Regional Land Use and Transportation Development Optimization Model for Delhi Region of India

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Rapid industrialization has brought rapid population growth in major metropolitan areas in India. The rapid population growth rates in the Delhi metropolitan area (created by strong expansion of the economic base due to industrialization) have led to the adoption of decentralization policies for the region. A regional scale land use and transportation model is developed that may be used for the analysis of decentralization options. The model searches for regional development configurations that minimize the combined costs of providing urban infrastructure and intercity transportation costs. The objective function is a nonlinear function of the regional activity distribution, and a sequential search procedure is used to identify the least-cost alternative. The capabilities of this allocation-simulation model are demonstrated by several example analyses for the Delhi commuter region.

The largest population growth rates in India in recent years have been in the biggest metropolitan areas of Delhi, Bombay, Calcutta, and Madras. In 1971 the Delhi region had a population of 13.05 million, and this population is expected to grow to 16.18 million in 1981 and 19.74 million in 1991. Between 1961 and 1971 the annual rate of urban population growth was 5.1 percent while the rural growth rate was only 1.2 percent. In 1971 the Delhi metropolitan area had more than 70 percent of the urban population of the region within an 80-km radius of Delhi.

Expansion in government employment and the industrial base of the Delhi area have been the major stimuli to rural to urban migration in the Delhi region. A policy of decentralization of industrial growth away from the Delhi metropolitan area has been pursued in an attempt to reduce the rate of growth of Delhi. The state governments adjoining Delhi have provided infrastructure and other incentives in various urban centers within the region in order to attract industries. Industries have responded positively to these policies, and many large and medium-sized industries have located in smaller towns within a 30-km radius of Delhi.

The decentralization of industries, population, and other types of employment to these centers, however, has led to increasing problems of intercity commuting. Studies and analyses conducted by the Central Road Research Institute (1) of these intercity commuter flows showed that large investments in new intercity transportation facilities would be required if these commuter flows continued to grow. These findings suggested that any attempts to decentralize employment and population within the Delhi region should recognize explicitly the costs of handling the commuter flows generated by future development patterns.

This paper describes a technique for exploring the public investment cost implications of alternative regional development policies in the Delhi region.

OPTIMIZATION MODEL

The basic approach of the optimization model is to allocate urban population growth and employment opportunities among urban centers so as to minimize the costs of regional urbanization, including the provision of intercity transportation costs. Figure 1 shows the broad flow of activities involved in the regional development optimization model. The model is described in general terms in this section of the paper and subsequent sections describe the detailed structure of each of the modules in Figure 1 along with the mathematical structure.

The allocation process starts by allocating a hypothetical increment of population to each urban center, and then the basic and service employment required to support this population increment at each urban center are estimated. The intercity flows likely to be created by this increment of urban activity are then estimated. The total annual costs of the increased activity at each urban center are then calculated and the population increment is allocated to the minimum cost urban center, subject to any development constraints. The activity level, cost, transportation flow, and travel-time vectors are then updated and the process is repeated until all of the regional population growth has been allocated. This sequential approach to the problem is required, since the underlying relations are nonlinear.

DELHI REGIONAL SYSTEM

Figure 2 illustrates the zone system used for the analyses described in this paper and the principal components of the regional transportation system of the Delhi commuter region (DCR). The region has been divided into 22 zones; each zone focuses on one of the urban centers of the region. Each zone has a dominant urban center and a rural population distributed throughout the zone in small villages. The 1971 population distribution is also illustrated in Figure 2.

Figure 3 illustrates that the railway and highway networks are radial in character and converge on Delhi. Most of the urban communities have direct transportation links with Delhi by both the highway and railway networks. There are no cross-connections in the regional transportation system with the Yamuna River, which flows from north to south in the region and provides a major constraint in the development process. The regional transportation facilities are all part of the intercity road and railway systems that have developed over many years.

CHARACTERISTICS OF INTERCITY COMMUTER DEMAND

Data on intercity commuter flows were collected by use of traditional survey techniques. The overall sample size was about 33 percent for intercity trips by mass transportation and 25 percent for trips by means other than mass transportation (1,2). In the survey year of 1969 there were approximately 60 000 one-way commuter trips/day, with about two-thirds of these trips traveling from residences in the regional urban centers to Delhi and one-third traveling from residences in Delhi to the surrounding regional centers. Approximately 89 percent of the total intercity trips were for purposes of work and about 10 percent were for educational purposes.

