Indirect and Spatial Impacts of Transportation Investment in a Less-Developed Country

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The overall impacts, especially indirect and spatial impacts, are rarely incorporated explicitly and evaluated quantitatively in transportation planning methodologies used in less developed countries. Such planning strategies that are used have resulted in an overemphasis of high-volume facilities to the detriment not only to the growth of rural regions but also to unwanted urban inmigration. In this study an attempt is made through the methodology of system dynamics to explicitly account for the diffused impacts of a given investment policy on the rural region itself and on the nation as a whole (i.e., in terms of shifts in population). Guyana is used for the case study to evaluate the impacts of three investment alternatives: (a) do nothing, (b) investment in roads only, and (c) investment in roads, drainage, and irrigation. The traditional economic analyses of net present worth and benefits/costs ratio are undertaken. However, the additional time-series information on production, income, unemployment, and migration provided by the modeling technique allowed for more astute decisionmaking in rural investment projects. The roads, drainage, and irrigation alternative provided the best overall impacts and is therefore recommended for implementation. The expected net present worth of this strategy at 10 percent interest rate is approximately G \$13 million (\$4.3 million U.S.) over a 20-year period. But even more important, it helps to reverse the severe urban inmigration over the analysis period-1980-2000.

In most less-developed countries, the overall impacts, especially indirect and spatial impacts, are rarely and not explicitly incorporated and quantitatively evaluated in their transportation planning models. 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. This strategy has resulted in an overemphasis on high-volume facilities to the detriment not only to the accessibility and growth of the rural agricultural regions but also to unwanted rural outmigration. In addition, the resultant benefits due to high-volume facilities were disappointing (1), 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 that have high unemployment rates and low vehicles per capita.

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 noneconomic impacts (for example, interregional migration and accelerated transfer of know how among others) and (b) transport is only one component (albeit a necessary one) for the development of a region. That is, transport-equal development is a misconception ($\underline{1-4}$).

These findings have resulted in researchers calling for a more comprehensive approach to the evaluation of transport investments. Odier (5), 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 result 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." Harral ($\underline{6}$), of the World Bank, 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.

Specifically then, the direct, indirect, and spatial impacts of transportation and related agricultural investments on the nation's production and shifts in population need to be evaluated if longterm benefits are to be realized. The systemdynamics methodology proposed in this paper has the capability to incorporate explicitly intrasectoral and intersectoral relations and feedback phenomena and thus may specifically address the above needs.

OBJECTIVES OF THE STUDY

There are definite linkages and feedback between the transport sector and the other main socioeconomic sectors in any region, and this feedback is even more pronounced, Hofmeier contends $(\underline{7})$, in poorly accessible agricultural based regions. This study intends to explicitly incorporate the transport activity (variable) in a comprehensive system model and to study the impacts of various investment strategies in transportation and related agricultural inputs on the economy as a whole through the methodology of system dynamics.

Specifically, the objectives are as follows:

1. To develop computer simulation submodels for the main sectors of both the agricultural based region (directly impacted) and the urban region (spatially impacted);

2. To link the submodels to form a comprehensive model, thereby accounting for the intraregional and interregional relations and interactions of the different sectors of the economy; and

3. To apply the model to Guyana, an agricultural based, less-developed country, as a tool for strategic transportation planning to determine primarily the indirect and spatial impacts of proposed investment strategies.

SCOPE AND ORGANIZATION

Conceptually, an agricultural based economy depends on accessibility and mobility; that is, if the desired level of transport is not provided, the economy is likely to stagnate at a subsistance level and produce possible unwanted urban inmigration. Furthermore, a significant portion of a lessdeveloped country's funds, at times, comes from foreign agencies, which request detailed feasibility studies to justify the loans. Thus, the proposed methodology 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 is presented, then the model is calibrated with data from Guyana, and used to evaluate the socioeconomic impacts of three investment strategies both at the rural (or directly impacted) and the urban (or spatially impacted) re-



gional levels. The direct impacts, i.e., road users savings due primarily to traffic flows, will not be considered in the feasibility analysis but will be used to determine the geometric and structural characteristics of the roadway facility to be con-structed. This approach is taken because traffic flow per se is a poor surrogate to determine feasibility in rural development projects. Changes in production and the contribution to national goals are the main determinants of socioeconomic feasibility and implementation. The list below summarizes typical goals, policies, and impacts of a transport investment strategy.

