A ROUTE CHOICE MODEL BASED ON EVOLUTIONARY GAME THEORY CONSIDERING THE TRAVEL TIME RELIABILITY AND TRAFFIC IMPEDIMENTS

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ABSTRACT

In this study we built a route choice model considering travel time reliability and traffic impediments including traffic accidents. Based on evolutionary game theory, we built the model to identify a route that a dispatcher chooses in consideration of the change of the daily route travel times and the situation of the traffic impediments using measured data. The evolutionary game theory is a game theory which is formulated in dynamics and analyzes the distribution and the change of the combination of strategies. We used a model of Roth & Erev(1995) given as a representative of models that assumed trial and error learning.
With the model that we built, we performed two case studies. One case study is that standard deviation of some routes goes down to 2/3, and the other case study is that the charge of toll road is half. As a result, the combination of route choice strategies changed significantly.

Keywords: Freight transport, route choice model, Evolutionary game theory, Travel time reliability

INTRODUCTION

With development of the just-in-time shipping, the delay to the shipping address is not permitted for logistics companies. Therefore, logistics companies plan the shipping time including additional time from average travel time with taking into consideration the variability of travel time by the traffic congestion and the traffic accidents. In the freight traffic, strict correspondence is required for the variability of travel time than the passenger traffic.

The construction of the model that considered the variability of the travel time has much examination case focusing on passenger traffic, for example Nagao (2007). Furthermore, Lo (2006) postulate that travelers acquire the variability of route travel times based on past experiences and factor such variability into their route choice consideration in the form of a travel time budget, and formulated a multi-class mixed-equilibrium mathematical program to capture the route choice behaviours of travelers. Fan (2006) formulated dynamic programming based on the adaptive routing algorithm to maximize travel time reliability. In addition, as the study that focused on freight traffic, Taniguchi (2001) built the Vehicle Routing and scheduling Problems with Time Windows-Probabilistic (VRPTW-P) model that considered the variability of the travel time.

As a model of the avoidance from a delay risk of unexpected events such as traffic accidents, Bell (2004) built the game theory model that assumed the game for a dispatcher and the devil who causes an impediment on links.

In the past study, there are some models that analyzed route choice behaviour for daily variability of travel time or unexpected events, but there are still few studies that analyzed route choice behaviour considered both daily variability and unexpected events.

Therefore, in this study, we built a route choice model considering travel time reliability and traffic impediments including traffic accidents. Based on evolutionary game theory, we built the model to identify a route that a dispatcher chooses in consideration of the change of the daily route travel times and the situation of the traffic impediments using measured data of 579 delivery trucks of 4 logistics companies, which were collected by probe investigation during one month.

This model was built based on the real route choice process that a dispatcher performs, such as considering additional time, choosing route based on past experience. And we can analyze the change of the route choice behaviour with real decision-making process by this model.

THE MODEL BUILDING

A policy of the model building

We built the model that a dispatcher determines route choice (strategy) considering the variability of the everyday route travel times and the situation of impediments.

With the evolutionary game theory that assumed the game of a dispatcher and the devil who causes an impediment (accidents) on a link, we built a route choice strategy estimation model. It is the model that supposed that the strategy changes whether it succeeded, and the evolutionary game theory is similar to dispatcher's route choice process looking for the best route, and thinking about risk aversion.

We made the route travel time distribution from the travel time distribution on each road section which is measured using probe freight vehicles. We built a model on a route of Toyota-city to Tahara-city and analyzed influence on route choice behaviour of the variability of the travel time and traffic impediments.

In addition, in the model building of this study, we used probe data which were measured using 579 delivery trucks of 4 logistics companies during one month in October, 2008.

