TOPIC 1
TRANSPORT AND
LAND USE (SIG)

URBAN GROWTH AND TRAFFIC ENVIRONMENT UNDER A ROAD NETWORK CONSTRAINT

MASUO KASHIWADANI
Department of Civil and Ocean Engineering
Ehime University
Matsuyama, 790
JAPAN

YASUO ASAKURA
Department of Civil and Ocean Engineering
Ehime University
Matsuyama, 790
JAPAN

Abstract

In this paper we discuss the relationships between urban growth and the traffic environment by examining the relationships between car travel demand and a road network capacity. We assume that the road network in a city is fixed. The congestion level allowed by the city society is a parameter of the traffic environment.

INTRODUCTION

As a city grows the number of car trips increases. It is necessary to invest sufficiently in highway and street networks that can fully handle transport demand. However, it is not easy to supply a greater infrastructure for increased road traffic. We see awfully congested cities such as Bangkok in developing countries like Thailand. But the problem is not solved even in more developed countries. It is very hard to build a new highway or railway system in large cities because of expensive land prices and construction costs. Moreover, we do not have enough space to accommodate new transportation facilities in the center of cities even if they are underground. Recently, planners in developed countries have been more concerned with controlling transportation demand than struggling for a new highway or railway building in these circumstances. People are changing their minds too. For a long time they have resigned themselves to public nuisances such as traffic congestion or air pollution as inevitable misfortunes in exchange for prosperity produced by urban development. But now people are aware that the most important thing is a high quality of life and that the volume of urban development should be controlled if their environment quality level is damaged by urban growth. We can point out those changes of attitude toward traffic congestion, in both planners and citizens, as a reason why the transportation demand management strategies occupy attention in large cities of developed countries.

In this paper we discuss the relationships between urban growth and traffic environment by examining the relationships between car travel demand and a road network capacity. We assume that the road network in a city is fixed in this paper. The congestion level allowed by the city society is a parameter of traffic environment. The effect of urban growth on traffic volume is shown through an effective land use allocation plan using a Herbert-Stevens type land use model under a road network capacity constraint.

LAND USE ALLOCATION PLANNING MODEL UNDER A ROAD NETWORK CONSTRAINT

Studies of road network capacity and land use patterns

The relationship of road capacity and urban land use pattern has been studied in the field of urban economics by Mills (1969), Vickrey (1969), and Solow (1973). Most studies are discussed in a theoretical framework, especially those with a monocentric city hypothesis. There are some comprehensive urban land use and transportation models with two dimensional space using a more sophisticated version of the Herbert-Stevens model by Mills (1972), Hartwick (1974) and Rho and Kim (1989). Particularly Rho and Kim studied combining input-output and transportation planning models on a fairly large transportation network with 57 nodes and 172 links. They introduced a network equilibrium route choice using the BPR function in the model in terms of shipment cost on each link. However, this model is too complex for city planners to analyze the general relationships of urban activities and the transportation network in a city. Handier, more widely applicable and simpler models are needed.

Traffic engineering studies defined the network capacity as the maximum number of produced trips that can be loaded on the network within specific restrictions: physical, economic and/or environmental constraints. The study by Buchanan (1963) was one of the fundamental studies on the maximum capacity of an urban center. For actual cities, the central area capacity could be decided only by the capacity of approach roads. Another study by Smeed (1966) was concerned with the area capacity. Regression analysis was applied to show the relation of the number of moving automobiles with their average speed and the area specific variables. Olszewski and Suchorzewski (1987) investigated practically the maximum capacity in relation to parking space. However, these studies did not explicitly consider a road network structure of many nodes and links.

Japanese traffic engineers have tried to estimate the volume of a network capacity by using linear programming model (Masuya and Saito 1984) or traffic assignment simulation methods (Iida 1972). But they do not pay much attention to the efficient land use pattern in a city when they estimate the volume of a network capacity. They suppose only one kind of abstract land use activity. However, urban space, like transportation facilities, is a very scarce resources. Land use efficiency is one of the most important principles of cities. Thus studies which do not consider land use efficiency may be misleading. We should consider the level of land use efficiency and examine the effect of land use pattern on the traffic volume of links in a road network by introducing various kinds of activities.