1. Goals--increase rural income and decrease urban inmigration;

2. Policies--do nothing (maintain status quo), invest in transport, or invest in transport, drainage, and irrigation;

3. Direct rural impacts--traffic volumes, travel time, and vehicle depreciation;

4. Indirect rural impacts--production, income, and employment; and

5. Spatial urban impacts--Migration and traffic volumes.

SYSTEM DYNAMICS METHODOLOGY IN PERSPECTIVE

Traditional transportation planning approaches have not seriously attempted to quantify time lags (in the case of construction), feedback, and nonlinear behavior and spatial impacts that are invariably evident after project implementation. The system dynamics approach has the capability of not only using realistic statistical relations (linear and nonlinear) but also of incorporating causalities and feedback relations explicitly.

Ever since the development of system dynamics by Forrester in 1958 (known as industrial dynamics), the methodology has been applied increasingly to a wide range of socioeconomic problems, as documented by Roberts (8). However, except for the work of Drew and others (9), little use has been made of the methodology in the field of transportation planning for rural regions.

The steps involved in undertaking system dynamics analysis are as follows:

- 1. Causal loop diagramming,
- 2. Flow diagramming, and

3. Conversion of the flow diagrams into sets of simultaneous difference equations.

According to the theory of system dynamics, the relation between two variables is positive if both of them vary in the same direction; otherwise it is Usually a dynamic model is composed of negative. many causal relations that often close on themselves to form feedback loops. The significance of a feedback loop is in the behavior that the system exhibits. There are basically two types of behavior pattern that are of interest in a qualitative analysis: explosive and asymptotic. An explosive growth pattern is exhibited by positive feedback structures and an asymptotic growth pattern is normally seen from negative feedback structures. Detailed information on system dynamics can be found in Drew and others (8).

DEVELOPMENT OF CAUSAL MODEL

The hypothesis of the model formulation is that investment is not spatially neutral; that is, decisions taken in any of the regions (rural or urban) 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 impact will depend on the baseline socioeconomic characteristics of the specific country under consideration. That is, in countries where there are significant regional disparities (in terms of job opportunities and incomes), there is a greater likelihood for shifts in population than in countries that have more equitable distributions of development. However, most less-developed countries can be typified as agricultural based or rural economies, in which there are a few or only a single welldeveloped urban center (generally the capital region), and the remainder of the nation experiences different levels of development as measured by population density and socioeconomic infrastructure such as schools, electricity, transportation, drainage, and irrigation. Furthermore, the urbanized centers are generally the attractors of population because of their relatively higher income per capita, better

ages of main sectors of economy.

Table 1. Basic statistics for study region.

Statistic	1970	1975	1980 ^a	1990 ^a
Rural				
Population ^b	30 000- 35 000	NA	30 000- 35 000	NA
Per capita income (G\$) Total arable area (acres)	260 70 000	NA	NA	NA
Cultivated area (acres) Collector and farm roads (miles)	30 000 150	33 000 175	35 000 200	NA NA
Road expenditure (G\$) Urban	600 000	1 250 000	1 500 000	NA
Population Jobs Land area (acres)	396 900 95 514 193 000	NA NA	516 500 133 010	708 800 189 250

Note: G\$3 = \$1 U.S. (1982).

Projected values.

Projected values. Population for rural area given in ranges because of the difficulty in accounting for everyone in poorly accessible regions.

social infrastructure, and perceived greater job prospects.

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. The boundary and the hypothesized socioeconomic characteristics and interactions of the impacted regions are illustrated in Figure 1.

The hypothesis of Figure 1 is that a poorly developed region (as measured by production level, income per capita, unemployment rate, and accessibility) will loose population to more-developed regions of the country, and this migration to urban centers defines the impacted system boundary to be studied.

The simplified block diagram shows the subdivision and main variables of the sectors of the impacted regions that interact dynamically to produce the regional socioeconomic characteristics, such as unemployment rate, jobs, income per capita, and production rate. It also implies that land availability is a constraint on regional growth and output.

The rural region (i.e., the region directly impacted through investments) is conceptualized as having three main sectors. The demographic sector (whose main components are population and housing) affects unemployment (through the labor force) and land availability (through housing), 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.