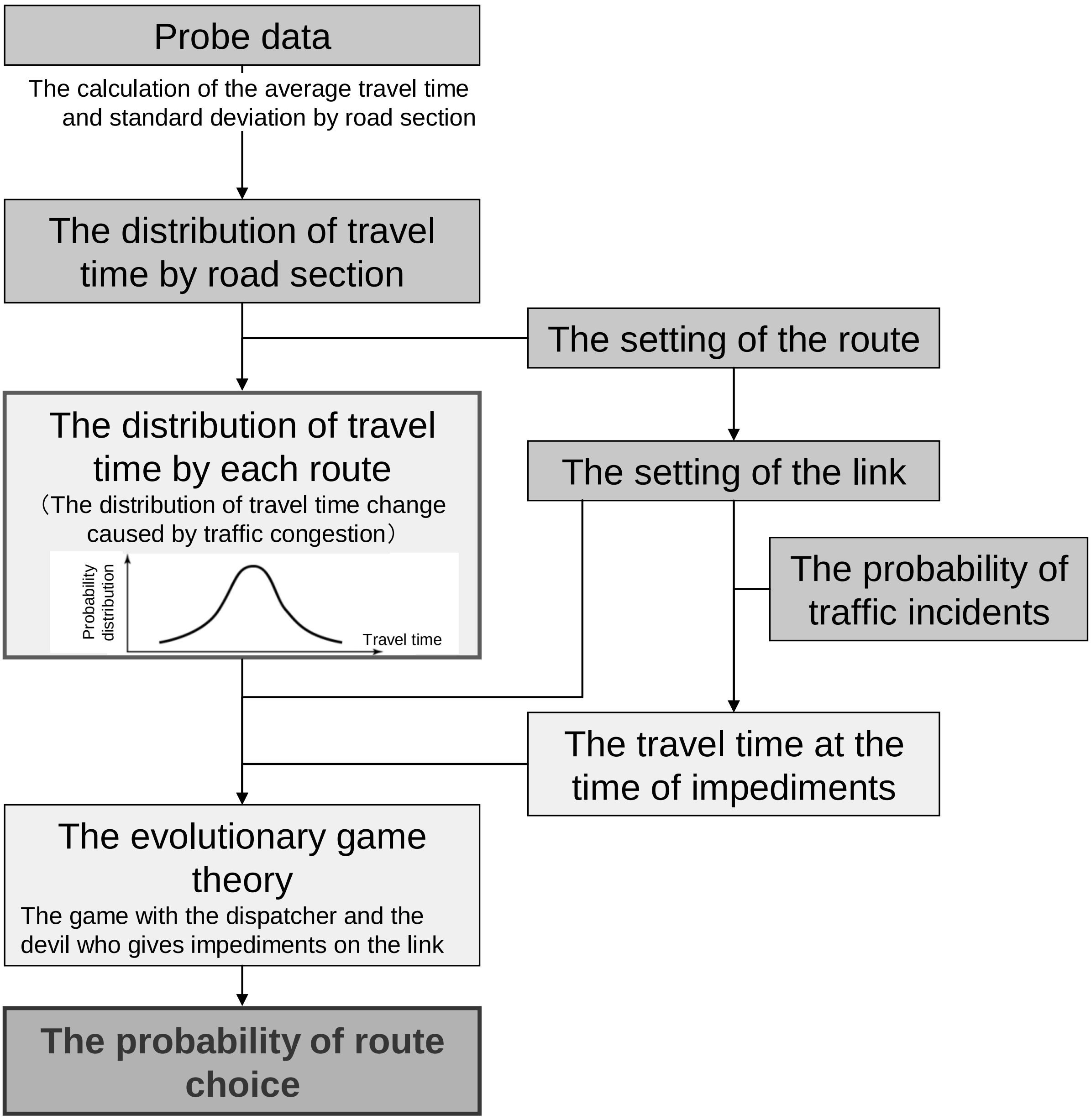

Figure 1 – Model flow diagram

Outline of the model

Outline of the evolutionary game theory model

In game theory of forward-looking expectations type, we assume that players choose the strategy looking good (the gain seems to be high) predicting whether result of own behaviour which change with other player’s behaviour is positive.
On the other hand, in the evolutionary game theory, we do not assume forward-looking expectations, we assume strategic share change whether the strategy succeeded, after a player actually did it. As a result, only a certain strategy is left, or strategy share dose not have the change because the gain of several strategy reaches equilibrium.

There were heredity dynamics model and learning dynamics model on evolutionary game theory. The learning dynamics is the dynamics that happen by change of strategy in some way. We chose the learning dynamics because the learning dynamics suit for modelling the society phenomenon of comparatively short time scale.

Furthermore, in the learning dynamics, trial and error dynamics, imitation dynamics, the most suitable reaction dynamics are thought about. The imitation dynamics is the dynamics that happen when a player imitates the strategy of another person, the trial and error dynamics is the dynamics that happen when a player decides a strategy from past own behaviour result, the most suitable reaction dynamics is the dynamics that happen when a player modifies the strategy to get greatest benefit with predicting the strategy of other person adopts from experience. We chose the try and error dynamics, because logistics companies determine their strategy based on their past behaviour rather than the behaviour of others.

When there are multiple alternatives, on the try and error learning, the alternative that resulted good is adopted with high probability and alternative that resulted bad is avoided. In this model, we think that the player has "tendency" that is going to adopt a certain strategy. The strategy that "tendency" is high is adopted with high probability, but the strategy that "tendency" is low is adopted with low probability. "Evaluation in the mind" is equivalent to this "tendency".

After a player actually adopts a certain strategy, evaluation for the strategy rises when its result was good, and "the tendency" that is going to adopt the strategy become higher. When its result was bad, its evaluation falls down, and "the tendency" that is going to adopt the strategy become lower.

This effect is called "reinforcement" by the term of the psychology of learning. Generally it is known that the high gain brings big reinforcement and the low gain and the negative gain bring small reinforcement and minus reinforcement.

Context of the model

As the evolutionary game theory is the dynamic game theory, we can analyze strategic distribution and the change of the combination. With this model, we analyze it by the following setting. The result of the game to be provided is the strategic convergence value of the player, the result of game is to converge in one strategy or converge in certain share.

1. The setting of players

   Player 1： The dispatcher (A logistics company)
   Player 2： The devil who causes traffic impediments (Assuming traffic accidents)

2. The strategy of players

   A strategy of player 1： Player chooses 1 route among n routes.
   A strategy of player 2： Player causes 1 traffic impediment among m links

The formulation

We applied a model of Roth & Erev(1995) given as a representative of a model assuming try and error learning. The basic equation of Roth & Erev model took in a process of reinforcement and oblivion like equation (1), and modelled the change of "tendency" that was going to adopt the certain strategy.

