Timing of transportation infrastructure investment and transportation behavior

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Mobility and Accessibility are declining in economically growing cities in Asia. However, we still have cities which may face the same situation several years later. Based on the hypothesis the timing to introduce railway affect the mobility and accessibility in future; this study investigates appropriate timing for railway investment. First, we define the appropriate timing by population level and railway fare depending on its building cost. Second, we examine the appropriate timing using theoretical model. Moreover we found equilibrium when the building cost is born by small number of passengers.

Key Words : *developing countries, railway investment, road congestion, modal choice*

1. INTRODUCTION

Mobility and Accessibility are declining in economically growing cities in Asia. Are they happening because of rapid motorization or, lack of mass transit system that corresponds to transportation demand? There are some researches and papers discussing about the situation, in view point of congestion, vehicle ownership, travel behavior, and system management of public transportation.

Gakenhimer (1999) mentioned that the vehicle registration are growing because of the population increase, wealth increase, commercial penetration increase, and probably persuasive picture adopted from developed countries as a part of advanced lifestyle. Pointing out the role of motorization which accurate economic growth through automobile production and consumption, Sun Sheng Han (2010) argued the importance to balance motorization and public transport. Han also suggested the timing and speed to introduce public transport is key issued for balancing motorization. In Singapore, the attempt to balance motorization with a public transport system was successfully made. Because it was at an early stage of development, and was implemented in a short time span.

In the view point of travel behavior of citizen, Senbil(2009) mentioned the difference feature of travel behavior in its history of cities ' , comparing Keihanshin area, Japan which represents railway oriented city, and Kualarinpor, Marisa which represents automobile oriented city. Nakamura (2010) showed the timing of railway development influences the speed of motorization. It was also mentioned that railway development in early stages, restrain motorization through restraining urbanization in Asian countries. In addition to policy integration, strategic consistency, and predictability, Roger (2008) pointd out the timing to construct railway is important for the successful implementation of urban transport project. Indicating the income elasticity for land, Glaeser (2008) mentioned relationship between urbanization of poverty and accessibility to public transportation. Showing the relationship between land use (residential choice) and travel behavior, Paul (2004) explained the existence of path-dependence in Kuala Lumpure Metropolitan Area. Once steering to road oriented structure, the city become automobile-dependent, moreover locked into urban structure. After the dependent is established, additional investment for public transport dose not show much effect to public transport dependent. Thus, it is important to invest railway early timing to form both urban transportation structure and travel behavior of citizen ' .

On the other hand, Ono (2012) pointed out the fare-paying ability for railway in developing country is low; GDP per capita is low. Nevertheless, the construction cost is high; using railway becomes expensive. For example, the ratio of average fare divided by GDP per capita of each country is 1/3,614 in Dehli case (Metro), and 1/6,933 in Bankok case (Metro); the comparing 1/13,015 in Tokyo case (Nanboku-Line), is quite high. Therefore, simultaneously the financial feasibility of urban railway projects tends to become low.

Considering both irreversibility of transportation investment and its financial feasibility, the timing of transportation investment may determine the mobility and accessibility in future.

There are cities, mostly in sub-Sahara Africa, which have following features:

- which are economically growing, result in rapid motorization,
- which population is growing fast,
- which road investment is proceeding,
- Which has no mass transit introduced, even has no plan to introduce.

For smart growth for those cities, not running after struggling Asian cities, it is necessary to consider appropriate timing for those cities to invest mass transit.

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In this study, we examine the timing to railway construction in urban area. Firstly we discuss how we define " the appropriate timing" using theoretical model. Secondly, we examine the scenarios assumed based on timing set using the model. Thirdly, we develop the dynamic model for scenarios under the consideration of interlocks between residential choices and modal choice. Finally, we discuss the result and conclude.

