too often, the expansion of the transport infrastructure has been determined on traffic flows per se, rather than the removal of a developmental bottleneck, to increased production and its concomitant impacts on the region and the nation as a whole.

There is also a widespread, uncoordinated decision making in the transportation planning hierarchy, as evidenced by: (a) the many "ministries" responsible for funding and implementation; and (b) the multimodal transfers required within short distances of travel.

The large allocation of funds (almost 1/3 of the annual gross national income) in transportation and related agricultural infrastructure demands an analytical methodology that explicitly incorporates the concerns of other sectors of the economy, if these large investments in transportation are to result in the most beneficial national impacts. System Dynamics Methodology, it is contended, can specifically address the above main problems and needs.

In Chapter 2, the literature search revealed that most of the earlier methodologies used for the evaluation of investments in rural roads are the outcome of work done for scenarios in developed countries where the demand for road (as evidenced by traffic flows) was not really in question. The benefits in these approaches were based primarily on direct road users impacts, resulting from traffic volumes. Where traffic volumes were low, the concept of the benefits from improved accessibility on production and shifts in population was never seriously considered.

In later studies, the limitation of direct road users' costs as the main criterion for economic viability was realized, and serious attempts are being made to incorporate the causal imapcts of transportation on a region. However, very little has been done so far to explicitly incorporate feedback behavior and impacts from, and on other sectors of the economy.

Chapter 3 discussed the underlying structure of the proposed methodology and presented the conceptual causal model that defines the impacted region's behavior.

The methodology of system dynamics consists of three distinct phases in the development of a model: (1) conceptual formulation; (2) mathematical simultaneous difference equations; and (3) computer simulation. The conceptual formulation allows for the explicit incorporation of the causality, interrelationships and feedback phenomena that are creating and sustaining the "problem" or "behavior" of the region through the use of di-graphs. The quantification of the system's behavior is undertaken through mathematical model building from available data base or assumed value for a hypothesized behavior where data is lacking. Finally, through the technique of simulation, model calibration and forecasting of future performance are undertaken.

The possible limits or boundary of the impacts of an investment in the economic infrastructure of a typical rural region was identified. The main sectors (demographic, economic and transport) and components (human, natural, and man-made) that "drive" the impacted region's economy were determined.

From a simplified block diagram of the linkages between and among these sectors and components through di-graphs, the complex structure and main feedback phenomena that underlie the behavior of rural investments were developed, discussed and presented as a comprehensive causal model. The comprehensive causal model presented the framework for data collection and model calibration and use for the evaluation of transport and related investments in rural regions.

The hypothesized "comprehensive" causal model consisted of two distinct regions: (1) the rural or directly impacted region through investments in roads, drainage and irrigation; and (2) the urban or spatially impacted region through shifts in population from the rural region.

The rural region is represented by three sectors: (1) demographic; (2) economic; and (3) transport. The demographic sector, through its two main components of population and housing, provides information (or inputs) on the labor and land consumed by housing. The economic sector is predominantly agricultural and is represented by six components: farmers, drainage, irrigation, arable land, mechanization, and technology (i.e., human, natural and man-made resources). The transport sector is represented by three components: road fund, road miles, and trucks. The dynamic interactions within and among these sectors' components defined the direct impacts.

The urban region is represented by two sectors: demographic and economic, the key sectors that determine the unemployment characteristics of the urban region. Further, the hypothesis of the spatial impacts is due primarily to the relative unemployment characteristics of the two regions; thus the interest is in only these two sectors. The demographic sector is represented by population and housing; the economic sector by businesses and jobs; and the dynamic interactions between their components determine the unemployment characteristics of the urban region. The synthesis of the two regions through their respective unemployment rates results in the development of the "comprehensive" causal model.

In Chapter 4, the data base of Guyana, a less developed country, with poorly accessible but potentially viable agricultural regions, is used to calibrate the hypothesized computer model.

Data for the Essequibo Coast (referred to as the rural of directly impacted region) and Georgetown (referred to as the urban or spatially impacted through population movement) were used for model calibration. Where data was lacking, hypotheses of the behavior were made; and from a series of simulation runs and modifications in an iterative manner, the model was accepted as "calibrated" when the outputs "reasonably" replicated the basic data of a ten-year period of the region.

Chapter 5 illustrated the characteristics and effectiveness of the methodology for the evaluation of investments in rural economic infrastructure of roads, drainage and irrigation.

The continuum of investment strategies that typifies less developed countries is reduced to three main alternatives to development: (1) Do Nothing or continuation of the status quo; (2) Investment in Road infrastructure; and (3) Investment in Roads, Drainage and Irrigation.

The typical road users' benefits of time savings, vehicle operating costs, etc., generally associated with road improvement were not specifically evaluated; but instead, the costs and benefits associated with expansion of the production base and increased production and productivity were the main variables involved in the evaluation of the direct consequences of the investments.

The accepted criteria of benefit/cost ratio and net present worth were used to evaluate the direct impacts of the investments. All three investment policies satisfied the above criteria with the "Do Nothing" policy showing the highest benefit/cost ratio, and the comprehensive policy showing the best net present worth returns.

In fact, the "Do Nothing" alternative was so "competitive" that if no other information on the impacts of these alternatives were available, it would indeed be difficult not to accept the "Do Nothing" policy for the next twenty years.

Because of the characteristics of the system dynamics methodology (i.e., a trace of the impacts through time, explicit and quantitative impacts on the key socio-economic indicators of population movements, income per capita, unemployment and timing of the utilization of regional resource), it was realized that the "Do Nothing" strategy resulted in the lowest regional and national impacts. The decreases in rural unemployment and increases in income per capita shown in this alternative were as a result of heavy rural migration. In addition, a rural region with the potential to support not only its existing population but also its natural growing population was losing its population base; and not until twenty years hence will capitalize on its natural resources.

Whereas, both capital investment strategies reversed the population outmigration trend in less than five years and almost doubled the gross regional output within ten years for the comprehensive investment policy, resulting in "real" increases in both rural population and income per capita.

In Chapter 6, the use of shadow prices and its limitations, as a "practical tool" for the adjustment of true project costs and benefits, were discussed.

Extensive use was made of the techniques of sensitivity analysis and computer simulation to identify the factors or variables which "drive" the model and determine the socio-economic characteristics of the region.

Sensitivity analyses showed quite conclusively the need for the use of inter-active modeling to reflect realistic demographic changes and resource complementarity of investment strategies. Without the linking of the rural and urban regions, unemployment rate rose to approximately 46%. Such a high rural unemployment rate would result in obvious rural outmigration in a real-world scenario, unless, of course, the whole country is suffering from the same degree of unemployment.

Transportation per se was found to be only one of the main resources needed for rural socio-economic expansion and improvements. The implicit assumption of the availability of other key resources (i.e., drainage, irrigation, fertilizer, mechanization, and technology) overstates the impacts of the investments in transportation per se. Sensitivity tests on the availability of other key resources reduced the impacts of transport investment by as much as 65%.

7.2 Conclusions and Recommendation

At first glance, the size and "seeming complexity" of the proposed model might be questioned for its usefulness for transportation planning, and even more so in less developed countries with obvious resource limitations, for which the model is developed. However, the allocation of large sums of money, in resource scarce economies, in transportation and realted economic infrastructures that eventually affect the lives of the present and future generations must of necessity be carefully analyzed if negative impacts are to be minimized.

Planning models that purport to deal with economic growth should provide insights into where the economy is likely to go for a given investment strategy. Such models should insure consistency, feasibility and a rational determination of priorities. This is not advocating perfection, but only the beginning of an attempt to look at a plan or strategy in toto and to evaluate projects within this context.

The current approaches tend to deal with the investment in transportation within the limited context of direct users impacts. Even in methodologies where extensions on the direct users impacts are considered, there are no explicit incorporations of the interrelationships and feedback phenomena that underlie the behavior of the economic system. That these complex interrelationships and feedback phenomona exist is verified by empirical evidence; and if we are to improve our ability to make shrewd investment decisions, attempts must be made to understand these complex interrleationships.

The methodology of system dynamics offers an opportunity for the quantitative analyses of these complex interrelationships and feedback phenomena that determine regional performance. The data base needed for model development and calibration might not be as formidable or unavailable as might be first thought. It is very likely that the basic data for preliminary model development already exists in the country in different ministries and organizations. What may be required is the processing of the data into an appropriate information base to develop a crudely calibrated model. Then, through the use of computer simulation and sensitivity analyses (characteristics of the methodology) an appropriate data base can be developed; thus avoiding the collection of large volumes of data and the development of statistical regression models that might not be pertinent to the analyses (as may be the case with some traditional transportation planning approaches).

Probably of equal importance too is that the effectiveness or usefulness of the developed model does not end with the project analyses and final recommendations, since the output from the model is a trace of the performance of the economy through time; and also because there are explicit incorporations of the other sectors of the economy, the model can be used to study post-project performance. If forecasted values are not realized, timely adjustment can be made to key resources to correct unwanted impacts.

The last step in the analytical procedure is to narrow the range of choice and finally to present a leading alternative program to the political authorities for decision. Alternative 3 -- the investment in Roads, Drainage and Irrigation -- provides the "best" positive impacts, and it is in keeping with Guyana's stated objective of expanding the agricultural base and improving the rural income per capita. It is, therefore, recommended that the "comprehensive" policy of investments in Roads, Drainage and Irrigation be implemented for the Essequibo Coast. This strategy requires a capital investment of G$25,000,000 in drainage and irrigation over seven years, and G$23,000,000 in road construction and maintenance over twenty years. The expected net present worth at 10 percent interest rate for this strategy is approximately G$13,000,000 over a twenty-year period, and should sustain a rural population of approximately 52,000 persons at an average income per capita of G$400 annually, and reverse urban inmigration between the years of 1981 and 1987.

7.3 Future Research

Updating the State of the Art

During the preparation of this dissertation, it became clear that the preparation of a text of the main methodologies and techniques used in case studies in this subject area would be of immense benefit to transportation planners in less-developed countries.

Significant strides, beyond the concept of direct users impacts, have been made through such planning approaches as producers surplus, linear programming, input/output, interactive structural model (digraphs), cost effectiveness and system dynamics. Moreover, other techniques which are of equal significance, such as micro-analyses by demographers, geographers, agriculturalists and engineers in such areas as urban migration, housing, technology and transportation impacts in rural scenarios of less-developed countries, have been undertaken. However, these works are strewn over a wide range of "specialized discipline" publications and are at best difficult to come by.

This situation may have resulted because over the past twenty years, the approaches to the analyses of investment in rural economic infrastructure was more or less project-by-project oriented, with specialists looking at their own specific problems (i.e., rural housing, transport, agriculture, etc.). However, the situation is "quite" different now, since it is felt that (a) the concept of a rural development plan rather than individual project financing (road, drainage, irrigation, housing, etc.), is generally more favored by the international lending agencies; and (b) over the past twenty years, a significant amount of work has been done to make such a text feasible.

A guide-line for such a work would be as follows. For each methodology, the items to be produced are:

- Description
- Data Base Requirement
- Probable Time and Cost
- Usefulness of Output Beyond Project Implementation
- Most Likely Scenario for Use
- A "Simplified" Example

Such a contribution, it is felt, would not only update the state of the art in this area; but would positively reduce pre-feasibility costs and time for actual project implementation, since the needs of an anticipated model would be more or less known.

Model Extension

The study addressed the impacts due to the removal of the bottlenecks (transportation, drainage and irrigation) to agricultural expansion on primarily production, income per capita and migration. However, the impacts of agricultural expansion per se is felt beyond the above factors. Typically, the farm sector provides foreign exchange, public and private investment resources, and labor to the more rapidly expanding sectors of the economy, as well as increased supply of food and raw materials to support a growing urban population and manufacturing sector. Thus, the strategy for agricultural development (in which transportation plays a key role) should be efficient in a broad sense as follows [31]:

- Achieving a satisfactory rate of increases in farm outputs at a minimum cost by encouraging sequences of innovations which exploit the possibilities for technical change most appropriate to the country's factor endowments.
- Achieving a broadly based improvement in the welfare of the rural population.
- Contributing to the overall rate of national economic growth and process of structural transformation.

A planning procedure that can assess the "total efficiency" of alternative rural investment strategies would be most useful. The concept of "total efficiency" is both difficult to define and to analyze; however, this is the problem, and it must be faced if maximization of investment funds are to be realized. It is contended that the system dynamics methodology and the model developed have the flexibility to incorporate other possible impacts due to the increased income from agricultural outputs. Of course, this would require a multi-disciplinary team since specific information on the percent of the increased income that is reinvested at national or regional levels would be needed.

A conceptual causal formulation of the possible linkages between the agricultural sector's increased earnings and the urban manufacturing or business sector is presented in Figure 7.1. The figure is an obvious simplification of the national economy in terms of investment strategies. The concept is that gross national income is obtained from two main sectors (i.e., the urban or industrialized sector, and the rural or farm sector), and it is in turn reinvested in these two sectors. The intent is to illustrate the positive impacts of increased farm income on national growth rate and improved rural standard of living through Loops 1 and 2. Loop 1 (Gross National Income GNI, Rural Investment Strategies RIS, Rural Infrastructure Growth Rate RIGR, Rural Infrastructure RI, Acreage Cultivated AC, Income From Farming IFF, National Income From Farming NIFF) is a positive feedback loop indicating that the expansion of the national agricultural base benefits not only the rural region, but the nation as a whole by providing the capital input to the Urban Sector. Loop 2 (Rural Income Per Capita RIPC, Rural Migration RM, Rural Population RPOP) is a negative feedback loop indicating the impact of rural income on population movements (i.e., the expansion of the farm sector positively impacts rural income (a measure of standard of living), which in turn negatively impacts rural migration, thereby reducing unwanted urban growth).