The player update tendency of strategy j at time t+1, adding reinforcement which is given as a result of strategy at time t to the tendency at time t. As the reinforcement value expressed evaluation of strategy by the last behaviour, in this model, we assumed provided gain.

$$p_{ij}(t+1)=(1-\phi)p_{ij}(t)+R_{ij}(t) \quad \cdots(1)$$

Pij(t)： The tendency that player i adopts strategy j at time t
Rij(t)： The reinforcement that is given for Pij (t) at the time t
ϕ ： A parameter to express the speed of the oblivion （$0 < \phi < 1$）

The probability that player i adopts strategy j is formulated as follows.

$$x_{ij}(t) = p_{ij}(t) \Big/ \sum_j p_{ij}(t) \quad \cdots(2)$$

xij(t)： The probability that player i adopts strategy j at the time t

However, $\sum_j x_{ij}(t)=1 \quad \cdots(3)$

In addition, the reinforcement (Rij(t)) sets it every player.

Player 1

As we supposed that the reinforcement added to the tendency of strategy j at time t+1 was equivalent to the gain at time t, we set reinforcement value as follows.

$$R_{ij}(t)=0;\quad r_j(t-1)=(TC_b+RC_b)-(TC_j(t-1)+RC_j(t-1)+\alpha\cdot T_j(t-1)+\beta\cdot D)<0$$
$$R_{ij}(t)=1;\quad r_j(t-1)=(TC_b+RC_b)-(TC_j(t-1)+RC_j(t-1)+\alpha\cdot T_j(t-1)+\beta\cdot D)>=0 \quad \cdots(4)$$

rj(t-1) : The gain by strategy j at time t-1（The cost that it was able to save from the cost by the normal travel time）

TCb,RCb : The time cost by the normal travel time, a running cost（we set the normal travel time from the time table of the logistics company to 150 minutes.）

TCj,RCj,Tj,D : The time cost by travel time of strategy j at time t-1, the running cost, the road toll, the Toyokawa Bridge passing dummy variable

α , β : The parameters（We set them from the situation of the real route choice.）

Player 2

We supposed player 2 does not learn (Rij(t)=0). Therefore, the tendency that player 2 adopts strategy j at time t, and the probability that player 2 adopts strategy j at time t do not change.

$$p_{ij}(t+1)=p_{ij}(t),\ \Delta x_{ij}=0,\ x_{ij}(t+1)=x_{ij}(t) \quad \cdots(5)$$

The travel time of the route

With the average travel time of each road section and the standard deviation of travel time which is given by probe data, we calculated the average travel time of each route and standard deviation of travel time by following equation. The travel time at time t is estimated that assumed that the distribution of travel time obeys the normal distribution of the average travel time and the standard deviation

The average travel time of routes is

$$\mu_l=\sum_i^n \mu_i \quad \cdots(6)$$

The standard deviation of the travel times of routes is

$$\sigma_l=\sqrt{\sum_i^n \sigma_i^{\,2}+2\sum_i^{n-1}\sum_{j=i+1}^{n} COV(X_i,X_j)} \quad \cdots(7)$$

μ i : The average travel time of route l
σ i : The standard deviation of route l
μ i : The average travel time of road section i
σ i : The standard deviation of road section i
COV(Xi,Xj) : The covariance of the travel time of road section I and section j

We assumed that travel time T of route l obeys normal distribution of the average travel time μ, and the standard deviation σi

$$f(T)=\frac{1}{\sqrt{2\pi\sigma_l}}exp\left[-\frac{1}{2}\left(\frac{T-\mu_l}{\sigma_l}\right)\right] \quad \cdots(8)$$

The probability of the impediment

We set it in each link by the following equation based on a probability of traffic accident by the road type at 6~9am in Aichi prefecture.
The probability of the impediment = Σ （"The probability of the traffic accident by road type i" X "link length of road type i"）

Therefore, the probability of an impediment the player 2 causes in each link is given following equation.
The probability of impediment in each link = link length X the probability of traffic accident by road type that the link belongs to.

The influence by the impediment

Based on mean delay time when the traffic jam was max, we supposed that an additional time, which is 30minutes on the expressway or 10 minutes on the highway, is needed to pass the link when player 1 pass the link with impediment.

THE TEST CALCULATION RESULT IN THE CURRENT CONDITION

We performed the test calculation with the distribution of travel time obtained from probe data and the setting that we showed above.

The formulation

The routes that player 1 chooses

We set six routes that player 1 chose based on an actual run route. In addition, to analyze selectability of many routes, we set some routes in combination of a number of actual routes, not only actually run through routes from Toyota-city to Tahara-city.

Route 1 : The Highway route (The route which passes the Toyokawa-bridge and The Kosakai-baypass (toll road).)
Route 2 : The Highway route (The route which passes the Toyokawa Bridge.)
Route 3 : The Highway route (The route which detours the Toyokawa-bridge, and pass the Toyohashi city centre.)
Route 4 : The Highway route (The route which detours the Toyokawa-bridge.)