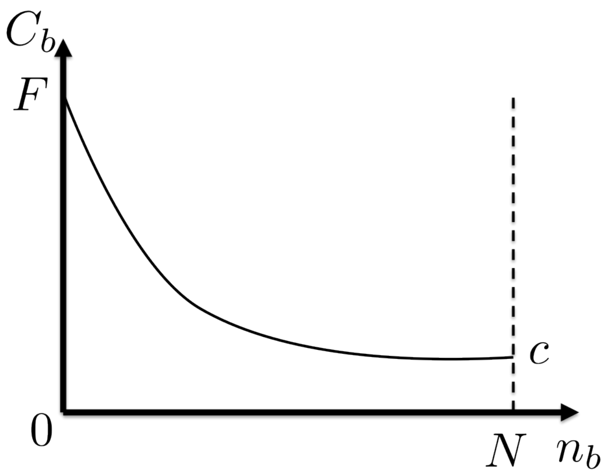
2. BASIC MODEL

(1) Framework

In this study, we consider relationship among road congestion level without railway, building cost of railway and fare of railway. Suppose the relationship among them strongly influence to the number of passenger for railway, we examine the appropriate timing based on them.

First, we consider travel behavior of commuter who commutes from a residential area to a Central Business District (CBD) through bottlenecked road or railway. In this study the railway building cost is born by the government. In actual case, the government has possibility to receive grant or loan as foreign aid, or collect building cost issuing bond or stocks. Here is assumptions follows:

- All people are live in the residential area and must commute to the CBD;
- Every commuter choose automobiles or train when they commute.



Figure–1 Cost function of railway commuter with respect to n_b

We denote the number of auto commuter is n_a and rail commuter is n_b. The total number of commuter are $N(= n_a + n_b)$.

When the number of auto commuter increases, the commuting cost becomes larger, because of congestion. We assume the cost of auto commuter C_a as

$$C_a(n_a) = \frac{\alpha n_a}{K} \tag{1}$$

This cost function is based on Tabuchi(1993), which derive that the cost function from an equilibrium condition of auto commuters' departure time decision. K is the bottleneck capacity and α is the time of value.

Second, we assume the commuting cost by railway. We assume that the commuting cost by railway $C_b(n_b)$ is as in **Figure–1** . If there is one railway commuter, the commuter must pay $c + F$ to use railway. F is the fixed construction cost and, which exclude governmental bearing cost. c is running cost of railway. So, $c + F$ is standing for the fare which railway commuter bear. But if there are enough railway users, fare born by each will be small.

Then we consider the cost function, which satisfies these conditions

$$C_b(0) = c + F \tag{2}$$

$$C_b(N) = c \tag{3}$$

We simplify this cost function as follows

$$C_b(n_b) = b(N - n_b)^2 + c \tag{4}$$

where $b = F/N^2$. This cost function satisfies the condition above. As the number of railway commuters become larger, C_b decreases.

(2) Equilibrium in static case

In this subsection, for examine scenario, we analyze the equilibrium number of commuters in static case. In equilibrium, supposing any auto commuter has no incentive to change the mode. Hence, the equilibrium condition satisfies,

$$C_a(n_a) = C_b(n_b) \tag{5}$$

From the equilibrium condition, it is straightforward that the number of auto and rail commuter, n_a^* and n_b^*, are given by proposition 1.

Proposition 1 *1)If the cost of automobile is not so large compared with the construction cost of railway, that is to say,*

$$0 \leq \frac{\alpha N}{K} \leq 2\sqrt{cF} \tag{6}$$

There exists an equilibrium, that is all commuter use the automobile,

$$(n_a^*, n_b^*) = (N, 0) \tag{7}$$

2)If the cost of automobile become larger and

$$2\sqrt{cF} < \frac{\alpha N}{K} < 2F \tag{8}$$

There exists 2 equilibria,

$$(n_a^*, n_b^*) = \left(\frac{\alpha}{2\kappa\phi} - \sqrt{\left(\frac{\alpha}{2\kappa\phi}\right)^2 - \frac{cN}{\phi}}, N - n_a^*\right) \tag{9}$$