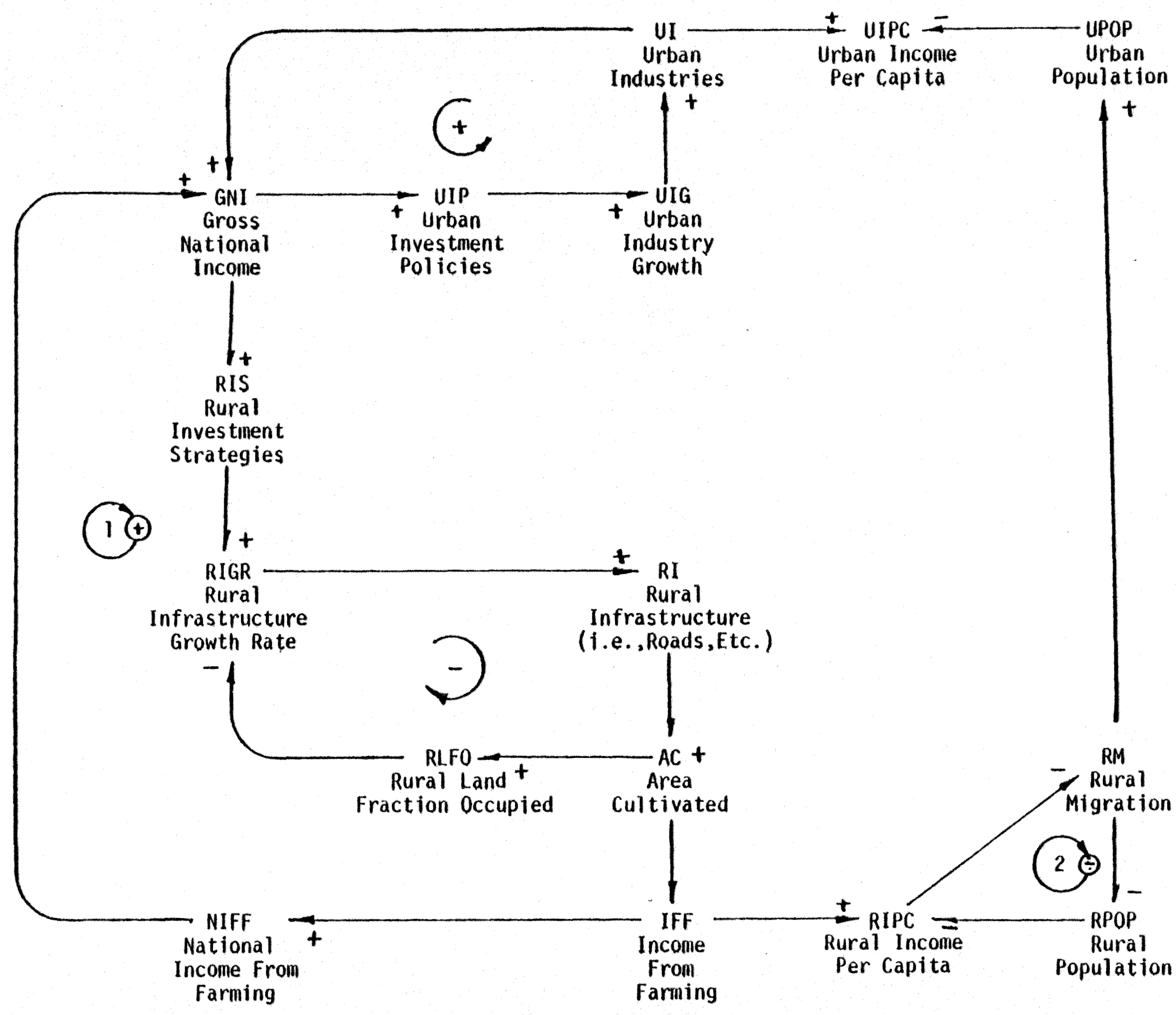


FIGURE 7.1 - Extension of Impacts of Rural Investment Strategy

In summary, ad hoc and/or piecemeal approach to transportation planning, using essentially non-interactive and feedback methodologies, have resulted in serious under-development or exploitation of the agricultural potentials of LDCs. And, agriculture is undoubtedly the mainstay of most LDCs' economies, as evidenced by the United Nations FAO 1973 report [32]), which stated that the real national growth rates of the majority of LDCs were highly correlated with their agricultural growth rates (i.e., "high-growth" developing countries (as measured by income per capita) were those that had a "high growth" in their agricultural sectors). Even if the perfect set of policies cannot be formulated and implemented, it is hoped that the methodology presented in this study, which is an attempt to explicitly incorporate the linkages and feedbacks that exist between investments in rural economic infrastructure and overall national impacts, would improve the decision-making process and maximize the allocation of scarce resources in LDCs.

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APPENDICES

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* APPENDIX 1.1
*
*
*
*    **********************************************
*        A RURAL TRANSPORTATION PLANNING MODEL
*    **********************************************
*
*
NOTE
NOTE
NOTE RURAL REGION-(DIRETLY IMPACTED--BY INVESTMENT)
NOTE
*
NOTE          DEMOGRAPHIC SECTOR SUB-MODEL
*
*
*                RURAL POPULATION
*
*
L RP.K=RP.J+(DT)(RBR.JK-RDR.JK-RM.JK)                  1,L
N RP=35000                                             1.1,N
R RBR.KL=RP.K*RBRN                                     2,R
C RBRN=.028                                            2.1,C
R RDR.KL=RP.K*RDRN                                     3,R
C RDRN=.006                                            3.1,C
*
*             RURAL MIGRATION
*
R RM.KL=UIM.K*RP.K                                     4,R
A GTURRUR.K=(GTUR.K/100)/RUR.K                         5,A
*
*
*   IMPACT OF UNEMPLOYMENT ON RURAL MIGRATION
*        (UNEMPLOYMENT MULTIPLIER)
*
A UIM.K=TABHL(UIMT,GTURRUR.K,.5,2,.1)                  6,A
T UIMT=.04/.03/.025/.01/.005/0/-.005/-.01/-.015/       6.1,T
X -.02/-.025/-.025/-.027/-.0275/-.03/-.035             6.2,X
*
*             RURAL LABOR FORCE
*
A RLF.K=RP.K*RPPF                                      7,A
C RPPF=.45                                             7.1,C
```

```
*
*        RURAL HOUSING
*
L RH.K=RH.J+(DT)(RHC.JK-RHD.JK)                        8,L
N RH=3000                                              8.1,N
R RHD.KL=RH.K*RHDN                                     9,R
C RHDN=.01                                             9.1,C
R RHC.KL=RH.K*RHCN*RHCM.K                             10,R
C RHCN=.017                                           10.1,C
*
* IMPACT OF RURAL POPULATION ON HOUSING CONSTRUCTION
*        (HOUSING DEMAND MULTIPLIER)
*
A RHCM.K=TABHL(RHCMT,RHHR.K,0,2,.2)                   11,A
T RHCMT=.2/.25/.35/.5/.7/1/1.35/1.6/1.8/1.95/2        11.1,T
A RHHR.K=RP.K/(RH.K*NPH)                              12,A
C NPH=10                                              12.1,C
*
*        RICE FARMERS
*
L RFMR.K=RFMR.J+(DT)(NF.JK-FLR.JK)                    13,L
N RFMR=3000                                           13.1,N
R  FLR.KL=RFMR.K*FLN*FLM.K                            14,R
C FLN=.01                                             14.1,C
A FLM.K=TABHL(FLMT,FTNIR.K,0,2,.2)                    15,A
T FLMT=2/1.9/1.8/1.6/1.2/1/.58/.3/.2/.1/0             15.1,T
R NF.KL=DNF.K*RURM.K                                  16,R
C LPRH=.5                                             16.1,C
*
*       RURAL LAND FRACTION OCCUPIED
*
A RLFO.K=(RROAD.K*AROW+RH.K*LPRH+RL.K)/RLA            17,A
C RLA=60000                                           17.1,C
A DNF.K=MAX(RAMLD.K-RLFO.K,0)*RLA/DLPF                18,A
C DLPF=25                                             18.1,C
*
*    AGRICULTURAL TECHNICIANS
*
L AT.K=AT.J+(DT)(ATT.JK-ATL.JK)                       19,L
N AT=100                                              19.1,N
R ATT.KL=(AT.K*ATTN)/TRT                              20,R
C TRT=4                                               20.1,C
C ATTN=.25                                            20.2,C
R ATL.KL=AT.K*ATLN                                    21,R
C ATLN=.05                                            21.1,C
A ATTFR.K=((AT.K*RFAT)/RFMR.K)                        22,A
C RFAT=.05                                            22.1,C
```

```
* IMPACT OF AGRI-TECH ON YIELD
*    (HUSBANDRY MULTIPLIER)
*
A   HM.K=TABHL(HMT,ATTFR.K,0,.005,.001)               23,A
T HMT=1/1.04/1.06/1.08/1.09/1.1                       23.1,T
*
*    RICE LAND CULITIVATION LEVEL
*
L RL.K=RL.J+(DT)(RLDR.JK-RLCR.JK)                     24,L
N RL=30000                                            24.1,N
R RLCR.KL=RL.K*RLCRN*RLCM.K                           25,R
C RLCRN=.001                                          25.1,C
R RLDR.KL=MAX(RLDM.K*RLA*(RAMLD.K-RLFO.K),0)/DILD     26,R
C DILD=5                                               26.1,C
*
*      RICE LAND DEVELOPMENT RATE MULTIPLIER
*
A RLDM.K=ALAM.K*FAM.K*MIM.K*PFRM.K*DIAM1.K            27,A
*
* LAND AVAILABILITY ON LAND DEVELOPMENT RATE
*     (LAND AVAILABILITY MULTIPLIER)
*
A ALAM.K=TABHL(ALAMT,RLFO.K,0,1,.1)                   28,A
T ALAMT=1/1.15/1.3/1.4/1.5/1.4/1.3/.9/.5/.25/0        28.1,T
*
*    FARM MECHANIZATION ON LAND DEVELOPMENYT RATE
*
A MIM.K=RLHRM.K*RLTRM.K                               29,A
*
*   HARVESTER AVAILABILITY MULTIPLIER
*
A RLHRM.K=TABHL(RLHRMT,RLHR.K,0,1.6,.2)               30,A
T RLHRMT=1/1/1/1/.95/.9/.8/.6/.5                      30.1,T
A RLHR.K=RL.K/(HV.K*LPHV)                             31,A
C LPHV=1000                                           31.1,C
*
*   TRACTOR AVAILABILITY MULTIPLIER
*
A RLTRM.K=TABHL(RLTRMT,RLTR.K,0,1.6,.2)               32,A
T RLTRMT=1.3/1.2/1.1/1/.95/.9/.8/.6/.5                32.1,T
A RLTR.K=RL.K/(TR.K*LPTR)                             33,A
C LPTR=100                                            33.1,C
*
*        HARVESTER
*
L HV.K=HV.J+(DT)(HVPR.JK-HVDR.JK)                     34,L
N HV=30                                               34.1,N
R HVDR.KL=HV.K*HVDRN                                  35,R
C HVDRN=.1                                            35.1,C
C HAT=2                                               35.2,C
R HVPR.KL=MAX((RL.K/LPHV)-HV.K,0)/HAT                 36,R
```

```
*         FARM TRACTORS
*
L TR.K=TR.J+(DT)(TRPR.JK-TRDR.JK)                          37,L
N TR=300                                                   37.1,N
R TRDR.KL=TR.K*TRDRN                                       38,R
C TRDRN=.1                                                 38.1,C
R TRPR.KL=MAX((RL.K/LPTR)-TR.K,0)                          39,R
*
*    FARMER AVAILABILITY ON LAND DEVELOPMENT RATE
*       (FARMER AVAILABILITY MULTIPLIER)
*
A FAM.K=TABHL(FAMT,FTLR.K,0,2,.2)                          40,A
T FAMT=.2/.25/.35/.5/.7/1/1.35/1.6/1.8/1.95/2              40.1,T
A FTLR.K=(RFMR.K*DLPF)/RL.K                                41,A
*
*  PROFIT FROM RICE FARMING ON LAND DEVELOPMENT RATE
*     (PROFIT MULTIPLIER)
*
A PFRM.K=TABHL(PFRMT,PPA.K/EPPA,0,1,.1)                    42,A
T PFRMT=.05/.1/.3/.4/.6/.8/1.5/1.6/1.7/1.8/2               42.1,T
*
*  DRAINAGE AND IRRIGATION EFFECT ON LAND DEVELOPMEN
*     (DRAINAGE AND IRRIGATION MULTIPLIER)
*
A DIAM1.K=TABHL(DIAM1T,RLTWR.K,0,2,.2)                     43,A
T DIAM1T=2/1.95/1.9/1.85/1.8/1.75/1.6/1.6/1.6/1.6/1.       43.1,T
C WRPA=5.2                                                 43.2,C
A RLTWR.K=(RL.K*WRPA)/IWA.K                                44,A
*
*    IRRIGATION LEVEL
*
L IWA.K=IWA.J+(DT)(IWAR.JK)                                45,L
N IWA=156000                                               45.1,N
R IWAR.KL=0                                                46,R
*
*    AFTER PRODUCTION LOSS LEVEL
*
L UMRL.K=UMRL.J+(DT)(UMRPR.JK-UMRTR.JK)                    47,L
N UMRL=0                                                   47.1,N
*
*   PADDY PRODUCTION RATE
*
R UMRPR.KL=YPA1.K*MIN(RL.K,RL1)+CLIP(YPA2.K,0,             48,R
X RL.K,RL1)*(RL.K-RL1)                                     48.1,X
C RL1=30000                                                48.2,C
*
*       YIELD PER ACRE
*
A YPA1.K=YPAN*FEAM.K*DIAM1.K*MIM.K*HM.K                    49,A
A YPA2.K=YPAN*FEAM.K*MIM.K*HM.K*DIAM2.K                    50,A
A DIAM2.K=1                                                51,A
C YPAN=.6                                                  51.1,C
A YPAM.K=FEAM.K*DIAM2.K*MIM.K*HM.K                         52,A
```

