A STUDY ON SERVICE SUPPLY PLANNING OF INTER-REGIONAL TRANSPORTATION NETWORK WITH THE HELP OF MULTI-OBJECTIVE OPTIMIZATION METHOD

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ABSTRACT

Recently, the need to reduce carbon dioxide (CO_2) emissions is an important concern. The purpose of the study is to propose a prototype of an evaluation method for the inter-regional transportation using a couple of indices of convenience of travel as well as CO_2 emissions, to show the effect of a flexible service supply measures. Using genetic algorithm (GA), the authors propose an evaluation system for service supply combinations of inter-regional transportation network where the target is to reduce CO_2 emissions. Simulated results suggest that flexible service will effectively reduce the environmental impact of CO_2 emissions with increasing inter-regional mobility simultaneously.

Keywords: Inter-Regional Transportation, CO_2 Emissions, Genetic Algorithm

1 INTRODUCTION

1.1 Environmental Problems and Inter-Regional Transportation

Many countries around the world should try to reduce carbon dioxide (CO_2) emissions in various fields in order to comply with the Kyoto Protocol. Japanese government has set a target that would reduce greenhouse gas by 25% by 2020 compared with 1990. Because CO_2 emissions from the Japanese transportation sector account for about 20% of total amount, it is important to reduce the emissions in inter-regional transportation systems in Japan. To achieve this target, it is necessary to diversify the service in inter-regional transportation. As it relates to transportation, diversification means to vary a number of cars in one train set or a frequency in response to passenger's demands, which vary throughout the day. For example, Shinkansen is well known as high-speed mass transportation system that links the metropolitan areas, but on the other hand there are short Shinkansen by four cars operation in Sanyo Line in response to the demand. Therefore, it is necessary that flexible transportation service such as the number of cars in one train set and frequency for service supply planning of future inter-regional transportation.

In the inter-regional transportation field in Japan, a lot of research works on the optimization of the network have been implemented. For example, Nomura et al. (2001) measured the user's and the supplier's benefits respectively using the EVGC (Expected Value of Generalized Costs) and the minimum generalized costs considering not only travel time but also frequency. Hazemoto et al. (2003) proposed a method to evaluate improvements of rail/air network, considering alternate paths. Murakami et al. (2006) discussed optimal railway operations in terms of frequency on railway links considering the complementary service with domestic airline from both viewpoints of travelers' convenience and operators' profitability.

However, these works do not take into account of the reduction of CO_2 emissions; focus only on improving the convenience of travel, e.g. easy transfers. In the study, the authors use case studies to examine service supply measures in a Japanese inter-regional transportation network using the indices of convenience of travel and CO_2 emissions.

1.2 Multi-Objective Optimization

Multi-objective optimization involves multiple objective functions. The Pareto optimum solution is used because a single optimum solution cannot be obtained in multipurpose optimization. Pareto optimum is a condition under which any utility from an objective function cannot be improved unless the other utility is decreased. It is said that the multiple functions in multi-objective optimization take the form of a trade-off. As discussed in Section **1.1,** convenience of travel for travellers and CO_2 emissions are used as objective measures. However, because an increase in the frequency of travel for the purpose of enhancing the utility of public transportation increases CO_2 emissions from public transportation, it is possible that the functions are not in the form of a trade-off. Consequently, the authors used the reduction of CO_2 emissions as a constraint. It is considered that the service supply measures with higher convenience can be implemented while achieving the target of reduced emissions.

2 PROBLEM SETTING

2.1 CO_2 Knapsack Problem

In the "Knapsack Problem", the weight and profit of some items and the size of the knapsack are assumed. The "Knapsack Problem" is well known as a problem to find the combination of items with maximum profit while the total weights remain within the size (Martello and Toth 1990). This problem is known as one of NP-hard (Nondeterministic Polynomial time) problems which means it is not easy to solve.