Route 5 : The Highway route (The route which was used at the Tomei Expressway concentration construction period)

Route 6 : The route including the expressway（The route which passes the Tomei expressway (from Higashi-Toyota IC to Otowa-Gamagoori IC), and the Toyokawa Bridge.）

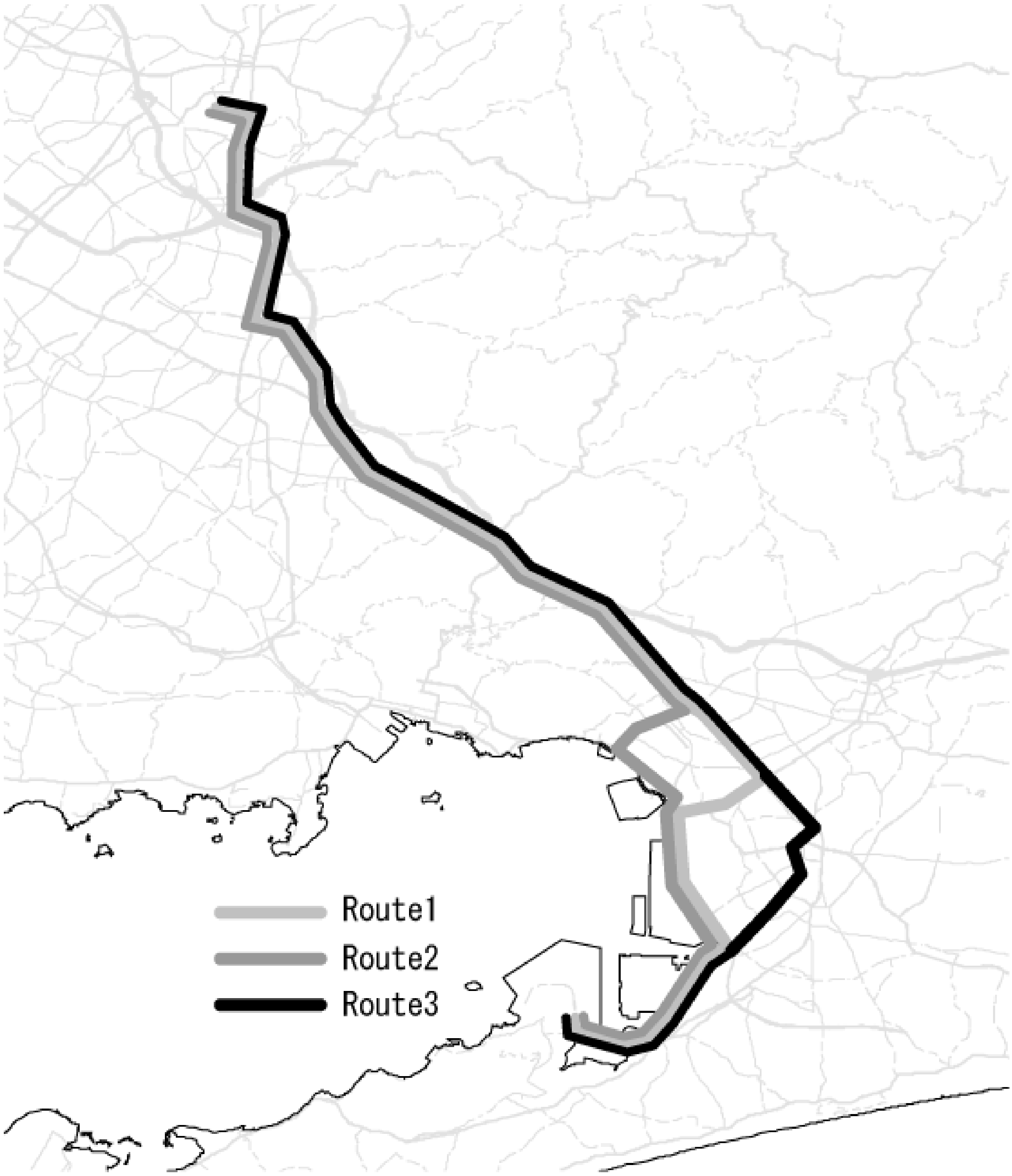

Figure 2 – The setting route (Route1~3)

