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A Integrated Model of Land/Transportation System

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토지이용규모와 교통수요의 크기, 그에 따른 혼잡정도를 이들간의 동적상호작용을 시뮬레이션화하여 동시에 산출할 수 있는 시스템다이나믹스(System Dynamics)모델이 제시된다. 이 모델은 토지이용과 교통에 관계되는 물리적, 사회경제적, 정책적 변수들간의 상호관계를 나타내는 다양한 함수와 피드백 루프(feedback loop)구조로 이루어져 있다. 전체모델은 크게 인구, 인구이동, 가구변동, 부문별 고용 및 토지개발, 주택개발, 통행수요, 혼잡레벨의 7개 서브모델로 구성되며 각 서브모델은 다시 부문별로 세분된다.

시스템다이나믹스모델의 주요 장점은 다음과 같다. 첫째, 토지이용과 교통시스템을 둘러싼 복잡한 변수들 간의 동적 상호작용을 효과적으로 다룰 수 있으며 어떤 정책에 대하여 시간적 변화에 따른 효과를 평가할 수 있다. 둘째, 시스템다이나믹스모델은 시뮬레이션에 의해 모델의 결과가 산출되므로 종래의 모델에서와 같이 토지이용과 교통체계의 균형상태(equilibrium state)를 가정할 필요가 없다. 세번째로, 시스템다이나믹스모델은 다수의 분리된 수식(equations)으로 구성되므로 새로운 변수 -- 특정한 정책, 새로운 현상, 다른 방법론에 기초한 테크닉, 등 -- 들을 도입하기 쉽다.

논문의 앞부분(I, II, III장)에서는 모델의 전반적인 구조를 Causal Loop Flow Diagram을 중심으로 논하고 있다. 구체적인 수식과 DYNAMO 프로그램, 모델계수의 추정 등 기술적인 내용은 생략되었다. 이에 대하여는 저자의 박사학위논문을 참조하기 바란다. V장이 응용부분으로서, 도로교통시설의 증대가 토지이용 및 교통수요, 그리고 교통혼잡에 각 년도별로 어떻게 그 영향이 나타나는가를 메릴랜드의 Montgomery County 지역을 대상으로 검증하였다. 분석결과에 의하면, 도로용량증대의 교통유발효과(Demand-inducing Effect)는 비교적 낮은 것으로 나타났다. 또, 도로용량이 같더라도 일반도로보다 Freeway의 교통유발이 훨씬 큰 것으로 나타났다. 도로용량증대가 토지이용에 미치는 효과를 보면 용량증대가 없었던 경우와 비교할 때 단기적으로는 차이가 거의 없으나 장기적으로는 큰 차이를 미치고 있다. (인구증가의 경우 도로시설을 설치하지 않을 경우보다 4년후에는 .8% 차이에 불과하나 19년후에는 15.5%의 차이를 보여주고 있다.)

이 논문은 다이나믹 시스템시뮬레이션을 이용하여 토지이용과 교통수요 및 혼잡도 간의 상호작용을 종합적으로 다룬 첫번째 시도라 생각된다. 이 토지이용/교통모델은 광범위한 규모를 다룬 매크로시뮬레이션모델로서 정교한 수준까지 발전시키려면 아직 많은 후속작업이 필요할 것으로 보이지만, 현재까지의 결과로 볼 때 복잡한 토지이용과 교통시스템을 종합적으로 다룰 수 있는 유력한 도구가 될 수 있을 것으로 평가된다.

Abstract

The current paper presents a system dynamics model which can generate the land use and transportation system performance simultaneously is proposed. The model system consists of 7 submodels (population, migration of population, household, job growth-employment-land availability, housing development, travel demand, and traffic congestion level), and each of them is designed based on the causality functions and feedback loop structure between a large number of physical, socio-economic, and policy variables.

The important advantages of the system dynamics model are as follows. First, the model can address the complex interactions between land use and transportation system performance dynamically. Therefore, it can be an effective tool for evaluating the time-by-time effect of a policy over time horizons. Secondly, the system dynamics model is not relied on the assumption of equilibrium state of urban systems as in conventional models since it determines the state of model components directly through dynamic system simulation. Thirdly, the system dynamics model is very flexible in reflecting new features, such as a policy, a new phenomenon which has not existed in the past, a special event, or a useful concept from other methodology, since it consists of a lots of separated equations.

In Chapter I, II, and III, overall approach and structure of the model system are discussed with causal-loop diagrams and major equations. In Chapter V., the performance of the developed model is applied to the analysis of the impact of highway capacity expansion on land use for the area of Montgomery County, MD. The year-by-year impacts of highway capacity expansion on congestion level and land use are analyzed with some possible scenarios for the highway capacity expansion.

This is a first comprehensive attempt to use dynamic system simulation modeling in simultaneous treatment of land use and transportation system interactions. The model structure is not very elaborate mainly due to the problem of the availability of behavioral data, but the model performance results indicate that the proposed approach can be a promising one in dealing comprehensively with complicated urban land use/transportation system.

I. Introduction

Conventional transportation planning models suffer from some serious weaknesses. First of all, no interactions between land use and transportation system performance are addressed since the model is processed sequentially without feedback mechanism between model phases. Secondly, the conventional land use or transportation planning model is based on the theoretical assumption that the urban systems including land use or transportation are in a state of equilibrium.[1]

Since 1990, in America the comprehensive and interactive planning of land use and transportation system has become more important, especially with Intermodal Surface Transportation Efficiency Act(ISTEA) of 1991 and Clean Air Act Amendment(CAAA) of 1990. The intermodal planning as a new key concept in planning is regarded as an interactive and dynamic process which incorporates all components involved.[2] In such context, land use and transportation system should be treated in a unified model.

In the current study, a system dynamics model which can generate the land use and transportation system performance simultaneously is proposed and applied to the evaluation of the impact of highway capacity expansion on land use. The model is designed based on the causality functions and feedback loop structure between a large number of physical, socio-economic, and policy variables as model components. The system dynamics model has some important merits. First, it can address the complex interactions between land use and transportation system performance dynamically. Therefore, the model can be a powerful tool for evaluating time-by-time effects of a policy over time horizons. Secondly, the system dynamics model is not relied on the assumption of equilibrium state of urban systems since it determines the state of model components directly through dynamic system simulation. Thirdly, the system dynamics model is very flexible in reflecting new features, such as a new policy, a new

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[1] However, it is not clear whether the urban systems reach such a state of equilibrium (Meyer and Miller, 1984; p.179). Rather, it is a more reasonable and realistic concept that actual urban activities occur in the process of dynamic interactions between the various components involved, regardless of equilibrium.

[2] Meyer(1993), p.6

behavior, a special event, or a useful concept from other methodology, since it consists of a lots of separated equations.

II. Literature Review[3]

System dynamics approach is an alternative approach for land use/transportation studies. It can recover the problems of static features of the conventional models by addressing the complex features of urban behaviors dynamically and incorporating more meaningful interactions among the model components.

Urban Dynamics Model (Forrester, 1969) is the earliest one in the urban-related models using system dynamics approach. It discusses the dynamic impacts of 3 major urban sectors in an imaginary city: population, industry, and housing. Tran(1979) applied system dynamics method to transportation policy evaluation. Shirazian(1981) attempted to develop a trip generation model using system dynamics approach which incorporates the various causal variables between land use and transportation system. Khana(1985, 1989) tried to construct a system simulation model for a transportation policy analysis to compare the effects of a wide range of transportation policy structures. Abbas(1990) tried to simulate the effects of different investment strategies and maintenance options on the road network. Drew(1990) proposed a methodology for linking transport investment, user benefits, and succeeding economic development so as to a basis for rational policy formation.[4]

III. Building System Dynamics Model for Land Use/Transportation System Performance[5]

1. Overall Model Structure

In the current model, the overall model system consists of seven submodels. They are

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[3] For the conventional land use/transportation models, refer to Meyer & Miller (1984), de la Barra(1989), Bly & Webster (1987), etc.

[4] There are many other transportation-related studies which applied system dynamics method, varying from demand forecasting to energy issues. Abbas & Bell(1994) reviewed extensive works of transportation-related studies applying system dynamics approach.

[5] For the basic concept and characteristics of system dynamics approach, refer to Richardson & Pugh (1981) and Goodman(1988)

1) Population Submodel, 2) Net Migration of Population Submodel, 3) Household Submodel, 4) Job Growth-Employment-Commercial Land Development Submodel, 5) Housing Development Submodel, 6) Travel Demand Submodel, and 7) Congestion Level Submodel.