The objective of the developed model is to investigate a strategy in transport and related investments in rural regions that provides the most beneficial indirect and spatial impacts. Furthermore, spatial impacts were defined as the shift in population due to differences in regional socioeconomic characteristics measured primarily by differences in unemployment rates. Therefore, the main interest in the urban region (i.e., zones to which population is 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 sec-

tor, whose main components are businesses and services, determines the job opportunities of the re-gion. Both sectors impact land availability and traffic generated.

Figure 1 presented the simplified but definite linkages that exists between the major sectors of the economy. The important intersectoral impacts are recognized through the following variables: (a) agricultural land development rate, (b) afterproduction loss, (c) agricultural jobs, (d) urbanto-rural unemployment ratio, and (e) urban inmigration. The first three variables link the sectors of the investment region, and the last two variables link the rural region with the urban region, thus providing explicitly for the spatial impacts.

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

CASE STUDY OF GUYANA

Guyana, a nation in South America, is chosen for the case study because (a) it is typical of lessdeveloped countries in which accessibility is perceived to be a main constraint to accelerated economic growth; (b) large sums of money are annually allocated for the expansion of the transport sector; (c) the nation's professed economic destiny is in the development of the agricultural potentials; and (d) the data on Guyana were available for model validation.

Directly Impacted Rural Region

The area of influence lies between the Essequibo and Pomeroon rivers, which are 40 miles apart. This boundary encompasses a potential arable land area of 70 000 acres. There are 150 miles of collector and dirt farm roads that serve the current 30 000 acres of rice cultivation, which is the main economic activity of the region. During the wet seasons (twice per year), these roads become impassable and seriously affect the rice production and productivity of the region.

Spatially Impacted Urban Region

Georgetown is Guyana's hub. It holds a commanding position in regard to Guyana's social and economic activities. It is Guyana's political and cultural center and will undoubtedly remain the main center of activities for the future. Decisions taken in any region will affect Georgetown and its future socioeconomic 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 and is a net receipient of interregional migration.

The basic information of the two regions is given in Table 1 (10).

System Dynamics Model's Levels and Main Assumptions

The behavior of a system is the outcome of the feedback loops that underlie the structure of the system. Feedback loops govern actions and changes in the system from the simplest to the most complex. A feedback loop is a closed path that connects an action to its effects on the surrounding conditions, and these resulting conditions in turn come back as

Table 2. Hierarchical order of model structure.	Region	Sector	Level	Concept
	Rural, Essequibo Coast ^a	Demographic	Population Housing	Births, deaths, migration, unemployment, and housing demand Depends on population and consumes land
		Agricultural	Rice land cultivated Farmers Drainage and irrigation Tractors and harvesters Road miles Trucks Road fund	Determines productions and jobs; affected by road accessibility Determine cultivation level Affect cultivation intensity and yield Affect cultivation intensity Impacts of accessibility on land development Impacts of transportation on postproduction loss Financial constraint on road development
	Urban, Georgetown ^b	Demographic	Population Housing	Distribution of population to urban zones Growth is constrained by land availability
		Economic	Businesses, services and wharfs	Determine employment and land use
	^a Directly impacted b	v investments.	^b Spatially impacted by m	igration

Table 3. Summary of model's main assumptions.

Multiplier	Influencing Variables	influenced Variables	Direction of Influences	
Urban immigration	Georgetown unemployment rate/rural unemployment rate	Rural migration	+/-	
Rural housing construction	Rural households/houses	Rural housing construction	+	
Agricultural land availability	Rural land fraction occupied	Rice land development rate	+/-	
Farmers availability	Farmers/land areas cultivated	Rice land development rate	+	
Drainage and irrigation	Rice land cultivated/water available	Rice land development rate	-	
Husbandry	Agricultural technicians/farmers	Yield per acre	+	
Mechanization	Rice land/tractor	Rice land development rate	-	
	Rice land/harvester	Yield per acre	-	
Road accessibility	Actual road density/desired road density	Rice land development rate	+	
Road transport cost	Actual road density/desired road density	Farming cost of transport	-	
Fertilizer availability	Fertilizer inputs	Yield per acre	+	
Georgetown civic land availability	Georgetown civic land fraction occupied	Georgetown housing, business, and service structure construction	+/-	
Urban labor force	Labor force/jobs	Georgetown housing, business, and service structure construction	+	

Table 4. Predicted and observed values of rural population, cultivation, and roads.