```
*     IMPACT OF FERTILIZER ON YIELD
*        (FERTILIZER MULTIPLIER)
*
*
A FEAM.K=TABHL(FEAMT,FI.K,0,130,10)                        53,A
A FI.K=FN+(FTCN-FCOT.K)/COF                                54,A
T FEAMT=1/1.05/1.1/1.15/1.2/1.25/1.3/1.35/                 54.1,T
X 1.4/1.45/1.5/1.6/1.7/1.75                                54.2,X
C FN=100                                                   54.3,C
C COF=.2                                                   54.4,C
C SPT=200                                                  54.5,C
*
*      COST OF FARMING PER ACRE
*
A CFA.K=NRCA+NLDA+NMICA+(FI.K*COF)+(FCOT.K*                55,A
X YPAM.K)+WTCT.K                                           55.1,X
C NRCA=15                                                   55.2,C
C NLDA=75                                                   55.3,C
C NMICA=100                                                 55.4,C
*
*      PROFIT OF FARMING PER ACRE
*
A PPA.K=(YPA1.K*SPT)-CFA.K                                 56,A
*
*     IMPACT OF PROFIT ON RICE DEVELOPMENT RATE
*       (PROFIT MULTIPLIER)
*
A RLCM.K=TABHL(RLCMT,PPA.K/EPPA,0,2,.2)                    57,A
T RLCMT=2/1.95/1.8/1.6/1.35/1/.7/.5/.35/.25/.2             57.1,T
C EPPA=100                                                 57.2,C
A APPF.K=PPA.K*APF                                         58,A
C APF=8                                                    58.1,C
A FTNIR.K=APPF.K/ANI                                       59,A
C ANI=1000                                                 59.1,C
*
*     IMPACT OF UNEMPLOYMENT ON NEW FARMERS
*       (UNEMPLOYMENT MULTIPLIER)
*
A RURM.K=TABHL(RURMT,RUR.K/NUR,0,1,.1)                     60,A
T RURMT=.1/.1/.2/.5/.8/1/1.2/1.4/1.5/1.8/2                 60.1,T
A AJ.K=RL.K*JPA                                            61,A
C JPA=.3                                                   61.1,C
C NUR=.16                                                  61.2,C
A JFRCM.K=(RCR.JK*20)+(RROAD.K*2)                          62,A
*
*      RURAL UNEMPLOYMENT RATE
*
A RUR.K=(RLF.K-(AJ.K+JFRCM.K))/RLF.K                       63,A
```

```
NOTE TRANSPORTATION SECTOR:RURAL ROAD TRANSPORT
*
*    RURAL ROAD FUND:
*
L RF.K=RF.J+(DT)(RFR.JK)                                 64,L
N RF=RFN                                                 64.1,N
C RFN=1000000                                            64.2,C
C RFRN=.1                                                64.3,C
R RFR.KL=RF.K*RFRN                                       65,R
R RER.KL=RCE.K+RME.K                                     66,R
*
*    CONSTRUCTION BUDGET
*
A RCB.K=RF.K*FPFC.K                                      67,A
A FPFC.K=DFRM.K*ETARM.K                                  68,A
*
* IMPACT OF ROAD DENSITY ON CONSTRUCTUION FUNDING
*      (DEMAND FOR ROAD MULTIPLIER)
*
A DFRM.K=TABHL(DFRMT,ARD.K/DRD,0,1,.1)                   69,A
T DFRMT=1/.95/.9/.9/.85/.75/.7/.6/.5/.2/0               69.1,T
A ETARM.K=TABHL(ETARMT,ETARR.K,0,1,.1)                   70,A
T ETARMT=0/.1/.2/.3/.4/.5/.7/.75/.9/.95/1                70.1,T
A RCE.K=MIN(RCB.K,RCR.JK*CCPM)                           71,A
C CCPM=100000                                            71.1,C
*
*    MAINTENANCE BUDGET
*
A RMB.K=RF.K*(1-FPFC.K)                                  72,A
A RME.K=MIN(RMB.K,RROAD.K*MCPM)                          73,A
C MCPM=5000                                              73.1,C
*
*    ROAD MILES
*
L RROAD.K=RROAD.J+(DT)(RCR.JK)                           74,L
N RROAD=150                                              74.1,N
C RCT=5                                                  74.2,C
L EROAD.K=EROAD.J+(DT)(RCR.JK-RRDR.JK)                   75,L
R RCR.KL=MIN(DFR.K,RCB.K/CCPM)*IFFM.K*RRLAM.K/RCT        76,R
R RRDR.KL=EROAD.K/(ARUL*RMM.K*TTM.K)                     77,R
N EROAD=140                                              77.1,N
A ETARR.K=EROAD.K/RROAD.K                                78,A
C ARUL=10                                                78.1,C
*
*    ROAD DETERIORATION IMPACT ON MAINTENANCE FUND
*      (MAINTENANCE FUND MULTIPLIER)
*
A RMM.K=TABHL(RMMT,MFPM.K/MCPM,0,1,.2)                   79,A
T RMMT=1/1.4/1.65/1.8/1.9/2                              79.1,T
```

```
*     IMPACT FROM TRUCK TRAFFIC ON ROAD DETERIORATION
*        (TRUCK TRAFFIC MULTIPLIER)
*
A TTM.K=TABHL(TTMT,(TT.K/300)/DADT,0,2,.2)            80,A
T TTMT=2/2/1.8/1.6/1.4/1/.9/.8/.5/.3/.2               80.1,T
A MFPM.K=RMB.K/RROAD.K                                81,A
C DADT=100                                             81.1,C
*
*        DEMAND FOR ROAD
*
A DFR.K=DRM.K-RROAD.K                                 82,A
A DRM.K=DRD*RLA                                       83,A
C DRD=.0055                                           83.1,C
A ARD.K=RROAD.K/RLA                                   84,A
A RDLFO.K=(RROAD.K*AROW)/RDLA                         85,A
C AROW=10                                             85.1,C
C RDLA=10000                                          85.2,C
A ERD.K=EROAD.K/RLA                                   86,A
*
* IMPACT OF LAND AVAILABILITY ON ROAD  CONSTRUCTION
*    (ROAD CONTRUCTION MULTIPLIER)
*
A RRLAM.K=TABHL(RRLAMT,RDLFO.K,0,1,.2)                87,A
T RRLAMT=1/1.3/1.45/1.3/.5/0                          87.1,T
A IFFM.K=TABHL(IFFMT,FTLR.K,0,2,.2)                   88,A
T IFFMT=.2/.25/.35/.5/.7/1/1.35/1.6/1.8/1.95/2        88.1,T
*
* ROAD TRANSPORT CAPACITY
*
R UMRTR.KL=MIN(RTC.K,UMRPR.JK)                        89,R
A ETT.K=(IGED/ANP)*ERDM.K                             90,A
C IGED=16                                             90.1,C
C ANP=20                                              90.2,C
C AWHD=10                                             90.3,C
A TTPD.K=AWHD/ETT.K                                   91,A
A RTC.K=TRUCK.K*TTPD.K*HPP*PLPT                       92,A
C HPP=60                                              92.1,C
C PLPT=7                                              92.2,C
A TT.K=(UMRTR.JK/PLPT)*2                              93,A
L TRUCK.K=TRUCK.J+(DT)(TPR.JK-TDR.JK)                 94,L
N TRUCK=20                                            94.1,N
R TPR.KL=MAX(DNT.K-TRUCK.K,0)/DIP                     95,R
C DIP=2                                               95.1,C
A DNT.K=UMRPR.JK/(TTPD.K*PLPT*HPP)                    96,A
R TDR.KL=TRUCK.K*TDN*TDRM.K                           97,R
*
* IMPACT OF ROAD MAINTENANCE ON TRUCK DETERIORATION
*    (ROAD MAINTENANCE MULTIPLIER)
*
A TDRM.K=TABHL(TDRMT,ETARR.K,0,1,.1)                  98,A
T TDRMT=1.9/1.75/1.7/1.65/1.6/1.55/1.5/1.4/1.2/1.1/1 98.1,T
*
*    RICE FOR MARKETING
*
A RFD.K=(UMRPR.JK*CF)-RP.K*RCPC                       99,A
C RCPC=.1                                             99.1,C
C CF=.5                                               99.2,C
C TDN=.1                                              99.3,C
```

```
*    IMPACT OF ROAD MAINTENANCE ON TRAVEL TIME
*     (ROAD MAINTENANCE MULTIPLIER)
*
A ERDM.K=TABLE(ERDMT,ETARR.K,0,1,.1)                  100,A
T ERDMT=2/2/2/2/1.9/1.8/1.7/1.5/1.2/1.1/1              100.1,T
*
* IMPACT OF ROAD ACCESS ON LAND DEVELOPMENT RATE
*  (ROAD ACCESSIBILITY MULTIPLIER)
*
A RAMLD.K=TABHL(RAMLDT,ARD.K/DRD,0,1,.1)              101,A
T RAMLDT=0/.2/.4/.5/.55/.6/.65/.7/.8/.9/1              101.1,T
*
A FCOT.K=FTCN*ARTCM.K                                  102,A
C FTCN=10                                              102.1,C
*
* IMPACT OF ROAD DENSITY ON TRANSPORT FARMING COST
*      (ROAD DENSITY MULTIPLIER)
*
A ARTCM.K=TABHL(ARTCMT,ARD.K/DRD,0,1,.1)              103,A
T ARTCMT=1.5/1.45/1.4/1.35/1.3/1.2/1.1/1/.9/.85/.8    103.1,T
*
* TRANSPORT SECTOR: WATER TRANSPORTATION SUB-MODEL
*
L VIS.K=VIS.J+(DT)(VPR.JK-VDESR.JK)                    104,L
N VIS=6                                                104.1,N
R VPR.KL=MAX(DNV.K-VIS.K,0)/VAT                        105,R
C VAT=3                                                105.1,C
R VDESR.KL=VIS.K*VDESRN                                106,R
C VDESRN=.025                                          106.1,C
A ATPR.K=ATD/(AVS*24)                                  107,A
A TTC.K=(ATPR.K*VCPD)/PLPV                             108,A
C VCPD=1000                                            108.1,C
C PLPV=300                                             108.2,C
A QDCT.K=(DCPD/PLPV)*QDM.K                             109,A
C DCPD=200                                             109.1,C
A QDM.K=TABHL(QDMT,QDPV.K,0,2,.25)                     110,A
T QDMT=1/1.125/1.25/1.375/1.5/1.625/1.75/1.875/2       110.1,T
A QDPV.K=TABHL(QDPVT,VIS.K,1,9,1)                      111,A
T QDPVT=0/.25/.5/.75/1/1.25/1.5/1.75/2                 111.1,T
C AVS=7                                                111.2,C
C ATD=100                                              111.3,C
A TPV.K=PHP/((ONLT+OFLT)+ATPR.K*QDM.K)                 112,A
C PHP=100                                              112.1,C
C ONLT=1                                               112.2,C
C OFLT=.5                                              112.3,C
A WTCT.K=(ONLC+OFLC+TTC.K+QDCT.K)                      113,A
C ONLC=.2                                              113.1,C
C OFLC=.2                                              113.2,C
A WTCPR.K=TPV.K*VIS.K*PLPV                             114,A
A DNV.K=QTW.K/(TPV.K*PLPV)                             115,A
A QTW.K=RFD.K*RTWCR.K                                  116,A
A RTMC.K=RTCN                                          117,A
C RTCN=100                                             117.1,C
A RTWCR.K=TABHL(RTWCRT,WTCT.K/RTMC.K,.5,2,.25)         118,A
T RTWCRT=1/.9/.45/.3/.1/.05/0                          118.1,T
A WTR.K=MIN(WTCPR.K,QTW.K)                             119,A
```