Figure 3.1 shows the structural interrelationships between submodels in the current model system. In the diagram, some positive and negative feedback loops can be identified. A positive loop increases or decreases the volume within the loop toward one direction, while other conditions being kept constant. A negative loop works toward equilibrium by bringing the decrease followed by the increase, or vice versa.

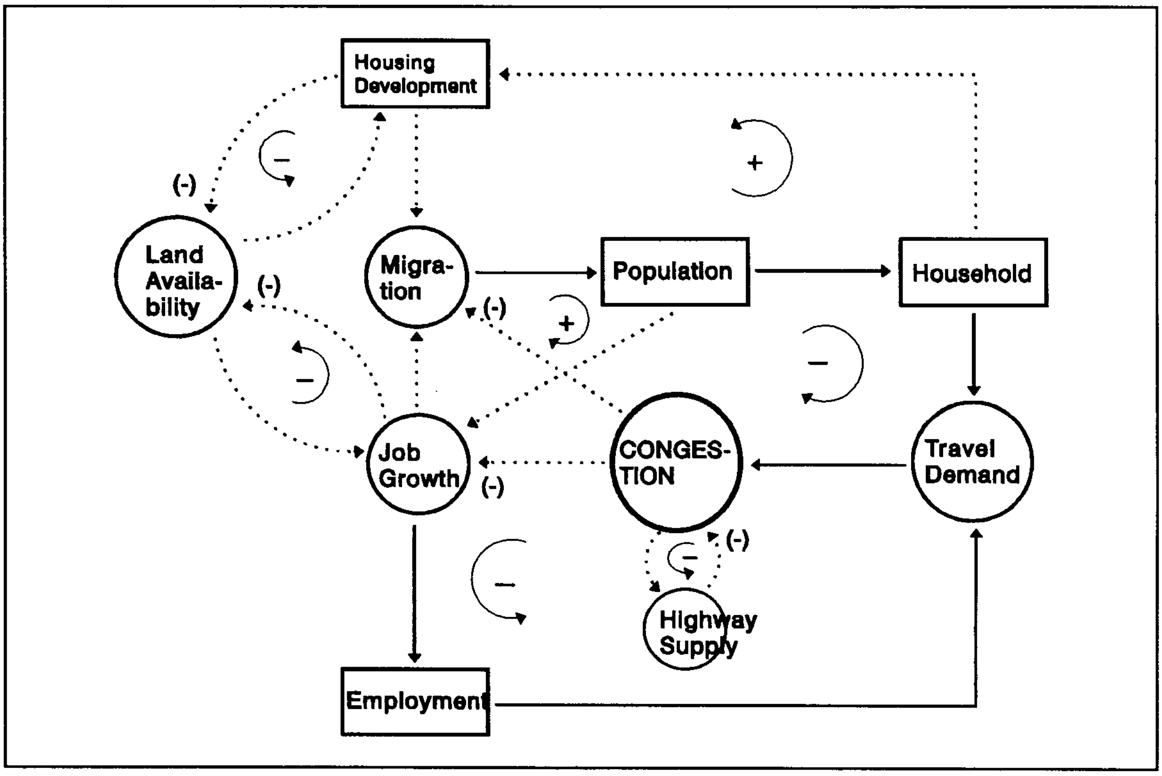

Figure 3.1 **Overall Interrelationships among Submodels**

o Positive Feedback Loops

- <u>Population - Job Growth - Migration Feedback Loop</u>
- <u>Population - Housing Development - Migration Feedback Loop</u>

o Negative Feedback Loops

- <u>Population - Household - Travel Demand - Congestion - Migration Feedback Loop</u>

- Housing Development-Land Availability Feedback Loop
- Job Growth - Land Availability Feedback Loop
- Highway Supply-Congestion Feedback Loop

2. Major Variables and Parameters

In the model, a large number of variables and parameters are defined.

Level Variables

A level variable is the one that accumulates or integrates an inflow and/or outflow over time periods. In the current model, 20 major level variables are defined, as shown in Table 3.1.[6]

Rate Variables and Auxiliary Variables

A rate variable is the one that represents an inflow or outflow during a unit time period. One or more auxiliary variables are used to define the rate variable or other auxiliary variable.[7]

3. Causal-Loop Flow Diagrams and Major Model Equations

A causal-loop flow model is used to show the interrelationships between the components in a model using diagrams with predefined characteristic symbols[8]. More specifically, it demonstrates the cause and effects -- feedback loops of the materials or information -- between major model components.

1) Population Submodel

In the model, population is divided into 8 groups by sex and age group (See Table 3.1). Change of population over time in each group is based on the cohort-survival concept. A typical causal-loop flow diagram for *male population in age group 1* (PM1) in Figure 3.2 shows it. PM1 increases by the births and decreases by deaths and move-up of age 17 group into *male age group 2* (PM2). *Net migration* (NMM1), which is determined in Migration Submodel, is another important factor for the population change.

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[6] For full list of variables and parameters, see Lee, Sang Y. (1995).

[7] For more details, refer to Richardson & Pugh(1981) and Lee(1995)

[8] For standard symbols for causal-loop flow diagram, see Richardson & Pugh(1981).

Table 3.1 Major Level Variables in the Model System

Sector	Level Variables	Description
1. Population		
	PM1, PF1	Population in age 0-17, male, female
	PM2, PF2	Population in age 18-44, male, female
	PM3, PF3	Population in age 45-64, male, female
	PM4, PF4	Population in age 65 + , male, female
2. Household		
	SNGL	Single person households
	MCOC	Married couple households w/o children
	MCWC	Married couple households w/ children
	MFWC	Male or female households w/ children
	OTHR	Other households
3. Employment		
	MCEMP	Employment in manufacturing
	RBEMP	Employment in retail business
	NRBEMP	Employment in non-retail business
	GEMP	Employment in governments
4. Land Availability		
	TLH	Total area of land for housing
	TLM	Total area of land for manufacturing
	TLB	Total area of land for business