where $\kappa = K/N$ is a road capacity per capita, $\phi = F/N$ is a construction cost per capita, and

$$(n_a^*, n_b^*) = (N, 0) \tag{10}$$

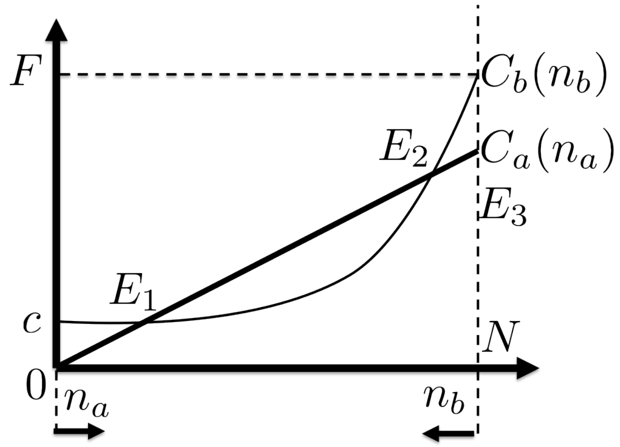
3)If the cost of automobile is large compared with the construction cost of railway, that is to say,

$$2F < \frac{\alpha N}{K} \tag{11}$$

An unique equilibrium exists,

$$(n_a^*, n_b^*) = \left(\frac{\alpha}{2\kappa\phi} - \sqrt{\left(\frac{\alpha}{2\kappa\phi}\right)^2 - \frac{cN}{\phi}}, N - n_a^*\right) \tag{12}$$

Proposition 1 1) implies that when there is enough road capacity for the total number of commuters, the cost of using road become smaller than that of railway. Therefore, automatically all commuters choose road.



Figure–2 Multiple equilibria in the basic model

Proposition 1 2) implies that when there is insufficient road capacity for the total number of commuters, some use road and the other use railway.

Proposition 1 3) implies that when there is insufficient road capacity for the total number of commuters, there exists 2 equilibria. We shows it in **Figure–2** E_1 and E_3 are stable equilibrium point, E_2 is unstable equilibrium point.

If the initial number of auto commuters are larger than E_2, every railway commuter feel fare is expensive comparing to commute by automobile. Since the railway commuter is not satisfied with the railway cost, they shift to auto as an economical choice. Then all commuter commute by auto.

But the initial number of railway commuters is larger than E_2. Some of auto commuter will chose railway as an economical choice. And commuters can achieve more cost effective equilibrium.

The discussion and measurement are required not causing E_3 situation. In the E_3 situation, even small number of railway commuter prefers to use road in spite of heavy congestion. When the user recognizes the railway more expensive than vehicle use, there exist multiple equilibria. In addition, the model indicates the possibility that, despite of the higher cost, E_3 is selected rather than E_1.

We mention a possibility for railway user to shift to auto, if the railway user, (which is small number and bearing expensive fare) feel inconvenience to railway. Under the situation, the equilibrium easily shifts to E_3.

Consequently, the countermeasure to prevent equilibrium to shift to E_3 is required. For instance, introducing commuter ' s ticket, which predict some amount travel demand and discount according to amount, is one of the measurement. In addition, in the perspective of the government or enterprises, introducing commutation allowance will be the measurement which reducing burden of railway users. In developing countries, enterprises commonly prepare and bearing commuter busses between residential area and working place, because of in-sufficient transportation system. However, after introducing mass transit such as railway, neither enterprises nor the government tend not to bear fare, result in imposing the burden of rail users.

3. DYNAMIC MODEL

(1) Framework

It is often mentioned that rigidity of modal choice is occurred because of close connection between modal choice and residential choice(e.g. Paul (2004)). In this section, we consider an adjustment process of commuter's mode choice to analyze the equilibrium selection. Considering to the situation that the commuters are not able to change the mode often and take account into the mode choice in the future, we develop dynamic model. We also consider time preference of commuter. It is often said that difference of human preference may exist among countries[11)] and the difference may affect the effectiveness of policy.