In the optimization in the study, combinations of level of service within the target of CO_2 emissions are found. Because, when the combinations change, which means both profit (convenience of travel) and loss (CO_2 emissions) change, the optimization problem in the study amounts to “Knapsack Problem”.

In the paper, the authors apply the “Knapsack Problem” to find service supply measures, and refer to it as a “CO_2 Knapsack Problem”. In the context of the Knapsack Problem, the level of service of the different modes of transportation (railway, airline and coach) are considered as the items, and the convenience of travel calculated from the level of service and CO_2 emissions are considered as the profit and the weight, respectively. The target for reduction of CO_2 emissions is placed to the size of the knapsack. It is possible to find much better service supply combinations of network while CO_2 emissions remain within the size (the target for the reduction) by doing optimization calculation as “CO_2 Knapsack Problem”.

2.2 How to Deal with the Problem

There are numerous solutions to the problem because the study focuses on multiple services within multiple modes. Consequently, the genetic algorithm (GA), which is a searching technique inspired by evolutionary biology including crossover, selection and mutation (Holland 1975), is applied to solving the optimization problem. However there are many algorithms to solve the “Knapsack Problem”, GA which possesses extensibility is applied to the paper among other algorithms.

3 NETWORK EVALUATION SYSTEM USING GA

3.1 Purpose of the System

In this chapter, the network evaluation system using GA is explained. As discussed in Section **2.1**, the purpose of the study is to find the service supply combinations in existing transportation network at the time point of evaluation using GA, which is applied to the CO_2 Knapsack Problem.

The research on evaluation of inter-regional network using GA includes a study by Hatoko and Nakagawa (2007) aims at improving the convenience of travel using level of improvement as the items for the Knapsack Problem. Haldenbilen and Ceylan (2005) proposed network optimization including a railway by using taxation to road users in their GA. Okumura and Tsukai (2007) applied GA to find the best combination of an airport’s operation capacity allocation for maximizing the consumer’s surplus of inter-regional passengers.

3.2 System Outline

When the GA is used for analysis, it is necessary to express the variables as chromosomes. In the study, (1) frequency of railway, airline and coach travel, (2) a number of cars in one train set (Shinkansen) and (3) CO_2 surcharge are the chromosomes. The authors assumed that the CO_2 surcharge shifts users from road travel, which has a large negative environmental impact, to public transportation and that fares are in proportion to the amount of CO_2 emissions generated per person based on traveller's movements.

With regard to the chromosome setting, the frequency that is converted into a five digit number by binary coding (0-1) is given from 0 to 160 in multiples of five. The number of cars in one train set varies between one and eight cars as defined by the present Shinkansen system. The CO_2 surcharge is set between 0 and 12,700-yen in multiples of 100-yen by binary coding.

To prevent the loss of diversity caused by long chromosomes, the authors adopted the approach that divides the chromosomes into three parts ((1) railway and CO_2 surcharge, (2) airline and (3) coach) and evaluates them in one.

3.3 Indices for Evaluation

The evaluation indices of CO_2 emissions and convenience of travel are described as below.

CO_2 emissions are calculated by multiplying the basic unit of CO_2 emissions from each transportation mode by travel distance and frequency and a number of cars in one train set (railway only), as was done in the authors' previous study (Okunobo et al. (2009)).The values of the basic unit from eco-friendly cars and diesel trains are added to what was used in the previous study as listed in Table 1 (Rand Transport Bureau (2009), Murakami et al. (2007), Shibahara et al. (2006) and Shibahara and Kato (2008)). The emissions from public transportation can be calculated by frequency; however, frequency cannot be used with the emissions from passenger cars. Therefore, demand volume is used to calculate the CO_2 emissions from road traffic, which is estimated based on demand estimation model consisted of the disaggregate logit model and gravity model. The logit model and utility are expressed in eqs. (1) and (2),

$$P_{in} = \frac{exp(V_{in})}{\sum exp(V_{in})} \quad (1)$$

$$V_{in} = \beta^t T_{in} + \beta^c C_{in} + \beta^f F_{in} + \beta^i \quad (2)$$

where;

P_{in} : the probability that sample n selects transportation mode i,
V_{in} : the observed utility,
T_{in}, C_{in} and F_{in} : represent travel time, cost and frequency, respectively, and
β^t, β^c, β^f and β^i : the parameters to be estimated.