```
NOTE  URBAN REGION (SPATIALLY IMPACTED)
*
*
*      GEORGETOWN = ZONE 1
*
L GTPOP.K=GTPOP.J+(DT)(GTBR.JK+GTI.JK-GTDR.JK-GTO.JK120,L
N GTPOP=199800                                        120.1,N
R GTO.KL=GTPOP.K*GTON                                 121,R
C GTON=.005                                           121.1,C
R GTBR.KL=GTPOP.K*GTBRN                               122,R
C GTBRN=.0318                                         122.1,C
R GTDR.KL=GTPOP.K*GTDRN                               123,R
C GTDRN=.0126                                         123.1,C
L GTH.K=GTH.J+(DT)(GTHC.JK-GTHDR.JK)                  124,L
N GTH=20000                                           124.1,N
R GTI.KL=(UI.K*(1-GTCLO.K))/((1-GTCLO.K)+(1-ECCLO.K)125,R
X (1-EBCLO.K))                                        125.1,X
R GTHC.KL=GTH.K*GTHCN*UHAM.K*GTCLAM.K                 126,R
C GTHCN=.01                                           126.1,C
R GTHDR.KL=GTH.K*GTHDRN                               127,R
C GTHDRN=.001                                         127.1,C
A GTCLAM.K=TABHL(GTCLAMT,GTCLO.K,0,1,.1)              128,A
T GTCLAMT=1/1.15/1.3/1.4/1.5/1.4/1.3/.9/.75/.5/0      128.1,T
A GTCLO.K=(GTH.K*GTLPH+GTBS.K*GTLPBS+GTSS.K*GTLPSS)  129,A
X /GTCLAN                                             129.1,X
C GTCLAN=5000                                         129.2,C
L GTSS.K=GTSS.J+(DT)(GTSSC.JK-GTSSD.JK)               130,L
N GTSS=500                                            130.1,N
R GTSSC.KL=GTSS.K*GTSSCN*GTCLAM.K*ULFAM.K             131,R
C GTSSCN=.03                                          131.1,C
R GTSSD.KL=GTSS.K*GTSSDN                              132,R
C GTSSDN=.001                                         132.1,C
L GTBS.K=GTBS.JK+(DT)(GTBSC.JK-GTBSD.JK)              133,L
N GTBS=50                                             133.1,N
R GTBSC.KL=GTBS.K*GTBSCN*ULFAM.K*GTCLAM.K             134,R
C GTBSCN=.03                                          134.1,C
R GTBSD.KL=GTBS.K*GTBSDN                              135,R
C GTBSDN=.001                                         135.1,C
L GTWS.K=GTWS.J+(DT)(GTWSC.JK-GTWSD.JK)               136,L
N GTWS=20                                             136.1,N
R GTWSC.KL=GTWS.K*GTWSCN*GTWLAM.K*ULFAM.K             137,R
C GTWSCN=.03                                          137.1,C
R GTWSD.KL=GTWS.K*GTWSDN                              138,R
C GTWSDN=.001                                         138.1,C
A GTJ.K=GTBS.K*JPGBS+GTSS.K*JPGSS+GTWS.K*JPGTWS       139,A
C JPGBS=30                                            139.1,C
C JPGSS=100                                           139.2,C
C JPGTWS=300                                          139.3,C
A GTWLAM.K=TABHL(GTWLAMT,GTWLFO.K,0,1,.1)             140,A
T GTWLAMT=1/1.15/1.13/1.4/1.5/1.4/1.3/.9/.5/.25/0     140.1,T
A GTLF.K=GTPOP.K*LFPR                                 141,A
A GTUR.K=((GTLF.K-GTJ.K)/GTLF.K)*100                  142,A
A GTWLFO.K=(GTWS.K*GTLPW)/GTWLA                       143,A
```

```
C GTLPW=600                                         143.1,C
C GTWLA=13220                                       143.2,C
C GTLPH=.1                                          143.3,C
C GTLPBS=10                                         143.4,C
C GTLPSS=2                                          143.5,C
C LPH=.25                                           143.6,C
C LPBS=5                                            143.7,C
C LPSS=5                                            143.8,C
C LPSMI=500                                         143.9,C
*
*   EAST BANK DEMERARA = ZONE 2
*
L EBPOP.K=EBPOP.J+(DT)(EBBR.JK+EBI.JK-EBDR.JK)      144,L
N EBPOP=36600                                       144.1,N
R EBBR.KL=EBPOP.K*EBBRN                             145,R
C EBBRN=.0318                                       145.1,C
R EBDR.KL=EBPOP.K*EBDRN                             146,R
C EBDRN=.0126                                       146.1,C
L EBH.K=EBH.J+(DT)(EBHC.JK-EBHDR.JK)                147,L
A UI.K=UPOP.K*UIN+GTPOP.K*GTON+UIM.K*RP.K           148,A
C UIN=.009                                          148.1,C
R EBI.KL=(UI.K*(1-EBCLO.K))/((1-EBCLO.K)+(1-ECCLO.K)149,R
X +(1-GTCLO.K))                                     149.1,X
N EBH=4000                                          149.2,N
R EBHC.KL=EBH.K*EBHCN*UHAM.K*EBCLAM.K               150,R
C EBHCN=.02                                         150.1,C
R EBHDR.KL=EBH.K*EBHDRN                             151,R
C EBHDRN=.015                                       151.1,C
A EBCLAM.K=TABHL(EBCLAMT,EBCLO.K,0,1,.1)            152,A
T EBCLAMT=1/1.15/1.3/1.4/1.5/1.4/1.3/.9/.5/.25/0    152.1,T
A EBCLO.K=(EBH.K*LPH+EBBS.K*LPBS+EBSS.K*LPSS)       153,A
X /EBCLA.K                                          153.1,X
A EBCLA.K=EBCLAN+EBSLC.JK                           154,A
C EBCLAN=18000                                      154.1,C
L EBSL.K=EBSL.J+(DT)(EBSLG.JK-EBSLC.JK)             155,L
N EBSL=12000                                        155.1,N
R EBSLG.KL=EBSL.K*EBSLGN*EBLAM.K*ULFAM.K            156,R
C EBSLGN=.03                                        156.1,C
R EBSLC.KL=EBSL.K*EBSLCN                            157,R
C EBSLCN=.002                                       157.1,C
L EBSS.K=EBSS.J+(DT)(EBSSC.JK-EBSSD.JK)             158,L
N EBSS=100                                          158.1,N
R EBSSC.KL=EBSS.K*EBSSCN*EBCLAM.K*ULFAM.K           159,R
C EBSSCN=.03                                        159.1,C
R EBSSD.KL=EBSS.K*EBSSDN                            160,R
C EBSSDN=.001                                        160.1,C
L EBBS.K=EBBS.J+(DT)(EBBSC.JK-EBBSD.JK)             161,L
```

```
N EBBS=50                                              161.1,N
R EBBSC.KL=EBBS.K*EBBSCN*ULFAM.K*EBCLAM.K              162,R
C EBBSCN=.05                                           162.1,C
R EBBSD.KL=EBBS.K*EBBSDN                               163,R
C EBBSDN=.001                                          163.1,C
L EBSMI.K=EBSMI.J+(DT)(EBSMIG.JK)                      164,L
N EBSMI=1                                              164.1,N
R EBSMIG.KL=EBSMI.K*EBSMIGN                            165,R
C EBSMIGN=.03                                          165.1,C
L EBWS.K=EBWS.J+(DT)(EBWSC.JK-EBWSD.JK)                166,L
N EBWS=10                                              166.1,N
R EBWSC.KL=EBWS.K*EBWSCN*EBWLAM.K*ULFAM.K              167,R
A EBWLAM.K=TABHL(EBWLAMT,EBWLFO.K,0,1,.1)              168,A
T EBWLAMT=1/1.15/1.13/1.4/1.5/1.4/1.3/.9/.5/.25/0      168.1,T
A EBWLFO.K=(EBWS.K*LPEBWS)/EBWLA                       169,A
C LPEBWS=600                                           169.1,C
C EBWLA=52000                                          169.2,C
L APJ.K=APJ.J+(DT)(APJGR.JK)                           170,L
N APJ=600                                              170.1,N
R APJGR.KL=APJ.K*APJGRN                                171,R
C APJGRN=.06                                           171.1,C
C EBWSCN=.001                                          171.2,C
R EBWSD.KL=EBWS.K*EBWSDN                               172,R
C EBWSDN=.0001                                         172.1,C
A EBLFO.K=(EBH.K*LPH+EBSMI.K*LPSMI+EBBS.K*LPBS+        173,A
X EBSS.K*LPSS+EBSL.K)/EBLA                             173.1,X
C EBLA=48000                                           173.2,C
A EBJ.K=EBSMI.K*JPEBSMI+EBBS.K*JPBS+EBSS.K*            174,A
X JPSS+EBWS.K*JPEBWS+EBSL.K*JPSL+APJ.K                 174.1,X
C JPEBSMI=2000                                         174.2,C
C JPBS=30                                              174.3,C
C JPSS=20                                              174.4,C
C JPEBWS=100                                           174.5,C
C JPSL=.15                                             174.6,C
A EBLAM.K=TABHL(EBLAMT,EBLFO.K,0,1,.1)                 175,A
T EBLAMT=1/1.15/1.13/1.4/1.5/1.4/1.3/.9/.5/.25/0       175.1,T
A EBLF.K=EBPOP.K*LFPR                                  176,A
C LFPR=.40                                             176.1,C
A EBUR.K=((EBLF.K-EBJ.K)/EBLF.K)*100                   177,A
A EBIET.K=EBIEWT.K+EBIENWT.K                           178,A
A EBIEWT.K=((EBUR.K*UFGTJ.K)/(EBUR.K+                  179,A
X ECUR.K+WDUR.K))*TPJ                                  179.1,X
C TPJ=3                                                179.2,C
A EBIENWT.K=EBPOP.K*TPP                                180,A
C TPP=.2                                               180.1,C
L EBEET.K=EBEET.J+(DT)(EBEETG.JK)                      181,L
R EBEETG.KL=EBEET.K*EBEETGN                            182,R
C EBEETGN=.03                                          182.1,C
```

```
N EBEET=3500                                             182.2,N
L EBEIT.K=EBEIT.J+(DT)(EBEITG.JK)                        183,L
N EBEIT=1500                                             183.1,N
R EBEITG.KL=EBEIT.K*EBEITGN                              184,R
C EBEITGN=.03                                            184.1,C
L EBTRT.K=EBTRT.J+(DT)(EBTRTG.JK)                        185,L
N EBTRT=1000                                             185.1,N
R EBTRTG.KL=EBTRT.K*EBTRTGN                              186,R
C EBTRTGN=.03                                            186.1,C
A EBADT.K=((EBEIT.K+EBEET.K+EBIET.K)*PA)/AO+(((          187,A
X EBIET.K+EBEET.K+EBEIT.K)*PB)/BO)*BE+(EBTRT.K*TE)       187.1,X
C PA=.8                                                  187.2,C
C AO=3                                                   187.3,C
C PB=.2                                                  187.4,C
C BO=20                                                  187.5,C
C BE=5                                                   187.6,C
A EBPHF.K=EBADT.K*PPH                                    188,A
C PPH=.15                                                188.1,C
C TE=3                                                   188.2,C
*
*      EAST COAST DEMERARA = ZONE 2
*
L ECPOP.K=ECPOP.J+(DT)(ECBR.JK+ECI.JK-ECDR.JK)           189,L
N ECPOP=78250                                            189.1,N
R ECBR.KL=ECPOP.K*ECBRN                                  190,R
C ECBRN=.0318                                            190.1,C
R ECDR.KL=ECPOP.K*ECDRN                                  191,R
C ECDRN=.0126                                            191.1,C
L ECH.K=ECH.J+(DT)(ECHC.JK-ECHDR.JK)                     192,L
N ECH=9000                                               192.1,N
R ECI.KL=(UI.K*(1-ECCLO.K))/((1-ECCLO.K)(1-EBCLO.K)      193,R
X +(1-GTCLO.K))                                          193.1,X
R ECHC.KL=ECH.K*ECHCN*UHAM.K*ECCLAM.K                    194,R
C ECHCN=.02                                              194.1,C
R ECHDR.KL=ECH.K*ECHDRN                                  195,R
C ECHDRN=.015                                            195.1,C
A ECCLAM.K=TABHL(ECCLAMT,ECCLO.K,0,1,.1)                 196,A
T ECCLAMT=1/1.15/1.3/1.4/1.5/1.4/1.3/.9/.5/.25/0         196.1,T
A ECCLO.K=(ECH.K*LPH+ECBS.K*LPBS+ECSS.K*LPSS)            197,A
X /ECCLA.K                                               197.1,X
A ECCLA.K=ECCLAN+ECSLC.JK                                198,A
C ECCLAN=25000                                           198.1,C
L ECSL.K=ECSL.J+(DT)(ECSLG.JK-ECSLC.JK)                  199,L
N ECSL=25000                                             199.1,N
R ECSLG.KL=ECSL.K*ECSLGN*ECLAM.K*ULFAM.K                 200,R
C ECSLGN=.03                                             200.1,C
R ECSLC.KL=ECSL.K*ECSLCN                                 201,R
```