Land use activity allocation plan

Suppose a city planning authority who plans to allocate new land use activities over zones in a city is concerned with land use efficiency and traffic environment. Let us assume the city is divided into many zones. Subscript i or j denotes a zone in the city and $N_{i.}$ the available land area in zone i. The road network in the city is given and subscript a denotes a link in the road network. It is also assumed that urban activities have already located in the zones and traffic volume on links are observed. Then the floor space in a zone which will be allocated in the plan indicates available volume of floor space added to the volume of floor space already used in the zone. Subscript k denotes the kind of activities. G_{ik} is the volume of floor space already located of activity k in zone i and X_{ik} is that allocated by the planning authority. V_a shows the traffic volume observed on a link a, that is generated by activities already located in the city and that passes the link. It is assumed that all trips which generate in a zone within the city end in any zone in the same city. The authority has to consider two conditions to attain a good urban environment in the land use activity allocation plan. The first concerns the relation of a building and the neighborhood, considering for example sunlight or good ventilation. Here these are referred to as neighborhood conditions. It is assumed that the neighborhood conditions are judged on the basis of the kind of land use activities. The second concerns the burden which activities in a building cast on the utility service network nearby, roads, water supply, sewage system and telecommunications, for example. Here these are referred to as utility service conditions. As for utility service conditions we consider only the road network in our model for simplicity's sake.

Link occupancy rate

The idea of equilibrium route choice should be introduced into our model because we consider the road network in a city. However, calculating user equilibrium traffic flow on a large scale network in the framework of a mathematical programming model is very complicated. Thus we propose a simpler method of the user's route choice. Our problem is to allocate additional available floor space in each zone. It is not improper to assume that the sum of floor space allocated in the model over zones and activities is considerably smaller than that already located there. Therefore, we assume that origin destination pattern and route choice rate of trips generated in additional floor space allocated in a zone is identical to that generated from activities already located in the same zone for all activities.

Suppose T_{ij} denotes the traffic volume whose origin is i and destination is j, T_{mij} the traffic volume which goes through path m, M_{ij} the set of paths between zone i and j. Destination choice rate P_{ij} and route choice rate g_{mij} are defined as follows,

$$P_{ij} = T_{ij} / \sum_j T_{ij} \tag{1}$$

$$g_{mij} = T_{mij} / T_{ij} \tag{2}$$

Using a variable d_{amij} which is equal to 1 in the case that a path m ($m \in Mij$) passes a link a and 0 otherwise, the link occupancy rate. Q_{ia} is defined by equation (3)

$$Q_{ij} = \sum_{j} \sum_{m} P_{ij} g_{mij} d_{amij} \tag{3}$$

The procedure for calculating the value of link occupancy rate Q_{ia} is as follows. First, the road network in a city and the values of traffic volume by origin and destination are given. Then traffic simulation is carried out using the usual incremental assignment method. The traffic flow pattern calculated is in an approximate equilibrium because passing time on a link is changed responding to the traffic volume on it at every step of the simulation. Link performance functions are used to represent the effect of congestion on passing time.

Strictly speaking, the assumption that the value of link occupancy rate does not respond to the solutions of the model is not true, because the pattern of trip generation responds to floor space allocated, that is the solution, and it affects the congestion level on links. Then the road network equilibrium assumed in calculation of Q_{ia} is not obtained with the solution of the allocation model. However, the purpose of our study is to analyze the relationships between floor space allocation and a road network capacity from the viewpoint of city planning which considers long term effects. Therefore, this assumption does not distort the conclusion of our study.

Allocation model

Suppose that the total amount of floor space for activity k, D_k in the goal year of our land use allocation plan is exogenously given in the model by the master plan of the city. Then the constraints of the planning are those related to the neighborhood and road network service conditions and the demand. Here we introduce a parameter which represents the service level of the road. There is no identically defined measure of road link capacity. Usually the amount of the capacity is calculated according to a standard method defined by the road transport department or bureau. Then a kind of coefficient called road service level or allowed congestion level is used to transform the amount of link capacity into actual traffic volume and a specific level of the coefficient is chosen by a planning agency. Suppose R denotes the allowed congestion level chosen by the planning agency.