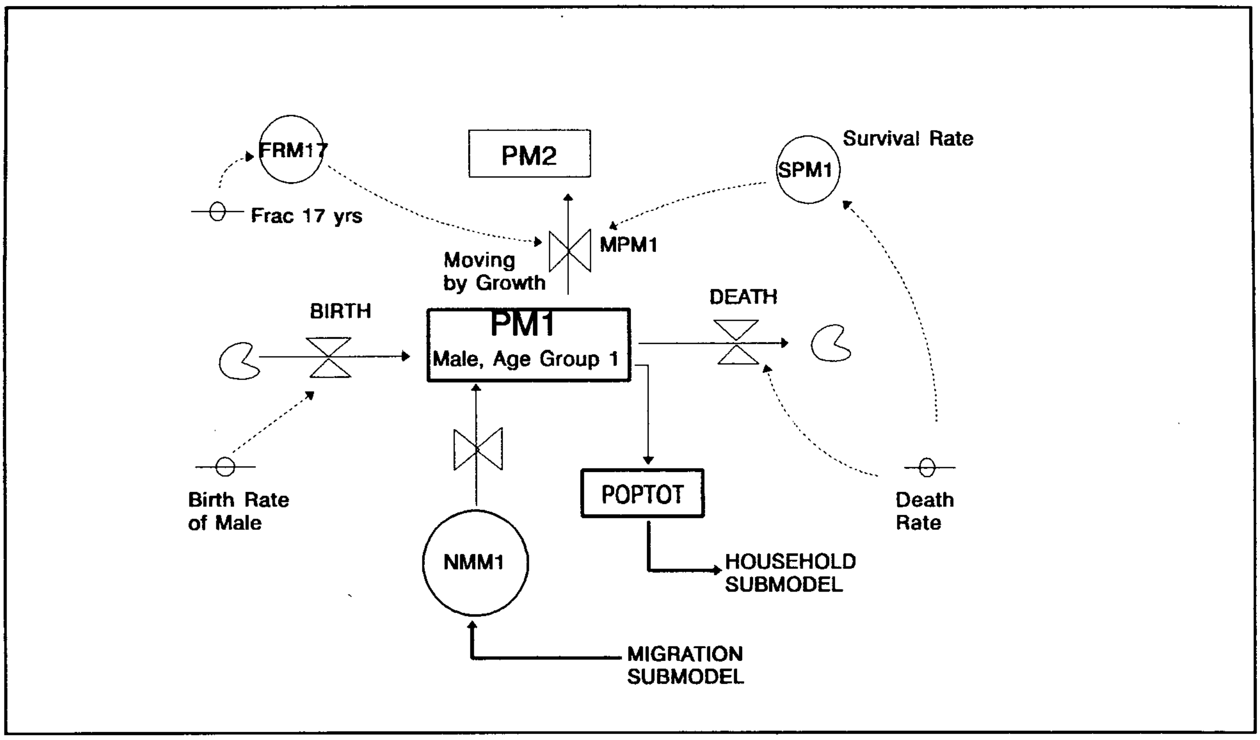

Figure 3.2 **Causal-Loop Flows in Male Population Group 1 (PM1)**

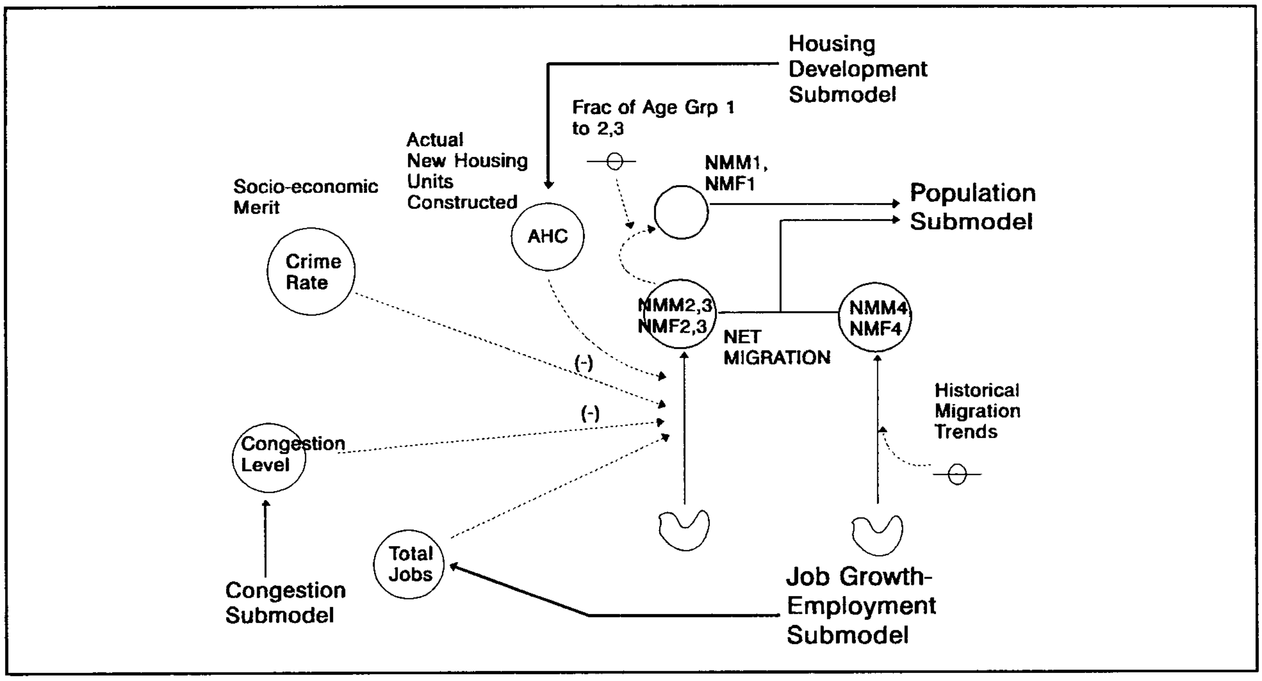

Figure 3.3 **Causal-Loop Flows in Migration Submodel**

2) Migration Submodel

In the current study net migration of population is defined as a function of some related socio-economic factors for each population group.[9] Net migrations of each population group and their factors are diagrammed in Figure 3.3. Net migrations of population group 2 and 3 (NMM2,3, NMF2,3) are defined as a linear function of total number of jobs, number of new housing units constructed, traffic congestion level, and total crime rate.

Migrations of population group 1 (NMM1, NMF1) are defined as the fractions of the sum of NMM2,3 and NMF2,3 since it is almost apparent that the migration of population group 1 is dominated by population group 2 and 3. Migration of population group 4 is not accounted for as in population group 2 and 3. It seems to be influenced much more by qualitative reasons or motives, such as climate, environment, or family affairs (Long,1985). In the current model, therefore, net migration of population group 4 is projected based on the historical trends.

3) Household Submodel

Two patterns of household changes are modeled; changes by internal cyclical transitions of families and changes by household-unit migration. Current study puts its focus to the former pattern of changes. Some of the cyclical evolution of household structure occurs mainly by any kind of family affair, such as marriage, divorce, birth of a child, etc. Some events result in the change of the number of households, but some (e.g. death of spouse, birth of a child) just change the type of household, not changing the number. Figure 3.4 shows such complex cyclic transitions between the household types.

4) Job Growth-Employment-Land Availability Submodel

Number of jobs or employment are projected for 4 subgroups; manufacturing, retail business, non-retail business, and government. Jobs or employment in any area, except government employment, are assumed to be encouraged by economy conditions and government

[9] In a study based on the Annual Housing Survey data in 1981, Long(1985) shows that job-related reason is the most principal one for the migration of working age group (about 60 %). Long's analysis also shows that the reasons of migrations of the age group of 65 or more are very different from those of the working age groups.

