Modeling Infrastructure Induced Development at National and Regional Levels

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Abstract

Infrastructure induced development is a process dominated by feedback in that it features the synthesis of demand and supply functions. For the demand function, we are seeking the infrastructure improvement required to accommodate a certain socioeconomic need; for the supply function we want to know the level of service obtained for a certain infrastructure improvement. The objectives of the project from which this paper is derived is to develop a methodology for generating models that can be used by planners and decision makers as instrumentalities for making reliable estimates of the economic health and productivity benefits of potential infrastructure investments, and for linking infrastructure investments, user benefits, and succeeding economic development to provide a basis for rational policy formation. The result is a methodology that permits one to answer the question: What would be the economic impact A, the social impact B, the demographic impact C, the land-use impact D, the environmental impact E, and the user benefit F over geographic scale G for an infrastructure investment H at time T? The approach is illustrated at both the regional and national levels.

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INFRASTRUCTURE AND DEVELOPMENT

Where the people go, public works follows--and vice versa. A ready supply of fresh, clean water must be available along with a sanitary sewer system to handle the wastes. A transportation network of highways, bridges, airports, and railroads make cities accessible to each other, while streets and public transit systems allow movement within the cities. Public works, however, are not limited to urban areas; they stretch far beyond to include rural highways, dams, power plants, irrigation systems, electric utility lines and others. This underlying foundation of public capital facilities, the basic framework which permits a nation to function is "infrastructure." As far as this paper is concerned, infrastructure can be defined as the physical facilities of a country, region or locality that depends on public decisions for planning, design, construction, operation, maintenance and management.

Development refers to the complex process by which society strives for greater control over its destiny. The relationship between infrastructure and development is a subject of considerable theoretical interest and practical importance, and one that has occupied a good deal of attention over many years in both advanced and less-developed countries. The interaction between the level and pattern of infrastructure resources and the average level of a population of an area is a critical factor affecting economic and social progress, and must be taken into account at all stages of national and regional development planning. In the advanced countries, much attention was paid to infrastructure innovation during the formative years of industrial growth; today, new strategies of economic planning require the modification or renewal of inherited infrastructural systems. In the less-developed countries there is a widespread concern for infrastructure in the context of the desire to promote rapid economic development.

NATURE OF THE PROBLEM

The growth, flourishing and decline of a civilization are closely mirrored by the life cycle of its total infrastructure. To thrive, great civilizations need an extensive system of roads, canals, communications facilities, bridges and other public works. Productivity and competitiveness depend in part on the efficiency and reliability of these complex systems. If the infrastructure falls into disrepair, civilization begins to unravel. The United States has passed through the up-cycle of civilization building. The nationwide spread of railroads, canals, highways, electric power and communication systems once bolstered rapid development and industrialization. The resulting infrastructure served as both the lubricant that sped development of American civilization and the glue that bound regions and citizens of the country together. Now this infrastructure is decaying because of age, deterioration, misuse, lack of repair and, in some cases, because it was not designed for current demand. The Federal Highway Administration reports, for example, that about 45 percent of the 575,000 highway bridges in the United States are functionally obsolete or structurally deficient. To meet the challenges and opportunities of the 21st century, the United States must address and solve the difficult technical problems and social issues related to rebuilding its aging infrastructure and to constructing new facilities to meet future demands.

The better and more complete a nation's infrastructure, the better and more effectively its economic activity can be carried on. The building up of a country's infrastructure, which generally involves projects with a high initial cost and a very long payoff period, is usually carried out either by government or with its aid. Except for isolated cases of company-town type development, private investment alone cannot finance such development. Indeed, ideas about the nature of the relationship between infrastructure and development have changed considerably over time. Beyond the basic level of infrastructural provision needed as a prerequisite for economic growth, where transportation (like labor, capital, markets, land and power supplies) is an obvious prerequisite for modern economic growth, it quickly becomes a matter for debate and inquiry whether, as development proceeds, it is advantageous to extend or otherwise improve infrastructural facilities, or whether limited capital resources available for investment might more efficiently and beneficially be used in other ways. This is a matter of concern to development planners, and it is important to maintain an awareness of the multidimensional nature of the problem: the economic, social, political and spatial dimensions of infrastructure are all important and in some respects complementary—although it may be argued that it is frequently the political dimension in which particular situations and problems are predominantly viewed.