Using X_{ik} floor space allocated for activity k in zone i and G_{ik} floor space already located the constrains of the land use allocation model is represented as follows.

a) demand constraint

$$\sum_{i} (G_{ik} + X_{ik}) = D_k \qquad \text{for all } k. \tag{4}$$

b) neighborhood condition constraint

$$\sum_{k} (G_{ik} + X_{ik}) / u_k = N_i \qquad \text{or all } i, \tag{5}$$

where u_k is the level of desirable standard neighborhood conditions for activity k and it is given exogenously.

c) link capacity constraint

$$\sum_{i} \sum_{k} Q_{ia} \alpha_k X_{ik} + V_a \leq R\, C_a \qquad \text{for all } a, \tag{6}$$

where α_k is the number of trips generated by activity k per unit floor space and C_a is the link capacity of a link a. Assume activity k is willing to pay b_{ik} bid floor rent of unit space in zone i and annual construction cost of buildings of unit floor space f is identical for all activities and zones. Then the imputed floor rent to land β_{ik} is defined as follows,

$$\beta_{ik} = b_{ik} - f \tag{7}$$

The total amount of imputed bid floor rent Y is shown as follows,

$$Y = \sum_i \sum_k \beta_{ik} X_{ik} \tag{8}$$

Then, the economically efficient allocation is to maximize the amount of Y. The land use allocation planning model is shown as follows,

$$max\ Y = \sum_i \sum_k \beta_{ik} X_{ik} \tag{9}$$

subject to

$$\sum_i (G_{ik} + X_{ik}) = D_k \qquad \text{for all } k, \tag{10}$$

$$\sum_k (G_{ik} + X_{ik}) / u_k = N_i \qquad \text{for all } i, \tag{11}$$

$$\sum_i \sum_k Q_{ia} \alpha_k X_{ik} + V_a \leq R\, C_a \qquad \text{for all } a. \tag{12}$$

The total amount of floor space for each activity D_k and an allowed congestion level R are both planning parameters of the land use allocation model. If we want urban growth on a large scale we choose a large amount of D_ks. If we want a very good traffic environment level we choose a strict level of, or a small value of R. According to the amount of each D_k and the value of R a land use allocation plan which is efficient economically is shown by the model, and the value of objective function Y is a measure of land use efficiency. We can understand the trade off in Y, D_k and R using this model.

COMPUTATION IN MATSUYAMA CITY

Zoning and road network

Matsuyama city has about 450 thousand people. Figure 1 shows 56 zones in the city. However, one central zone is removed from the set of available zones because it is a public park. The area where urban development is allowed is measured in each zone and the value of N_i is fixed for 70% amount of the area because it is assumed that 30% would be used as open space.

Figure 2 shows the road network which is used in our computation example. It is composed of the existing road network at present and some road links which will be completed in the near future. Travel demand in 1990 is assigned on the network using the standard incremental assignment technique. It is confirmed that there are no links in major roads where the rate of traffic volume assigned to link capacity is larger than 1.25. This value, 1.25, is the standard value to judge whether a road link is congested or not in Japanese road transportation planning. It means that the road network can sustain the future traffic demand increase. The number of nodes is 208 and the number of links is 673 which are counted in such a way that different directions on a link mean two links. Only links along major routes in the city are used in the land use allocation model because the number of links in the network is too large to compute. They are shown in bold lines in the Figure. The number of link capacity constrains in the model is 272.