```
C ECSLCN=.002                                                201.1,C
L ECSS.K=ECSS.J+(DT)(ECSSC.JK-ECSSD.JK)                      202,L
N ECSS=100                                                   202.1,N
R ECSSC.KL=ECSS.K*ECSSCN*ECCLAM.K*ULFAM.K                    203,R
C ECSSCN=.015                                                203.1,C
R ECSSD.KL=ECSS.K*ECSSDN                                     204,R
C ECSSDN=.001                                                204.1,C
L ECBS.K=ECBS.J+(DT)(ECBSC.JK-ECBSD.JK)                      205,L
N ECBS=100                                                   205.1,N
R ECBSC.KL=ECBS.K*ECBSCN*ULFAM.K*ECCLAM.K                    206,R
C ECBSCN=.015                                                206.1,C
R ECBSD.KL=ECBS.K*ECBSDN                                     207,R
C ECBSDN=.001                                                207.1,C
L ECSMI.K=ECSMI.J+(DT)(ECSMIG.JK)                            208,L
N ECSMI=2                                                    208.1,N
R ECSMIG.KL=ECSMI.K*ECSMIGN                                  209,R
C ECSMIGN=.001                                               209.1,C
A ECLFO.K=(ECH.K*LPH+ECOCL.K+ECSMI.K*LPSMI+ECBS.K            210,A
X *LPBS+ECSS.K*LPSS+ECSL.K)/ECLA                             210.1,X
C ECLA=70000                                                 210.2,C
A ECJ.K=ECSMI.K*JPECSMI+ECBS.K*JPECBS+ECSS.K*                211,A
X JPSS+ECSL.K*JPSL+ECOCL.K*JPECOCL                           211.1,X
C JPECBS=10                                                  211.2,C
C JPECOCL=.3                                                 211.3,C
L ECOCL.K=ECOCL.J+(DT)(ECOCLG.JK)                            212,L
N ECOCL=1000                                                 212.1,N
R ECOCLG.KL=ECOCL.K*ECOCLGN                                  213,R
C ECOCLGN=.03                                                213.1,C
C JPECSMI=1000                                               213.2,C
A ECLAM.K=TABHL(ECLAMT,ECLFO.K,0,1,.1)                       214,A
T ECLAMT=1/1.15/1.13/1.4/1.5/1.4/1.3/.9/.5/.25/0             214.1,T
A ECLF.K=ECPOP.K*LFPR                                        215,A
A ECUR.K=((ECLF.K-ECJ.K)/ECLF.K)*100                         216,A
A ECIET.K=ECIEWT.K+ECIENWT.K                                 217,A
A ECIEWT.K=((ECUR.K*UFGTJ.K)/(ECUR.K+                        218,A
X EBUR.K+WDUR.K))*TPJ                                        218.1,X
A ECIENWT.K=ECPOP.K*TPP                                      219,A
L ECEET.K=ECEET.J+(DT)(ECEETG.JK)                            220,L
R ECEETG.KL=ECEET.K*ECEETGN                                  221,R
C ECEETGN=.03                                                221.1,C
N ECEET=3500                                                 221.2,N
L ECEIT.K=ECEIT.J+(DT)(ECEITG.JK)                            222,L
N ECEIT=1500                                                 222.1,N
R ECEITG.KL=ECEIT.K*ECEITGN                                  223,R
C ECEITGN=.03                                                223.1,C
A ECADT.K=((ECEIT.K+ECEET.K+ECIET.K)*PA)/AO+(((              224,A
X ECIET.K+ECEET.K+ECEIT.K)*PB)/BO)*BE+(ECTRT.K*TE)           224.1,X
L ECTRT.K=ECTRT.J+(DT)(ECTRTG.JK)                            225,L
N ECTRT=1000                                                 225.1,N
R ECTRTG.KL=ECTRT.K*ECTRTGN                                  226,R
C ECTRTGN=.03                                                226.1,C
A ECPHF.K=ECADT.K*PPH                                        227,A
```

```
*
*      WEST DEMERARA = ZONE 4
*
L WDPOP.K=WDPOP.J+(DT)(WDBR.JK-WDDR.JK)                 228,L
N WDPOP=82250                                           228.1,N
R WDBR.KL=WDPOP.K*WDBRN                                 229,R
C WDBRN=.0318                                           229.1,C
R WDDR.KL=WDPOP.K*WDDRN                                 230,R
C WDDRN=.0126                                           230.1,C
L WDH.K=WDH.J+(DT)(WDHC.JK-WDHDR.JK)                    231,L
N WDH=10000                                             231.1,N
R WDHC.KL=WDH.K*WDHCN*UHAM.K*WDCLAM.K                   232,R
C WDHCN=.02                                             232.1,C
R WDHDR.KL=WDH.K*WDHDRN                                 233,R
C WDHDRN=.001                                           233.1,C
A WDCLAM.K=TABHL(WDCLAMT,WDCLO.K,0,1,.1)                234,A
T WDCLAMT=1/1.15/1.3/1.4/1.5/1.4/1.3/.9/.5/.25/0        234.1,T
A WDCLO.K=(WDH.K*LPH+WDBS.K*LPBS+WDSS.K*LPSS)           235,A
X /WDCLA.K                                              235.1,X
A WDCLA.K=WDCLAN+WDSLC.JK                               236,A
C WDCLAN=25000                                          236.1,C
L WDSL.K=WDSL.J+(DT)(WDSLG.JK-WDSLC.JK)                 237,L
N WDSL=40000                                            237.1,N
R WDSLG.KL=WDSL.K*WDSLGN*WDLAM.K*ULFAM.K                238,R
C WDSLGN=.03                                            238.1,C
R WDSLC.KL=WDSL.K*WDSLCN                                239,R
C WDSLCN=.002                                           239.1,C
L WDSS.K=WDSS.J+(DT)(WDSSC.JK-WDSSD.JK)                 240,L
N WDSS=200                                              240.1,N
R WDSSC.KL=WDSS.K*WDSSCN*WDCLAM.K*ULFAM.K               241,R
C WDSSCN=.015                                           241.1,C
R WDSSD.KL=WDSS.K*WDSSDN                                242,R
C WDSSDN=.001                                           242.1,C
L WDBS.K=WDBS.J+(DT)(WDBSC.JK-WDBSD.JK)                 243,L
N WDBS=100                                              243.1,N
R WDBSC.KL=WDBS.K*WDBSCN*ULFAM.K*WDCLAM.K               244,R
C WDBSCN=.015                                           244.1,C
R WDBSD.KL=WDBS.K*WDBSDN                                245,R
C WDBSDN=.001                                           245.1,C
L WDSMI.K=WDSMI.J+(DT)(WDSMIG.JK)                       246,L
N WDSMI=3                                               246.1,N
R WDSMIG.KL=WDSMI.K*WDSMIGN                             247,R
C WDSMIGN=.001                                          247.1,C
A WDLFO.K=(WDH.K*LPH+WDSMI.K*LPSMI+WDBS.K*LPBS+         248,A
X WDSS.K*LPSS+WDSL.K+WDOCL.K)/WDLA                      248.1,X
C WDLA=70000                                            248.2,C
A WDJ.K=WDSMI.K*JPWDSMI+WDBS.K*JPBS+WDSS.K*             249,A
X JPSS+WDSL.K*JPSL+WDRL.K*JPRL+WDOCL.K*JPOCL            249.1,X
C JPWDSMI=1000                                          249.2,C
L WDRL.K=WDRL.J+(DT)(WDRLG.JK)                          250,L
N WDRL=12000                                            250.1,N
```