The tie between future economic growth and improved productivity is clear. What is unclear is whether infrastructure improvement contributes more to increasing productivity than other investments (whether they are public or private). Questions concerning cause and effect and how public capital stocks are incorporated as components of production are extremely relevant if infrastructure investment is to be used as an element of a fiscal policy for simulating growth beyond the localized benefits of individual infrastructure projects. If public investment simulates private investment or if they reinforce one another (i.e., there is feedback) then infrastructure investment could be interpreted as a policy variable for stimulating growth. Since causality between infrastructure and economic development may be mutual, it presents a major challenge in estimating how much of the observed change is attributable to the prior availability and how much to economic development and income growth. The frequently found correlation between the level of infrastructure services and income does not tell us much about which caused which. In fact, we have a feedback process and this feedback process can easily be modeled using system dynamics and the causal diagram display of the model readily comprehended by policy makers. Theories of the infrastructure-development interaction must be advanced and tested which requires communiction between different professionals and, indeed, between infrastructure professionals and the society served.

OBJECTIVES AND APPROACH

A body of dynamic behavior and principles of structure is emerging that allows us to organize and understand the development process of a region or a whole nation -- a process dominated by feedback in that it features the synthesis of demand and supply functions. For the demand function, we are seeking the infrastructure improvement required to accommodate a certain socio-economic load, for the supply function we want to know the level of service obtained for a certain infrastructure improvement. Since higher levels of service attract socio-economic activity, the feedback loop is closed.
Infrastructure systems are closely related to important attributes of society. They are the foundations of population distribution, land use planning and development, regional and local economic growth, industrial productivity, and quality of life. The following examples highlight important socioeconomic issues and opportunities.

> Technologies for infrastructure design, construction, and maintenance should be evaluated in terms of societal impact and socioeconomic benefits. Efforts should concentrate on evaluating alternatives and setting priorities for infrastructure technology development.
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> There is a need to understand the impact of degraded (loss-of-use) capacity to civil infrastructure systems on community life, industrial productivity, and regional economy.
>
> Rational methods must be established to determine priorities for resource allocation.
>
> There is a need to better understand the interactive effects among infrastructure systems due to their interdependency (such as electric power, water supply and local transportation systems).

The objectives of the project from which this paper is derived is to develop a methodology for generating models that can be used by planners and decision makers as instrumentalities: (1) for making reliable estimates of the economic health and productivity benefits of potential infrastructure investments and managements; and (2) for linking infrastructure investments, user benefits, and succeeding economic devleopment to provide a basis for rational policy formation. Basically, infrastructure impact analysis is an attempt to answr the following question: What would be the economic impact A, the social impact B, the demographic impact C, the land-use impact D, the environmental impact E, and the user benefit F over geographic scale G for an infrastructure investment H at time T? The requirement of this infrastructure impact methodology are documented in another paper [Drew, 1991]. The approach will be illustrated at both the regional and national levels in the next sections.

MODELING REGIONAL SYSTEMS

The impact of infrastructure on national development is usually focused on regions within a country. Regions often targeted for socio-economic development include river basins, frontier regions, depressed regions and metropolitan areas. The most common infrastructure initiatives are transportation, water resource and electric power systems. Consider the relationship of one of these infrastructure systems -- transportation -- on one of the regional types -- cities.