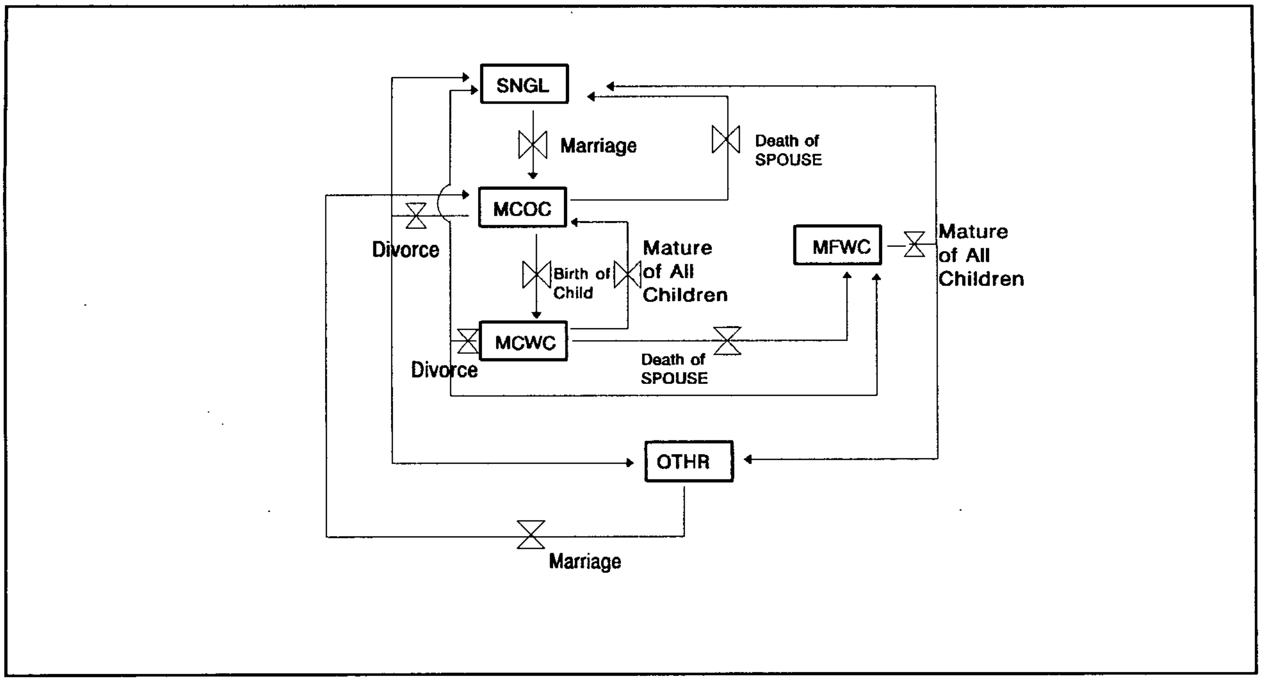

Figure 3.4 Cyclic Transitions between Households by Type

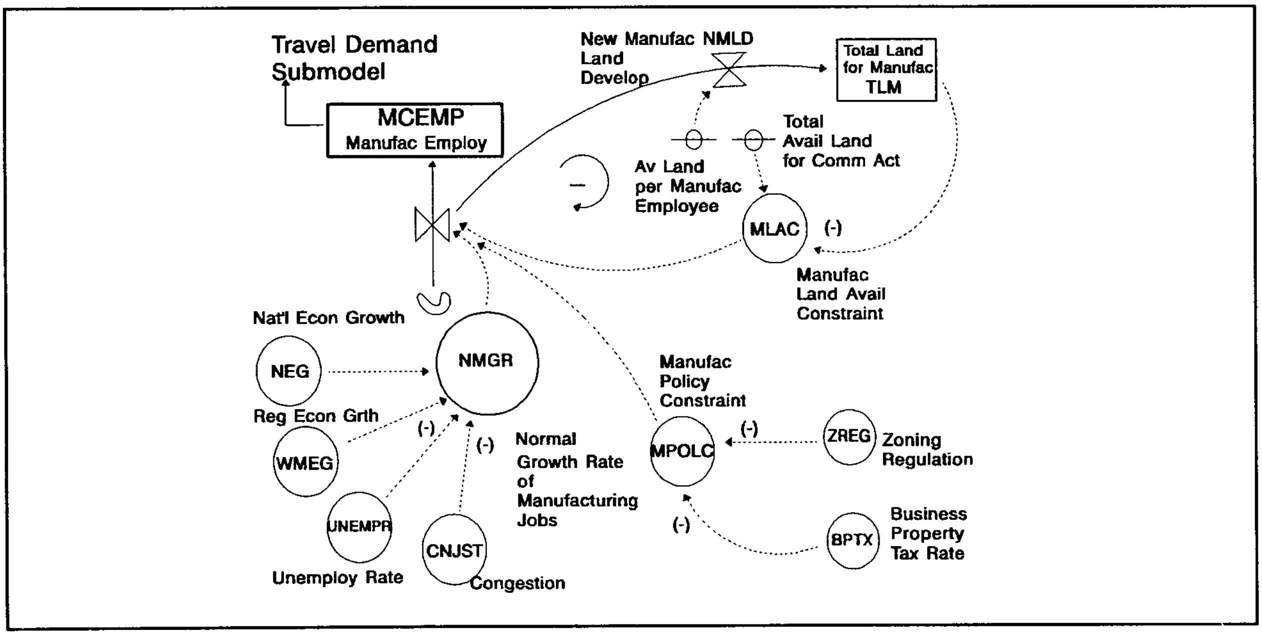

Figure 3.5 Causal-Loop Flows for Manufacturing Jobs-Employment-Land Availability

expenditures, and to be constrained by land availability, policy regulations, and traffic condition. Figure 3.5 shows a typical case of causal-loop flows; one for manufacturing. Each of other subgroups has a similar causal-loop flows.

5) Housing Development Submodel

Major factor for housing development is the generation of new households. Additionally, the housing development is influenced by housing market factors such as sales price of housing unit, rent, and other factors. In the current model, the number of normal housing units which can be constructed in a time period (NHC) is defined as a linear function of the number of new households (NHLD), average sales price of a new housing unit (NHSALE), and median gross rent (MGRNT). However, actual housing units constructed (AHC) is controlled by housing land availability constraint (HLAC), housing policy constraint (HPOLC), and other factors (HOTHER). Figure 3.6 shows the causal-loop flows in housing development submodel.[10]

6) Travel Demand Submodel

In the current model, travel demand is expressed as an average number of daily vehicle trips which are generated based on the number of households and the number of employment by type. Causal-loop flows for travel demand submodel are shown in Figure 3.7.

Trip production rate per household by type is constructed based on the historical data in NPTS (Nationwide Personal Transportation Study) reports[11]. Trips are divided into HBW (Home-based Work), HBNW (Home-based Non-work), and NHB(None-home-based) trips.[12]

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[10] In this model, housing demolition is ignored since the fraction of the housing units demolished per year to the total housing units is very small.

[11] NPTS is performed every seven years by FHWA. In the current study, data were drawn from *1969, 1977, 1983, 1990 NPTS* reports.

[12] Current paper does not discuss on the trip attraction. For them, see Lee, Sang Y. (1995).

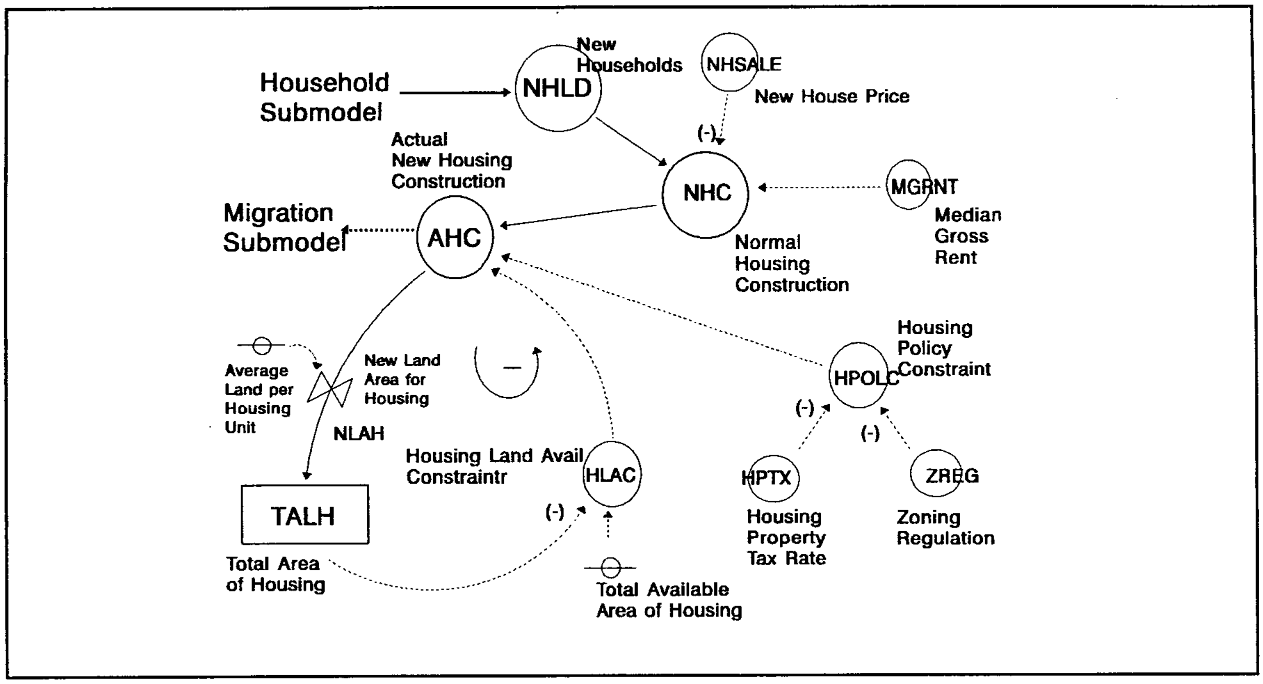

Figure 3.6 **Causal-Loop Flows for the Housing Development Submodel**

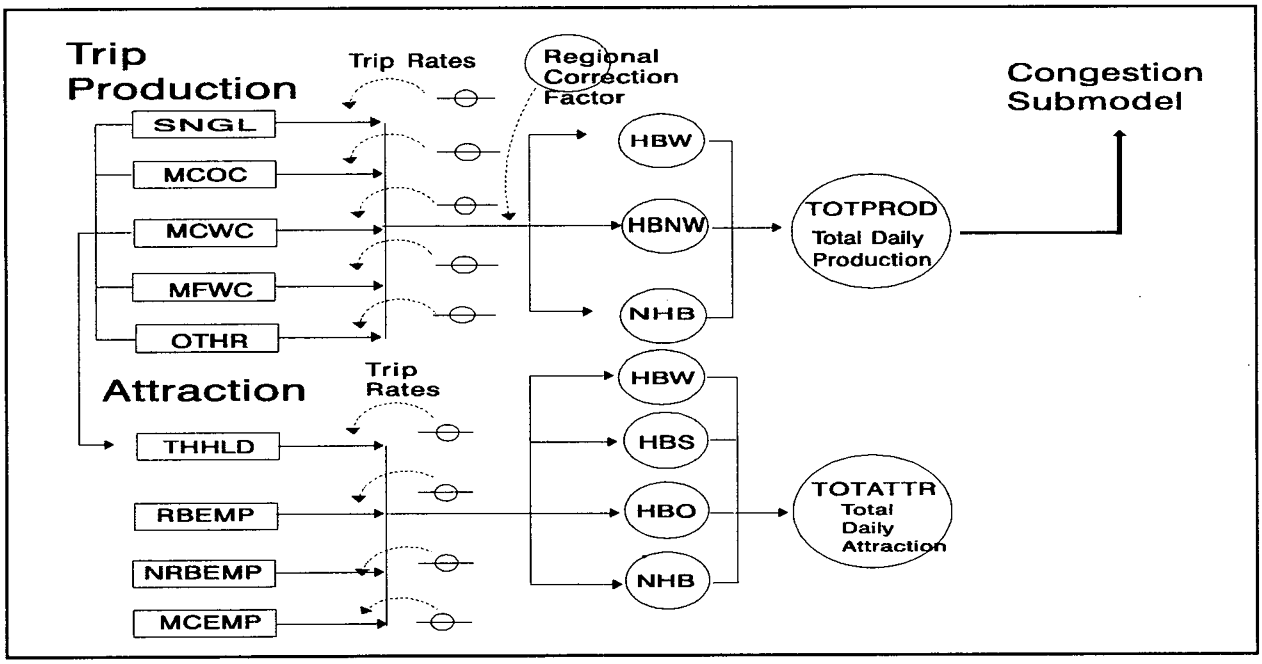

Figure 3.7 **Causal-Loop Flows for the Travel Demand Submodel**

Table 3.2 Average Vehicle Trip Rates per Day by Household Type

Home-based Work Trips

	1969	1977	1983	1990
Single Adult, No children	1.14	1.10	1.06	1.15
Two or More Adults, No Children	2.39	2.27	2.22	2.40
Two or More Adults with Children	2.87	2.74	2.67	2.89
Single Adult with Children	1.31	1.25	1.22	1.32
Average All Households	1.71	1.63	1.59	1.72