Variable	1970	1975	1980 ^a	1990 ^a
Population				
Model	35 000	34 500	32 800	36 000
Observed	35 000	35 000	30 000-35 000	NA
Difference (%)		1.5	6-8	
Cultivation				
Model (acres)	30 000	33 100	35 000	44 800
Observed (acres)	30 000	33 000	35 000	NA
Difference (%)		<1	<1	
Roads				
Model (miles)	150	171	198	284
Observed (miles)	150	175	200	NA
Difference (%)		~1	<1	

^aForecast values.

information to influence further actions (<u>11</u>). Two kinds of variables dominate a feedback loop--levels and rates. Levels are the accumulation (integrations) that describe the state or condition of a system at any point in time. Rates are flows that cause the level to change and are generally associated with policies or decisionmaking in the system.

Before the mathematical model of a large and complex socioeconomic system is developed, it is first necessary to understand the behavior of the main components or levels of the system and then to link the components to form a representative model of the system. Table 2 gives a breakdown of the proposed rural transportation planning model (RURTRAN) in terms of (a) the regions represented, (b) the sectors of the regions, (c) the main components or levels that underlie the structure and determine the behavior of the regions, and (d) the concepts and hypothesized phenomena represented by the main components or levels.

Twelve levels have been chosen to develop the rural region (i.e., the directly impacted investment region), and five levels to represent the urban region (i.e., the spatially impacted region). The comprehensive model has a total of 277 simultaneous difference equations and its main assumptions are illustrated in Table 3.

Model Calibration

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

Calibration was attempted as follows: a set of variables (over a 10-year period) whose characteristics more or less determine the regional behavior were compared with the simulation output for the same period. Table 4 compares the model values and the observed values (data) for population, cultivation, and road miles. The differences between predicted and observed values are less than 10 percent and thus the model is accepted as adequately realistic.

Analyses of Alternative Investment Strategies

The traditional analyses that use benefits/costs and net present worth value will be undertaken because, for all intent and purpose, quantification in monetary terms is still the single-most desirable and used indicator of the impacts of the investments. But benefits from production instead of traffic

Table 5. Results of economic analyses of three strategies.

Strategy	Present Wort	h (G\$)			
	Costs				
	Roads	Drainage and 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, and irrigation	23 739 400	17 868 400	55 121 500	13 513 700 ^a	1.32 ^a

Notes: G\$3 = \$1 U.S. (1982).

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

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

flows are evaluated for the given outlay. However, recognize also that the estimates of output are not based only on marginal reduction in transport costs. The development project, which embodies a variety of factors, is instead 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 the project, a set of socioeconomic characteristics are used in the evaluation process. Final evaluation is based on the following factors:

 At the rural regional level--impacts on production and productivity; population, jobs, and unemployment rate; and per capita income.

2. At the urban regional level--impacts on urban inmigration (i.e., spatial impacts).

The following alternatives were analyzed.

Do Nothing

In a real-world scenario, nations never really completely neglect their rural regions. Whereas the desired level of investment may not be forthcoming, cognizance is taken of the contribution of these rural regions to the national economy. Funds are generally allocated to at least maintain the status quo and in some cases to also provide for minimum expansion of the economic infrastructure. The Essequibo Coast (i.e., the rural region in the study) falls in the category of receiving some funding every year, as shown in Table 1, and an average of \$1 million Guyana/year for funding was used for this scenario (note G \$3 = \$1 U.S.). Further, a mile of new road was estimated at G \$100 000 and G \$5000/mile for routine annual maintenance. For this alternative the calibrated model was simply simulated for 20 years to year 2000, and the output was analyzed.

Investment in Roads

Roads influence the intensiveness and extensiveness of socioeconomic activities in Guyana. Accessibility by roads is, therefore, perceived as the main bottleneck to the expansion of the agricultural base of the region. A sum of G \$20 million was assumed for road funds and the model was simulated to the year 2000.