There are four targeted modes: railway, airline, coach and passenger car. The dummy constant is introduced to three modes — railway, airline and coach (not passenger car). The values of the estimated parameters are shown in Table 2 in which it is noted that there is no contradiction in the sign of parameters. Moreover, the t value and likelihood ratio are both significant values. The results indicate that this model sufficiently expresses the modal choice behaviour.

In the paper, the gravity model is prepared as the trip distribution model. The gravity model and accessibility are expressed in eqs. (3) and (4),

$$T_{OD} = exp(\beta^0) \cdot (N_O)^{\beta^1} \cdot (N_D)^{\beta^2} \cdot exp(\beta^3 \cdot \Lambda_{OD}) \tag{3}$$

$$\Lambda_{OD} = ln \left\{ \sum exp(V_i) \right\} \tag{4}$$

Where;

N_O and N_D : population of the respective zones: origin and destination,
β^0, β^1, β^2 and β^3 : parameters to be estimated, and
Λ_{OD} : the logsum variable that shows ease of travel between origin and destination.

This model considers the induced traffic because the trip distribution changes depending on accessibility.

Table 1 – Basic Unit of CO_2 Emissions from Each Transportation Mode

Basic Unit of CO_2 Emission ($kg\text{-}CO_2$/km/unit)						
Railway					Passenger Car	
Shinkansen	Limited Express	Diesel Train	Airline	Coach	Gasoline Car	Eco Friendly Car
0.77	1.36	2.60	111.37	0.64	0.16	0.07

Table 2–Estimated Parameter of Mode Choice Model

	Estimated Parameter					
	Time (hour)	Cost (ten thousand JPY)	Frequency (Log(service/day))	Railway Dummy	Airline Dummy	Coach Dummy
value	-0.58	-0.71	0.18	-1.23	-1.75	-1.53
t value	-16.29	-8.09	-1.96	-9.54	-8.20	-9.79
Likelihood Ratio	0.39					
Value of Time (JPY/hour)	8170					

Table 3 –Estimated Parameter of Distribution Model

	Estimated Parameter			
	constant term	Population of Origin Zone (million)	Population of Destination Zone (million)	LogSum Variable
value	-12.93	1.45	1.20	0.77
t level	-501.77	544.83	445.43	280.60
coefficient of determination	0.92			

The values of the estimated parameters are shown in Table 3. As shown in Table 3, there is no contradiction in the sign of parameters. Moreover, the *t* value and coefficient of determination are both significant values. The result means this trip distribution model expresses the trip distribution with acceptable accuracy.

CO_2 emissions are calculated by the estimated traffic volume and other values. The evaluation indices of CO_2 emissions are expressed in eqs. (5) – (9). The values of estimated traffic volume and travel distance of passenger car are placed on in each OD pair, while the values of frequency and travel distance of public transportations are placed on in each link of each mode.

$$\begin{cases} Ep = Bp\sum_{OD} Tp_{OD} \cdot Lp_{OD} & (5) \\ Er = \sum_{i} Br^{i} \sum_{j} Fb_{j}^{i} \cdot Lb_{j}^{i} & (6) \\ Ea = Ba\sum_{j} Fa_{j} \cdot La_{j} & (7) \\ Ec = Bc\sum_{j} Fc_{j} \cdot Lc_{j} & (8) \\ Ew = Ep + Er + Ea + Ec & (9) \end{cases}$$

Where;