Home-based Non-Work(HBNW) Trips

	1969	1977	1983	1990
Single Adult, No children	.94	1.00	1.05	1.23
Two or More Adults, No Children	1.70	1.82	1.91	2.23
Two or More Adults with Children	2.48	2.65	2.80	3.27
Single Adult with Children	1.77	1.90	2.00	2.34
Average All Households	1.79	1.92	2.02	2.37

Non-Home-based(NHB) Trips

	1969	1977	1983	1990
Single Adult, No children	.43	.45	.48	.56
Two or More Adults, No Children	.77	.83	.87	1.02
Two or More Adults with Children	1.13	1.21	1.27	1.49
Single Adult with Children	.81	.86	.91	1.06
Average All Households	.82	.87	.92	1.08

Source;FHWA, *1990 Nationwide Personal Transportation Survey:Summary of Travel Trends*, Mar 1992
FHWA, *1990 NPTS: 1990 Data Book, Vol.II (Draft)*, 1994

7) Congestion Level Submodel

It is reasonable to assume that travel demand has a negative impact on land use through the congestion effect in the long run. To evaluate the congestion effect on the land use, an adequate form of congestion measurement should be defined. In the current model, *Roadway Congestion Index(RCI)* model developed by Lomax et al (1990) is used since it is suitable for the evaluation of congestion level on an area-wide basis.

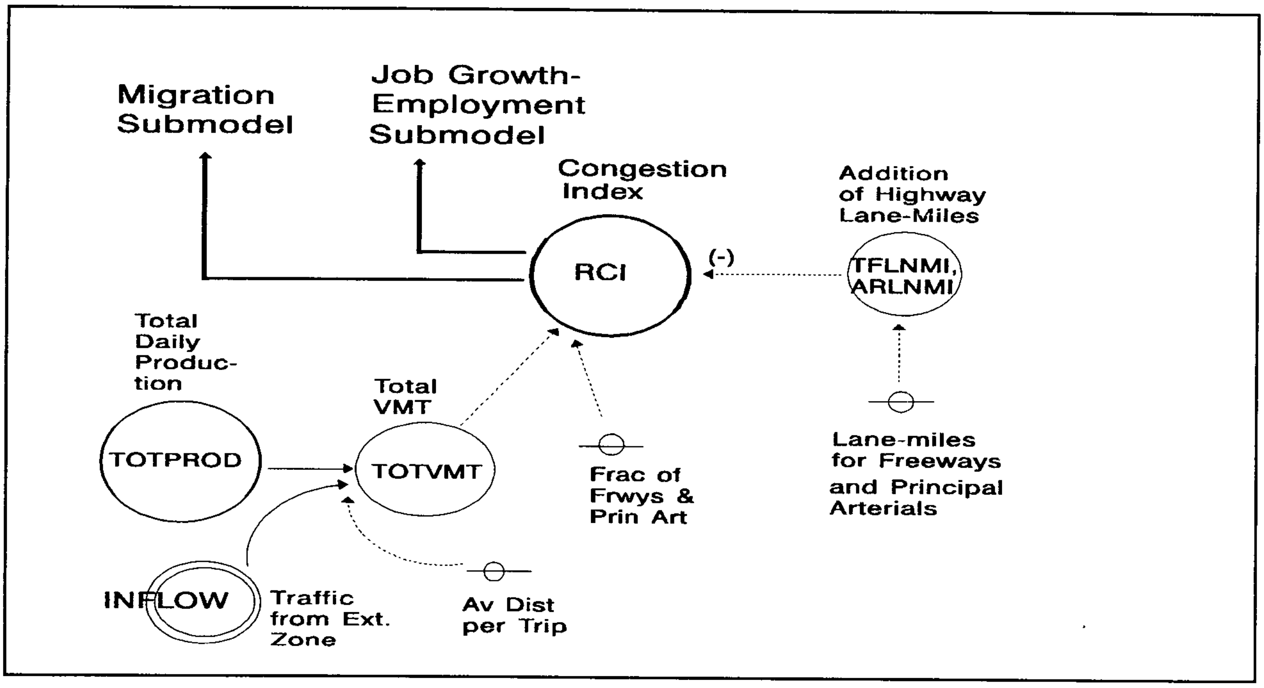

Figure 3.8 **Causal-Loop Flows for the Congestion Level Submodel**

Roadway Congestion Index is defined as a ratio of the actual traffic density to the assumed traffic capacity on a daily basis, combining the freeway terms and principal arterial street terms. Maximum traffic capacities in freeway and in principal arterial street are given by 13000, 5000 VMT/lane-mile/day, respectively.

RCI is defined by

$$RCI = \frac{(Frwy\ VMT/Ln\text{-}Mi)*Frwy\ VMT + (Pr\ Art\ VMT/Ln\text{-}Mi)*Pr\ Art\ VMT}{13000*Frway\ VMT\ +\ 5000*Pr\ Art\ VMT}$$

where

Frwy VMT	= Daily Freeway VMT(Veh-Mile Traveled)
Pr Art VMT	= Daily Principal Arterial Road VMT
Ln-Mi	= Total Lane-Miles for Freeway and Principal Arterial Road, respectively

IV. Model Formulation, Model Calibration and Validation

The proposed model system is formulated using DYNAMO simulation language. Model parameters are estimated in two ways using the historical data of Montgomery County, Maryland; statistical technique and overall system behavior. With the sensitivity test, the calibrated model is validated with the historical trend of land use and transportation system performance of the Montgomery County.[13]

[13] for the details of model formulation, parameter estimation, and model validation, refer to Lee (1995).

V. Policy Impact Analysis; Impact of Highway Capacity Expansion on Land Use

1. Introduction

An important advantage of the current model is that it can be useful as a policy analysis tool, as well as land use and travel demand forecasting tool, since the model generates outputs over all time periods for any variable.[14] Policy impact analysis in system dynamics model is different from other impact analysis in that the time-by-time impact is identified through dynamic process.

In current paper, the impacts of highway capacity expansion are discussed. Highway capacity expansion includes both of lane additions in existing highway and the extension of new network extension. Amount of expansions are measured by lane-miles and traffic capacity of highway is defined by 13,000 and 5,000 veh-miles/day/ln-mi for freeway and for arterial roads, respectively, according to Lomax Model. Discussion includes the following issues.

1. What is the induced travel demand by highway capacity expansion ?
2. What is the impact of highway capacity expansion on congestion level ?
3. What is the impact of highway capacity expansion on land use ?
4. What is the difference in impact between the expansion of freeway and that of arterial roads with same traffic capacities ?

First, some possible scenarios for highway capacity expansion are constructed. Next, the original model[15] is revised and run according to each scenario. Finally, model outputs for the scenarios are compared and analyzed.

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[14] Policy variables are different from the parameters in that they can be controlled by the political decision. Most of parameters are uncontrollable ones, such as birth rate.

[15] Current policy impact analysis is done using land use/transportation system performance forecasting model for the years 1990-2010 for the study area, Montgomery County, MD. The forecasting model is validated and its performance is proved to be sufficiently meaningful. For them, see Chapter VI. Future Forecast of Land Use and Transportation System Performance in Lee, Sang Y. (1995).

2. Induced Travel Demand by Highway Expansion

There may be assertion that highway capacity expansion is useless for reducing the traffic congestion since it induces extra travel demand. However, it has not been evaluated clearly how much demand can be induced by the highway expansion. To analyze the amount of induced travel demand[16], 4 policy scenarios are constructed as follows.

- Scenario 1; All highways are fixed at initial year(1990) level.
- Scenario 2; Only freeways are expanded by 1 % every year.
- Scenario 3; Only arterial roads are expanded by 1 % every year.
- Scenario 4; Both of freeway and arterial roads are expanded by 1 % every year.