Modal choice data showed that about 75 percent of the trips were carried by mass transportation, 7.5 percent by individual fast vehicles, and the remaining trips by slow vehicles, including bicycles. These data also showed that about 11 percent of the trips were by the high-income group, about 19 per-

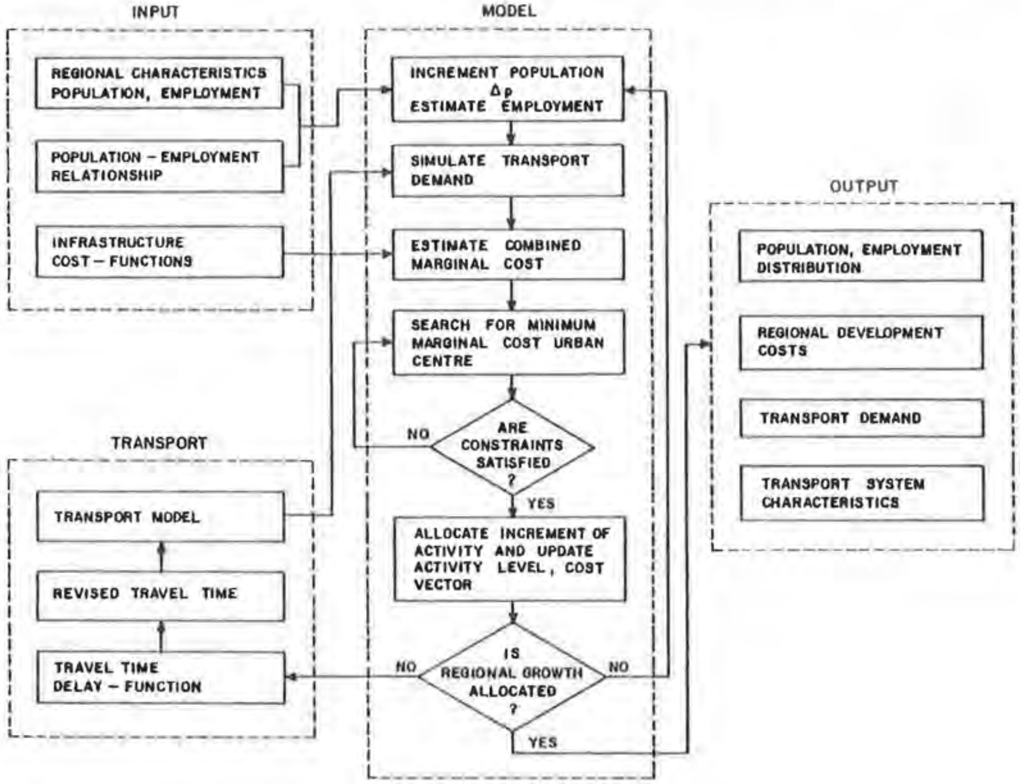


Figure 1. Regional development optimization model.

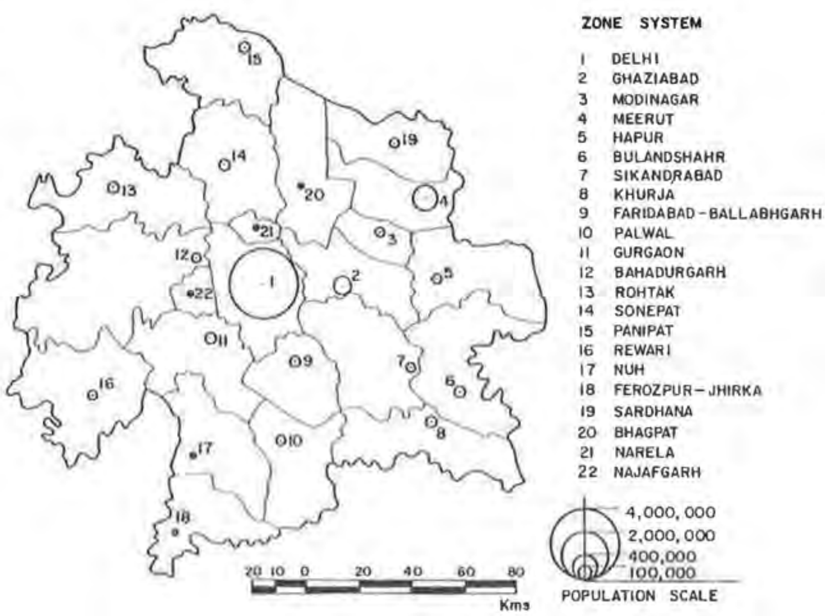


Figure 2. Zone system and urban population distribution in DCR.

cent by the middle-income group, and 70 percent by the low-income group.

A number of alternative equation structures for estimating intercity transportation flows were explored, and the following equations were selected from those considered:

$$T_{jd} = 192.8\, P_j^{-0.5129} \exp(-0.0213 t_{jd}) \quad (R^2 = 0.87) \qquad (1)$$