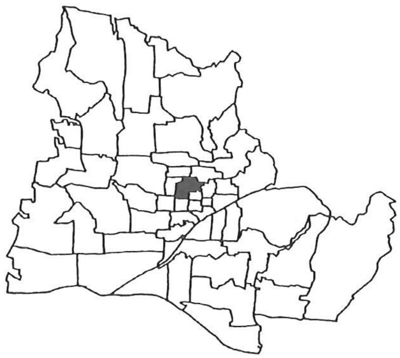


Figure 1 Zoning

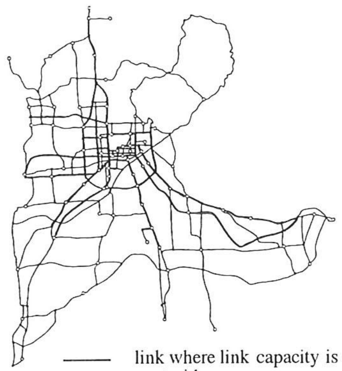


Figure 2 Road network

Land use activities

Land use activities are commercial, business, industrial, houses, apartments and other facilities. Estimating the amount of bid floor rent by zone and activity is difficult due to lack of the market floor rent data. Instead we estimated the approximate bid floor rent by use of land price data because we have fairly accurate and detailed land price data for the city. It is assumed that the value of the land price is twenty times the amount of one year's land rent and the rent is equal to the value of floor space rent multiplied by the observed floor area ratio in 1990. The average land price of activity k at a zone is calculated and it is divided by the number of average observed floor area ratio over all buildings in the zone. Bid floor rents used in the model are estimated this way. Table 1 shows the average value of estimated bid floor rent for each activity in concentric rings from the city center. The value of bid floor rent of commercial or business is much larger in the first ring than that in the other rings, and than that of the other activities in the first ring. As for the other four activities, the value of bid floor rent n the second ring for each activity is the highest of the rings. This is because although the land price in the first ring is higher than that in the second ring, the value of observed floor area ratio in the first ring is much larger than that in the second ring, in the case of apartments, houses and industry. In the case of other facilities the land price in the first ring itself is less than that in the second ring.

Table 1 Average value of estimated bid floor rent by ring (100 yen /m^2/year)

Ring	1	2	3	4	5	6	7	8	9	10
Distance(km)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Houses	39.1	51.4	48.4	43.9	35.6	27.0	27.9	22.7	12.6	13.5
Apartments	49.9	60.3	53.7	45.3	36.8	28.4	30.7	24.6	13.3	12.5
Commerce	215.1	79.2	64.9	46.1	38.8	29.8	33.5	37.6	19.0	6.0
Business	102.6	67.3	57.3	47.5	41.7	28.6	32.0	30.2	16.3	8.5
Industry	37.4	49.2	46.5	41.8	34.9	23.7	23.7	19.1	11.4	9.7
Other Facilities	20.7	42.4	41.9	38.5	33.2	24.4	25.8	18.3	11.1	12.2

Table 2 shows the total amount of floor space by activity in the city. The incremental amount from 1979 to 1991 is fixed as the standard amount of D_k. It is denoted as D_k^0 for activity k in this computation example. Then the parameter S which satisfies the following equation is introduced

$$D_k = S\, d_k^0 + \sum_i G_{ik} \qquad (13)$$

As a whole, the rate of the incremental floor space to floor space already located in 1991 is about 25%. The value of u_k the level of desirable standard floor area ratio values for neighborhood conditions is selected from the standard code of the Japanese City Planning Act. They are 200% for houses, 600% for business and commercial and 400% for apartments, industrial and other facilities.

Table 2 The amount of floor space by activity (1000m²)

	1979	1991	increment (1979-91)
Houses	9466	11847	2381
Apartments	1289	2797	1508
Commerce	1493	1852	359
Business	774	1302	528
Industry	2225	2561	336
Other Facilities	787	1159	372

