THE EFFECTS OF TRANSPORT FACILITY IMPROVEMENTS ON RESIDENTIAL LOCATION AND HOUSING SIZE.

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INTRODUCTION

The aim of this study is to discuss the effects which the transportation facility improvements affect the residential location and the housing size of individual households, on the basis of a simplified housing demand mechanism.

It is an important subject in urban planning studies to analyze the effects of transportation improvements on the distribution pattern of residences. However, this is a macroscopic problem. In order to seek a solution to the problem, the microscopic phenomena should be settled first. That is to say, the response of each household's behavior in the housing demand to the transportation improvements should be examined .

Many studies on the individual household's behavior in the housing demand have been made up to now. Their theories can be classified broadly into two groups ; one is the deterministic theory which has been developed on the basis of the marginal utility theory [1 ~ 3], and the other is the stochastic disaggregate theory of which the logit model is typical[4 ~ 8]. These theories are elaborately developed, but they have some shortcomings.

The traditional deterministic theory has two serious shortcomings in the budget constraint. The one is that though the budget for leisure time is an important factor for deciding the residential location, this budget has not been considered in the traditional theory. The other is that the rent gradient in an urban area is regarded as a given condition in the budget constraint. The rent per unit of land must not be exogenous to the system, but endogenous. Because it is considered that the demand for land causes such rents.

A weak point in the stochastic disaggregate theory is that the mutual relationships among the factors constituting the theory are unclear and inaccurate, because each factor in the theory is considered as a random variable. Therefore, the stochastic model is not always adequate for analyzing the effects of transportation improvements on the individual household's behavior in housing demand.

A simplified housing demand mechanism in this study comes under the deterministic theory. This study examines, theoretically, the following question on the basis of the simplified theory ; what effects does a change in the travel speed to and from work have on the residential location and housing size of individual households ?

And numerical examples of this are also shown.

1. REAL STATES OF POPULATION DISTRIBUTION TRANSITION

It goes without saying that an increase in travel speed is one of the major causes that bring about a change in the population distribution in an urban area. Here is a typical example of it.

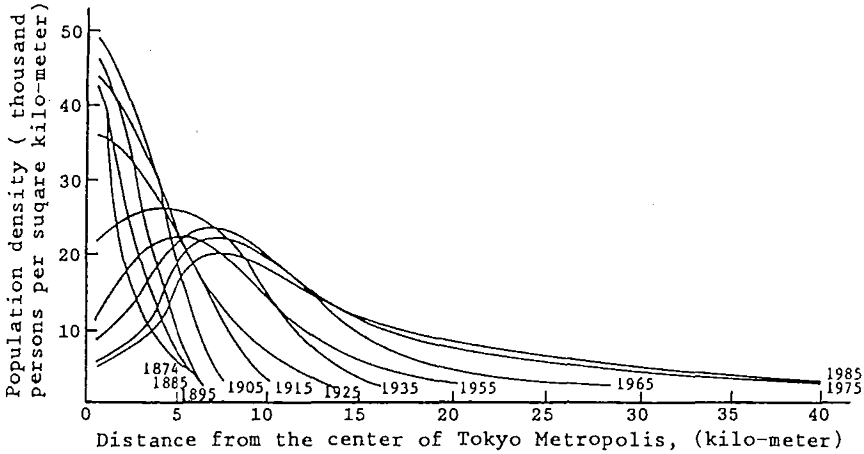

Fig.1 The changes in Population Distribution in Tokyo Metropolitan Area, 1874-1985.