Ep, *Er*, *Ea*, *Ec* and *Ew* : CO_2 emissions from passenger car, railway, airline, coach and whole modes,
Bp, *Br*, *Ba* and *Bc* : basic unit of CO_2 emissions from each transportation modes, especially railway divided to three types: Shinkansen ($i = 0$), limited express ($i = 1$) and diesel train ($i = 2$) ,
Tp : estimated traffic volume of passenger car,
Fr_j, Fa_j, and Fc_j : frequency of each transportation modes and
Lp_{OD}, Lr_j, La_j and Lc_j : travel distance of each transportation modes,

In the paper, convenience of travel is measured by passenger-kilometer that is an index of activeness of travel. The passenger-kilometer is maximized in eqs. (10).

$$\max P_{km} = \sum_{OD} T_{OD} \cdot L_{OD} \qquad s.t. \quad Ew \leq Eg \qquad (10)$$

Where;

P_{km} : passenger kilometer and
L_{OD} : travel distance in each OD pairs and
Eg : the target for CO_2 emissions.

As discussed in Section **2.1**, eqs. (10) is to be solved by the Knapsack problem.

4 SIMULATION AND DISCUSSION

4.1 Framework and Assumption of the Analysis

In the paper, the network is limited to the Kyusyu area, a region that is located in the southwest area of the Japanese Islands and with 40000km^{2}s (Figure 1). The Kyusyu area is applied in this case study because of the number of competitive transportation routes and diversity of transportation types including coach unlike metropolitan areas in the Tokyo Metropolitan Area. Trip data and the origin-destination table from the “2005 Inter-Regional Net Flow Survey” implemented by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT 2005), are applied to the analysis. Every five year since 1990, the “Inter-Regional Net Flow Survey in Japan” has been conducted in order to create a database of inter-regional passenger travel in Japan. In the survey, the Kyusyu area is divided into 26 zones except isolated islands.

There are three types of public inter-regional transportation in Kyusyu. The expressway network in Kyusyu is mainly constructed from the Kyusyu Longitudinal Expressway between Kitakyusyu and Kagoshima in the north-south direction and the Kyusyu Transversal Expressway between Nagasaki and Ohita in the east-west direction. The Kyusyu Shinkansen has been running between Yatsushiro in Kumamoto and Kagoshima since 2004 and will start to operate full service between Fukuoka and Kagoshima from the spring of 2011. The airline network connects Fukuoka and Nagasaki with Miyazaki and Kagoshima. The coach network in Kyusyu is well developed compared with other regions; about 14 million travellers use this network (Kyusyu District Transport Bureau 2008).

The authors compare the inter-regional transportation network in Kyusyu in 2005 which the survey was conducted and that predicted in 2020. The reason to focus on 2020 is that the Kyusyu Shinkansen will begin full service in 2011 and the Japanese government