We assume a Poisson modal choice opportunities such that

$$\dot{n}_a(t) = \lambda(n_a^* - n_a(t)) \tag{13}$$

where λ is a Poisson parameter. Equaion (13) is based on Oyama(2008). $b(t)$ is the optimal number of auto commuter. The auto commuter have an opportunity to change the mode during the short time interval $[t, t + dt)$. Then $\lambda b(t)$ is the number of commuter who can change to the auto mobile. Equation (13) is able to interpret that distance between optimal number and current number of auto commuter is adjusted by λ.

$$\begin{aligned} V_i(t) &= (\lambda + \theta) \int_0^\infty \int_t^{t+s} e^{-\theta(z-t)} C_i(n_i(z))dz \lambda e^{-\lambda s} ds \\ &= (\lambda + \theta) \int_t^\infty e^{-(\lambda+\theta)(s-t)} C_i(n_i(s)))ds \end{aligned} \tag{14}$$

where $i = a, b$ and $n_i(s)$ is anticipated feasible path and $\theta > 0$ is the time preference. We normalized by multiplying $(\lambda + \theta)$. Let us consider the feasible path as follows,

$$n_a(t) = n_{a0} + (n_a^* - n_{a0})(1 - e^{-\lambda t}) \tag{15}$$

where $n_{a0}(0 \leq n_{a0} \leq N)$ is initial value and n_a^* is equilibrium value. This dynamics converge to n_a^* as the time t increase.

We define and compute the difference between the cost of auto and railway commuters to pay at period t as

$$\begin{aligned} f(n_a(t)) &= C_a(n_a(t))) - C_b(N - n_a(t)) \\ &= \frac{\alpha n_a(t)}{K} - bn_a(t)^2 - c \end{aligned} \tag{16}$$

when $f(n_a(t))$ is negative, auto commuter can commute by smaller cost than railway commuter do. We define the potential function as

$$F(n_a(t)) = \int_0^{n_a(t)} f(m_a(t))dm_a(t) \tag{17}$$

where $n_{a0}(0 \leq n_{a0} \leq N)$ is some positive constant value.

We define $V(t)$ and computed as

$$\begin{aligned} V(0) &= V_a(0) - V_b(0) \\ &= (\lambda + \theta) \int_t^\infty e^{-(\lambda+\theta)(s)} f(n_a(s))ds \\ &= \frac{1 + \delta}{n_a^* - n_{a0}} \int_{n_{a0}}^{n_a^*} \left(\frac{n_a^* - n_a(t)}{n_a^* - n_{a0}}\right)^\delta f(n_a(t))dn_a(t) \end{aligned} \tag{18}$$

by substituting equation (15).

(2) In case of small friction

We consider the degree of friction is small, which implies that the commuter consider future sufficiently($\theta = 0$). When the degree of friction is sufficiently small, the equation (14) become

$$\begin{aligned} \lim_{\delta \to 0} V(0) &= \frac{1}{n_a^* - n_{a0}} \int_{n_{a0}}^{n_a^*} f(n_a(t))dn_a(t) \\ &= \frac{F(n_a^*) - F(n_{a0})}{n_a^* - n_{a0}} \end{aligned} \tag{19}$$

Proposition 2 *The equilibrium number of the auto commuter depends on the condition of the commuting cost without railway, $\alpha N/\delta$.*
1) If the commuting cost without railway is not so large compared to the construction cost of railway, (because of large road capacity and population is small,)