Figure 1 shows the transition of the approximate population distribution in the Tokyo Metropolitan Area from 1874 to 1985, and how the suburbanization of the population has been promoted largely during the past 110 years[10]. And, between 1874 and 1985, the Metropolitan Area's population has grown from one million to twenty five millions. Figure 2 shows the extension of one hour's distance from the center of the Metropolitan Area for the same period[10]. Where, the " one hour's distances " since 1925 have been calculated based on the assumptions that the main mode of trans-

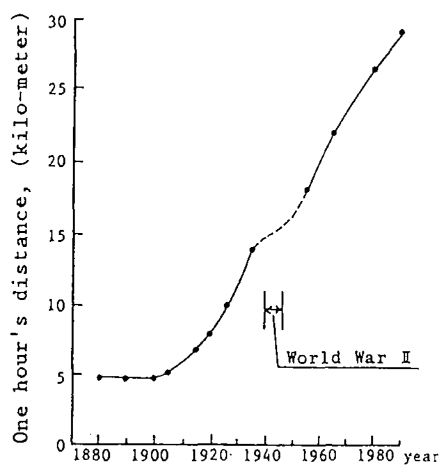

Fig.2 The extension of one hour's distance from the center of Tokyo Metropolis, 1880-1990.

portation has been rail transit and the out-of-vehicle time has been nearly equal to 20 minutes. This expansion of one hour's distance has depended on the innovations in railroading skills alone.

It can be considered that the trend of suburbanization in population shown in Figure 1, unquestionably, has been caused by an increase in travel speed.

2. OUTLINE OF SIMPLIFIED HOUSING DEMAND MECHANISM

A paper describing a simplified housing demand mechanism has been published[9]. In this section, a summing-up of it is given. The following summarization is expressed with an improved mode of expression, however the basic concept of the paper has not been changed in the least.

2.1. Indifference Curve and Budget Line

The basic factors comprising the housing - demand mechanism, other things being equal, are the per capita income (I), the per capita floor space (A)(hereafter called housing size), the per capita housing demand price (P) (hereafter called housing demand price), and the per capita travel impedance to and from work (T)(hereafter called travel impedance). And, the mutual relationships among these basic factors are introduced as follows;

$$A = A_o \exp (\gamma \Pi + \nu T) \qquad (1)$$

$$P = \beta \Pi \qquad (2)$$

where,

- Π : the housing-cost-bearing capacity per capita ($I-I_o$), and I_o the per capita income of a household without any housing-cost-bearing capacity
- A_o : the smallest housing size which the households without any capacity (Π) ask for at the residential place where the travel impedance to work is zero
- β and γ : coefficients

$$\nu = 1 / \beta \Pi \qquad (3)$$

Moreover, (T) denotes the value dividing the real travel impedance by the number of household members.

Equation (1) represents the indifference curve in the combinations of the housing size and the travel impedance when the housing-cost-bearing capacity (Π) is fixed.

A budget line is introduced from a view point that a worker who needs much more leisure time tends to choose his home close to his work place. Then, the budget line can be represented as the following equation :

$$E'' = p\ A - T \tag{4}$$

where,
E'' : the per capita budget for leisure time
p : the housing price per unit floor area

2.2. Travel Impedance, [11]

This study assumes that a trip to work consists of an access trip(: walk to station), a line-haul trip, and an egress trip (: walk to work place). And then, the relationships between travel impedance to and from work (T), travel time (one way) (t), and travel distance(one way) (D) are set up as shown in Figure 3. In order to simplify the following theoretical development, it has been assumed that there is no waiting time at any station. In Figure 3, T_o, t_o and D_o respectively stand for the travel impedance of the access and the egress(round trip), the sum of the access time and the egress time (one way) and the sum of distances for the access and the egress (one way).