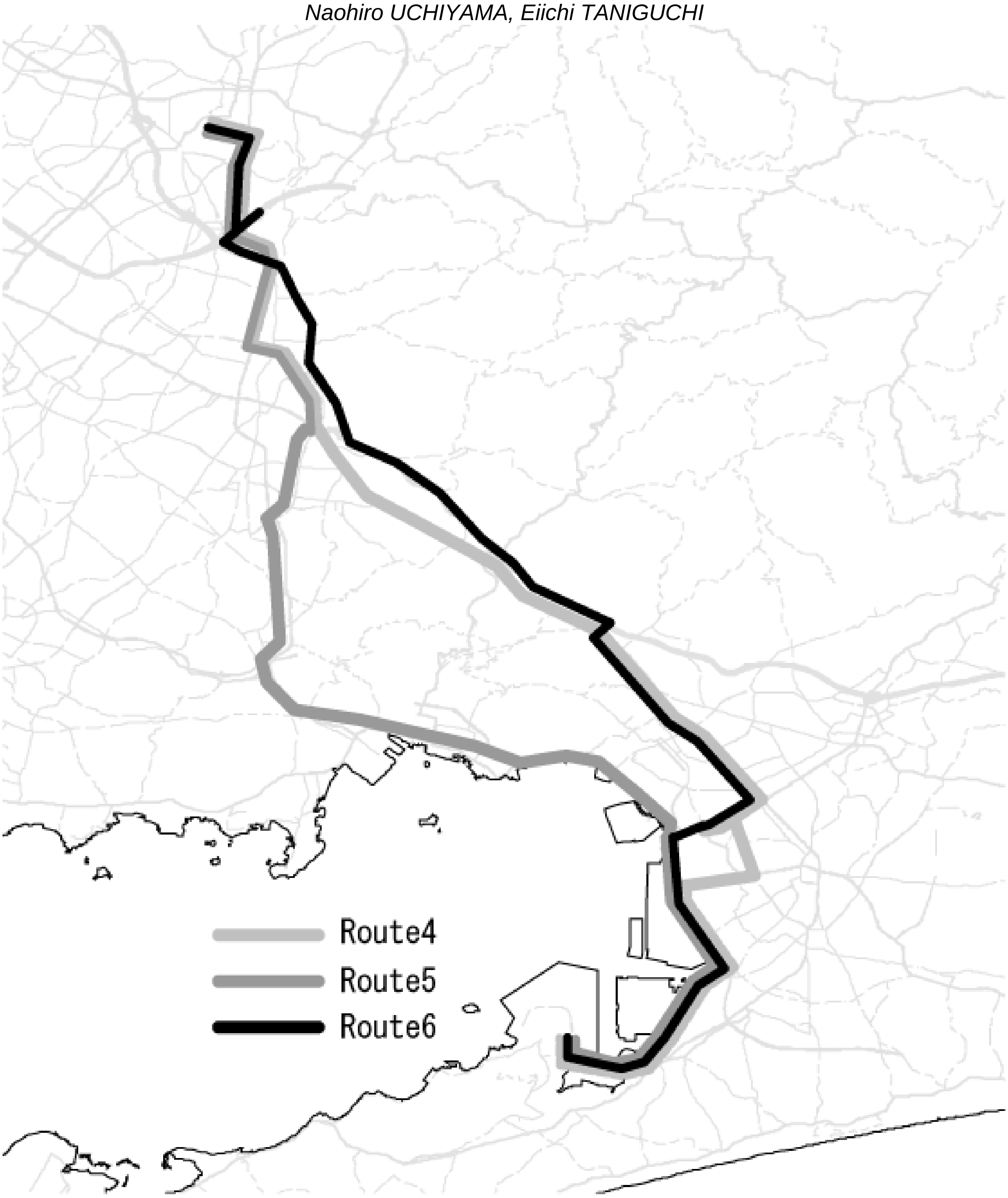

Figure 3 – The setting route (Route1~3)

The link that player 2 causes an impediment

We set 17 links which make up 6 routes.

The travel Time distribution and setting parameters

We set route travel time at time t which is used to estimate such as reinforcement with probe data at 7-9 am on a weekday except for Tomei Expressway concentration construction period. In addition, we estimated the average travel time, the standard deviation of travel time, and the covariance with the next road section.

The average travel time of each route and the standard deviation is shown in Table -1. Both the average travel time and the standard deviation, the values were smallest in the route 6 that pass the expressway. Among without the expressway passage, route 1 values were smallest, both the average travel time and the standard deviation.

In addition, we set α, β in equation (4), to 4, 70 based on actual route choice share obtained from probe data.

Table 1 – The route condition of each route of the present

	Distance (km)	Average travel time (minutes)	Standard deviation of travel time (minutes)	ref.) 95 percentail travel time (minutes)
route1 (The Toyokawa-bridge and The Kosakai-baypass passage)	60.0	127.4	7.6	139.9
route2 (The Toyokawa Bridge passage)	60.5	132.7	8.8	147.1
route3 (The Toyokawa-bridge detour, The Toyohashi city centre passage)	59.5	152.2	11.6	171.2
route4 (The Toyokawa-bridge detour)	64.8	132.8	7.7	145.4
route5 (The route which was used for Tomei Expressway concentration construction period)	62.3	139.3	8.0	152.4
route6(The express-way use, The Toyokawa Bridge passage)	62.9	101.8	7.2	113.6

note) 95 percentile travel time = average travel time +1.64*standard deviation
The value was calculated with probe data at 7-9 am on a weekday except for Tomei Expressway concentration construction period

The result of the estimation

As a result of 1,000 times of iterations, a choice ratio of route 2 was the highest with 64%, and subsequently route 4 was 34%, route 1 was 2%, and route 3, 5, 6 were not chosen.

Actually there was the use of 12% in route 3, but since the average and standard deviation of travel times were large, it was not chosen on the model calculation.