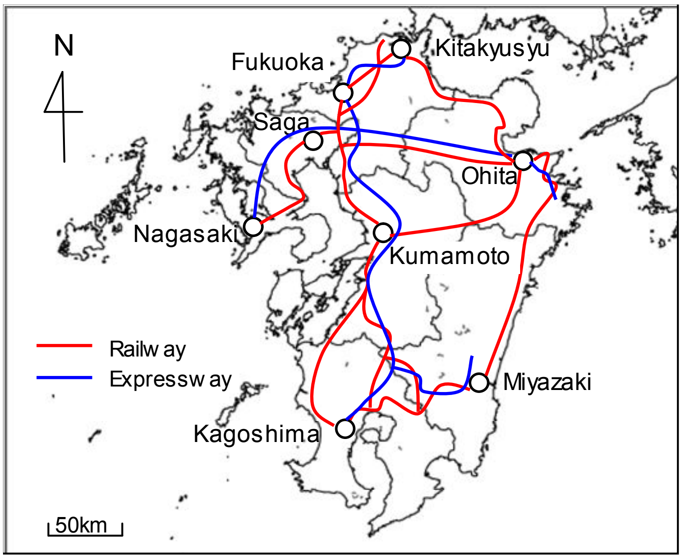

Figure 1 – Major Cities and Transportation Network in Kyusyu

announced the target for reduction of CO_2 emissions by 2020. In this system, the values for level of service, i.e. frequency, the number of cars in one train set and CO_2 surcharge vary, while the other values — time and price — are fixed at 2005 levels except Kyusyu Shinkansen. The authors determine time and cost for the Kyusyu Shinkansen by referring to other Shinkansen data. The links where frequency is changed are 19, 4 and 24 links in railway, airline and coach, respectively. The number of cars in one train set is set in two sections: Fukuoka — Kumamoto and Kumamoto — Kagoshima. In addition, the coverage rate of the eco-friendly cars like a hybrid car and the policy for expressway tolls are set as policy variables.

4.2 Comparison of 2020 with 2005

Using the system developed, an effective combination of levels of service is calculated by simulating the inter-regional transportation network for 2020. The target for CO_2 emissions reduction in 2020 is set at 5,893 (tons/day), which is a 25% reduction from the emission level of 7,858 (tons/day) in 2005 predicted by the authors' previous study. In this simulation, the penetration rate is assumed to be at 20% and the expressway toll is left unchanged from the 2005 level.

Table 4 shows the calculation results for passenger-kilometer and CO_2 emissions in 2005 and 2020. As shown in Table 4, although a large reduction in CO_2 emissions is achieved, the convenience of travel decreases. Table 5 shows the results for emissions from each transportation mode. As shown in Table 5, the emissions from passenger cars decrease greatly, while the emissions from all types of public transportation increase.

It is probable that CO_2 emissions decrease because travellers shift their transportation mode from passenger car to public transportations which increase the utility by increasing the frequency. The detailed simulation results of the frequency are described later. The results also show the passenger-kilometer in 2020 decreased compared with 2005. In this simulation, the value of passenger-kilometer decreases, although the value is calculated to be brought in closer with maximum value. Probably, it is because the CO_2 surcharge brings a negative impact on travel. The target for reduction of CO_2 emissions by 25% is lofty and is hard to be achieved. Therefore it is reasonable that the results show decrease in travel flow. The CO_2 surcharge is estimated at 2,300 JPY/tons, as shown in the results.

4.3 Frequency of Transportation

The results for frequency of three transportation modes (railway, airline and coach) are compared with the value observed in 2005. In the following paragraphs, the three transportation modes are explained independently; however, they are calculated at the same time. In the figures, the thickness of the link shows the frequency, the circle shows the location of major cities and the size of the circle shows the magnitude of the degree of the representative cities in each prefecture.

Table 4– Evaluation Indices

Years	convenience of movement (million passenger-kilometer)	CO_2 emission (tons/day)
2005	20.81	7858
2020	20.43	5788

Table 5– CO_2 Emissions from Each Transportation Mode

Years	CO_2 emission (tons/day)			
	Railway	Airline	Coach	Car
2005	431	991	118	6318
2020	1581	1878	375	1954

4.3.1 Railway

Figure 2 shows the results for frequency of railway. The figure shows that the frequency in 2020 increases overall compared with 2005. The change in frequency is remarkable in the annular part of the Kyusyu area including the east side. This result means that the increase of utility of railway leads the emissions to decrease in links where a lot of passenger cars are used. On the other hand, the figure shows that the change in frequency is lowl in the link where the east and west sides are connected. These links cross the mountains that run through the Kyushu region, thus railway in these links have a sharp inclination. In addition, the emissions reduction in these links is low because these sections do not have electricity. Therefore, frequency in these links does not increase because the advantage of railway transportation is minimal.