$$0 \leq \frac{\alpha N}{K} \leq 4\sqrt{\frac{cF}{3}} \tag{20}$$

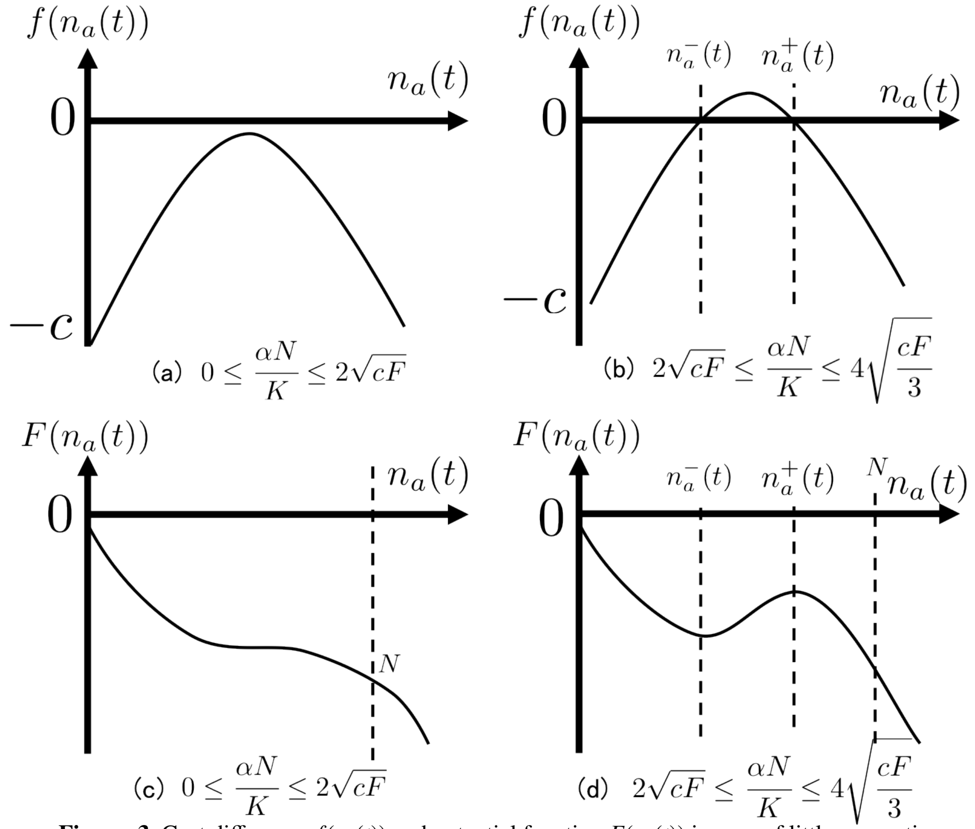
The equilibrium number of commuter is

$$(n_a^*, n_b^*) = (N, 0) \tag{21}$$

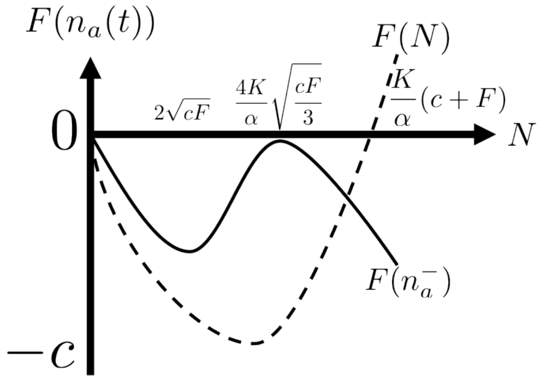
and a feasible path

$$n_a(t) = n_{a0} + (N - n_{a0})(1 - e^{-\lambda t}) \tag{22}$$

is a perfect foresight path and converge to $(N, 0)$, all commuters use automobile. N is globally accessible and absorbing[10)].