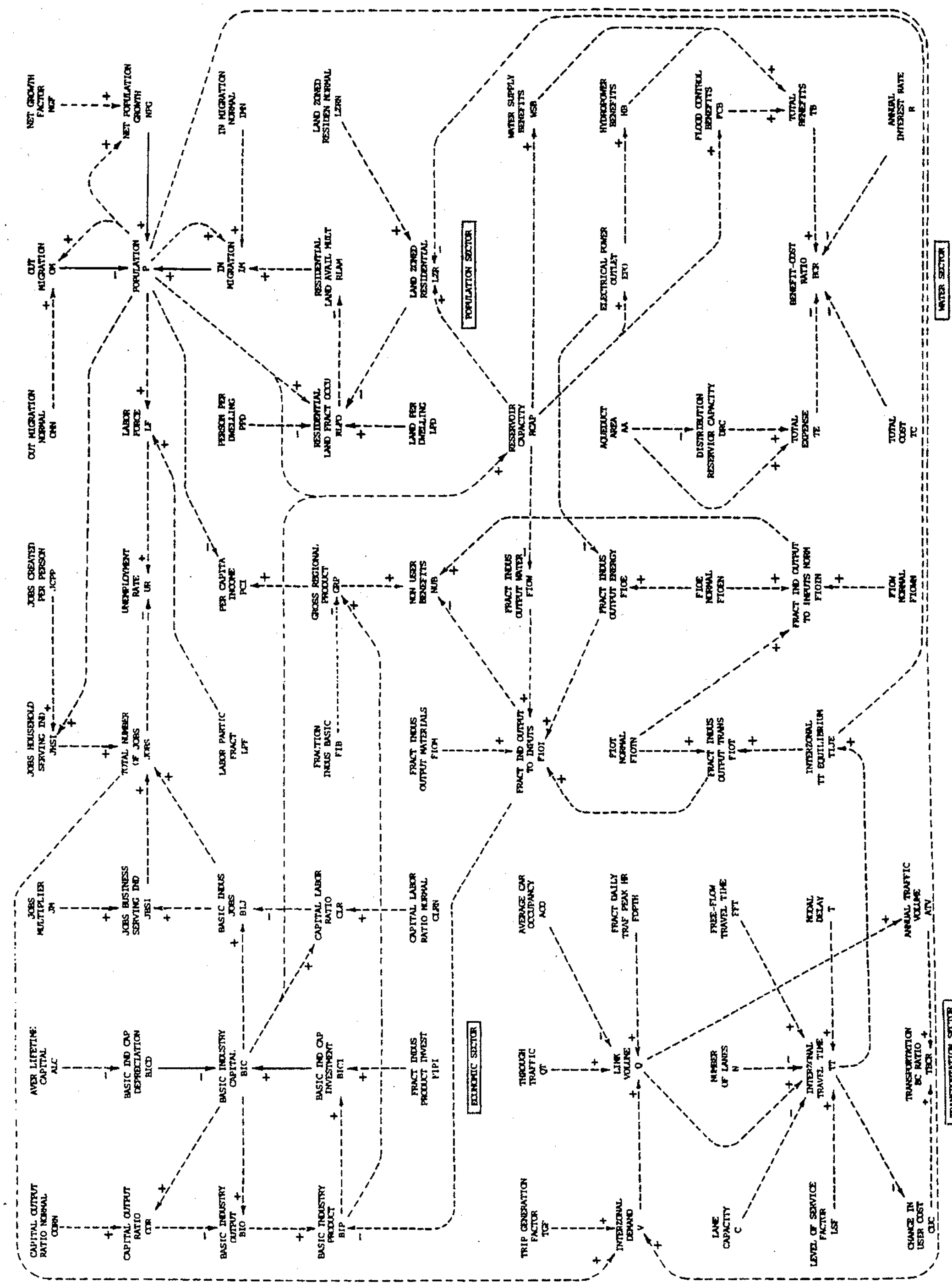
Transportation is truly the bloodstream of the urban community, because spatial interdependence is the very rationale of the urban area. A given transportation system both influences the location of activities within the city and is itself influenced by the location of these activities, because each location pattern constitutes a set of trip demands that is responded to by investment and operating decisions within the transportation system. Despite this strategic importance, unfortunately, there may be a number of grounds on which the system diverges from efficient resource use: economies of scale, mixed public and private sector decision making and lack of decision making coordinated for the whole affected metropolitan area and across different transportation modes. Before one can model the impact of transportation or regional or urban development, one must model the region or the urban area, whichever applies.

The region to be modeled can be arbitrarily divided into two categories: (1) those that are related to the regional socio-economic structure such as population, industrial, and residential systems; and (2) those that serve the regional community and are called the "regional technological systems," such as water supply, energy, transportation and the environment. The basic knowledge of how the regional systems are formed and interact with each other provides a basis for a better learning process and, thus, a better decision making process. Because the interrelationships among the regional systems, a sound solution to infrastructure and development problems, can hardly be attained without knowing the possible effects caused to other systems. The lack of understanding of this causality in forecasting usually leads to the treatment of symptoms rather than causes.