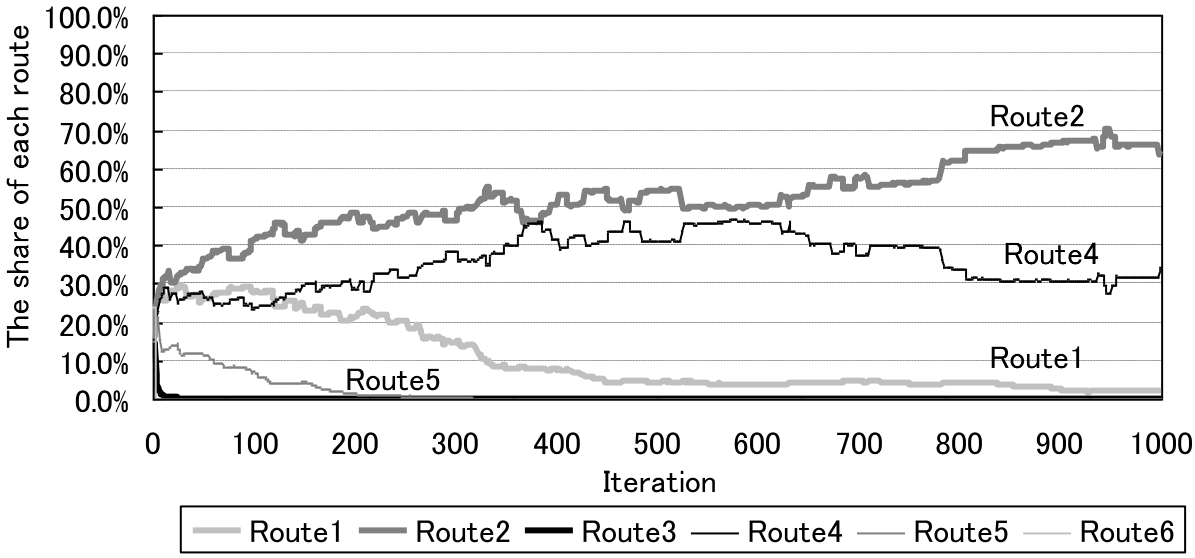

Figure 4 – The estimation result of the present condition

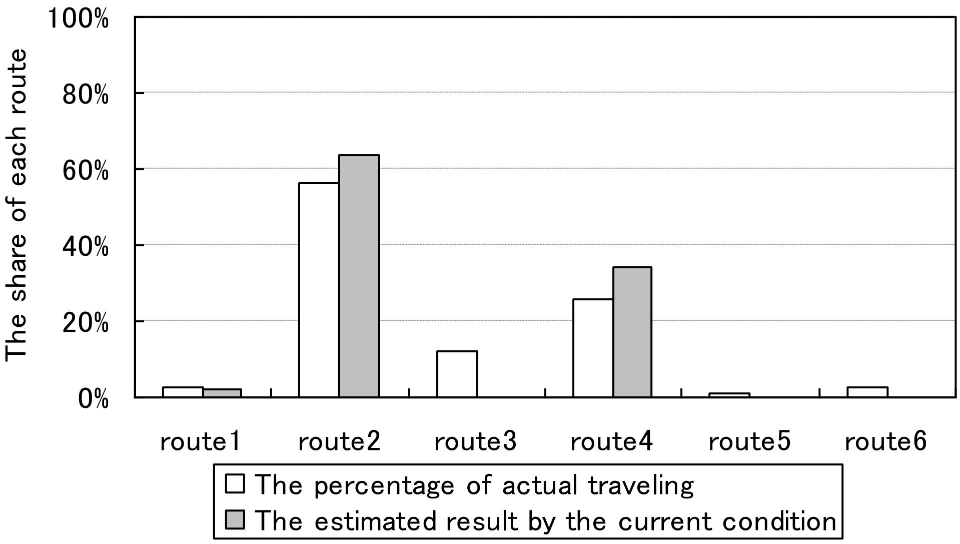

Figure 5 – Comparison with the estimation result in true data and the present condition

CASE STUDY

We set two cases as the case study that the standard deviation is reduced and the toll road charge is reduced, and we tried to estimated influence to the route choice.

The distribution of the travel time

Case1

On the route which did not pass the Toyokawa-Bridge, we assumed that the variability of the travel time goes down by road improvements, and we analyzed influence on the share of the route choice. We estimated the case when standard deviation became 2/3 on routes 3 and 4. Except for a route of the highway use, route 4 became smallest by the standard deviation because standard deviation of route 3 and 4 was shortened, but route 1 was the smallest by the average travel time. But route 1 is the smallest by the 95 percentile travel time. （Table - 2）

Table 2 – The route condition of each route of the case study

	Distance (km)	Average travel time (minutes)	Standard deviation of travel time (minutes)	ref.) 95 percentail travel time (minutes)
route1 (The Toyokawa-bridge and The Kosakai-baypass passage)	60.0	127.4	7.6	139.9
route2 (The Toyokawa Bridge passage)	60.5	132.7	8.8	147.1
route3 (The Toyokawa-bridge detour, The Toyohashi city centre passage)	59.5	152.2	7.7	164.8
route4 (The Toyokawa-bridge detour)	64.8	132.8	5.1	141.2
route5 (The route which was used for Tomei Expressway concentration construction period)	62.3	139.3	8.0	152.4
route6 (The express-way use, The Toyokawa Bridge passage)	62.9	101.8	7.2	113.6

Case2

We set the case that the charge of toll road is half without changing of the average travel time and the standard deviation. By this case, the reinforcement of route 1 and route 6, that passes the toll road, are enlarged.