```
R WDRLG.KL=WDRL.K*WDRLGN                                 251,R
C WDRLGN=.03                                             251.1,C
L WDOCL.K=WDOCL.J+(DT)(WDOCLG.JK)                        252,L
N WDOCL=2000                                             252.1,N
R WDOCLG.KL=WDOCL.K*WDOCLGN                              253,R
C WDOCLGN=.01                                            253.1,C
C JPOCL=.5                                               253.2,C
C JPRL=.3                                                253.3,C
A WDLAM.K=TABHL(WDLAMT,WDLFO.K,0,1,.1)                   254,A
T WDLAMT=1/1.15/1.13/1.4/1.5/1.4/1.3/.9/.5/.25/0         254.1,T
A WDLF.K=WDPOP.K*LFPR                                    255,A
A WDUR.K=((WDLF.K-WDJ.K)/WDLF.K)*100                     256,A
A WDIET.K=WDIEWT.K+WDIENWT.K                             257,A
A WDIEWT.K=((WDUR.K*UFGTJ.K)/(WDUR.K+                    258,A
X ECUR.K+EBUR.K))*TPJ                                    258.1,X
A WDIENWT.K=WDPOP.K*TPP                                  259,A
L WDEET.K=WDEET.J+(DT)(WDEETG.JK)                        260,L
R WDEETG.KL=WDEET.K*WDEETGN                              261,R
C WDEETGN=.03                                            261.1,C
N WDEET=1500                                             261.2,N
L WDEIT.K=WDEIT.J+(DT)(WDEITG.JK)                        262,L
N WDEIT=2000                                             262.1,N
R WDEITG.KL=WDEIT.K*WDEITGN                              263,R
C WDEITGN=.03                                            263.1,C
A WDADT.K=((WDEIT.K+WDEET.K+WDIET.K)*/AO+(((             264,A
X WDIET.K+WDEET.K+WDEIT.K)*PB)/BO)*BE+(WDTRT.K*TE)       264.1,X
L WDTRT.K=WDTRT.J+(DT)(WDTRTG.JK)                        265,L
N WDTRT=500                                              265.1,N
R WDTRTG.KL=WDTRT.K*WDTRTGN                              266,R
C WDTRTGN=.03                                            266.1,C
A WDPHF.K=WDADT.K*PPH                                    267,A
```

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NOTE    URBAN REGIONAL VARIABLES
*
*      URBAN POPULATION
*
A UPOP.K=ECPOP.K+EBPOP.K+WDPOP.K+GTPOP.K                 268,A
*
*    URBAN LABOR FORCE
*
A ULF.K=UPOP.K*LFPF                                      269,A
C LFPF=.4                                                269.1,C
*
*     URBAN JOBS
*
A UJ.K=ECJ.K+GTJ.K+EBJ.K+WDJ.K                           270,A
A ULFTJR.K=ULF.K/UJ.K                                    271,A
*
*   URBAN UNEMPLOYMENT RATE
*
A UUR.K=((ULF.K-UJ.K)/ULF.K)*100                         272,A
*
* IMPACT OF URBAN LABOR FORCE ON CONSTRUCTION
*      (LABOR FORCE MULTIPLIER)
*
A ULFAM.K=TABHL(ULFAMT,ULFTJR.K,0,2,.2)                  273,A
*
*     URBAN HOUSING
*
A UH.K=ECH.K+EBH.K+GTH.K+WDH.K                           274,A
T ULFAMT=.1/.15/.2/.3/.5/1/1.3/1.5/1.7/1.9/2             274.1,T
A UHHR.K=UPOP.K/(UH.K*PH)                                275,A
A UFGTJ.K=GTJ.K-((1-UUR.K/100)*GTLF.K)                   276,A
C PH=6                                                   276.1,C
*
*    IMPACT OF URBAN POPULATION ON HOUSING
*     (URBAN HOUSING DEMAND MULTIPLIER)
*
A UHAM.K=TABHL(UHAMT,UHHR.K,0,2,.2)                      277,A
T UHAMT=.1/.2/.35/.5/.7/1/1.6/1.8/1.9/1.95/2             277.1,T
N TIME=1970
SPEC DT=1/LENGTH=2000/PLTPER=1/PRTPER=1
PRINT RL,CFA,RROAD,RCE,RME,RER,UMRPR
RUN
QUIT
/*
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APPENDIX 1.2

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*      ***********************************************
            DEFINITION OF VARIABLES
*      ***********************************************
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AJ: AGRICULTURAL JOBS (JOBS)
ALAM : AGRICULTURAL LAND AVAILABILITY MULTIPLIER (DIMENSIONLESS)
ALAMT : AGRICULTURAL LAND AVAILABILITY MULTIPLIER TABLE FUNCTION
ANI : AVERAGE NATIONAL URBAN INCOME ($/YEAR)
ANP : AVERAGE TRAVEL SPEED (MILES/HOUR)
AO : AUTO EQUIVALENT
APF : ACRE PER FARMER (ACRE/FARMER)
APJ : AIRPORT JOBS (JOBS)
APJGR : AIRPORT JOBS GROWTH RATE (JOBS/YEAR)
APJGRN : AIRPORT JOBS GROWTH RATE NORMAL (FRACTION)
APPF : AVERAGE PROFIT PER FARMER ($/CROP)
ARD : ACTUAL ROAD DENSITY (FRACTION)
AROW : AVERAGE RIGHT OF WAY (ACRES/MILE)
ARTCM : ACTUAL ROAD TRANSPORT COST MULTIPLIER (DIMENSIONLESS)
ARTCMT : ACTUAL ROAD TRANSPORT COST MULTIPLIER TABLE FUNCTION
ARUL : AVERAGE ROAD USEFUL LIFE (YEARS)
AT : AGRICULTURAL TECHNICIANS (TECHNICIANS)
ATD : AVERAGE TRAVEL DISTANCE (MILES)
ATL : AGRICULTURAL TECHNICIAN LEAVING RATE (TECHNICIANS/YEAR)
ATLN : AGRICULTURAL TECHNICIAN LEAVING RATE NORMAL (FRACTION)
ATPR : AVERAGE TIME PER ROUTE (DAYS)
ATT : AGRICULTURAL TECHNICIAN TRAINING RATE (TECHNICIANS/YEAR)
ATTFR : AGRICULTURAL TECHNICIANS TO FARMERS RATIO (FRACTION)
ATTN : AGRICULTURAL TECHNICIAN TRAINING RATE NORMAL (FRACTION)
AVS : AVERAGE VESSEL SPEED (MILES/HOUR)
AWHD : AVERAGE WORKING HOUR PER DAY (HOURS/DAY)

BE : BUS EQUIVALENT (PASSENGER CAR UNITS/BUS)
BO : BUS OCCUPANCY

CCPM : CONSTRUCTION COST PER MILE ($/MILE)
CF : UNMILLED RICE CONVERSION FACTOR (FRACTION)
CFA : COST OF FARMING PER ACRE ($/ACRE)
COF : COST OF FERTILIZER ($/LB)

DADT : DESIGN AVERAGE DAILY TRAFFIC (TRUCK TRIPS/DAY)
DCPD : DELAY COST PER DAY ($/DAY)
DFR : DEMAND FOR ROADS (MILES)
DFRM : DEMAND FOR ROAD MULTIPLIER (DIMENSIONLESS)
DFRMT : DEMAND FOR ROAD MULTIPLIER TABLE FUNCTION
DIAM : DRAINAGE AND IRRIGATION MULTIPLIER (DIMENSIONLESS)
DIAMT : DRAINAGE AND IRRIGATION MULTIPLIER TABLE FUNCTION
DILD : DELAY IN LAND DEVELOPMENT RATE (YEARS)
DIP : DELAY IN TRUCK PURCHASE TIME (YEARS)
DLPF : DESIRED LAND PER FARMER (ACRES/FARMER)
DNF : DESIRED NUMBER OF FARMERS (FARMERS)
DNT : DESIRED NUMBER OF TRUCKS (TRUCKS)
DNV : DESIRED NUMBER OF VESSELS (VESSELS)
DRD : DESIRED ROAD DENSITY (FRACTION)
DRM : DESIRED ROAD MILES (MILES)

EBADT : EAST BANK AVERAGE DAILY TRAFFIC (TRIPS/DAY)
EBBR : EAST BANK BIRTH RATE (PEOPLE/YEAR)
EBBRN : EAST BANK BIRTH RATE NORMAL (FRACTION)
EBBS : EAST BANK BUSINESS STRUCTURES (BUSINESS)
EBBSC : EAST BANK BUSINESS STRUCTURES CONSTRUCTION (BUSINESS/YEAR)

EBBSCN : EAST BANK BUSINESS STRUCTURES CONSTRUCTION NORMAL
EBBSD : EAST BANK BUSINESS STRUCTURES DETERIORATION (BUSINESS/YEAR)
EBBSDN : EAST BUSINESS STRUCTURES DETERIORATION NORMAL (FRACTION)
EBCLA : EAST BANK CIVIC LAND AREA (ACRES)
EBCLAM : EAST BANK CIVIC LAND AVAILABILITY MULTIPLIER
EBCLAMT : EAST BANK CIVIC LAND MULTIPLIER TABLE FUNCTION
EBCLAN : EAST BANK CIVIC LAND AREA NORMAL (ACRES)
EBCLO : EAST BANK CIVIC LAND FRACTION OCCUPIED (FRACTION)
EBDR : EAST BANK DEATH RATE (PEOPLE/YEAR)
EBDRN : EAST BANK DEATH RATE NORMAL (FRACTION)
EBEET : EAST BANK EXTERNAL EXTERNAL TRIPS (TRIPS/DAY)
EBEETG : EAST BANK EXTERNAL EXTERNAL TRIP GROWTH (TRIPS/DAY)
EBEETGN : EAST BANK EXTERNAL EXTERNAL TRIP GROWTH NORMAL (FRACTION)
EBEIT : EAST BANK EXTERNAL INTERNAL TRIPS (TRIPS/DAY)
EBEITG : EAST BANK EXTERNAL INTERNAL TRIP GROWTH (TRIPS/DAY)
EBEITGN : EAST BANK EXTERNAL INTERNAL TRIP GROWTH NORMAL (FRACTION)
EBH : EAST BANK HOUSES (HOUSES)
EBHC : EAST HOUSING CONSTRUCTION (HOUSES/YEAR)
EBHCN : EAST BANK HOUSING CONSTRUCTION NORMAL (FRACTION)
EBHDR : EAST BANK HOUSING DETERIORATION RATE (HOUSES/YEAR)
EBHDRN : EAST BANK HOUSING DETERIORATION RATE NORMAL (FRACTION)
EBI : EAST BANK INMIGRATION (PEOPLE/YEAR)
EBIENWT : EAST BANK INTERNAL EXTERNAL NON WORK RIPS (TRIPS/DAY)
EBIET : EAST BANK INTERNAL EXTERNAL TRAFFIC (TRIPS/DAY)
EBIEWT : EAST BANK INTERNAL EXTERNAL WORK TRIPS (TRIPS/DAY)
EBJ : EAST BANK JOBS (JOBS)
EBLA : EAST BANK LAND AREA (ACRES)
EBLAM : EAST BANK LAND AVAILABILITY MULTIPLIER (DIMENSIONLESS)
EBLAMT : EAST BANK LAND AVAILABILITY MULTIPLIER TABLE FUNCTION
EBLF : EAST BANK LABOR FORCE (PEOPLE)
EBLFO : EAST BANK LAND FRACTION OCCUPIED (FRACTION)
EBPHF : EAST BANK PEAK HOUR FLOWS (PASSENGER CAR UNITS/HOUR)
EBPOP : EAST BANK POPULATION (PEOPLE)
EBSGLG : EAST BANK SUGAR LAND GROWTH (ACRES/YEAR)
EBSL : EAST BANK SUGAR LAND (ACRES)
EBSLC : EAST SUGAR LAND CONVERSION (ACRES/YEAR)
EBSLCN : EAST BANK SUGAR LAND CONVERSION NORMAL (FRACTION)
EBSLGN : EAST BANK SUGAR LAND GROWTH NORMAL (FRACTION)
EBSMI : EAST BANK SUGAR MANUFACTURING INDUSTRY (INDUSTRIES)
EBSMIG : EAST BANK SUGAR MANUFACTURING INDUSTRY GROWTH
EBSMIGN : EAST BANK SUGAR MANUFACTURING INDUSTRY GROWTH NORMAL
EBSS : EAST BANK SERVICE STRUCTURES (SERVICE STRUCTURES)
EBSSC : EAST BANK SERVICE STRUCTURES CONSTRUCTION (STRUCTURES/YEAR)
EBSSCN : EAST BANK SERVICE STRUCTURE CONSTRUCTION NORMAL (FRACTION)
EBSSD : EAST BANK SERVICE STRUCTURES DETERIORATION RATE (STRUCTURES
EBSSDN : EAST BANK SERVICE STRUCTURES DETERIORATION NORMAL
EBTRT : EAST BANK TRUCK TRIPS (TRIPS/DAY)
EBTRTG : EAST BANK TRUCK TRIP GROWTH (TRIPS/DAY)
EBTRTGN : EAST BANK TRUCK TRIP GROWTH NORMAL (FRACTION)
EBUR : EAST BANK UNEMPLOYMENT RATE (PERCENT)
EBWLA : EAST BANK WHARF LAND AVAILABLE (FEET)
EBWLAM : EAST BANK WHARF LAND AVAILABILITY MULTIPLIER
EBWLAMT : EAST BANK WHARF LAND MULTIPLIER TABLE FUNCTION
EBWLFO : EAST BANK WHARF LAND FRACTION OCCUPIED (FRACTION)
EBWS : EAST BANK WHARF STRUCTURES (WHARFS)
EBWSC : EAST BANK WHARF STRUCTURES CONSTRUCTION (WHARFS/YEAR)
EBWSCN : EAST BANK WHARF STRUCTURES CONSTRUCTION NORMAL (FRACTION)
EBWSD : EAST BANK WHARF STRUCTURES DETERIORATION (WHARF/YEAR)
EBWSDN : EAST BANK WHARF STRUCTURES DETERIORATION NORMAL (FRACTION)
ECADT : EAST COAST AVERAGE DAILY TRAFFIC (TRIPS/DAY)
ECBR : EAST COAST BIRTH RATE (PEOPLE/YEAR)
ECBRN : EAST COAST BIRTH RATE NORMAL (FRACTION)
ECBS : EAST COAST BUSINESS STRUCTURES (BUSINESS STRUCTURES)
ECBSC : EAST COAST BUSINESS STRUCTURES CONSTRUCTION
ECBSCN : EAST BUSINESS STRUCTURES CONSTRUCTION NORMAL (FRACTION)
ECBSD : EAST COAST BUSINESS STRUCTURES DETERIORATION
ECBSDN : EAST COAST BUSINESS STRUCTURES DETERIORATION NORMAL

ECCLA : EAST COAST CIVIC LAND AREA (ACRES)
ECCLA : EAST COAST CIVIC LAND AREA (ACRES)
ECCLAM : EAST COAST CIVIC LAND AVAILABILITY MULTIPLIER