Induced Demand by the Expansion of Freeways

The analysis results show that the demand-inducing effect of highway capacity expansion is not much serious. Adding 1 % lane-miles of freeways every year (Scenario 2) brings additional total trip production by .04 % (2nd year), 1.73 % (10th year) and 6.42 % (20th year), while total freeway facility increases by 2.01 %(2nd year), 10.46 %(10th year), and 22.02 %(20th year). Induced daily trips per increased lane-mile are from 170.1 trips(2nd year) to 2328.5 (20th year). It implies that the addition of new highway facilities needs some time delays for inducing the travel demands.

[16] Here, the induced travel demand means any extra vehicle trips which are created *newly* due to the improved highway traffic condition.

Table 5.1 Induced Daily Trip Production by Highway Capacity Expansion (1)

Unit; lane-miles, 1000 veh trips/day

	Scenario 1			Scenario 2		
	Freeways (A)	Arterial Roads (B)	Daily Trips[1] (C)	Expanded Free-ways (% to A)	Total Induced Daily Trips(%)	Induced Trips/ln-mi
1991	292.58	1261.9	2351.0	2.93(1.00%)	0.0 (0.0%)	0.0
1992	292.58	1261.9	2463.0	5.88(2.01%)	1.0 (.04%)	170.1
1995	292.58	1261.9	2664.0	14.92(5.1%)	10.0(.37%)	670.2
2000	292.58	1261.9	2717.0	30.61(10.5%)	47.0(1.73%)	1535.4
2005	292.58	1261.9	2555.0	47.10(16.1%)	98.0(3.83%)	2080.7
2010	292.58	1261.9	2337.0	64.42(22.0%)	150.0(6.4%)	2328.5

1) These are the total amount of daily trips produced, not freeway traffic volume.

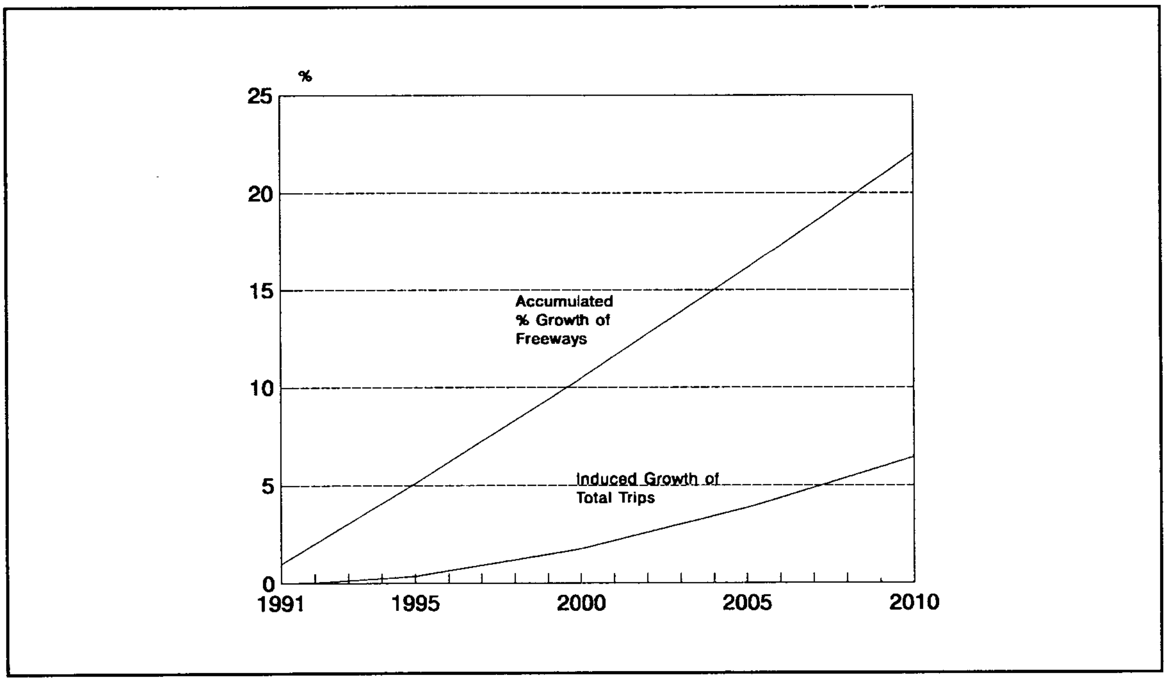

Figure 5.1 Accumulated Growth of Freeways and Induced Total Trips

Induced Travel Demand by the Expansion of Arterial Roads

Demand-inducing effect of expanded arterial roads are shown in Table 5.2. Adding 1 % lane-miles of arterial roads every year (Scenario 3) induces new daily trips by .04 %(2nd year), 2.61 %(10th year) and 9.80 %(20th year). Table 5.2 also shows the case of induced travel demand both by freeway and arterial roads (Scenario 4). The results indicate that induced demand by Scenario 4 is almost the same as arithmetic summation of the demands by Scenario 2 and 3. It implies that there is no multiplication effect even if freeways and arterial roads are added together. Induced daily trips per increased lane-mile are far less than in freeway (See Figure 5.1)

Table 5.2 Induced Daily Trip Production by Highway Capacity Expansion (2)

Unit; lane-miles, 1000 veh trips/day

	Scenario 3				
	Expanded Arterial Roads(% to **B**)	Total Induced Daily Trips (% to **C**)	Induced Trips/ln-mi	Freeways & Art. Rds (% to **A+B**)	Daily Trips (% to **C**)
1991	12.6 (1.00 %)	0.0 (0.0 %)	0.0	15.53 (1.00 %)	0.0 (0.0 %)
1992	25.3 (2.00 %)	1.0 (.04 %)	39.5	31.18 (2.00 %)	2.0 (.08 %)
1995	64.3 (5.10 %)	15.0(.56 %)	233.3	79.22 (5.10 %)	24.0 (.90 %)
2000	132.0 (10.46%)	71.0(2.61%)	537.9	162.61 (10.46%)	119.0 (4.38%)
2005	203.1 (16.10%)	149.0 (5.83%)	733.6	250.20 (16.10%)	254.0 (9.94%)
2010	277.8 (22.01%)	229.0 (9.80%)	824.3	342.22 (22.01%)	394.0 (16.86%)

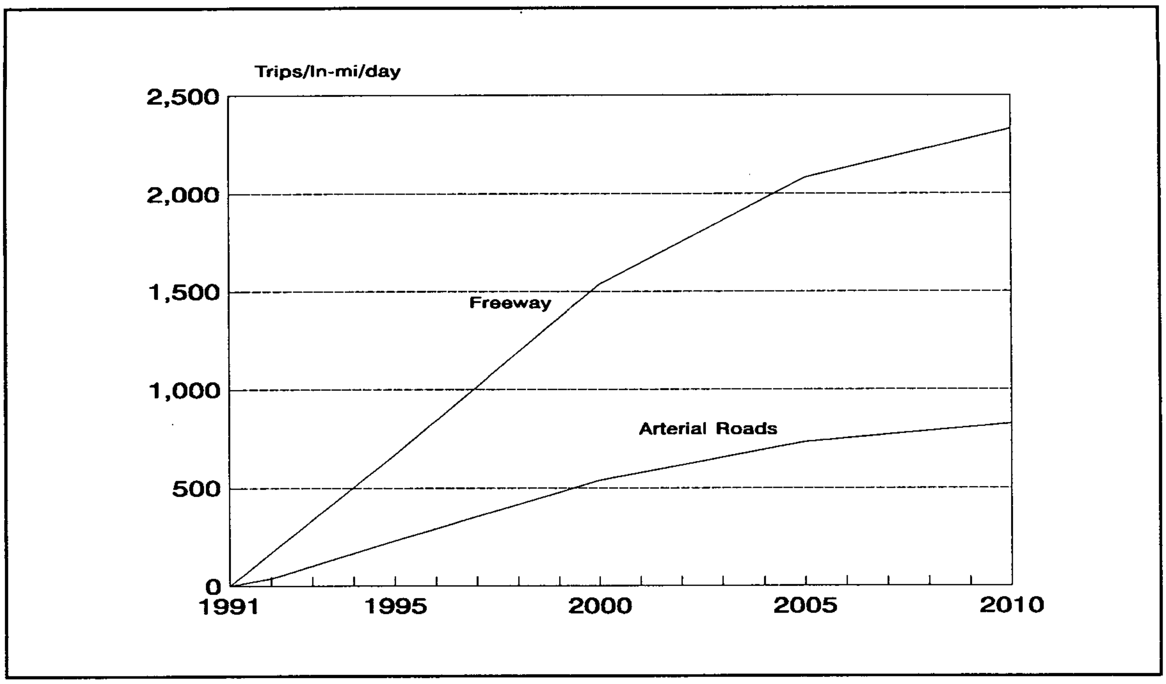

Figure 5.2 Induced Trips per Increased Highway Lane-Mile

Model running results discussed so far indicate the following inferences for the induced travel demand by highway capacity expansions.