The result of the estimation

Case1

As a result of 1,000 times of iterations, the choice ratio of route 4 increased to 98%, and that of route 2 decreased to 2% because of the shortening of the standard deviation of route 3 and 4.

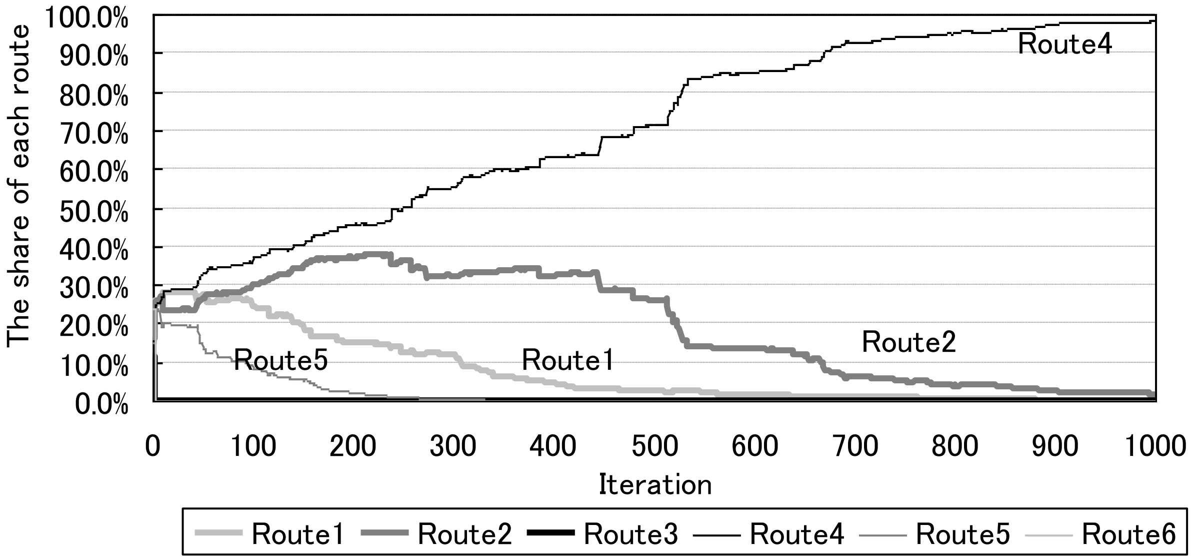

Figure 6 – The estimation result of the case 1

Case2

As a result of 1,000 times of iterations, the choice ratio of route 1 increased to 84%, and that of route 2 decreased to 10% because toll road charge was reduced to half-price and the reinforcement of route 1 and route 6 were enlarged. .Although the half price on toll road charge, ratio of route 6 was 0%.