Link occupancy rate and trip generation rate

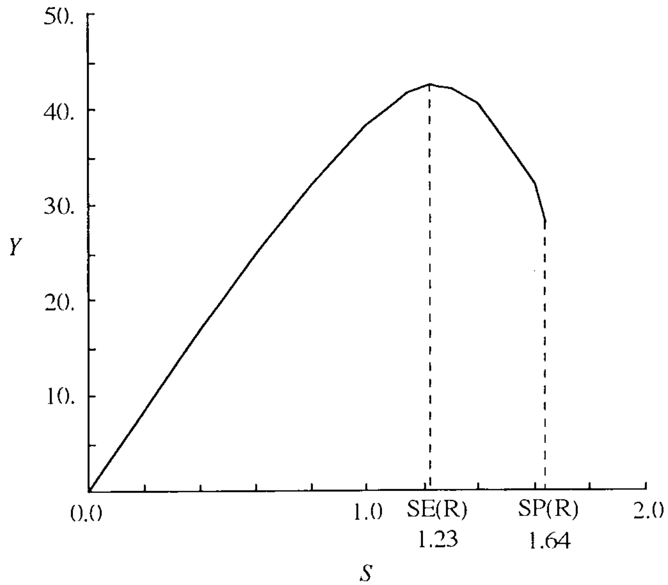
The value of link occupancy rate is obtained by traffic assignment simulation results of 1990 travel demand on the network which is used in the model. The amount of V_a at each link is obtained at the same time. Capacity of each link is calculated using a traffic engineering manual of the Ministry of Construction, and road data offered by local governments before the traffic assignment simulation. The values of trip generation rate per unit floor space are specified by using the 1979 Person Trip Survey in the Matsuyama metropolitan area. They are 75.52 / $1000m^2$ for business, 38.18 for commercial, 11.69 for industry, 25.52 for other facilities, and 9.11 for both apartments and houses.

Computation results

A series of land use allocation plans were computed by changing the value of R and S.

Standard congestion level results with various S levels

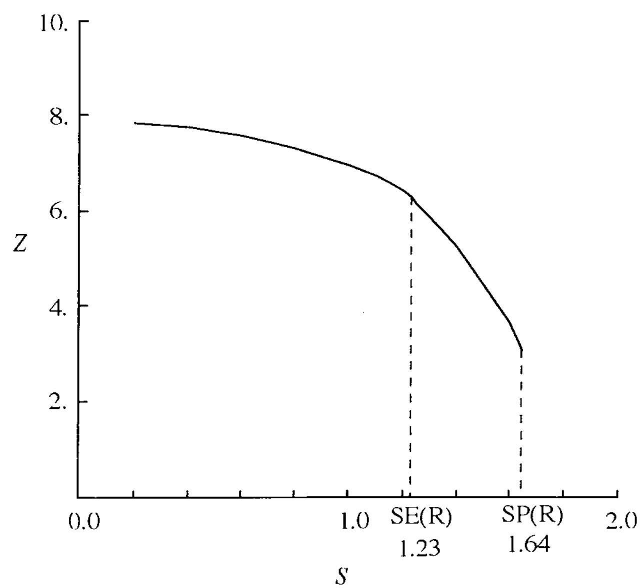
Figure 3 shows the relationships between S and Y, where the value of R is kept at 1.25. The amount of objective function in the land use allocation model increases almost proportionally to the value of S in the domain of lesser S values. However, the amount Y peaks at a point, SE(R), on S=1.23, and decreases thereafter. The model has no feasible solutions after the value S exceeds 1.64. This S value means the maximum S value where the model has a feasible solution. Then S is considered to be the physical maximum capacity of floor space which the road network can sustain and it is denoted by SP(R).



Note: Y (billion yen /year)

Figure 3 S-Y Relationship at R=1.25

Figure 4 shows the gross average floor rent over zones where activities are allocated along the value of *S*.



Note: Z (thousand yen/m^2/year)

Figure 4 Gross average floor rent and S (R=1.25)

The gross average floor rent Z is defined as follows:

$$Z = Y/\left(\sum_i \sum_k X_{ik}^*\right) \tag{14}$$

where X^*_{ik} is the amount of allocated floor space for activity k and at zone i. It decreases slightly along increasing S where the value of S is small. This is because land use activities are allocated in smaller bid rent zones as the value of S increases. It proceeds gradually because link capacity constraints do not strongly affect the solutions in the small S domain. The degree of increasing S is larger than that of decreasing Z. As a result the amount of Y is increasing in the small S domain. On the other hand, The average floor rent is sharply decreasing as the S value goes over SE(R) and towards SP(R). This is because the link capacity constraints dominate the characteristics of solutions in the larger S domain. Some of the link capacity constraints become full and they push out land use activities towards lower bid rent zones. A dispersed floor space allocation plan is needed for the road network to sustain a very large number of trips generated from the floor space allocated. The greatest volume of activities are allocated in remote suburban zones where bid floor rents are lower as the S value approaches SP(R). The decreasing degree of bid rent prices in zones where activities are allocated is much larger than the increasing degree of S in the domain where the value of S is over SE(R). As a result , the total amount of bid rent obtained in the city, the objective function value Y is decreasing while the city size is increasing where the value of S is over SE(R).