Investments in Roads, Drainage, and Irrigation

There is no doubt that road is the main catalyst to the initial expansion of an agricultural region, but sustained and continued growth and productivity depend on other inputs of which dependable drainage and irrigation may be equally as important as roads. Simply put, dependable drainage and irrigation not only complement the farming infrastructure but maximize the benefits derived from improved access due to roads.

In this case the only modification made to the roads only alternative was the removal of the drainage and irrigation constraints and incorporation of the time lag needed to construct the increased drainage and irrigation capacity.

Analyses of the Outputs of the Three Investment Alternatives

Table 5 summarizes the results of the economic analyses (i.e., the impacts on product only) of the three investment strategies. All of the alternatives satisfy the feasibility criteria of net present worth and benefits/costs ratio. The do nothing performs best on benefit/cost ratio and roads, drainage, and irrigation performs best on the net present worth concept.

Analyses of Other Indirect Impacts

Table 6 provides a summary of the information on the main regional socioeconomic indicators at steady state (i.e., that point in time when the rural region's output stabilizes or further growth in production depends on inputs other than land area farmed or such economic infrastructure as roads, drainage, and irrigation). A close examination of Table 6 reveals the following impacts.

Within 10 and 13 years, respectively, the roads, drainage, and irrigation alternative and the roads only alternative sustain a population of 52 300. The do nothing case takes 20 years to sustain a much lower population of 48 000.

The 25-percent unemployment under the do nothing alternative seems much better than the other two investment strategies. This, however, is because of heavy rural outmigration, as shown in the time series data and also that, within 10 years, 16 100 jobs are provided by the other investment policies. Only 15 500 jobs are provided by the do nothing alternative in year 2000.

The rural regional income per capita, a measure of improvement in standard of living, has risen to \$443 from \$357 in 1985--as much as 24 percent in a mere six years of the comprehensive investment strategy.

Impacts on the Urban Region

Spatial impacts, as hypothesized in this study, are due primarily to population movements. The inflow of people from the rural region increases urban population, labor force, and unemployment rates. It creates additional stresses on the urban socioeconomic infrastructure of housing, schools, and trans-

Table 6. Steady state values for main socioeconomic indicators.

Indicator	Do Nothing	Roads	Roads, Drainage and Irrigation
Steady	2000 or in 20 years	1993 or in 13 years	1990 or in 10 years
Rural roads (miles)	324	350	330
Rice land cultivated (acres)	51 800	53 300	53 000
Gross regional income (G\$000 000s)	14.8	15.1	20.0
Population	48 000	52 300	53 200
Gross income/capita (G\$)	308	288	382
Jobs	15 500	16 100	16 100
Unemployment (%)	25	29	29
Out migration (persons/year)	-46	310	310
Out migration in 1985 ^a (persons/year)	311	-624	-624
Gross income/capita in 1985 (\$)	357	375	443

^aTransient state values for 1985.

port. The overall urban inmigration rose from approximately 7000 persons in 1980 to approximately 13 000 persons in 2000; but of real significance here is that the Essequibo region has contributed to less than 3 percent for both investment policies, as opposed to as much as 15 percent for the do nothing alternative.

Figure 2 shows a trace of the behavior of migration over the analysis period from 1980 to 2000. The net effect of the do nothing alternative is that 1146 persons leave the rural region. On the other hand, the investment policies result in a net inflow of 470 persons to the rural region.

CONCLUSION AND RECOMMENDATIONS

A planning procedure that can assess the total efficiency of alternative rural investment strategies would be most useful. The concept of total efficiency is difficult to define and analyze. However, it must be faced if maximization of investment funds is to be realized. The system dynamics methodology and the developed model have the flexibility to incorporate indirect, spatial, and other possible impacts due to transport and related investments in rural regions of less-developed countries.

The additional information on income, unemployment rate, and rural outmigration, provided through the system dynamics approach, showed that the investment alternatives in roads only and roads, drainage, and irrigation provided the best overall impacts. The latter was superior in all respects and is therefore recommended for implementation in Guyana. The expected net present worth of this strategy at 10-percent interest rate is approximately G \$13 million over a 20-year period. It should sustain a rural population of 52 000 persons at an average income per capita of G \$400 annually. Even more important, it helps to reverse the severe urban inmigration over the analysis period, from 1980 to 2000.

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Figure 2. Trace of migration over analysis period, 1980-2000.



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