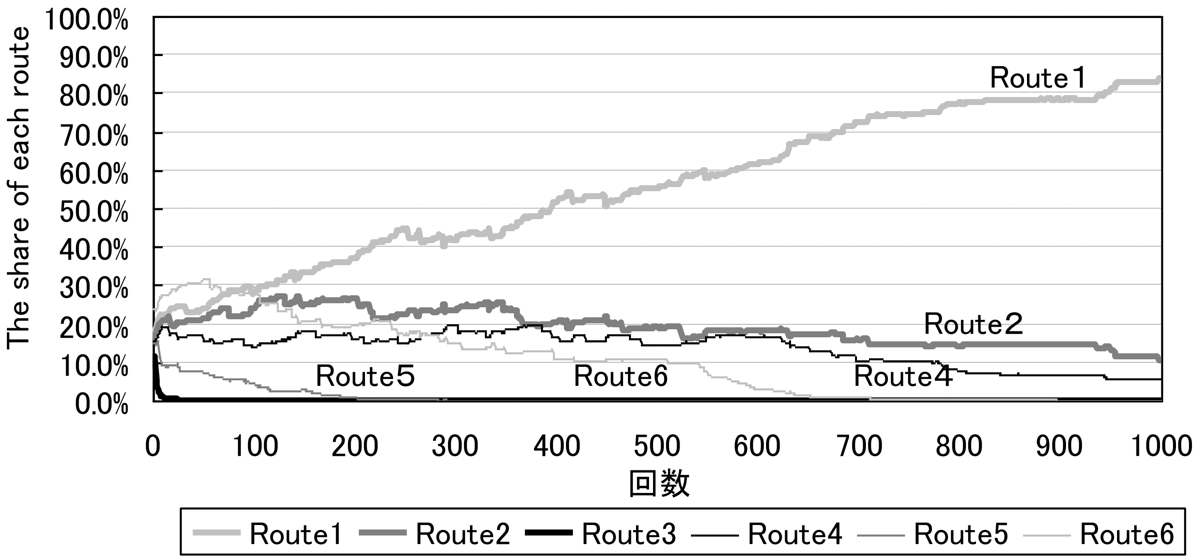

Figure 7 – The estimation result of the case 2

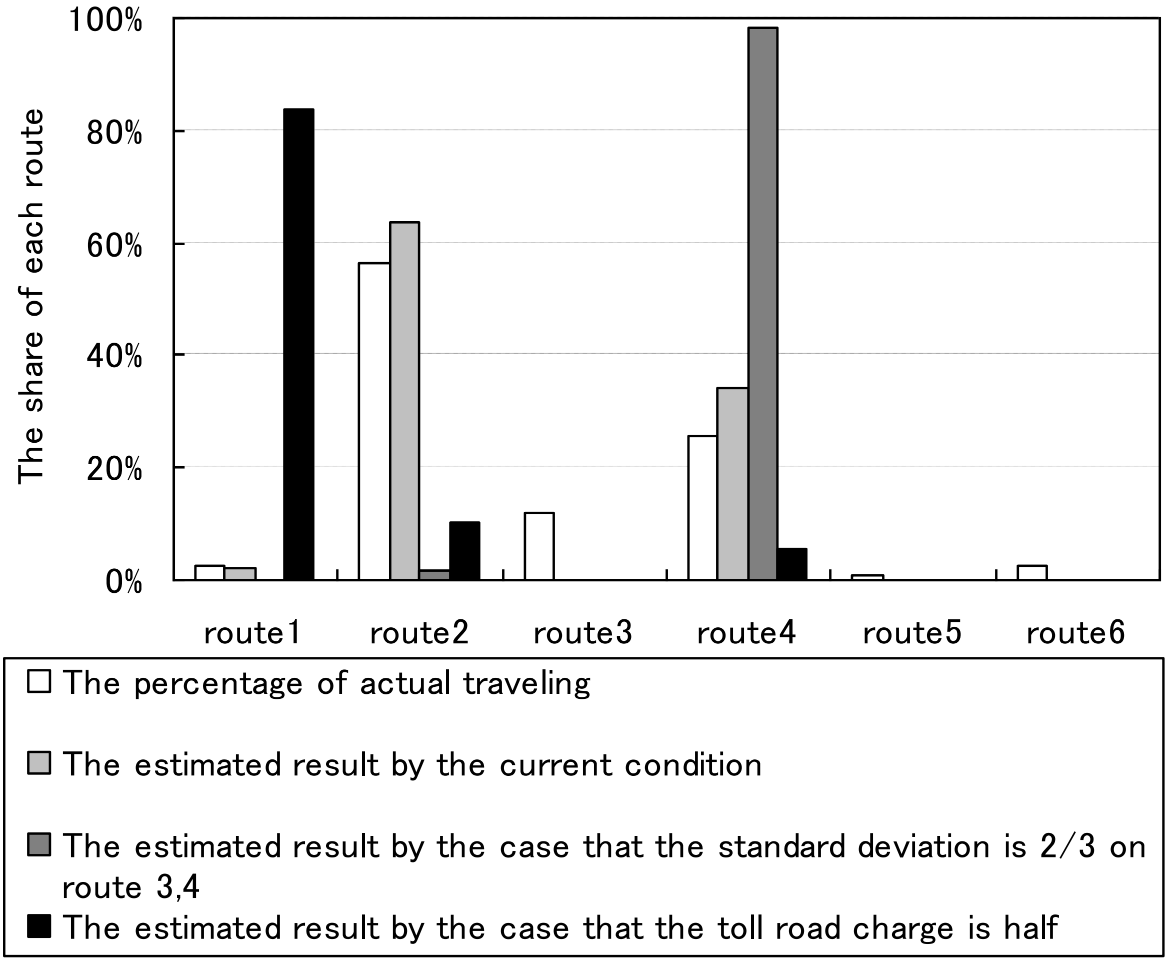

Figure 8 – Comparison with the estimation result

THE SUMMARY OF RESULTS AND FUTURE TASKS

The summary of results

In this study, we focused on the evolutionary game theory and built the model that supposed that a strategy change whether the strategy succeeded (a gain), after actually took a certain strategy (shipping of goods). This model was built based on the really route choice process that a dispatcher performs, such as considering additional time, choosing a route based on past experience. And we can analyze the change of the route choice behaviour with real decision-making process by this model.

Specifically, we can find which road improvements have a greater influence on a route choice behaviour, and the model contribute to extraction of the road improvements that should take priority.

On the model construction, we assumed that the logistics company thought that as the difference of sum of the time cost, the running cost and the toll of the road is the gain, the gain reinforce the next behaviour. And we built the model considering the distribution of travel times and the probability of traffic accidents, and set the parameters of gain structure in the model based on the real route choice behaviour which obtained from the probe data. As a result, we can built the model that the route choice ratio estimated by the model is similar to actual route choice ratio.

In addition, with the model that we built, we performed the case study that standard deviation of route 3,4 which did not pass Toyokawa-Bridge goes down to 2/3. As a result, route 4 became about 98% shares. Route 3 is 0%, this reason arises from the largeness of the average travel time and standard deviation, so there was no influence even if standard deviation goes down.

Future tasks

In this study, only using travel tiem data from Toyota-city to Tahara-city, we described the method of thinking of the gain structure and the route choice within a certain assumption (the method of thinking of the reinforcement on the tendency to choose a certain strategy based on the past experience). And we built a model and estimated a share of the route choice behaviour. For the future, we need to built model on many OD pairs, and analyze the setting method of the gain structure, the reinforcement, and other parameters. Furthermore, improving the duplication of the model, we need to analyze influence on route choice behaviour by the road improvements actually planed.

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