The road network capacity which has been estimated by Japanese traffic engineering researchers so far corresponds to SP(R). Thus it is doubtful whether the value of physical capacity of the road network is useful for city planning. The domain of S beyond SE(R) to SP(R) is an overcrowded area for the road network. The city can accept a greater traffic volume but looses economic benefit. If the idea that the increase of Y benefits society is accepted, the maximum capacity of floor space that should be allowed by city authority lies on the point SE(R).

S-Y relationships with various R value

Figure 5 shows relationships between S and Y with various R values. The computation results when R value is 1.10 or 1.05 are not shown because they are not feasible solutions. It is seen that both SE(R) and SP(R) become larger as the value of R increases. This means that decreasing the traffic environment level brings about larger urban development capacity. In other words, if we want a good traffic environment, a low congestion level, we should strictly control urban development. It seems that SE(R) and Y at each point are both increasing proportionally to the increase of R value. In this computation, decreasing traffic environment level easily and effectively enlarges the urban development capacity. This is because link capacities are essential constraints in the model. Neighborhood condition constraints are a kind of variation of available area constraints and there are enough space for floor space demand in the city.

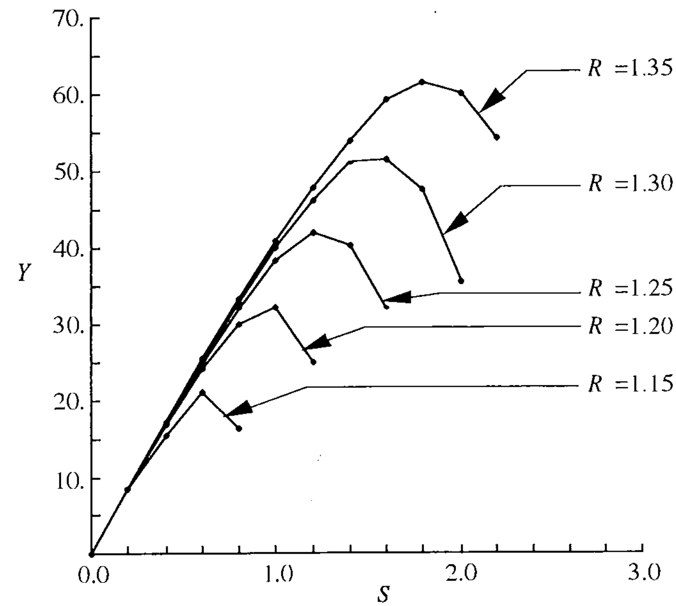
Increasing floor bid rent with urban scale

It is well known that economic activities in a larger city enjoy greater of profit than those in a smaller city because of the agglomeration economy effect. Nevertheless, the bid rent price of each activity has been constant to the urban scale so far in this paper. Therefore, the average floor bid rent over zones where activities are allocated decreases as the city grows (see Figure 4). Let us introduce an increasing floor bid rent with urban scale λik as follows:

$$\lambda ik = \beta ik(1+\theta S) \tag{15}$$

where θ is a parameter to represent agglomeration economy effect. The gross average floor bid rent corresponding to the increasing bid rent ZI is defined with equation (16)

$$ZI = \left(\sum_i \sum_k \lambda_{ik} X_{ik}^*\right) \div \left(\sum_i \sum_k X_{ik}^*\right) \tag{16}$$