ECCLAMT : EAST COAST CIVIC LAND AVAILABILITY MULTIPLIER TABLE
ECCLAN : EAST COAST CIVIC LAND AREA NORMAL (ACRES)
ECCLFO : EAST COAST CIVIC LAND FRACTION OCCUPIED (FRACTION)
ECCLO : EAST CIVIC LAND FRACTION OCCUPIED (FRACTION)
ECDR : EAST COAST DEATH RATE (PEOPLE/YEAR)
ECDRN : EAST COAST DEATH RATE NORMAL (FRACTION)
ECEET ; EAST COAST EXTERNAL EXTERNAL TRIPS (TRIPS/DAY)
ECEETG : EAST COAST EXTERNAL EXTERNAL TRIPS GROWTH (TRIPS/DAY)
ECEETGN : EAST COAST EXTERNAL EXTERNAL TRIPS GROWTH NORMAL
ECEIT : EAST COAST EXTERNAL INTERNAL TRIPS (TRIPS/DAY)
ECEITG : EAST COAST EXTERNAL INTERNAL TRIPS (TRIPS/DAY)
ECEITGN : EAST COAST EXTERNAL INTERNAL TRIPS GROWTH NORMAL
ECH : EAST COAST HOUSES (HOUSES)
ECHC : EAST COAST HOUSING CONSTRUCTION (HOUSES/YEAR)
ECHCN : EAST COAST HOUSING CONSTRUCTION NORMAL (FRACTION)
ECHDR : EAST COAST HOUSING DETERIORATION (HOUSES/YEAR)
ECHDRN : EAST COAST HOSING DETERIORATION NORMAL (FRACTION)
ECI : EAST COAST INMIGRATION (PEOPLE/YEAR)
ECIENWT : EAST COAST INTERNAL EXTERNAL NON WORK TRIPS (TRIPS/DAY)
ECIET : EAST COAST INTERNAL EXTERNAL TRAFFIC (TRIPS/DAY)
ECIEWT : EAST COAST INTERNAL EXTERNAL WORK TRIPS (TRIPS/DAY)
ECJ : EAST COAST JOBS (JOBS)
ECLAM : EAST COAST LAND AVAILABILITY MULTIPLIER (DIMENSIONLESS)
ECLAMT : EAST COAST LAND AVAILABILITY MULTIPLIER TABLE FUNCTION
ECLF : EAST COAST LABOR FORCE (PEOPLE)
ECOCL : EAST COAST OTHER CROP LAND (ACRES)
ECOCLG : EAST COAST OTHER CROP LAND GROWTH (ACRES/YEAR)
ECOCLGN : EAST COAST OTHER CROP LAND GROWTH NORMAL (FRACTION)
ECPHF : EAST COAST PEAK HOUR FLOW (TRIPS/HOUR)
ECPOP : EAST COAST POPULATION (PEOPLE)
ECSL : EAST COAST SUGAR LAND (ACRES)
ECSLC : EAST COAST SUGAR LAND CONVERSION (ACRES/YEAR)
ECSLCN : EAST COAST SUGAR LAND CONVERSION NORMAL (FRACTION)
ECSLG : EAST COAST SUGAR LAND GROWTH (ACRES/YEAR)
ECSLGN : EAST COAST SUGAR LAND GROWTH NORMAL (FRACTION)
ECSMI : EAST COAST SUGAR MANUFACTURING INDUSTRY (INDUSTRIES)
ECSMIG : EAST COAST SUGAR MANUFACTURING INDUSTRY GROWTH
ECSMIGN : EAST COAST SUGAR MANUFACTURING INDUSTRY GROWTH NORMAL
ECSS : EAST CCOAST SERVICE STRUCTURES (SERVICE STRUCTURES)
ECSSC : EAST COAST SERVICE STRUCTURES CONSTRUCTION (STRUCTURES/YEAR
ECSSCN : EAST COAST SERVICE STRUCTURES CONSTRUCTION NORMAL
ECSSD : EAST COAST SERVICE STRUCTURES DETERIORATION
ECSSDN : EAST COAST SERVICE STRUCTURES DETERIORATION NORMAL
ECTRT : EAST COAST TRUCK TRIPS (TRIPS/DAY)
ECTRTG : EAST COAST TRUCK TRIPS GROWTH (TRIPS/DAY)
ECTRTGN : EAST COAST TRRUCK TRIPS GROWTH NORMAL (FRACTION)
ECUR : EAST COAST UNEMPLOYMENT RATE (PERCENT)
EPPA : EXPECTED PROFIT PER ACRE ($/ACRE)
ERD : EFFECTIVE ROAD DENSITY (FRACTION)
ERDM : EFFECTIVE ROAD DENSITY MULTIPLIER (DIMENSIONLESS)
ERDMT : EFFECTIVE ROAD DENSITY MULTIPLIER TABLE FUNCTION
EROAD : EFFECTIVE ROAD (MILES)
ETARM : EFFECTIVE TO ACTUAL ROAD MULTIPLIER (DIMENSIONLESS)
ETARMT : EFFECTIVE TO ACTUAL ROAD MULTIPLIER TABLE FUNCTION
ETARR : EFFECTIVE TO ACTUAL ROAD RATIO (FRACTION)
ETT : EFFECTIVE TRAVEL TIME (HOURS/TRIP)

FAM : FARMERS AVAILABILITY MULTIPLIER (DIMENSIONLESS)
FAMT : FARMERS AVAILABILITY MULTIPLIER TABLE FUNCTION
FCOT : FARMING COST OF TRANSPORT ($/ACRE)
FEAM : FERTILIZER AVAILABILITY MULTIPLIER (DIMENSIONLESS)
FEAMT : FERTILIZER AVAILABILITY MULTIPLIER TABLE FUNCTION
FI : FERTILIZER INPUT (LBS/ACRE)
FLM : FARMERS LEAVING MULTIPLIER (DIMENSIONLESS)

FLMT : FARMERS LEAVING RATE MULTIPLIER TABLE FUNCTION
FLN : FARMERS LEAVING RATE NORMAL (FRACTION)
FLR : FARMERS LEAVING RATE (FARMERS/YEAR)
FN : FERTILIZER INPUT NORMAL (LBS/ACRE)
FPFC : FRACTION FOR CONSTRUCTION (FRACTION)
FTCN : FARMING COST OF TRANSPORT NORMAL ($/ACRE)
FTLR : FARMERS TO LAND RATIO (FRACTION)
FTNIR : FARMERS TO NATIONAL URBAN INCOME (RATIO)

GTBR : GEORGETOWN BIRTH RATE (PEOPLE/YEAR)
GTBRN : GEORGETOWN BIRTH RATE NORMAL (FRACTION)
GTBS : GEORGETOWN BUSINESS STRUCTURES (STRUCTURES)
GTBSC : GEORGETOWN BUSINESS STRUCTURES CONSTRUCTION
GTBSCN : GEORGETOWN BUSINESS STRUCTURES CONSTRUCTION NORMAL
GTBSD : GEORGETOWN BUSINESS STRUCTURES DETERIORATION
GTBSDN : GEORGETOWN BUSINESS STRUCTURES DETERIORATION NORMAL
GTCLAM : GEORGETOWN CIVIC LAND AVAILABILITY MULTIPLIER
GTCLAMT : GEORGETOWN CIVIC LAND AVAILABILITY TABLE FUNCTION
GTCLAN : GEORGETOWN CIVIC LAND AREA NORMAL (ACRES)
GTCLO : GEORGETOWN CIVIC LAND FRACTION OCCUPIED (FRACTION)
GTDR : GEORGETOWN DEATH RATE (PEOPLE/YEAR)
GTDRN : GEORGETOWN DEATH RATE NORMAL (FRACTION)
GTH : GEORGETOWN HOUSES (HOUSES)
GTHC : GEORGETOWN HOUSING CONSTRUCTION (HOUSES/YEAR)
GTHCN : GEORGETOWN HOUSING CONSTRUCTION NORMAL (FRACTION)
GTHDR : GEORGETOWN HOUSING DETERIORATION RATE (HOUSES/YEAR)
GTHDRN : GEORGETOWN HOUSING DETERIORATION RATE NORMAL(FRACTION)
GTI : GEORGETOWN INMIGRATION (PEOPLE/YEAR)
GTJ : GEORGETOWN JOBS (JOBS)
GTLF : GEORGETOWN LABOR FORCE (PEOPLE)
GTLPBS : GEORGETOWN LAND PER BUSINESS STRUCTURE (ACRE/BUSINESS)
GTLPH : GEORGETOWN LAND PER HOUSE (ACRE/HOUSE)
GTLPSS : GEORGETOWN LAND PER SERVICE STRUCTURE
GTLPW : GEORGETOWN LAND PER WHARF (FEET)
GTO : GEORGETOWN OUTMIGRATION (PEOPLE/YEAR)
GTON : GEORGETOWN OUTMIGRATION NORMAL (FRACTION)
GTPOP : GEORGETOWN POPULATION (PEOPLE)
GTSS : GEORGETOWN SERVICE STRUCTURES (STRUCTURES)
GTSSC : GEORGETOWN SERVICE STRUCTURES CONSTRUCTION (STRUCTURES/YEAR
GTSSCN : GEORGETOWN SERVICE STRUCTURES CONSTRUCTION NORMAL
GTSSD : GEORGETOWN SERVICE STRUCTURES DETERIORATION
GTUR : GEORGETOWN UNEMPLOYMENT RATE (PERCENT)
GTURRUR : GEORGETOWN TO RURAL UNEMPLOYMENT RATIO (FRACTION)
GTWLA : GEORGETOWN WHARF LAND AVAILABLE (FEET)
GTWLAM : GEORGETOWN WHARF LAND AVAILABILITY MULTIPLIER
GTWLAMT : GEORGETOWN WHARF LAND MULTIPLIER TABLE FUNCTION
GTWLFO : GEORGETOWN WHARF LAND FRACTION OCCUPIED (FRACTION)
GTWS : GEORGETOWN WHARF STRUCTURES (WHARFS)
GTWSC : GEORGETOWN WHARF STRUCTURES CONSTRUCTION (WHARFS/YEAR)
GTWSCN : GEORGETOWN WHARF STRUCTURES CONSTRUCTION NORMAL (FRACTION)
GTWSD : GEORGETOWN WHARF STRUCTURES DETERIORATION (WHARFS/YEAR)
GTWSDN : GERGETOWN WHARF STRUCTURES DETERIORATION NORMAL (FRACTION)

HAT : HARVESTER ACQUISITION TIME (YEARS)
HM : HUSBANDRY MULTIPLIER (DIMENSIONLESS)
HMT : HUSBANDRY MULTIPLIER TABLE FUNCTION
HPP : HARVEST PEAK PERIOD (DAYS)
HV: HARVESTERS
HVDR : HARVESTER DEPRECIATION RATE (HARVESTERS/YEAR)
HVDRN : HARVESTER DEPRECIATION NORMAL (FRACTION)
HVPR ; HARVESTER PURCHASE RATE (HARVESTERS/YEAR)

IFFM : INFLUENCE FROM FARMERS MULTIPLIER (DIMENSIONLESS)
IFFMT : INFLUENCE FROM FARMERS MULTIPLIER TABLE FUNCTION)
IGED : INITIAL GRID DISTANCE (MILES)
IWA : IRRIGATION WATER AVAILABLE (ACRE-FEET)

JFRCM : JOBS FROM ROAD CONSTRUCTION (JOBS/MILE OF CONSTRUCTION)
JPA : JOBS PER ACRE (JOBS/ACRE RICE LAND)
JPBS : JOBS PER BUSINESS STRUCTURES (JOBS/BUSINESS)
JPEBSMI : JOBS PER EAST BANK SUGAR MANUFACTURING INDUSTRY
JPEBWS : JOBS PER EAST BANK WHARF STRUCTURES (JOBS/WHARF)
JPECBS : JOBS PER EAST COAST BUSINESS STRUCTURES (JOBS/STRUCTURES)
JPECOCL : JOBS PER EAST COAST OTHER CROP LAND (JOBS/ACRE)
JPECSMI : JOBS PER SUGAR MANUFACTURING INDUSTRY (JOBS/INDUSTRY)
JPGBS : JOBS PER BUSINESS STRUCTURE (JOBS/BUSINESS)
JPGSS : JOBS PER SERVICE STRUCTURE (JOBS/SERVICE STRUCTURE)
JPGTWS : JOBS PER WHARF (JOBS/WHARF)
JPOCL : JOBS PER OTHER CROP LAND (JOBS/ACRE)
JPRL : JOBS PER RICE LAND (JOBS/ACRE)
JPSL : JOBS PER SUGAR LAND (JOBS/ACRE)
JPSS : JOBS PER SERVICE STRUCTURES (JOBS/SERVICE STRUCTURES)
JPWDSMI : JOBS PER WEST DEMERARA SUGAR MANUFACTURING INDUSTRY

LFPF : LABOR FORCE PARTICIPATION FRACTION (FRACTION)
LFPR : LABOR FORCE PARTICIPATION RATE (FRACTION)
LPBS : LAND PER BUSINESS STRUCTURES (ACRE/BUSINESS)
LPEBWS : LAND PER EAST BANK WHARF STRUCTURES (FEET)
LPH : LAND PER HOUSE (ACRE/HOUSE)
LPRH : LAND PER RURAL HOUSE (ACRES/HOUSE)
LPSMI : LAND PER SUGAR MANUFACTURING INDUSTRY (ACRES/SUGAR INDUSTRY
LPSS : LAND PER SERVICE STRUCTURES (ACRES/SERVICE STRUCTURES)
LPTR : LAND PER TRACTOR (ACRES)

MCPM : MAINTENANCE COST PER MILE ($/MILE)
MFPM : MAINTENANCE FUND PER MILE ($/MILE)
MIM : MECHANIZATION MULTIPLIER (DIMENSIONLESS)

NF : NEW FARMERS (FARMERS)
NLDA : NORMAL LABOR COST PER ACRE ($/ACRE)
NMICA : NORMAL MECHANICAL INPUT COST ($/ACRE)
NPH : NUMBER OF PERSONS PER HOUSE (PEOPLE/HOUSE)
NRCA : NORMAL LAND RENTAL COST ($/ACRE)
NUR : NATIONAL UNEMPLOYMENT RATE (PERCENT)

OFLC : OFFLOADING COST PER TON ($/TON)
OFLT : OFFLOADING TIME (DAYS)
ONLC : ONLOADING COST PER TON ($/TON)
ONLT : ONLOADING TIME (DAYS)

PA : PERCENT BY AUTO (FRACTION)
PB : PERCENTAGE BY BUS (FRACTION)
PFRM ; PROFIT FROM RICE FARMING MULTIPLIER (DIMENSIONLESS)
PFRMT : PROFIT FROM RICE FARMING MULTIPLIER TABLE FUNCTION
PH : PERSON PER HOUSE (PEOPLE/HOUSE)
PHP : PEAK HARVEST PERIOD (DAYS)
PLPT : PAYLOAD PER TRUCK (TONS/TRUCK)
PLPV : PAY LOAD PER VESSEL (TONS/VESSEL)
PPA : PROFIT PER ACRE ($/ACRE)
PPH : PERCENT PER PEAK HOUR (FRACTION)

QDCT : QUEUE DELAY COST PER TON ($/TON)
QDM : QUEUE DELAY MULTIPLIER (DIMENSIONLESS)
QDMT : QUEUE DELAY MULTIPLIER TABLE FUNCTION
QDPV : QUEUE DELAY VESSELS MULTIPLIER (DIMENSIONLESS)
QDPVT : QUEUE DELAY VESSELS MULTIPLIER TABLE FUNCTION
QTW : QUANTITY TO BE TRANSPORTED BY WATER (TONS/CROP)

RAMLD : ROAD ACCESSIBILITY MULTIPLIER (DIMENSIONLESS)
RAMLDT : ROAD ACCESSIBILITY ON LAND DEVELOPMENT TABLE FUNCTION
RBR : RURAL BIRTH RATE (PEOPLE/YEAR)
RBRN : RURAL BIRTH RATE NORMAL (FRACTION)
RCB : ROAD CONSTRUCTION BUDGET ($)
RCE : ROAD CONSTRUCTION EXPENSES ($)

RCPC : RICE CONSUMPTION PER CAPITA (TONS/PERSON)
RCR : ROAD CONSTRUCTION RATE (MILES/YEAR)
RCT : ROAD CONSTRUCTION TIME (YEAR)
RDFLO : ROAD LAND FRACTION OCCUPIED (FRACTION)
RDLA : ROAD LAND AVAILABLE (ACRES)
RDR : RURAL DEATH RATE (PEOPLE/YEAR)
RDRN : RURAL DEATH RATE NORMAL (FRACTION)
RER : ROAD EXPENSES ($)
RF : RURAL FUND ($)
RFAT : REGIONAL FRACTION OF AGRICULTURAL TECHNICIANS (FRACTION)
RFD : RICE FOR DISTRIBUTION (TONS)
RFMR : RICE FARMERS (FARMERS)
RFN : ROAD FUND NORMAL ($)
RFR : ROAD FUNDING RATE ($/YEAR)
RFRN : ROAD FUNDING RATE NORMAL (FRACTION)
RH : RURAL HOUSES (HOUSES)