Referring to the causal diagram in Fig. 1, we see that the system dynamics model for this typical regional system contains six sectors: a population sector, an economic sector, an employment sector, and the infrastructure sectors of transportation, water and energy. The example, while admittedly simple, shows why infrastructure induced development is not a panacea. There are two causal streams from the decision variables, NUMBER OF LANES and RESERVOIR CAPACITY, to the measure of effectiveness, UNEMPLOYMENT RATE, that tend to offset each other. Obviously, the modeling of infrastructure induced development in the real world is serious business. The advantage of the system dynamics approach is that there are none of the restrictions inherent in the many methodologies [Drew et al., 1990].

MODELING NATIONAL ECONOMIES

A national development model should, ideally, be structured to accommodate three development orientations: (1) resource development, (2) regional development, and (3) sectoral development. Resource components include natural resources, land resources, water resources, and human resources (manpower). Regional development is organized on the basis of rural and urban. Sectors represented in the model are agriculture, manufacturing, business, infrastructure and government. Obviously, the three orientations overlap. They are also tied together by two quantities most responsible for material growth: (1) population-including the effects of all economic and environmental factors that influence human birth, death, and migration rates, and (2) capital-including the means of producing industrial, service, and agricultural outputs.



REGIONAL INFRASTRUCTURE DEVELOPMENT MODEL
Figure 1

Many of the sectors of a national/regional model can be thought of as elements in a national account. The national account is concerned with the measure of aggregate product originating within some geographical area so that a picture of economic performance can be gained.

The end results of economic activity is the production of goods and services and the distribution of those goods and services to the members of society. The most comprehensive measure of national output is the gross national product, usually abbreviated GNP. It is the value of all goods and services produced annually in the nation. The task of estimating the GNP, however, is not merely adding up the value of all output because that would be double-counting. In our approach the value of any product is created by a large number of different industries; each firm buys materials or supplies from other firms, processes or transports them, and thus adds to their value.

There are four major components of GNP, each representing a final use of GNP: consumption, investment, government purchases, and net exports. Investment refers to that portion of the final output which takes the form of additions to or replacements of capital. Government purchases of goods and services are a second component of GNP. In addition, government makes other expenditures, "transfer payments," which do not represent the purchase of output and are consequently excluded from GNP. Consumption refers to the portion of nation's output devoted to meeting consumer wants. Net exports, exports minus imports of goods and service, are a final use of GNP and must be included in our total. Three of the four major components can be grouped under the heading of GDP for gross domestic product: consumption, investment, and government purchases. It is evident, then, that the GNP is the sum of the GDP plus net exports.