Next, the authors discuss the number of cars in one train set which is one of the indices presenting the level of service. The Kyusyu Shinkansen has been running only in the southern part in 2005, and the number of cars in one train set is six cars. The calculated results for 2020 show that the train is one car train between Fukuoka and Kumamoto and eight cars train between Kumamoto and Kagoshima. Currently, the minimum number of cars in one train set for Shinkansen is four cars. The authors suggest it is necessary to consider flexible service like “light” Shinkansen on inter-regional transportation, however, “light” Shinkansen with one car is not actual service.

The results for railway travel suggest that flexible service is necessary in both frequency and a number of cars in one train set.

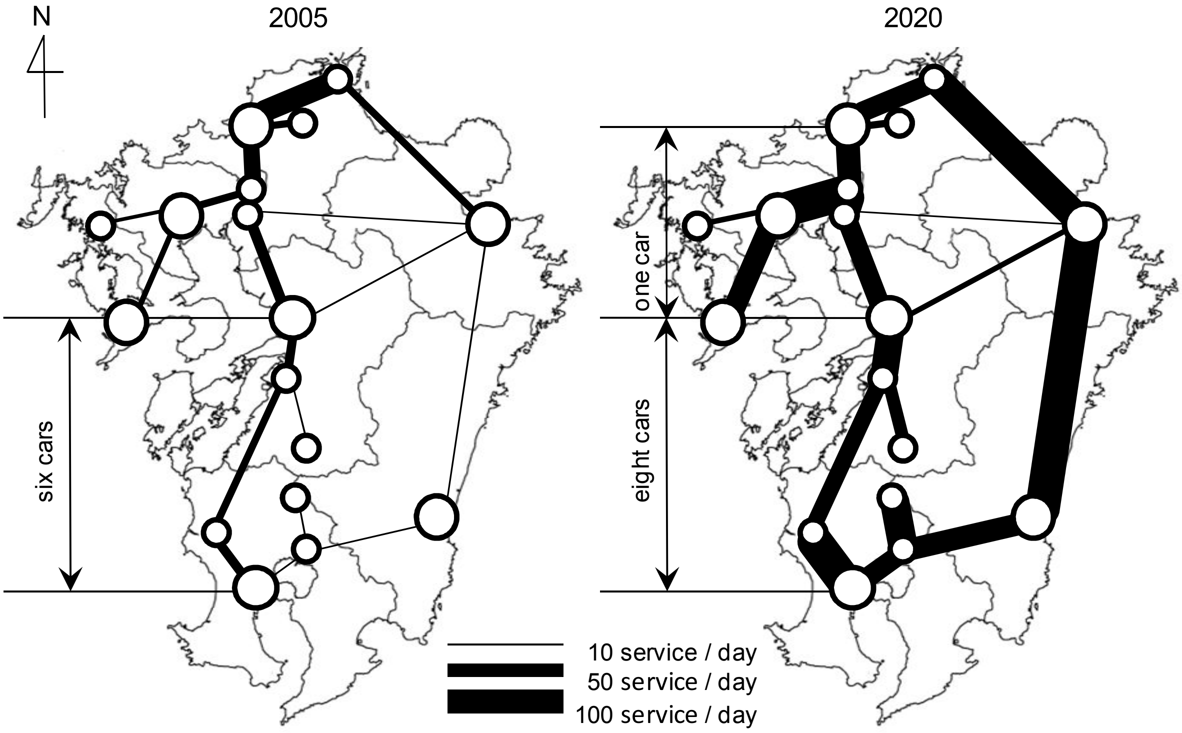

Figure 2 –Level of Service Comparison for Railway Travel, 2005 and 2020

4.3.2 Airline

Figure 3 shows the results for airline travel. In the Kyusyu area, there are not many airline passengers compared with other areas, and frequency of service is not high. In the result in 2020, the frequency increases between Nagasaki and Miyazaki. This is probably because that airline travel is more dominant than other types of transportation in this link because an indirect route is necessary when travelling by land transportation.