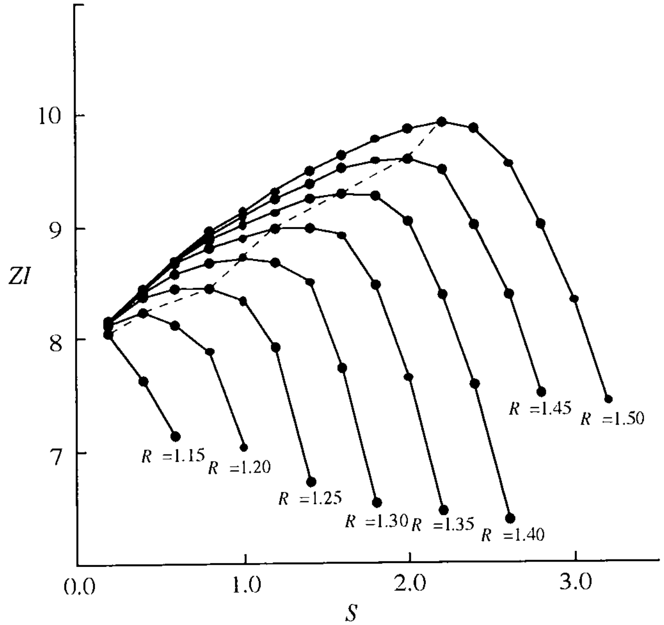
Note: Y(billion yen/year)

Figure 5 S-Y relationship with various levels of R

Figure 6 shows the relationships between *S* and *ZI* with various values of *R* when the value of θ is specified 0.2. It is seen that the value of *ZI* is increasing as the value of *S* increases in the smaller *S* domain. It is considered that link capacity constraints in the model do not strongly affect the solution where the value of *S* is small. While the area where activities are allocated gradually enlarges to the lower bid rent zones the price of floor bid rent in each zone itself is increasing as the value of *S* increases. The effect of introducing the increasing floor bid rent is larger than that of activity allocation to lower bid rent zones. As a result the amount of gross average floor bid rent *ZI* is increasing. However, link capacity constraints become more powerful and zones where activities are allocated are dispersed toward remote suburban areas even after introducing increasing floor bid rent as the value of S becomes larger. The effect where activities are allocated in lower floor bid rent zones overrides the increasing floor bid rent effect in the larger *S* domain.

It is seen that the peak value of *ZI* and its location on *S* measure is increasing as the value of *R* increases. The dotted line in the figure shows connected *ZI* peak values along increasing *R* value. If we want more economic prosperity rather than better traffic environment we can go along the dotted line. If we tolerate a worse level of traffic environment we can accommodate a greater traffic volume, and a larger number of land use activities, in the city. And economic agglomeration produces more monetary benefits as the city grows. The less *R* value leads to larger *S* value and the larger *S* value supports a greater *ZI*, and economic agglomeration produces more monetary benefits as the city grows.

Suppose we are approaching the SE(R) point with a road network system. We are aware of loosing economic benefit if the city continues to grow. There are three alternative scenarios for the city. The first is the investment to improve the road network, the second is the people's endurance of traffic environment and the third is controlling the city growth. Investment gives possibilities to enable the city to have both more growth and a better environment level, but it takes a lot of money. We do not need so much money in the other cases. However, each scenario improves one element but reduces another. People's endurance enables the city growth and economic prosperity but reduces environment quality. Growth control enables us to keep the environment quality level but we have to give up the greater economic prosperity of the agglomeration effect.



Note: Z (thousand yen/m^2/year)

Figure 6 Gross average floor rent and S with various R level

In developing countries people are more eager to obtain economic prosperity and urbanization pressure is more powerful. It is plausible that people prefer urban growth to traffic environment. People's endurance for the environment does not cost much, while building new transportation facilities is expensive. Moreover, investment in new highways may not effectively enlarge the road network capacity. Even if the highways relieve some heavily congested links they can give rise to another bottle neck links as the city grows gradually, because of the decreasing marginal effect characteristics of the road network system. Improving a road network system often brings only local effects. However, further endurance, that is decreasing traffic environment level, increases all the link capacities in the city at once at no cost. Endurance of a worse traffic environment is a very powerful strategy to enlarge the urban scale with more economic efficiency. On the other hand, people come to attach equal or more importance to environment quality in cities as against economic prosperity and there is less urbanization pressure in developed countries. The decreasing marginal utility of the road network system is seen in those countries, too. Therefore, traffic demand management is a reasonable and sometimes attractive strategy to improve the quality of life in developed countries.