Figure–3 Cost difference $f(n_a(t))$ and potential function $F(n_a(t))$ in case of little congestion



Figure–4 Relationship between N and $F(n_a(t))$

2) if there is enough population and congestion to construct a railway,

$$4\sqrt{\frac{cF}{3}} \le \frac{\alpha N}{K} \le c + F \tag{23}$$

The equilibrium number of auto and railway commuter is

$$(n_a^*, n_b^*) = \left(\frac{\alpha}{2\kappa\phi} - \sqrt{\left(\frac{\alpha}{2\kappa\phi}\right)^2 - \frac{cN}{\phi}}, N - n_a^*\right) \tag{24}$$

3) Under the condition

$$c + F \le 4\sqrt{\frac{cF}{3}} \tag{25}$$

there exists an equilibrium

$$(n_a^*, n_b^*) = \left(\frac{\alpha}{2\kappa\phi} - \sqrt{\left(\frac{\alpha}{2\kappa\phi}\right)^2 - \frac{cN}{\phi}}, N - n_a^*\right) \tag{26}$$

and a feasible path

$$n_a(t) = n_{a0} + (n_a^* - n_{a0})(1 - e^{-\lambda t}) \tag{27}$$

is a perfect foresight path and converge to $n_a^* = n_a^-$, all commuters use automobile. N is globally accessible and absorbing.

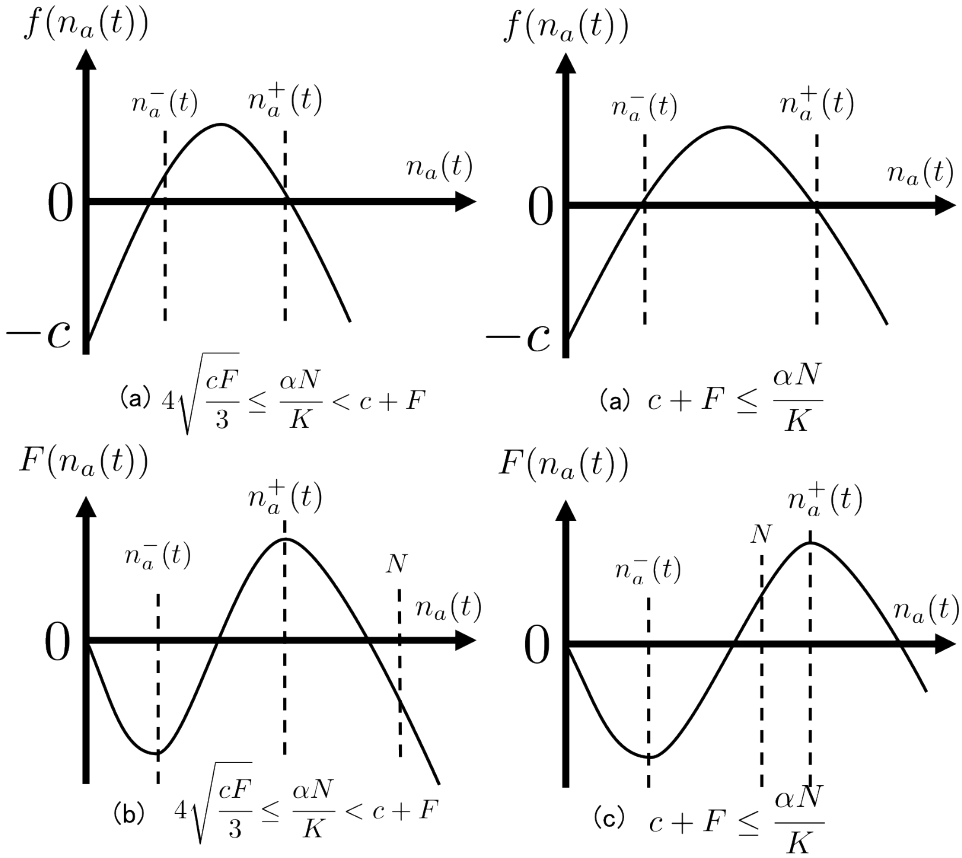
Next, we provide a proof of the proposition 2. When $\alpha K/N$ satisfies

$$0 \le \frac{\alpha N}{K} \le 2\sqrt{cF} \tag{28}$$

$f(n_a(t))$ and $F(n_a(t))$ are shown in the **Figure–3** (a) and (c). As shown in the figures, if condition (28) holds, $f(n_a(t))$ is always negative, and hence $F(n_a(t))$ become monotonically decreasing function with respect to $n_a(t)$. Then, if the condition (28) holds, $F(n_a(t))$ is global minimizer and computed as

$$F(N) = N\left(\frac{1}{2}\frac{\alpha N}{K} - \frac{bN^2}{3}F - c\right) \le 0 \tag{29}$$