4.3.3 Coach

Figure 4 shows the results for coach travel. In Section **4.1,** the authors describe that a lot of travellers use coach in Kyusyu. However, the results for 2005 show that frequency is high close to Fukuoka and low in other areas. On the other hand, the results for 2020 show that frequency is greater in other areas, especially Kumamoto and Nagasaki. Coach is the same as passenger car in terms of fossil fuel use; moreover, its basic unit of emissions is not small. At the same time a dominance of coach is that a lot of travellers can be transported at the same time. The results for coach travel suggest that it is effective in reducing CO_2 emissions that using not only railway but also coach.

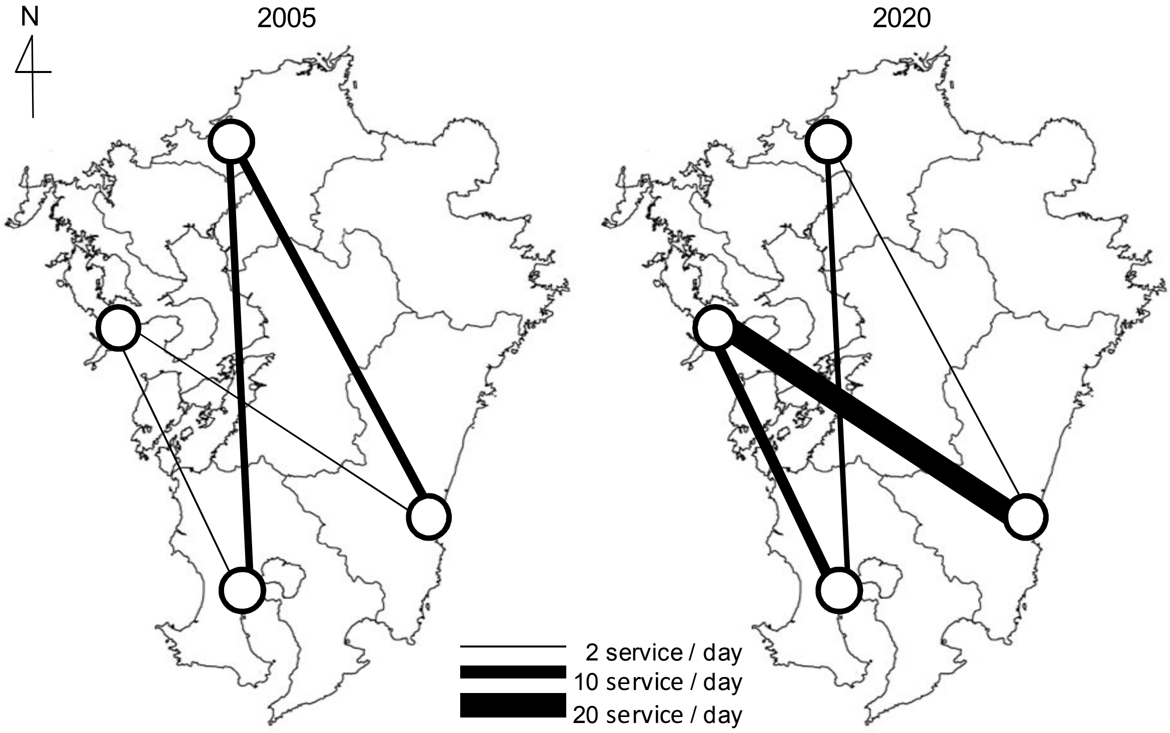

Figure 3 – Level of Service Comparison for Airline Travel, 2005 and 2020

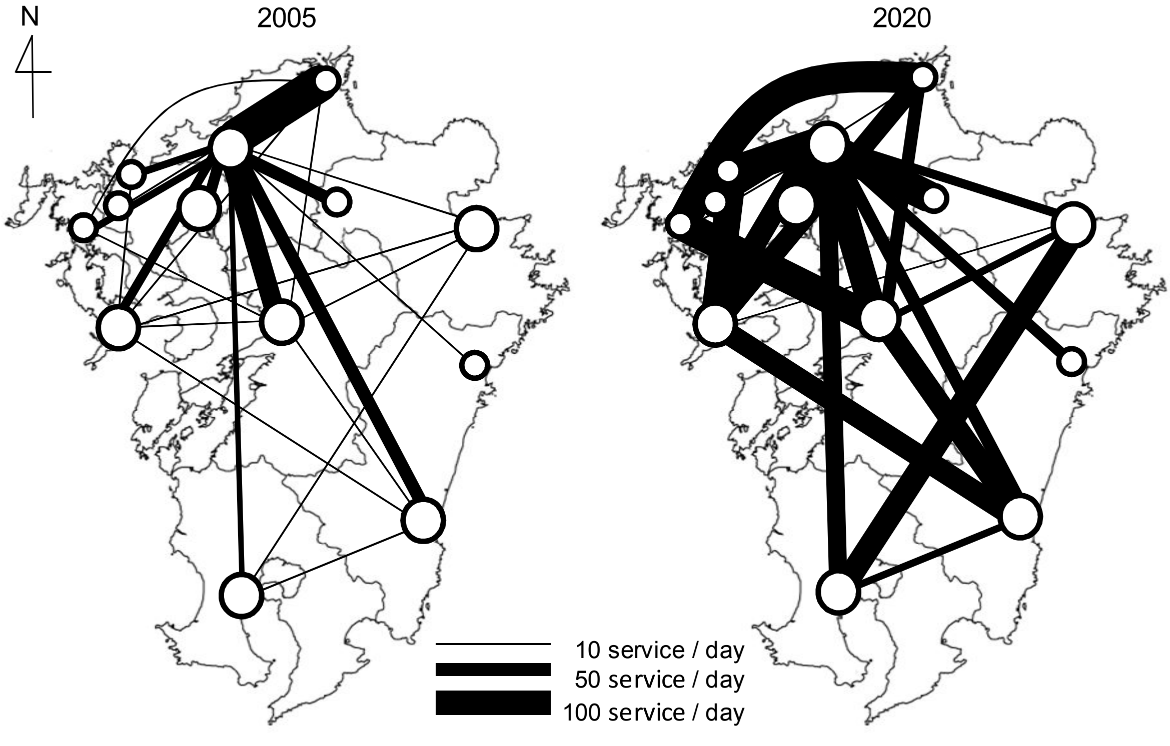

Figure 4 – Level of Service Comparison for Coach Travel, 2005 and 2020

5 CONCLUSIONS

In the paper, the authors propose a prototypical model of the evaluation system for service supply combinations of inter-regional transportation network with the target of reducing CO_2 emissions as constraint with the help of introducing GA. The authors also simulate the inter-regional transportation network in 2020 in the Kyusyu area as a case study. The simulated results suggest that flexible service such as frequency of public transportation and a number of cars in one train set, is effective to minimize the environmental impact of CO_2 emissions. The discussion in the paper suggests the fact that there are a lot of alternatives of transpiration planning because of the obligation to reduce CO_2 emissions and the increment of flexibility of transportation unit brought by the improvement of technology about inter-regional transportation.

In this evaluation system, the level of service for passenger car is fixed except for the CO_2 surcharge. If the expressway is free as being discussed, time required probably change because of congestion. Further study will be required in order to include the relation between expressway toll and time within the system and to set a new supply constraint for consideration of limitation of management resources of private companies of public transportation, for example rolling stocks, crew, etc. Also it is pointed out that it is necessary to reduce discrepancy between the supply from public transportation and the demand for the transportation for the sake of social optimal. Therefore it will be necessary to introduce the balance of the supply and the demand into an evaluation index. The proposed method here, however, may easily extend to simulate the entire Japanese transportation network in order to evaluate future policies of the inter-regional transportation systems.

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