First, we consider the travel impedance in the case where a trip to and from work is made by only one mode m, namely, the trip does not have any terminal trips. In this case, the relationships between T, t and D, and the indexes related to them are as follows :

$$T = 2\,a_m\ t = 2\,a_m\ D\ /\ V_m \tag{5}$$

$$a_m = \beta\ \Pi\ \eta_m \tag{6}$$

$$\eta_m = 1\ /\ t_{m.max} \tag{7}$$

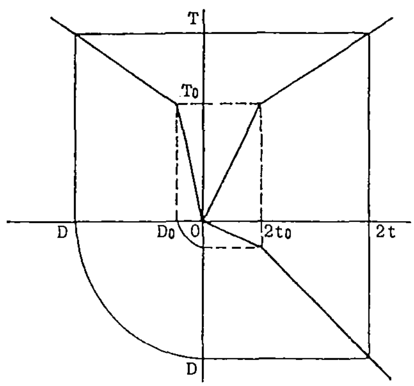

Fig.3 A relationship between travel impedance (to and from work) T, travel time (to and from work) 2t, and travel distance (one way) D.

where,
a_m : the travel impedance per unit travel time by mode m
V_m : the travel speed by mode m
$t_{m.max}$: the real maximum travel time to work by mode m
Each travel mode has its own real maximum travel time. Therefore, each travel mode has its own value of η_m.

Next, in the case where a trip to and from work has some terminal trips, the travel impedances to and from work (T) in the first and second quadrants of Figure 3 are expressed as follows :

$$T = 2\,a_m\ t - 2\ (\ a_m - a_w\ )\ t_o\ \ ,\quad t > t_o \tag{8}$$

$$T = 2 \left(\frac{a_m}{V_m} D - 2 \left(\frac{a_m}{V_m} - \frac{a_w}{V_w} \right) \right) D_o \tag{9}$$

2.3. Equilibrium Travel Impedance and Equilibrium Housing Size

When a worker makes a budget for organizing his house and leisure time, if he is a rational consumer, he must decide on his residential location and housing size to get the maximum utility from them. This maximum utility is yielded at the equilibrium point$(\hat{A}, \hat{T})$ where the budget line just touches the indifference curve as shown in Figure 4. The indifference curve in this case is represented by equation (1) and the budget line can be represented by equation (4).

The equilibrium travel impedance to and from work $(\hat{T})$ and the equilibrium housing size $(\hat{A})$ are obtained as follows:

$$\hat{T} = \beta\, \Pi - E'' \tag{10}$$

$$\hat{A} = A_o \exp\,(\, \gamma\, \Pi + \nu\, T\,) \tag{11}$$

And the equilibrium housing price per unit floor space (p) is

$$\hat{p} = \beta\, \Pi \,/\, \hat{A} \tag{12}$$

Accordingly, if the per capita budget for leisure time (E'') and the housing-cost-bearing capacity per capita (Π) are given, the equilibrium values $\hat{T}$, $\hat{A}$, and $\hat{p}$ are obtained from equations (10), (11) and (12).

If a worker does not budget his leisure time, he is obliged to live in the furthest residential place where travel impedance (T) attains maximum value (T_{max}). This maximum value is

$$T_{max} = \beta\, \Pi \tag{13}$$

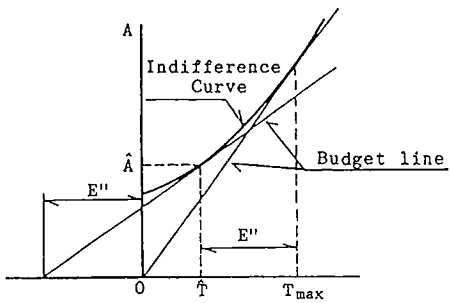

Fig.4 Consumer optimal equilibrium between per capita floor area and travel impedance.

3. EFFECTS OF AN INCREASE IN TRAVEL SPEED

In this section, we will develop a theory for the following subject : in what way does an increase (from V_L to V_H) in the travel speed of the main mode affect the residential location and housing size of individual households? Particularly, we will consider the case in which a new high-speed transit named (H) takes the place of an old low-speed transit named ⟨L⟩.

3.1. Basic Premises

As the travel impedance is expressed by equation (9), the indifference curve in the combinations of housing size (A) and travel impedance (T) can be transferred to that in the combinations of housing size (A) and travel distance to work (D). In this case, the equation of indifference curve in the A-D combinations is a little complicated. Therefore, in order to develop a clear-cut theory, every trip to work is assumed not to have any terminal trips. That is to say, $D_0 = 0$ and $T_0 = 0$. This assumption should not vary the essential qualities of the issue.