CONCLUSION

Overcrowding phenomena are common and a serious problem in the worlds' large cities. Such congestion is caused by too heavily concentrated demands or lack of capacity in the infrastructure. Peoples' judgment of overcrowding depends on their standard level of quality of life. Therefore, if we want to discuss congestion problems in cities we must analyze relationships of the level of infrastructure improvement, the amount of urban development demands and the standard level of the quality of life through economically efficient land use patterns.

A model for this is presented in this paper. The model is a mixture of the maximum road network capacity model and a Herbert -Stevens type land use allocation model. The model is applied to

Matsuyama city and some interesting results are found. First, the revenue of society increases for a while but after that decreases as the amount of demand increases. Too much demand does not produce more revenue. Second, there are two kinds of development capacity under a level of infrastructure. They are economic capacity from the viewpoint of the amount of revenue of society, and physical capacity. The domain between economic capacity and physical capacity can be called the overcrowding demand area for the infrastructure. The economic capacity is more interesting and the physical capacity estimated by Japanese traffic researchers is less meaningful for city planners, because the total amount of revenue decreases as the value of S becomes larger beyond the economic capacity. Third, improving the quality of life decreases the amount of urban development capacity very effectively in this model.

The trade off between urban growth and traffic environment is more interesting under the assumption of an agglomeration economy, increasing floor bid rent to scale. Preference of economic prosperity over environment quality level and large urbanization pressure which are seen in developing countries lead people to choose urban growth with higher income in a worse traffic environment level. It is possible explanation why many large cities in developing countries suffer from heavy traffic congestion and their situation becomes worse year by year. On the other hand, traffic demand management is an attractive strategy for city planning in developed countries where people prefer environment quality to economic prosperity, and urbanization pressure is weak.

There are some restrictions in this paper. First, some of these results may reflect the characteristics of the model presented and the road network given exogenously. Therefore, they may not be concluded to be general relationships. Second, we do not sufficiently discuss the improvement effect of the road network system in this paper. Investment in transportation facilities is basic and a powerful strategy to improve the economic and environmental conditions of a city in spite of its difficulties in both developing and developed countries. We should study it in the near future. However, the results shown in this paper suggest solutions and are useful for us to understand congestion problems in cities.

REFERENCES

Buchanan, C. (1963) *Traffic in Town*, Report of the Steering Group and Working Group appointed by the Minister of Transport, London.

Hartwick, P.G. and Hartwick, J.M. (1974) Efficient resource allocation in a multi-nucleated city with intermediate goods, *Quarterly Journal of Economics*88, 340-352.

Iida, Y. (1972) Methodology for maximum capacity of road network, *Transactions of Japan Society of Civil Eng*, 200-201.

Masuya, Y. and Saito, K. (1989) Application of T-Region in a linear programming problem to the calculation of zonal trip generation and attraction, *Proc. of Japan Society of Civil Eng,* 407 147-150 (in Japanese)

Mills, E. (1969) Value of Urban Land in H. Perloff (ed) *The Quality of Urban Environment*, R.F.F.

Mills, E. S. (1972) Markets and efficient resource allocation in urban areas, *Swedish Journal of Economics* 74, 100-113.

Olszewski, P. and Suchorzewski, W. (1987) Traffic capacity of the city center, *Traffic Engineering and Control*, 28, 363-343.

Rho, J. H. and Kim, T.J. (1989) Solving a three-dimensional urban activity model of land use intensity and transport congestion, *Journal of Regional Science* Vol.29, No.4, 595-613.

Smeed R.I. (1966) Road Capacity of City Centers, *Traffic Engineering and Control,* 8, 455-458.

Solow, R. M. (1973) Congestion cost and the use of land for streets, *Bell Journal of Economics and Management Science* 4, 602-618.

Vickrey, W. S. (1969) Congestion theory and transport investment. *American Economic Review Proceedings* 59, 251-260.