1) Expansion of highway capacity does not induce so much travel demand. It is probably because the increase of land use and travel demand occurs by the combination of many complex factors. Highway supply is just one of many factors for the creation of new travel demand, and its impact on total land use and travel demand is not so serious. It is supported by the analysis results for the impacts of highway capacity expansion on land use.

2) There exist some delays for new highway facility to induce new travel demand. A new highway facility induces the land uses first - housing or commercial development, households and employment - and then invokes travel demand.

3) In the induced daily trips per increased highway lane-mile, freeways induces much more

trips than arterial roads. Its difference is more than that in normal traffic capacity. That is, freeway induces about 3 times more trips per lane-mile than arterial road, while assumed traffic capacity per lane-mile of freeway (= 13000) is 2.6 times of arterial road(= 5000).

3. Impacts of Highway Capacity Expansion on Congestion Level and Land Use

Impact of Highway Expansion on Congestion Level

The fact that new highway expansion does not induce much travel demand, and that it does with some time lags implies that it can contribute significantly to the reduction of the traffic congestion. Table 5.1 and Figure 5.3 show to what extent highway expansion can reduce congestion. They indicate that the effect of highway expansion on congestion reduction is immediate. However, despite increase of the fraction of new highway facilities year by year, the extent of congestion reduction is almost constant (See Figure 5.3). It implies that congestion reduction per expanded lane-mile decreases gradually as more trips are induced year by year, as shown in Table 5.1 and 5.2.

Table 5.3 **Congestion Level by Highway Expansion Scenario**

Unit; RCI unit

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1991	1.686	1.680	1.676	1.669
1992	1.768	1.756	1.748	1.735
1995	1.917	1.887	1.872	1.841
2000	1.963	1.921	1.899	1.855
2005	1.852	1.817	1.798	1.754
2010	1.701	1.679	1.665	1.629

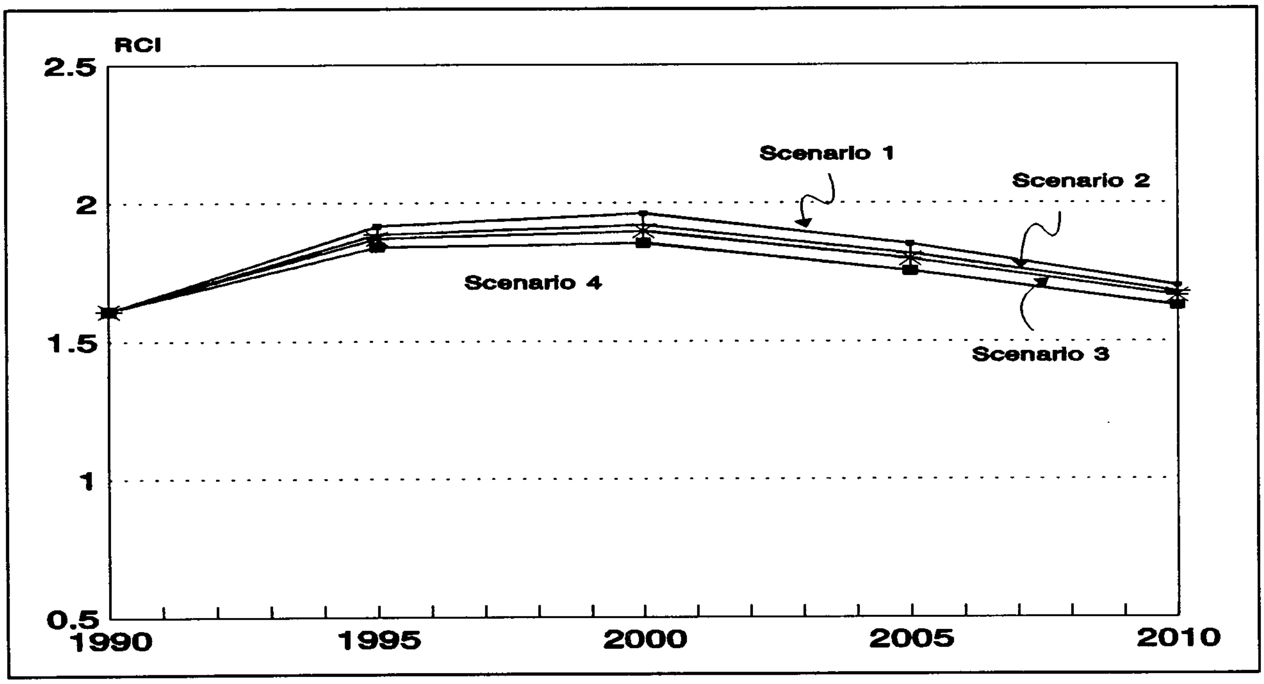

Figure 5.3 **Congestion Level by Highway Expansion Scenario**

Impact of Highway Expansion on Land Use

Impacts of highway expansion on land use are as shown in Table 5.4. There exist no significant differences between Scenario 1(No Expansion) and other scenarios in short-term period. That is, the impacts of highway facility on land use occurs gradually with some time delays.[17]

Table 5.4 Impacts of Highway Expansion on Land Use by Scenario

		1990	1991	1992	1995	2000	2005	2010
Total Population (in thousands)	Scenario 1	757.0	776.8	797.0	822.5	821.8	818.9	802.8
	Scenario 2	757.0	776.8	797.2	825.2	834.8	847.7	850.2
	Scenario 3	757.0	776.8	797.3	826.5	841.3	862.6	875.1
	Scenario 4	757.0	776.8	797.5	829.1	854.5	893.0	927.4
Total Households (in thousands)	Scenario 1	282.9	291.6	300.4	311.8	316.3	322.9	325.4
	Scenario 2	282.9	291.6	300.5	312.9	321.7	335.1	345.8
	Scenario 3	282.9	291.6	300.5	313.5	324.5	341.4	356.6
	Scenario 4	282.9	291.6	295.6	314.6	330.0	354.4	379.1
Total Employments (in thousands)	Scenario 1	429.6	432.7	419.3	436.8	464.8	481.7	505.8
	Scenario 2	429.6	432.7	419.5	438.4	470.9	492.5	520.1
	Scenario 3	429.6	432.7	419.6	439.2	474.0	498.1	527.8
	Scenario 4	429.6	432.7	419.8	440.8	480.4	509.8	544.5

4. Difference in Impact between Freeway Expansion and Arterial Road Expansion

Is there any difference in impact of highway expansion between freeways and arterial roads ? To analyze this, 3 more scenarios are set up as follows.

- Scenario 5; Only freeways are expanded by 5 lane-miles every year.
- Scenario 6; Only arterial roads are expanded by 13 lane-miles every year.

[17] However, this is not a general observation, but area- and time-specific phenomena. The extent and promptness of the impact of highway expansion on land use may vary depending on the type, areal characteristics, and stage of development.