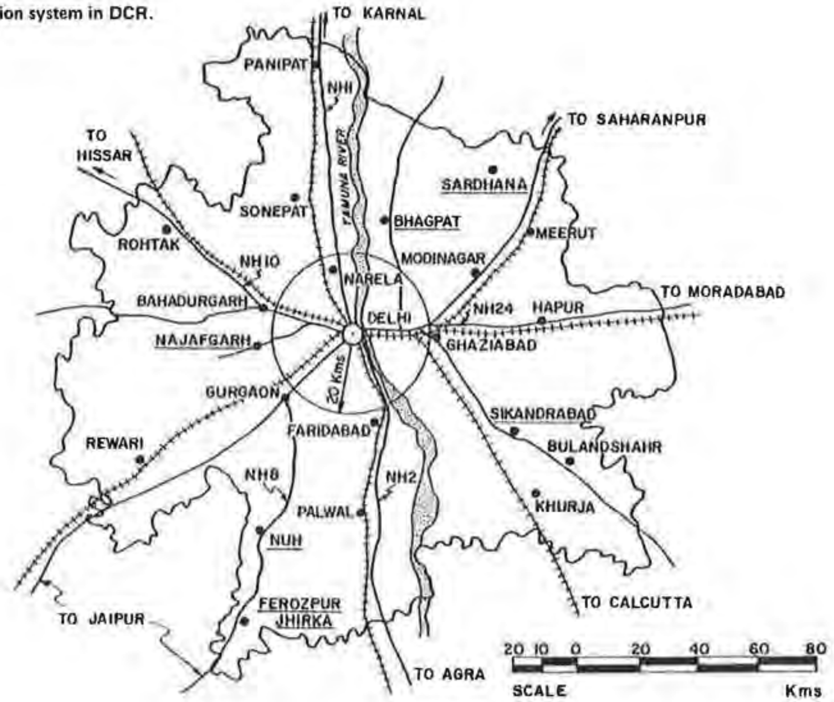
and

$$T_{dj} = 404.9\, EB_j^{-0.2293} \exp(-0.025 t_{dj}) \quad (R^2 = 0.89) \qquad (2)$$

where

- T_{jd} = number of person trips for purposes of work from urban center j to Delhi per 100 population of urban center j,
- P_j = population of urban center j (in thousands),
- t_{jd}, t_{dj} = travel time between urban center j and Delhi d and vice versa (in minutes),
- T_{dj} = number of person trips for the purpose of work from Delhi to urban center j per 100 basic jobs at urban center j,

Figure 3. Regional transportation system in DCR.



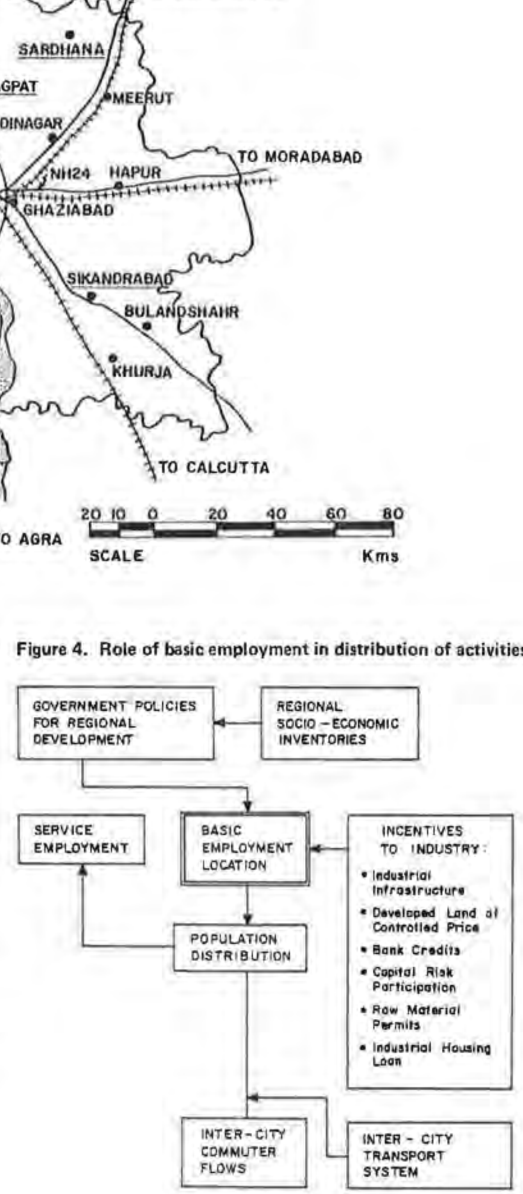
EB_j = basic employment at urban center j (in hundreds), and
R^2 = coefficient of determination.

Although the above equations have been developed by regression analysis, they are both of the unconstrained-gravity type. Equation 1 shows that trip production from the urban centers that surround Delhi depends on the travel time to Delhi and the population of the urban center. The equation suggests that a continued supply of commuter transportation will continue to stimulate intercity commuting, whereas the negative exponent of the population term indicates increasing self-containment of the urban centers with increasing population size. Equation 2 has a similar structure to the trip-production equation. The commuting trip-attraction rate of the urban centers throughout the region decreases with increasing travel time from Delhi and with increasing basic employment in the urban centers. An inspection of the residuals of both equations suggested that other factors influence the intercity commuting patterns for some of the communities, but significant correlations could not be established. These equations also suffer from the traditional limitations of using any empirically derived equations for estimating future conditions. This does not mean that these equations are not stable for future trip estimations. However, it does mean that trip-generation equations can only be considered stable for future trip estimates if one assumes that the socioeconomic conditions remain the same over the forecast period. The structure of the trip-generation equations is quite logical.

REGIONAL POPULATION AND EMPLOYMENT CHARACTERISTICS

The regional activity system consists of three main activities: population, basic employment, and service employment. Among these activities, basic employment is the most important and is a driving force in the regional urban system. This is recognized by the India government as the basic approach to urbanization and regional development, as shown in Figure 4. Figure 4 illustrates that governments have a strong influence on the location decision of industries through a variety of programs and regulatory powers. These include the supply of industrial land at a regulated price, water supply, sewerage and electrical power connections, bank credits, risk participation in capital, raw materials permits, import-export licenses, and loans for industrial housing. These incentives and powers exert a very strong leverage in the Indian economy, where private capital is scarce and most of the basic infrastructure is absent in the majority of urban centers.