When the main mode is the low-speed transit, from equation (9), the relationship between travel impedance (T) and travel distance (D) becomes

$$T = (2 \alpha_L / V_L) D \qquad (14)$$

And, from equations (1) and (14), the indifference curve in the combinations of housing size (A) and travel distance (D) can be obtained as follows:

$$A = A_0 \exp \{ \gamma \Pi + \nu (2 \alpha_L / V_L) \} D \qquad (15)$$

Equation(14) illustrates the line V_L in the fourth quadrant of Figure 5, and equation(15) the curve U_1 in the first quadrant. Here, using Figure 5, we discuss the following questions : if the travel speed increases from V_L to V_H, where does the household (which locates itself at point D_1 and lives in a residence of size (A_1)) move their residential location to ? Also what size of house do they choose there ?

If the household which lived at the point D_1 before the transportation improvement stays there after its improvement, the household can enjoy the amount of the reduction (ΔT) in the travel impedance as a benefit caused by the speed up. In this, we meet a problem that there may be some households which are unwilling to get the benefit (ΔT) without compensation and who will move their residential location from point D_1 under the equilibrium point ① from point D_2 under the equilibrium point ①′. However, this case seems to be quite unusual.

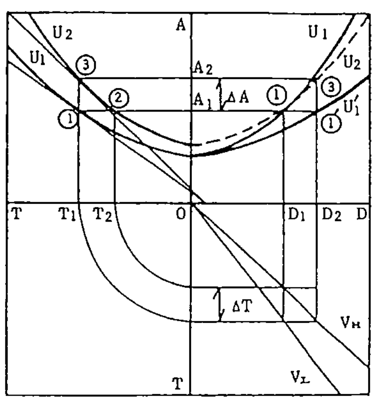

Fig.5 Effects of increase in travel speed on equilibrium.

It is quite natural for households to enjoy the increases in quality of life brought about by societies efforts, despite having contributed nothing to those improvements themselves. Therefore a new indifference curve under the new situation is set up and a new residential location and a new housing size are decided on. If the household stays at the same point(D_1) and lives in a residence of the same size (A_1) before and after the transportation improvement, its travel impedance decreases by ΔT, and the residential location on the travel impedance shifts from ① to ② in the second quadrant of Figure 5. Then the indifference curve in the quadrant may shift from curve U_1 to curve U_2. This curve U_2 is in accord with the indifference curve of a household whose housing cost-bearing-capacity (Π) might be higher than the one on curve U_1 before the transportation improvement.

Here, representing the remainder between these two housing cost-bearing-capacities by $\Delta\Pi$, it can be regarded that the increase in travel speed apparently has the same effect on the household as the housing cost-bearing-capacity increases by $\Delta\Pi$. And the reduction (ΔT) in the travel impedance that is produced by the improvement increases with the residential location of a worker's before the improvement. The following theories have been developed under the above view points.

3.2. Indifference Curve

Indifference curve $U_2(A,T)$, and indifference curve $U_2(A,D)$ after the transportation improvement can be easily introduced as follows : for U_2 (A,T),

$$A = A_0 \exp\left(\gamma \left(\Pi + (\nu / \gamma)\, \Delta T \right) + \nu T \right) \qquad (16)$$

and for U_2 (A,D),

$$A = A_0 \exp\left(\gamma \Pi + 2\nu \left(\frac{a_L}{V_L} - \frac{a_H}{V_H} \right) D_1 + 2\nu \frac{a_H}{V_H} D \right) \qquad (17)$$

where,

$$T = 2\, (a_H / V_H)\, D \qquad (18)$$

$$\Delta T = T_1 - T_2 = 2\, (a_L/V_L - a_H/V_H)\, D_1 \qquad (19)$$

The curve expressed by equation (16) or (17) corresponds to the indifference curve of households whose housing cost - bearing - capacities were higher by $(\nu / \gamma)\,\Delta T$ before the improvement. So that, it can be said that a reduction in the travel impedance is just like having an increase in the income.