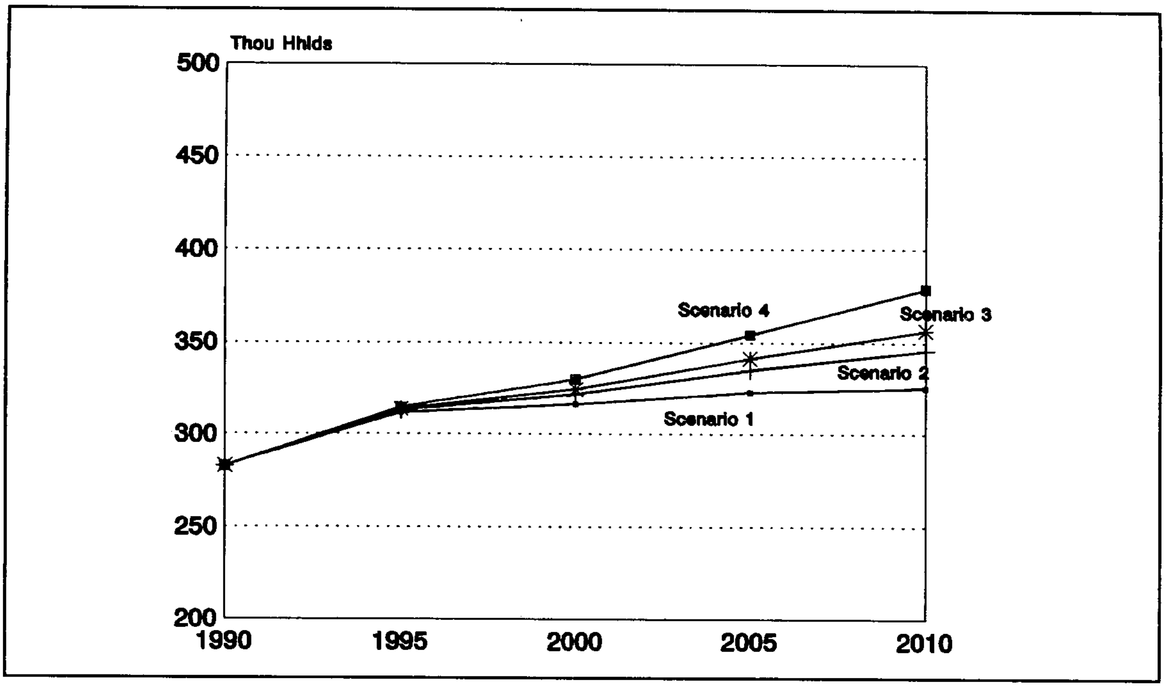

Figure 5.4 **Total Number of Households by Highway Expansion Scenario**

- Scenario 7; Both of freeways and arterial roads are expanded by 2.5 and 6.5 lane-miles, respectively.

Since in Lomax Model traffic capacity of 1 lane-mile in freeway and arterial road are 13,000 and 5000 vehicle trips per day, Scenarios 5, 6, and 7 have the same condition in traffic capacity. Model outputs for Scenarios 5, 6, and 7 are shown in Table 5.5 and Figure 5.5. The model outputs from Scenarios 5, 6, and 7 are almost same, though in strict values Scenario 7 produced slightly more and Scenario 6 least. Therefore, it can be stated that there is no significant differences in impact of highway expansion between freeway and arterial road.

Table 5.5 Differences in Impact of Highway Expansion between Freeway and Arterial Roads

Unit; 1000

		1990	1991	1992	1995	2000	2005	2010
Total Population	Scenario 1	757.0	776.8	797.0	822.5	821.8	818.9	802.8
	Scenario 5	757.0	776.8	797.4	826.9	842.6	864.5	875.1
	Scenario 6	757.0	776.8	797.3	826.6	941.4	862.0	873.1
	Scenario 7	757.0	776.8	797.4	826.8	842.8	865.8	880.2
Total Households	Scenario 1	282.9	291.6	300.4	311.8	316.3	322.9	325.4
	Scenario 5	282.9	291.6	300.5	313.7	325.0	342.1	356.5
	Scenario 6	282.9	291.6	300.5	313.5	324.5	341.2	355.7
	Scenario 7	282.9	291.6	300.5	313.6	325.1	342.8	358.7
Total Employments	Scenario 1	429.6	432.7	419.3	436.8	464.8	481.7	505.8
	Scenario 5	429.6	432.7	419.6	439.5	474.6	498.3	527.1
	Scenario 6	429.6	432.7	419.6	439.3	474.0	497.7	526.9
	Scenario 7	429.6	432.7	419.6	439.4	474.8	599.2	529.3
Total Trip Production	Scenario 1	2245.0	2351.0	2463.0	2664.0	2717.0	2555.0	2337.0
	Scenario 5	2245.0	2351.0	2464.0	2680.0	2793.0	2709.0	2565.0
	Scenario 6	2245.0	2351.0	2464.0	2679.0	2788.0	2702.0	2559.0
	Scenario 7	2245.0	2351.0	2464.0	2680.0	2794.0	2715.0	2582.0

VI. Conclusion

In the current paper, a system dynamics model which can generate the land use and transportation system performance simultaneously is proposed and applied to the evaluation of the impact of highway capacity expansion on land use for the Montgomery County, MD in USA. A policy impact analysis for the highway capacity expansion was performed using the developed system dynamics model. To analyze the induced travel demand, 7 policy scenarios for the highway capacity expansion are tested. The test results show that:

1) Demand-inducing effect of highway expansion is not so much. When the freeways are

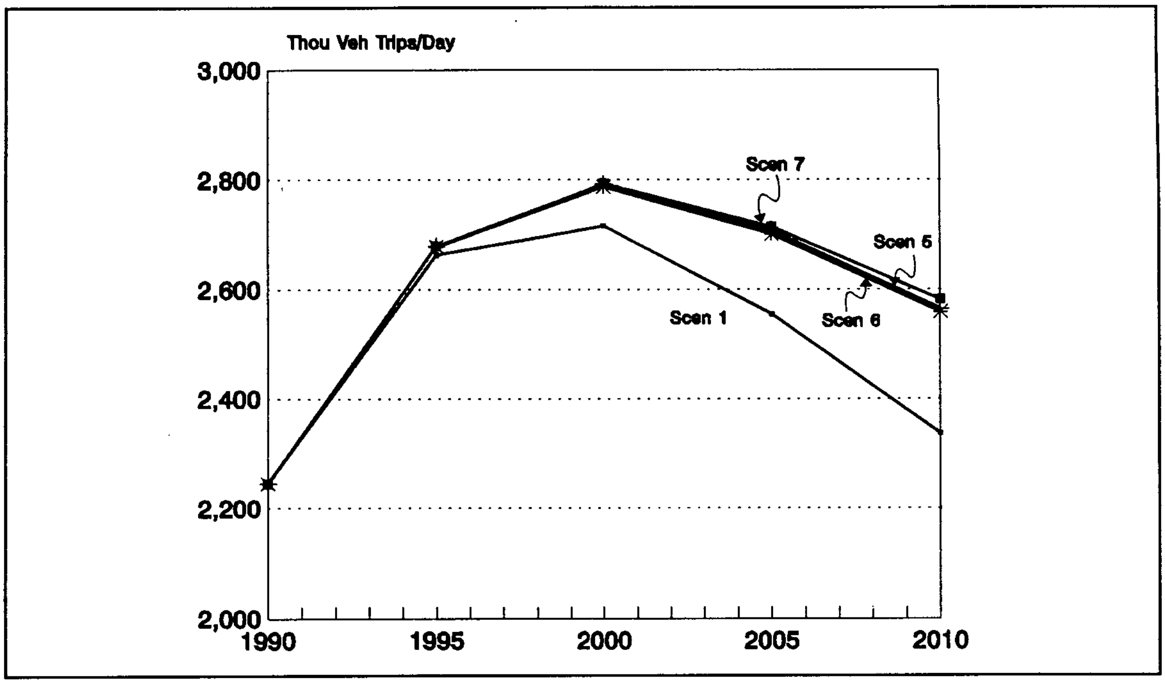

Figure 5.5 **Differences in Trip Production by Highway Expansion Scenario with Same Traffic Capacity**

expanded up to 22.02 % by 1 % every year from 1991 to 2010, daily trips are induced up to 6.42 % in 2010.

2) The freeway induces about 3 times more trips per lane-mile than arterial road.

3) It takes some time delays for new highway facility to induce new travel demand. In case of freeways, induced daily trips per expanded lane-mile is just 170.1 vehicle trips in the next year of the expansion and growing year by year.

4) Congestion reduction effect of highway expansion is immediate, but the effect per expanded lane-mile decreases gradually as more trips per new lane-mile are induced year by year.

5) The impacts of highway expansion on land use are considerably slow. For 4 years when the highways are expanded by 1 % every year, differences in land use performance

between Scenario 1 (No Expansion) and Scenario 4 (Both Expansion of Freeway and Arterial Roads) are .8 % increase in population, .9 % increase in households, and .9 % increase in employment. The 19 years' highway expansions induce 15.5 % more population, 16.5 % more households, and 7.65 % more employment.

Perspective for Future Research

This study is an attempt to develop and examine a comprehensive dynamic system simulation model for treating the interactions of land use and transportation system simultaneously. It is still in a preliminary stage and has some limitations. First, the model should be developed to a more detailed model at the traffic zonal level. Secondly, the model covers automobile mode only and should be expanded to include transit mode. Thirdly, for more accurate and powerful simulation of actual conditions, more behavioral variables are addressed. Additionally, more elaborate equations and parameter estimation techniques are needed to enhance the model performance.

The most advanced and challenging task is to developa full-scale land use/transportation model based on the system dynamics approach which contains the whole process of transportation planning and accounts for the interactions between land use, transportation planning, and other related areas such as air quality or energy use. Such a model can be a new comprehensive trasnportation planning tool which overcomes the shortcomings of conventional transportation planning models.

- The End -

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