Figure 4. Role of basic employment in distribution of activities in region.



Analyses of population growth rates in the urban centers of the Delhi region have shown that these industrial incentives and other decentralization policies have been the primary reason for the differential rates of population growth that have occurred at the various urban centers. Employment has been partitioned into basic and nonbasic categories to reflect the growth processes that have occurred in the urban centers of the region. The basic category includes employment in government, industry, trade, and commerce. The nonbasic category includes employment in retail trade and personal services. Regression equations have been developed that capture the interrelations between the two employment categories and population. These equations are as follows:

$$\text{Basic employment rate} = 7.4030 + 0.5706 \cdot \ell n \quad \text{population} \tag{3}$$

where $R^2 = 0.89$, and

$$\text{Service employment rate} = -0.3507 + 0.9784 \cdot \ell n \quad \text{population} \tag{4}$$

where $R^2 = 0.99$. Equations 3 and 4 allow the basic and nonbasic employment required to support an increase in population at each urban center to be estimated, given an existing population level. The equations show that both the basic and nonbasic employment rates increase with population, but at a decreasing rate.

COMMUTER TRAVEL SUPPLY CHARACTERISTICS

The supply of commuter transportation facilities should be demand-oriented, but in India the transportation services are not supplied exclusively for intercity commuters. Intercity commuters share the regional and national transportation system with other users. The current transportation facilities in the DCR have a fixed capacity and are unlikely to be expanded dramatically because of limited resources.

A review of the supply and demand characteristics of the regional highway network indicated that some excess capacity existed that could accommodate future volume increases. The 1971 demand-capacity ratios ranged from a low of about 0.2 to a high of about 0.9; most links operated at ratios of 0.4-0.5. The railway links consist primarily of single lines with conventional signaling systems. Many of the lines were operating at capacity in 1971, although some residual capacity existed, particularly to the west of Delhi.

The marginal costs of handling additional public transportation passengers by bus and rail have been estimated for each link of the road and rail networks. The annual transportation supply costs per passenger per kilometer by the bus mode have been calculated to be 9.62 rupees and by the rail mode to be 5.74 rupees [$1 (1978) = 7.5 rupees] (3). These costs are for those facilities with available excess capacity and do not involve major new capital investments in capacity. The private costs incurred by road users are not included in these analyses, which focus only on public-sector costs.

The optimization process illustrated in Figure 1 also requires travel-time-delay functions for the road and railway networks in order to reflect the impacts that increased intercity commuting might have on travel times. The travel-time-delay functions for the highway and railway networks have been derived from some earlier work by the World Bank (4,5). Modification to these delay functions was carried out for inclusion in the optimization process. Details of the modification may be found in Gupta (3).

URBAN INFRASTRUCTURE COST FUNCTION

The marginal-cost concept was used in developing the urban infrastructure cost function. This concept will provide a tool or some objective means to planners and politicians for evaluating their decisions of investing public money.

The 22 urban centers in the Delhi region have been grouped into six categories on the basis of population size and geographic locations, and these groupings are shown in the table below:

Group	Urban Center	Constraints on Development
1	Delhi	Urban land, water supply
2	Meerut	Urban land
	Faridabad-Ballabhgarh	
	Najafgarh	
3	Ghaziabad	
	Modinagar	
	Hapur	
	Bulandshahr	
	Khurja	
	Palwal	
	Panipat	
	Narela	
4	Sikandrabad	Rail
	Sardhana	
	Bhagpat	
5	Gurgaon	Moderate water supply reserves
	Bahadurgarh	
	Rohtak	
	Sonepat	
	Rewari	
6	Nuh	Rail and poor water supply reserves
	Ferozpur-Jhirka	

Urban development cost functions have been estimated for each town group by calculating the infrastructure requirements for population magnitudes that range from 50 000 to 1 million. Equations have been fitted to the cost data in order to produce the marginal-cost functions summarized in Table 1. The cost functions in Table 1 for residential activities include the infrastructure costs required by the associated service employment.

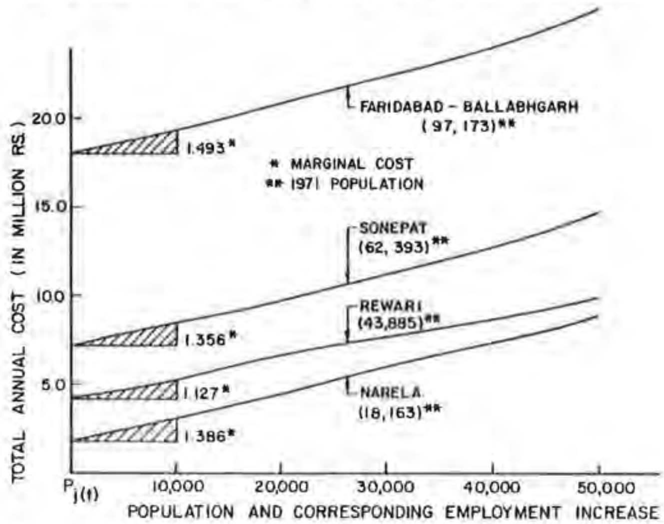
Figure 5 shows total annual cost curves and the marginal costs for a few urban centers of the Delhi

Table 1. Marginal infrastructure cost functions for residential and basic employment activities, by town group.