3.3. Budget Line

From equations (4) and (18) a budget line in the combinations of housing size (A) and travel distance (D) is obtained as follows:

$$E'' = pA - 2(\alpha_H / V_H) D \qquad (20)$$

3.4. Shifts in Residential Location and Housing Size

This sub-section will examine the effects of a change (from V_L to V_H) in travel speed on the residential location (D) and the housing size(A).

In the same way as that in section 2, we can get the new equilibrium point (A_H,D_H) in combinations of the housing size and the travel distance to work after the transportation improvement, using equations (17) and (20) (see Figure 6).
The results are

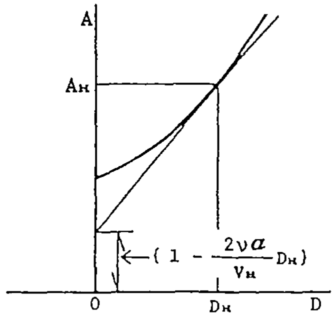

Fig.6 A consumer's optimal equlibrium in combinations of the housing size(A) and the travel distance to work (D).

$$D_H = (1/2)(V_H/\alpha_H)(\beta \Pi - E'') \qquad (21)$$

$$A_H = A_o \exp\left\{ \gamma \Pi + 2\nu\left(\frac{\alpha_L}{V_L} - \frac{\alpha_H}{V_H} \right) D_L + 2\nu \frac{\alpha_H}{V_H} D_H \right\} \qquad (22)$$

This new equilibrium point corresponds to the point ③ (A_2,D_2) in the first quadrant of Figure 5, where $A_H = A_2$ and $D_H=D_2$.

In order to find out the effects of an increase (from V_L to V_H) in the travel speed on the residential location and housing size of individuals, we must get the equilibrium point (A_L,D_L) before the transportation improvement. In the same way as above, we have

$$D_L = (1/2)(V_L / \alpha_L)(\beta \Pi - E'') \qquad (23)$$

$$A_L = A_o \exp(\gamma \Pi + 2\nu(\alpha_L/V_L) D_L) \qquad (24)$$

The equilibrium point decided by equations (23) and (24) corresponds to the point ① (A_1,D_1) in the first quadrant of Figure 5.

First, we examine how much the residential location shifts before and after the transportation improvement. From equations (21) and (23), we have

$$D_H = (V_H / V_L)(\alpha_L / \alpha_H) D_L \qquad (25)$$

This equation (25) indicates that a shifting of the residential location (D_H) may be in proportion to the travel speed (V_H) and in inverse proportion to the value of leisure time(α_H).

Next, the effects of an increase in the travel speed on the housing size is considered. From equations (22),(24) and (25), we can get a relationship between A_H, A_L and D_L as follows :

$$A_H = A_L \exp\{ 2\nu(\alpha_L / V_L) - (\alpha_H / V_H) D_L \} \qquad (26)$$

This equation (26) makes clear that the housing size(A_H) increases as the travel speed (V_H) increases. Furthermore, the increasing power (dA_H/dV_H) decreases as the travel speed (V_H) increases.

4. NUMERICAL EXAMPLE

In the first section, we have shown a real state of how sensitively the population distribution in the Tokyo Metropolitan Area has responded to the increase in travel speed. Rail transit has been the main mode in the area since 1925 and it is as of yet. Accordingly, in this section we try to calculate the effects of an increase in travel speed of rail transit on the residential location and housing size of each household which lives by the railway.