Therefore, from the equation V1, $V(0)$ is always negative against any initial value n_{a0}. Hence the cost of commuting automobile is smaller than that of commuting railway($V_a(0) \le V_b(0)$). Thus $(n_a^*, n_b^*) = (N, 0)$ is an unique equilibrium and globally accessible.



Figure–5 Cost difference $f(n_a(t))$ and potential function $F(n_a(t))$ in case of heavy congestion

When $\alpha K/N$ is

$$2\sqrt{cF} \le \frac{\alpha N}{K} \le 4\sqrt{\frac{cF}{3}} \tag{30}$$

$f(n_a(t))$ and $F(n_a(t))$ are shown in the **Figure–3** (b) and (d). As shown in these figures, $f(n_a(t))$ become positive within the range of $n_a^-(t) < \alpha K/N < n_a^+(t)$. $F(n_a^-(t))$ and $F(N)$ may be a minimizer of $F(n_a(t))$. $F(n_a^-(t))$ and $F(N)$ are compared in **Figure–4**.As shown the figure, $F(N)$ is smaller than $F(n_a^-(t))$, if the condition (30).Therefore $F(N)$ is a global minimizer. Hence the cost of commuting automobile is smaller than that of commuting railway($V_a(0) \le V_b(0)$). $(n_a^*, n_b^*) = (N, 0)$ is an unique equilibrium and globally accessible. Therefore, $n_a(t)$ will converge N and a feasible path (22) is a perfect foresight dynamics When $\alpha K/N$ holds the condition (23), $f(n_a(t))$ and $F(n_a(t))$ are shown in the **Figure–5** (a) and (c). **Figure–5** (c) shows that $n_a^-(t)$ and N has a possible to be a minimizer. As shown in **Figure–4**, $F(N^-(t))$ is smaller than $F(N)$ within the range of

$$4\sqrt{\frac{cF}{3}} \le \frac{\alpha N}{K} \le \bar{n}_a \tag{31}$$

$F(n_a^-(t))$ is smaller than $F(N)$ within the range of

$$\bar{n}_a \le \frac{\alpha N}{K} \le N \tag{32}$$

We have not derived closed form of $\bar{n}_a$.

When $\alpha K/N$ holds the condition (25), $f(n_a(t))$ and $F(n_a(t))$ are shown in the **Figure–5** (b) and (d). If the condition holds, $n_a^+(t)$ is smaller than $N(n_a^+(t) < N)$. Hence $F(n_a(t))$ is minimized at $n_a^-(t)$. Therefore, $n_a^+(t)$ is a global minimizer. And a feasible path (27) is a perfect foresight dynamics path.

4. CONCLUSION

In this study, we indicate that the number of railway commuter become distinct because of the congestion level of road, under the situation commuter necessity to choose bottlenecked road and railway. Especially, we found a equilibrium that all commuter choose auto even railway is existing; under the situation that the number of railway commuter is small and result in bearing cost for rail user become high. For avoiding the situation mentioned above, we indicate the measurement such as commuting ticket, and commuting allowance, maintaining reasonable fare regardless the number of users, are effective. Moreover, considering the close connection between modal choice and residential choice, which result in rigidity of modal choice; we propose dynamic model for modal choice.

The future challenge of this study is to consider actual features of developing cities, such as population increase in urban area and income disparity. In addition to analyze how these issues influence to modal choice and the number of railway user and auto user is remaining issue. Moreover, the empirical research using actual database in developing countries and cities is also issue in the future. We believe this research makes several important contributions to the smart growth of developing cities in the world.

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