Town Group	Residential Activities: Equation	Residential Activities: R^2	Basic Employment Activities: Equation	Basic Employment Activities: R^2
1	$MCP_{j(G)} = 16.9981\ P_{j(G)}^{0.1323}$	0.8950	$MCB_{j(G)} = 58.3465\ EB_{j(G)}^{0.1247}$	0.9197
2	$MCP_{j(G)} = 17.7290\ P_{j(G)}^{0.1282}$	0.9120	$MCB_{j(G)} = 57.9048\ EB_{j(G)}^{0.1349}$	0.9216
3	$MCP_{j(G)} = 18.0835\ P_{j(G)}^{0.1258}$	0.9044	$MCB_{j(G)} = 60.1956\ EB_{j(G)}^{0.1196}$	0.9197
4	$MCP_{j(G)} = 18.0835\ P_{j(G)}^{0.1258}$	0.9044	$MCB_{j(G)} = 60.1956\ EB_{j(G)}^{0.1196}$	0.9197
5	$MCP_{j(G)} = 19.0621\ P_{j(G)}^{0.1339}$	0.9158	$MCB_{j(G)} = 62.3273\ EB_{j(G)}^{0.1169}$	0.9139
6	$MCP_{j(G)} = 19.6642\ P_{j(G)}^{0.1234}$	0.9254	$MCB_{j(G)} = 64.3412\ EB_{j(G)}^{0.1147}$	0.9044

Note: $MCP_{j(G)}$ = marginal cost in rupees per increment of population in urban center j of town group G, $P_{j(G)}$ = population of urban center j in town group G, $MCB_{j(G)}$ = marginal cost in rupees per increment in basic employment in urban center j of town group G, and $EB_{j(G)}$ = basic employment of urban center j of town group G.

Figure 5. Application of marginal-cost concept in regional development process.



region. These costs include residential, service, and basic-employment infrastructure along with the intercity transportation costs. These curves indicate that total investment in the development of infrastructure and transportation increases with increasing population. The marginal cost is shown by the shaded area and indicates that there are significant differences in the marginal costs between urban centers.

ALLOCATION-SIMULATION MODEL STRUCTURE

The general form of the allocation-simulation process illustrated in Figure 1 may be expressed mathematically as follows:

$$\begin{aligned} Z = & \sum_{j\epsilon G} \left\{ (1/2)\, K^{(1)}_{j\epsilon G} \left[P^{\gamma j\epsilon G}_{j\epsilon G(t+1)} + P^{\gamma j\epsilon G}_{j\epsilon G(t)} \right] * \left[P_{j\epsilon G(t+1)} - P_{j\epsilon G(t)} \right] \right\} \\ & + \sum_{j\epsilon G} \left\{ (1/2)\, K^{(2)}_{j\epsilon G} \left[EB^{\rho j\epsilon G}_{j\epsilon G(t+1)} + EB^{\rho j\epsilon G}_{j\epsilon G(t)} \right] * \left[EB_{j\epsilon G(t+1)} - EB_{j\epsilon G(t)} \right] \right\} \\ & + \sum_{j=2}^{n} (1/2)\, K^{P} \exp(-\alpha_1 t_{jd}) * C_{jd} \left[P^{-\beta_1}_{j(t+1)} + P^{-\beta_1}_{j(t)} \right] * \left[P_{j(t+1)} - P_{j(t)} \right] * R_{P_j} \\ & + \sum_{j=2}^{n} (1/2)\, K^{EB} \exp(-\alpha_2 t_{dj}) * C_{dj} \left[EB^{-\beta_2}_{j(t+1)} + EB^{-\beta_2}_{j(t)} \right] * \left[EB_{j(t+1)} \right. \\ & \left. - EB_{j(t)} \right] * R_{Aj} \end{aligned} \tag{5}$$

subject to the following constraints:

$$\sum_{j=1}^{n} P_{j(t+1)} - P_{j(t)} = P^{u}_{(t+1)} \tag{6}$$

$$\sum_{j=1}^{n} EB_{j(t+1)} - EB_{j(t)} = EB^{u}_{(t+1)} \tag{7}$$

$$P_{j(t+1)} \geq P^{min}_{j(t)} \tag{8}$$

$$P_{j(t+1)} \leq P^{max}_{j} \tag{9}$$

$$EB_{j(t+1)} \geq EB_{j(t)} \tag{10}$$

$$T^{im}_{jd(t)} + T^{m}_{jd} \leq X^{im}_{jd} \tag{11}$$

$$T^{im}_{dj(t)} + T^{m}_{dj} \leq X^{ij}_{dj} \tag{12}$$

where

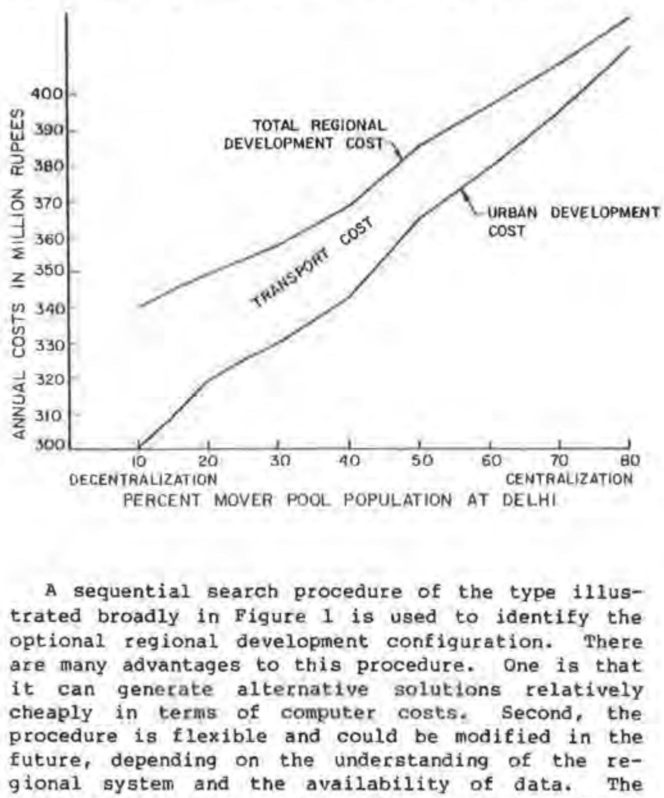
- n = number of urban centers;
- G = number of homogenous town groups;
- $P_{j(t)}, EB_{j(t)}$ = level of population and basic employment, respectively, at urban center j for the base year time period t;
- $P_{j(t+1)}, EB_{j(t+1)}$ = level of population and basic employment, respectively, at urban center j for the horizon year time period t+1;
- $K_{j\epsilon G}(^{1}), K_{j\epsilon G}(^{2})$ = constants for population and basic-employment activities derived from the infrastructure cost function for urban center j of town group G;
- $\gamma_{j\epsilon G}, \rho_{j\epsilon G}$ = parameter values associated with population and basic employment, respectively, in the infrastructure cost function for urban center j of town group G;
- K^{P}, K^{EB} = constants associated with the trip-production and trip-attraction rates of the transportation models;
- α_1, α_2 = parameter values associated with travel time in the trip-production and trip-attraction rates of the transportation models;
- t_{jd}, t_{dj} = travel time (in minutes) between urban center j and the regional center Delhi, and vice versa;
- c_{jd}, c_{dj} = transportation supply costs per trip from urban center j to the regional center Delhi, and vice versa;
- β_1, β_2 = parameter values associated with trip-production and trip-attraction rates of the transportation models;
- R_{Pj}, R_{Aj} = expansion factor for the trips produced and the trips attracted by urban center j for purposes other than work;
- $P_{(t+1)}{}^{u}, EB_{(t+1)}{}^{u}$ = total urban population and basic-employment growth in the region at the horizon year;
- $T_{jd}{}^{m}, T_{dj}{}^{m}$ = peak-hour transportation flows from urban center j to the regional center, and vice versa, on transportation mode network m;
- $X_{jd}{}^{im}, X_{dj}{}^{m}$ = transportation capacity of link i for the transportation corridor that serves j to d, or vice versa, by transportation network m; and
- $T_{jd}{}^{im}, T_{dj}{}^{m}$ = existing peak-hour transporta tion flows on link i for the corridor that serves j to d, or vice versa, by transportation network mode m.

The objective function shown in Equation 5 is nonlinear in the decision variables. The basic problem in this formulation is to find the values of $P_{j(t+1)}$ that optimize the objective function. With each level of $P_{j(t+1)}$ there are associated jobs that are expressed by the second term $EB_{j(t+1)}$. The objective function estimates the total costs of development for total regional urban growth. There are many solution procedures to nonlinear optimization problems, but the efficiency of the procedure depends on the number of independent variables.

Table 2. 1991 population holding capacities and employment targets for urban centers of DCR.

Urban Center	Population (000s)	Employment (000s)		
		Basic	Service	Total
1	5200	843.8	768.6	1612.4
2	400	60	50	110
3	150	22	17	39
4	600	122	105	227
5	100	14	11	25
6	100	14	11	25
7	60	8.5	6.3	14.8
8	100	14	11	25
9	300	50	36	86
10	70	10	8	18
11	100	14	11	25
12	75	11	8	19
13	200	30	24	54
14	200	30	24	54
15	200	30	24	54
16	80	11.5	9	20.5
17	17	2.3	1.7	4
18	24	3.2	2.3	5.5
19	50	7	5.2	12.2
20	30	4	3	7
21	60	8.5	6.3	14.8
22	40	5.5	4.1	9.6
Total	8156	1315.3	1146.5	2461.8

Figure 6. Annual regional development costs versus degree of centralization.