4.1. Preconditions

To perform the calculations we must set up some assumptions(see Figure 7): (A) the main mode is rail transit, (B) the mode of access trip and egress trip is walking,and the sum of distances for the access and the egress(one way) (D_o) is fixed to 1.4 kilo-meters(where, walking speed = 70 meters per minute, and the sum of travel times for the access and the egress (t_o) (one way) is 20 minutes), (C)only the travel speed of rail transit increases from V_L to V_H, and (D) the monetary cost to and from work is left out because most of the employers in Japan provide their workers' monetary travel costs.

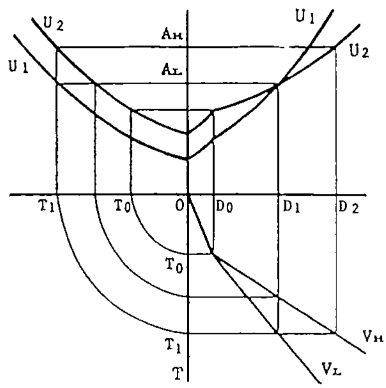

Fig.7 Effects of an increase in travel speed on residential location and housing size. Residential location shifts from D_1 to D_2 with an increase (from V_L to V_H) in the travel speed of rail transit and housing size is enlarged from A_L to A_H simultaneously.

4.2. Indexes and Coefficients

In the above, we have assumed that the transportation improvement makes only the travel speed of rail transit change. So that, we have no need of all the foregoing indexes and coefficients for the calculations. The index (η_R) of rail transit alone is quite enough for them. The η_R is 0.3700×10^{-2} (per minute),[11].

4.3. The Effects of Travel Speed on Residential Location

We consider the shifting of residential location from D_1 to D_2 with an increase (from V_L to V_H) in the travel speed of rail transit (see Figure 7). From equation (25), the new residential location (D_2) in this case can be introduced as follows:

$$D_2 = (V_H / V_L)(D_1 - D_o) + D_o \tag{27}$$

Then, the effects of an increase in travel speed on the residential location can be calculated with this equation. The results are graphed in Figure 8. This Figure shows that the new residential location (D_2) extends nearly in proportion to the ratio of V_H to V_L. For example, the new residential locations of a household which lived at D_1 = 15km are, for V_H/V_L = 2.0, D_2 = 28.6km and, for V_H/V_L = 3.0, D_2 = 42.2km.

At this point, it is best to apply the above results to the real states described in section 1. Here, we regard the points with population densities of 50 persons per hectare as urban fringes. 1925 is considered the base year. Then, the relationships between the distance from the city center to the urban fringe and the ratio of V_H to V_L for the following years 1935, 1955, 1965, 1975, and 1985, are obtained as shown in Figure 9. But they are approximate values. The straight line in this figure represents the new residential location of households which lived at point (D_1 = 10km) before the transportation improvement. This line has been calculated using equation (27). From this examination, it is consider-

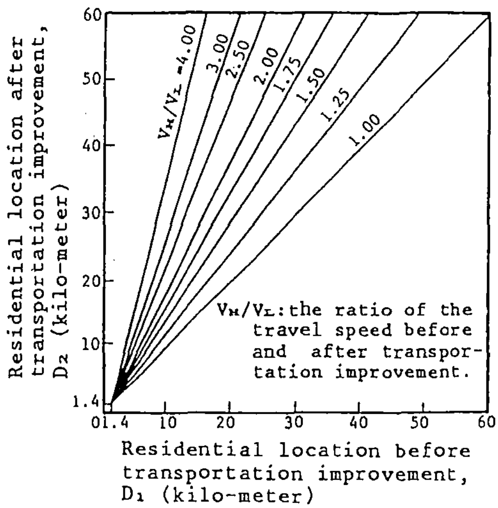

Fig.8 Effects of increases in travel speed on residential location.