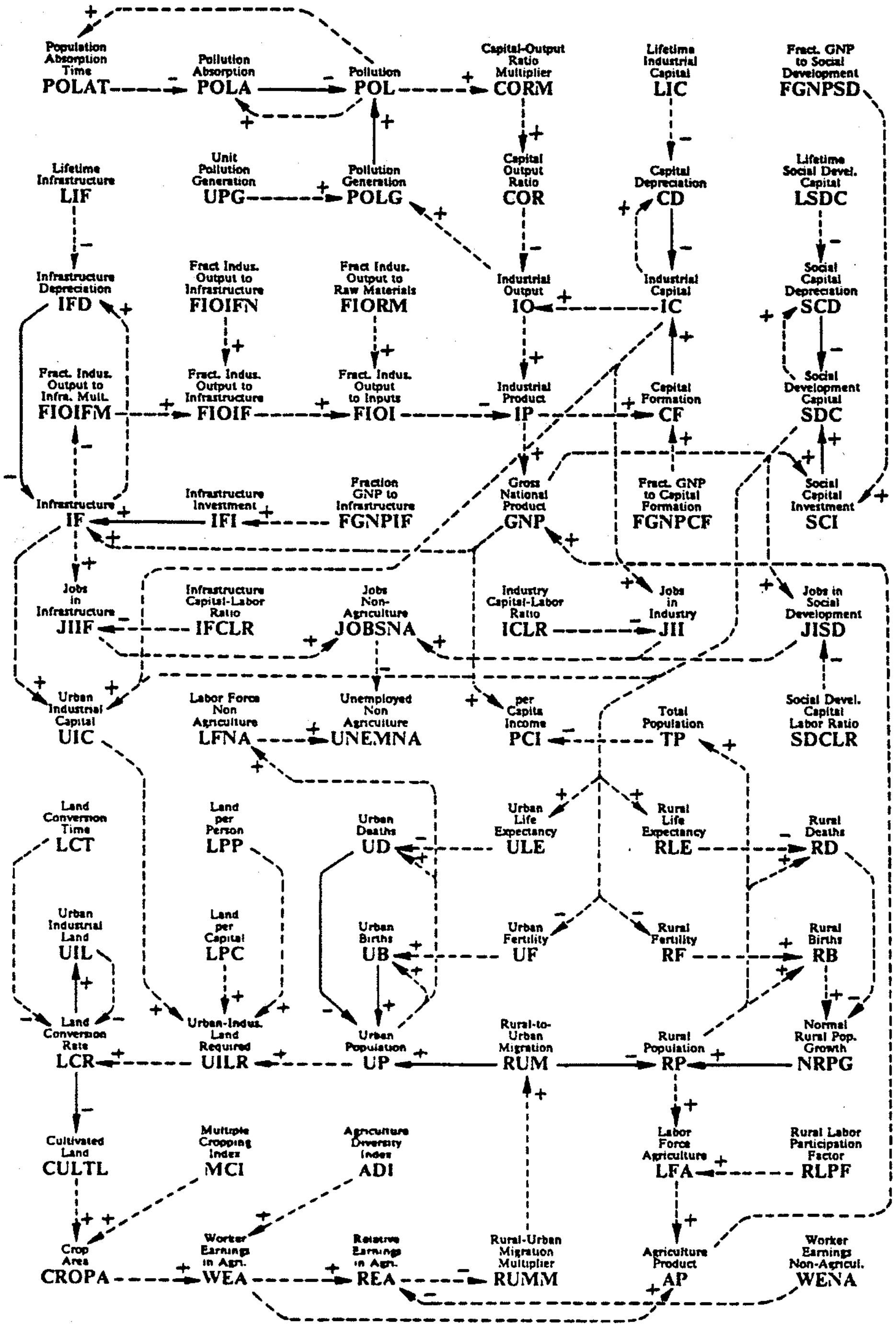
For purposes of national income analysis, GNP statistics are subdivided into mutually exclusive, collectively exhaustive categories. The most commonly used scheme for subdivision is that based on the International Standard Industrial Classification (ISIC). The nine major ISIC categories are listed in Table 1.

Table 1. International Standard Industrial Classification

Code	Classification and Description
1	Agriculture, hunting, forestry, and fishing
2	Mining and Quarrying
3	Manufacturing
4	Electricity, gas, and water
5	Construction
6	Wholesale and retail trade, restaurants, and hotels
7	Transport, storage, and communication
8	Financing, insurance, real estate, and business services
9	Community, social, and personal services

Each of the nine ISIC economic output divisions in Table 1 is associated with a particular capital stock. In a typical model the agriculture sector provides most of the output in the first ISIC division; manufacturing capital stock provides the output in ISIC divisions 2 and 3; and business capital in a model is associated with the activities listed under ISIC divisions 6 and 8. The infrastructure sector including transportation in a model corresponds to ISIC divisions 4 and 7, and the government services sector to ISIC division 9 (see Fig. 2).
The National Development Model depicted in Fig. 2 is written in DYNAMO 3 which facilitates further disaggregation. The components of the Infrastructure Sector are Highways, Railroads, Ports, Airports, Water Supply, Power & Energy, Telecommunications and Sewage Treatment. The Social Development Sector is divided into Health, Education, Housing and Family Welfare.

Five general policy experiments are identified: (1) Government Support of Agriculture, (2) Government Allocation to Social Services, (3) Industrial Development Policy, (4) Infrastructure-



DEVELOPMENT MODEL OF TAIWAN

FIGURE 2

Induced Development Policy, (5) Environmental Protection Policy. The scenarios were executed for four countries -- Taiwan, Ethiopia, Philippines and Japan -- by choosing parameter values for these countries. [Drew 1987, Drew and Lewi 1988, Drew et al. 1975, Drew 1993].

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