A sequential search procedure of the type illustrated broadly in Figure 1 is used to identify the optional regional development configuration. There are many advantages to this procedure. One is that it can generate alternative solutions relatively cheaply in terms of computer costs. Second, the procedure is flexible and could be modified in the future, depending on the understanding of the regional system and the availability of data. The solution procedure ensures that a minimum total public investment for regional urban development is achieved.

MODEL APPLICATION TO HORIZON YEAR STRATEGIC REGIONAL PLANNING

Population and employment targets have been set for future time horizons for the Delhi region in the National Capital Regional Plan (6), and these targets are listed in Table 2 for the 22 urban centers. A number of alternative regional development policies have been prepared where these policies may be expressed in terms of deviations from the population and employment targets listed in Table 2. For each of the alternatives examined, the expected growth in regional population was allocated in two steps. The natural population growth expected in each urban center was allocated to the urban center in which it occurred while migrant population was allocated in the second step on the basis of the costs of development.

An issue of concern to governments involved with the management of urban growth is the extent to which urbanization should be decentralized. Figure 6 shows the annual costs of development for a range of development policies, which range from almost complete decentralization of rural-urban migrant growth to almost complete centralization of this growth. The diagram illustrates that the annual costs of development are about 80 million rupees/year, with the transportation cost component varying from 41 million rupees/year with heavy decentralization to about 8 million rupees/year with a policy that encourages the strong centralization of growth. Intercity transportation flows ranged from 19 000 to about 122 000 trips/day for the range of policy options.

Within this range of broad regional development strategies there is a large number of more specific policy issues, such as the efficacy of investments in water supply and transportation in various parts of the region. The table below lists seven alternative regional development strategies in terms of variations in the population holding capacities from the regional plan targets listed in Table 2:

Alternative	Variation Over Target Population (%)			
	Delhi	East of Delhi	Northwest Delhi	Southwest Delhi
1				
2		+10		
3		+20	+10	
4		+50	+20	+10
5		+20	+50	+50
6		+50	+50	+50
7	-10		+50	+50

Figure 7 shows the migrant population allocations to the various urban centers for four of the alternatives listed in the table above, including alternative 1, the regional plan population targets, and alternative 6 with the minimum total annual development costs. The information presented in Table 3 shows that the annual development costs may be reduced by some 28 million rupees from the development costs that would be required by the regional plan population distribution if alternative 6 was implemented. Growth would be directed into the corridors to the northwest of Delhi and to the outermost urban centers in some of the other corridors, particularly in the southeast.

Alternative development strategies that involve significant investments in water supply systems in the groundwater-deficient areas to the west and southwest of Delhi have also been analyzed. These alternatives were translated into increased population holding capacities for those areas that also have significant amounts of unused intercity transportation capacity. Population growth was directed toward these urban centers and there were significant changes from the regional plan population targets.

Several alternative policies that involve investments in new highway capacity were analyzed; these had little impact on regional development patterns but did incur a significant increase in transportation investment costs. Although two of the invest-

Figure 7. Migrant population allocation for four strategies.

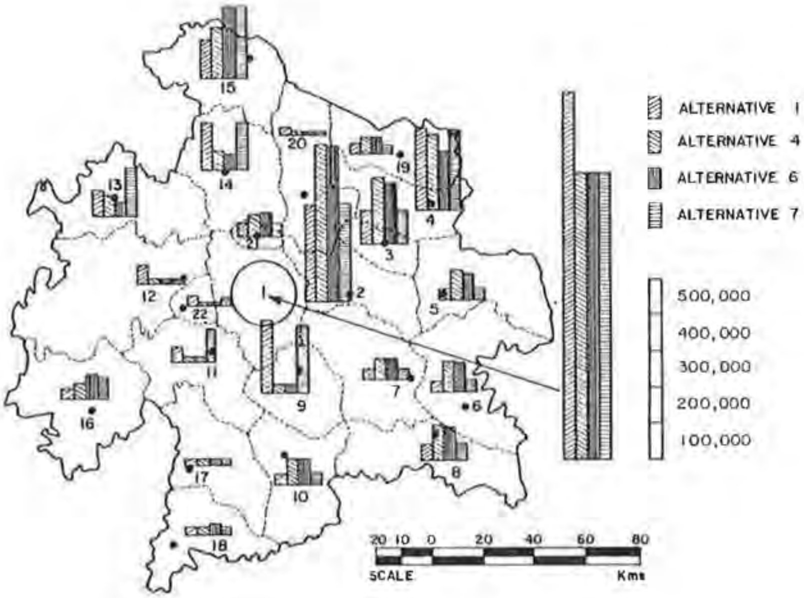


Table 3. Migrant population at Delhi, regional basic employment growth, and development costs for alternative regional development.

Alternative	Mover Pool Population at Delhi		Basic Employ-ment	Cost (rupee 000 000s)		
	No.	Percent		Urban De-velopment	Transpor-tation	Total Regional Development
1	1 023 199	40.76	375 540	353.07	31.62	384.69
2	813 199	32.40	372 072	335,75	34.61	370.35
3	803 199	32.00	372 772	335.53	29.57	365.10
4	803 199	32.00	372 304	332.59	25.34	357.93
5	803 199	32.00	372 282	334.52	27.79	362.31
6	803 199	32.00	371 808	331.23	25.18	356.41
7	803 199	32.00	371 686	336.46	33.11	369.57

ment strategies reduced the annual development costs from the regional plan alternative, these changes were small and much greater than the minimum achieved under different development policies. Major investments in new railway capacity were not considered.