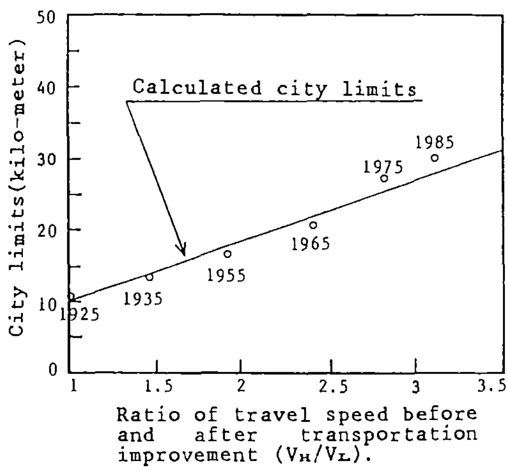

Fig.9 A comparison of the calculated city limits and the real ones.

ed that the estimations acquired from the use of equation (27) simulate a phenomenon nearly equal to that of the actual suburbanization of Tokyo.

4.4. The Effects of Travel Speed on Housing Size

We consider the enlargement in housing size(from A_L to A_H) with an increase in the travel speed(from V_L to V_H). From equation(26), the ratio of A_L to A_H in this case is expressed as follows :

$$\frac{A_H}{A_L} = \exp\left\{ 2\,\eta_R \left(\frac{1}{V_L} - \frac{1}{V_H} \right)\left(D_1 - D_0 \right)\right\} \qquad (28)$$

Here, if we assume that the travel speed before transportation improvement (V_L) is 0.5 kilo-meter per minute, the relationships between the three factors (A_H/A_L, V_L/V_H and D_1) can be easily calculated. The results are graphed in Figure 10. This Figure 10 shows that, when V_H/V_L is fixed at some value, the ratio of A_H to A_L increases as the residential location before transportation improvement (D_1) increases, and when D_1 is fixed at some value, the ratio of A_H to A_L increase as V_H/V_L rises. But the effects of travel speed on the housing size is not as much as the effects on the residential location. For instance, when the residential location before the transportation improvement (D_1) is 15 km, for V_H/V_L = 2.0, the ratio of D_2 to D_1 becomes 1.91, but for V_H/V_L = 2.0 and V_L = 0.5 kilo-meter per minute, the ratio of A_H to A_L rises only to 1.11.

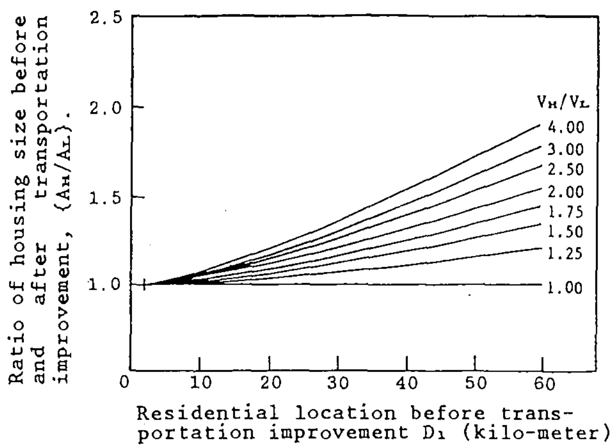

Fig.10 Effects of increases in travel speed on housing size.

5. CONCLUSION

This study has discussed, theoretically, the effects of a change in the travel speed to and from work on the residential location and housing size of individual households, on the basis of a simplified housing demand mechanism. Numerical examples have also been tried.

The theoretical developments have produced good results. They are as follows : (A) a shifting of the residential location caused by the transportation improvement may be in proportion to the improved travel speed and in inverse proportion to the value of leisure time, (B) the housing size of individual households also increases as the travel speed increases, and in contrast with this, the size decreases as the value of leisure time increases.

On the basis of the theoretical results, a few numerical examples have been tried. From these, it has been ascertained that an increase in the travel speed will produce a significant effect on residential location, but just a minor effect on housing size.

We can use the results for studies of how much a transportation improvement confers a benefit on each commuter who lives along the line, and how much each beneficiary should pay for part of the project.

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