RHC : RURAL HOUSING CONSTRUCTION (HOUSES/YEAR)
RHCM : RURAL HOUSING CONSTRUCTION MULTIPLIER (DIMENSIONLESS)
RHCMT : RURAL HOUSING CONSTRUCTION MULTIPLIER TABLE FUNCTION
RHCN : RURAL HOUSING CONSTRUCTION NORMAL (FRACTION)
RHD : RURAL HOUSES DETERIORATION (HOUSES/YEAR)
RHDN : RURAL HOUSES DETERIORATION NORMAL (FRACTION)
RHHR : RURAL HOUSEHOLDS TO HOUSES RATIO (FRACTION)
RL : RICE LAND (ACRES)
RLA : RURAL LAND AREA (ACRES)
RLCM : RICE LAND CONVERSION MULTIPLIER (DIMENSIONLESS)
RLCMT : RICE LAND CONVERSION MULTIPLIER TABLE FUNCTION
RLCR : RICE LAND CONVERSION RATE (ACRES/YEAR)
RLCRN : RICE LAND CONVERSION RATE NORMAL (FRACTION)
RLDM : RICE LAND DEVELOPMENT MULTIPLIER (DIMENSIONLESS)
RLDR : RICE LAND DEVELOPMENT RATE (ACRES/YEAR)
RLF : RURAL LABOR FORCE (PEOPLE)
RLFO : RURAL LAND FRACTION OCCUPIED (FRACTION)
RLHR : RICE TO HARVESTER RATIO (FRACTION)
RLHRM ; RICE TO HARVESTER MULTIPLIER (DIMENSIONLESS)
RLHRMT : RICE LAND TO HARVESTER MULTIPLIER TABLE FUNCTION
RLI: LIMIT OF IRRIGATION AREA (ACRES)
RLTWR : RICE LAND TO WATER RATIO (FRACTION)
RM : RURAL MIGRATION (PEOPLE/YEAR)
RMB : ROAD MAINTENANCE BUDGET ($)
RME : ROAD MAINTENANCE EXPENSES ($)
RMM : ROAD MAINTENANCE MULTIPLIER (DIMENSIONLESS)
RMMT : ROAD MAINTENANCE MULTIPLIER TABLE FUNCTION
RP : RURAL POPULATION (PEOPLE)
RPPF : RURAL POPULATION PARTICIPATION FRACTION (FRACTION)
RRDR : ROAD DETERIORATION RATE (MILES/YEAR)
RRLAM : ROAD LAND AVAILABILITY MULTIPLIER (DIMENSIONLESS)
RRLAMT : ROAD LAND AVAILABILITY MULTIPLIER (DIMENSIONLESS)
RROAD : RURAL ROAD (MILES)
RTC : ROAD TRANSPORT CAPACITY (TONS/CROP)
RTMC : ROAD TRANSPORT MODE COST ($/TON)
RTMCN : ROAD TRANSPORT MODE COST NORMAL ($/TON)
RTWCR : ROAD TO WATER TRANSPORT COSTS RATIO MULTIPLIER
RTWCRT : ROAD TO WATER COSTS MULTIPLIER TABLE FUNCTION
RUR : RURAL UNEMPLOYMENT RATE (PERCENT)
RURM : RURAL UNEMPLOYMENT MULTIPLIER (DIMENSIONLESS)
RURMT : RURAL UNEMPLOYMENT MULTIPLIER TABLE FUNCTION

SPT : SELLING PRICE OF UNMILLED RICE PER TON ($/TON)

TDN TRUCK DEPRECIATION NORMAL (FRACTION)
TDR : TRUCK DEPRECIATION RATE (TRUCKS/YEAR)
TDRM : TRUCK DEPRECIATION RATE MULTIPLIER (DIMENSIONLESS)
TDRMT : TRUCK DEPRECIATION RATE MULTIPLIER TABLE FUNCTION
TE : TRUCK EQUIVALENT (PASSENGER CAR UNITS/TRUCK)
TPJ : TRIPS PER JOB (DAILY TRIPS/JOB)
TPP : TRIPS PER POPULATION (DAILY TRIPS/PERSON)

TPR : TRUCK PURCHASE RATE (TRUCK/YEAR)
TPV : TRIPS PER VESSEL (TRIPS/VESSEL/CROP)
TR : TRACTORS
TRDR : TRACTOR DEPRECIATION RATE (TRACTORS/YEAR)
TRDRN : TRACTOR DEPRECIATION RATE NORMAL (FRACTION)
TRPR : TRACTOR PURCHASE RATE (TRACTORS/YEAR)
TRT : TECHNICIAN TRAINING TIME (YEARS)
TRUCK : TRUCKS
TT : TRUCK TRIPS (TRIPS/CROP)
TTC : TRAVEL TIME COST PER TON ($/TON)
TTM : TRUCK TRAFFIC MULTIPLIER (DIMENSIONLESS)
TTMT : TRUCK TRAFFIC MULTIPLIER TABLE FUNCTION
TTPD : TRUCK TRIPS PER DAY (TRIPS/DAY)

UFGTJ : UNFILLED GEORGETOWN JOBS (JOBS)
UH : URBAN HOUSES (HOUSES)
UHHR : URBAN HOUSEHOLDS TO HOUSES RATIO (FRACTION)
UI : URBAN INMIGRATION (PEOPLE/YEAR)
UIM : URBAN INMIGRATION MULTIPLIER (DIMENSIONLESS)
UIMT : URBAN INMIGRATION MULTIPLIER TABLE FUNCTION
UIN : URBAN INMIGRATION NORMAL (FRACTION)
UJ : URBAN JOBS (JOBS)
ULF : URBAN LABOR FORCE (PEOPLE)
ULFAM : URBAN LABOR FORCE AVAILABILITY MULTIPLIER (DIMENSIONLESS)
ULFAMT : URBAN LABOR FORCE AVAILABILITY MULTIPLIER TABLE FUNCTION
ULFTJR : URBAN LABOR FORCE TO JOBS RATIO (FRACTION)
UMRL : UNMILLED RICE LOSS (TONS/CROP)
UMRPR : UNMILLED RICE PRODUCTION RATE (TONS/CROP)
UMRTR : UNMILLED RICE TRANSPORT RATE (TONS/CROP)
UPOP : URBAN POPULATION (PEOPLE)
UUR : URBAN UNEMPLOYMENT RATE (PERCENT)

VAT : VESSEL ACQUISITION TIME (YEARS)
VCPD : VESSEL COST PER DAY ($/DAY)
VDESR : VESSEL DETERIORATION RATE (VESSELS/YEAR)
VDESRN : VESSEL DETERIORATION RATE NORMAL (FRACTION)
VIS : VESSELS
VPR : VESSEL PURCHASE RATE (VESSELS/YEAR)

WDADT : WEST DEMERARA AVERAGE DAILY TRAFFIC (TRIPS/DAY)
WDBR : WEST DEMERARA BIRTH RATE (PEOPLE/YEAR)
WDBRN : WEST DEMERARA BIRTH RATE NORMAL (FRACTION)
WDBS : WEST DEMERARA BUSINESS STRUCTURES (BUSINESS)
WDBSC : WEST DEMERARA BUSINESS STRUCTURES CONSTRUCTION
WDBSCN : WEST DEMERARA BUSINESS STRUCTURES CONSTRUCTION NORMAL
WDBSD : WEST DEMERARA BUSINESS STRUCTURES DETERIORATION
WDBSDN : WEST DEMERARA BUSINESS STRUCTURES DETERIORATION NORMAL
WDCLA : WEST DEMERARA LAND AREA (ACRES)
WDCLAM : WEST DEMERARA CIVIC LAND AREA AVAILABILITY MULTIPLIER
WDCLAMT : WEST DEMERARA CIVIC LAND AREA MULTIPLIER TABLE FUNCTION
WDCLAN : WEST DEMERARA CIVIC LAND AREA NORMAL (ACRES)
WDCLO : WEST DEMERARA CIVIC LAND FRACTION OCCCUPIED (FRACTION)
WDDR : WEST DEMERARA DEATH RATE (PEOPLE/YEAR)
WDDRN : WEST DEMERARA DEATH RATE NORMAL (FRACTION)
WDEET : WEST DEMERARA EXTERNAL EXTERNAL TRIPS (TRIPS/DAY)
WDEETG : WEST DEMERARA EXTERNAL EXTERNAL TRIPS GROWTH (TRIPS/DAY)
WDEETGN : WEST DEMERARA EXTERNAL EXTERNAL TRIPS GROWTH NORMAL
WDH : WEST DEMERARA HOUSES (HOUSES)
WDHC : WEST DEMERARA HOUSING CONSTRUCTION (HOUSES/YEAR)
WDHCN : WEST DEMERARA HOUSING CONSTRUCTION NORMAL (FRACTION)
WDHDR : WEST DEMERARA HOUSING DETERIORATION RATE (HOUSES/YEAR)
WDHDRN : WEST DEMERARA HOUSING DETERIORATION RATE NORMAL (FRACTION)
WDIENWT : WEST DEMERARA INTERNAL EXTERNAL NON WORK TRIPS (TRIPS/DAY
WDIET : WEST DEMERARA INTERNAL EXTERNAL TRAFFIC (TRIPS/DAY)
WDIEWT : WEST DEMERARA INTERNAL EXTERNAL WORK TRIPS
WDJ : WEST DEMERARA JOBS (JOBS)
WDLA : WEST DEMERARA LAND AREA (ACRES)

WDLAM : WEST DEMERARA LAND AVAILABILITY MULTIPLIER (DIMENSIONLESS)
WDLAMT : WEST DEMERARA LAND AVAILABILITY MULTIPLIER TABLE FUNCTION
WDLF : WEST DEMERARA LABOR FORCE (PEOPLE)
WDLFO : WEST DEMERARA LAND FRACTION OCCUPIED (FRACTION)
WDOCL : WEST DEMERARA OTHER CROP LAND (ACRES)
WDOCLG : WEST DEMERARA OTHER CROP LAND GROWTH (ACRES/YEAR)
WDOCLGN : WEST DEMERARA OTHER CROP LAND GROWTH NORMAL (FRACTION)
WDPHF : WEST DEMERARA PEAK HOUR FLOW (TRIPS/HOUR)
WDPOP : WEST DEMERARA POPULATION (PEOPLE)
WDRL : WEST DEMERARA RICE LAND (ACRES)
WDRLG : WEST DEMERARA RICE LAND GROWTH (ACRES/YEAR)
WDRLGN : WEST DEMERARA RICE LAND GROWTH NORMAL (FRACTION)
WDSL : WEST DEMERARA SUGAR LAND (ACRES)
WDSLC : WEST DEMERARA SUGAR LAND CONVERSION (ACRES/YEAR)
WDSLCN : WEST DEMERARA SUGAR LAND CONVERSION NORMAL (FRACTION)
WDSLG : WEST DEMERARA SUGAR LAND GROWTH (ACRES/YEAR)
WDSLGN : WEST DEMERARA SUGAR LAND GROWTH NORMAL (FRACTION)
WDSMI : WEST DEMERARA SUGAR MANUFACTURING INDUSTRY (INDUSTRIES)
WDSMIG : WEST DEMERARA SUGAR MANUFACTURING INDUSTRY GROWTH
WDSMIGN : WEST DEMERARA SUGAR MANUACTURING INDUSTRY GROWTH NORMAL
WDSS : WEST DEMERARA SERVICE STRUCTURES (SERVICE STRUCTURES)
WDSSC : WEST DEMERARA SERVICE STRUCTURES CONSTRUCTION
WDSSCN ; WEST DEMERARA SERVICE STRUCTURES CONSTRUCTION NORMAL
WDSSD : WEST DEMERARA SERVICE STRUCTURES DETERIORATION
WDSSDN : WEST DEMERARA SERVICE STRUCTURES DETERIORATION NORMAL
WDTRT : WEST DEMERARA TRUCK TRAFFIC (TRIPS/DAY)
WDTRTG : WEST DEMERARA TRUCK TRIPS GROWTH (TRIPS/DAY)
WDTRTGN : WEST DEMERARA TRUCK TRIPS GROWTH NORMAL (FRACTION)
WDUR : WEST DEMERARA UNEMPLOYMENT RATE (PERCENT)
WRPA : WATER REQUIREMENT PER ACRE (ACRE-FEET/ACRE)
WTCPR : WATER TRANSPORT CAPACITY PER ROUTE (TONS/CROP)
WTCT : WATER TRANSPORT COST PER TON ($/TON)
WTR : WATER TRANSPORT RATE (TONS/CROP)

YPA : YIELD PER ACRE (TONS/ACRE)
YPAN : YIELD PER ACRE NORMAL (TONS/ACRE)

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A SYSTEM DYNAMICS APPROACH TO RURAL TRANSPORTATION PLANNING IN LESS DEVELOPED COUNTRIES

By

Gowkarran Budhu

(ABSTRACT)

Transportation is not merely a derived demand, but a determinant of new production possibilities. In developing economies, where the lack of mobility is self-evident, it is absolutely necessary to consider the catalytic impacts of transport services. Transportation not only directly affects the overall output in an economy through accessibility and costs, but also stimulates and influences the shift in the demographic sector in terms of population movements and unemployment rates. To successfully plan for the development of a region, one must understand the possible causal relationships, feedbacks and interactions between the different sectors of both the investment region and the possible spatially impacted region.

In this study, the impacts of three investment strategies for the Essequibo Coast region, in Guyana, are evaluated through the use of a computer simulation and system dynamics methodology. The model consists of two regions -- the region in which investment is provided and the region that is spatially impacted due to this investment. The hypothesized interrelationships of the main sectors (demographic, economic and transport) and components of each region were first developed as causal submodels. Secondly, the submodels were synthesized to form a compre-

hensive system dynamics computer model represented by approximately 280 equations to evaluate the three strategies: (1) Do Nothing; (2) Investments in Roads Only; and (3) Investment in Roads, Drainage and Irrigation.

Sensitivity analyses were performed on the key socio-economic variables (Drainage, Irrigation, Fertilizer, Mechanization and Regional Migration) to determine which variables most significantly influence regional behavior. These tests showed that a tacit acceptance (i.e., not explicitly incorporating the above factors in a model) of the availability of these resources overstates the impacts due to transport investments -- i.e., roads equal development is also a misconception.

The investment strategy in Roads, Drainage and Irrigation provided the greatest net benefits and most favorable socio-economic characteristics in terms of population level, regional income per capita, outmigration and unemployment. So, given its financial feasibility, it is recommended for implementation. Further, it is also suggested, because of the model's demonstrable flexibility, that it be used for post-investment analyses and future model calibration.