The examples of regional development policy analysis presented above provide an illustration of the types of policy analysis that may be performed quickly and cheaply in any developing region with the allocation-simulation model described in this paper.

CONCLUSIONS

The changing socioeconomic environment in developing countries, including the emphasis on industrialization, has resulted in more emphasis being placed on regional land use and transportation planning. The primary aim of many of these regional planning initiatives has been to achieve balanced development of a region and to have an equitable distribution of resources throughout the region. The Delhi region of India provides an excellent example of the planning and resource-allocation problems that face many countries with similar problems. Policies of regional decentralization have been pursued in many countries and simple policy analysis tools are required to highlight the costs and impacts of alternative regional development strategies.

A technique has been described that identifies regional development patterns that minimized development costs subject to a variety of constraints. Two major cost components are recognized: the costs of supporting activities at different urban places and the costs of supplying the intercity transportation demands likely to be created by a particular development strategy.

The search procedure operates by allocating a hypothetical increment of population growth to each urban center and then estimates the employment growth necessary to support this population increment along with the expected increase in intercity travel demands. The total costs of development are then estimated and the increment in population is allocated to the urban center with the minimum marginal costs subject to any constraints on population and employment holding capacities and on intercity transportation capacities. A simple sequential search procedure is used to identify the optimal allocation of activities. The combinatorial nature of the problem is greatly simplified by the radial structure of the Delhi region.

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Multimodal Logit Travel-Demand Model for Small and Medium-Sized Urban Areas

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The development and application of a one-step modal-split process that uses the logit approach and is oriented toward the needs and attributes of small and medium-sized urban areas are described. The essence of this study lies in the tailoring of commonly available aggregate (zonal) data for use in the disaggregate-based logit model, which is currently included in the Urban Transportation Planning System planning package. The development of work-trip and non-work-trip models is presented separately for the Flint urban area in Michigan. Each model studied the following five modes: (a) automobile, drive alone; (b) automobile, one passenger; (c) automobile, two passengers; (d) automobile, three or more passengers; and (e) transit, bus service. The results of the study indicate that the development of multimodal logit modal-split models is feasible by using aggregate data, and that the potential of applying this approach in other urban areas is quite high, although further calibration and validation efforts are needed before a more widespread application is practiced. The study also shows that, unlike traditional modal-split (diversion-curve-type) models, the resource requirements for these models are nominal and thus can be used for transportation planning purposes in small and medium-sized urban areas. The model is also sensitive to changes in transportation system attributes as well as in tripmaker characteristics and can be applied for testing air quality, energy, and other impacts of transportation strategies typical of smaller urban areas.

The increasing concern about traffic congestion, air pollution, and energy shortages in recent years has caused most urban areas in the United States to promote public transportation and ridesharing programs. Historically, the emphasis on such transit-related activities has been directed toward large urban areas. It is only during the past few years that small and medium-sized urban areas have been receiving significant attention on transit, ridesharing, and other transportation system management (TSM) programs.

Travel-demand forecasting constitutes the most critical element of the urban transportation planning process. The traditional approach to transit-demand analysis has been criticized as being oriented toward larger cities and being insensitive to the needs and attributes of small and medium-sized urban areas (1). Typically, travel-demand models are cross sectional in nature, as these are developed on the basis of data for a single time period (2,3). Empirical relations are developed from observed data on travel, land use, and demographic characteristics of the area that are used to forecast future travel desires. The data needs for these models are generally very high, and smaller urban areas are hard-pressed to commit the resources necessary for the collection and retrieval of such a data base. The process of allocating travel among a number of competing modes, commonly known as the modal-split process, has posed particularly significant problems to these small areas.

The recent emphasis on different types of ride-sharing programs presents further problems to these smaller areas. Most of the available demand models can allocate travel between two modes at a time as opposed to many modes at the same time. When a multiple number of modes are involved, the analyst must take recourse to a submodal-split process that successively allocates travel between two modes at each step. This process of successive allocation can get complicated due to the need to calibrate the model at each step and to trace backward whenever the model output might not provide an acceptable match to observed data.

Obviously, any modeling error committed at a given step would be propagated to all successive steps by this submodal-split process. Thus, the overall reliability of such a model is likely to be questionable when a multiple number of modes are involved. This process becomes lengthy, involved, and costly, which makes it somewhat inappropriate for application to smaller areas.

The above-mentioned procedure, despite the complexities involved, has been successfully used in multimodal travel-demand forecasting for large urban areas (2). There is, however, a need to develop a simpler procedure for smaller urban areas, where resources are constrained and where transit options are quite limited and bus travel is the only feasible mode. This need becomes more evident when one considers the current emphasis on developing plans that involve different levels of automobile occupancy. For example, How does the transportation planner assess air quality, energy, and other impacts of a shift in automobile travel from a low occupancy level to higher occupancy level? What are the overall effects of such a shift in the total ve-