A METHODOLOGY FOR IDENTIFYING LOWER CARBON TRANSPORT SYSTEMS FOR INTER-REGIONAL PASSENGERS: RAIL VS AVIATION

Naoki SHIBAHARA, Nagoya University, nshiba@urban.env.nagoya-u.ac.jp

Hirokazu KATO, Nagoya University, kato@genv.nagoya-u.ac.jp

Yoshitsugu HAYASHI, Nagoya University, yhayashi@genv.nagoya-u.ac.jp

ABSTRACT

The carbon dioxide (CO_2) emissions reduction policies for the inter-regional passenger transport system highlight two factors: 1) the aviation sector is the slowest to eliminate use of carbon fuels; and 2) aviation is expected to contribute more to greenhouse gas emissions than other transport modes. A methodology for identifying an inter-regional transport system with lower CO_2 emissions is proposed. This study aims to explore the possible changes in life cycle CO_2 (LC-CO_2) per passenger-km and eco-efficiency indicators including considering travel speed as a result of a shift from aviation to the high-speed railway system (Shinkansen). CO_2 emissions both for Shinkansen and aviation are estimated by applying the life cycle assessment (LCA) method and taking into account dominant parameters such as passenger demand.

CO_2 exhausted from aviation and Shinkansen during operation and the additional LC-CO_2 from providing new infrastructure are estimated. First, the sensitivity associated with the number of passengers for a 500-km long corridor is analyzed. The main results are as follows: 1) CO_2 per passenger-km from aviation hardly vary with the number of passengers; 2) LC-CO_2 per passenger-km for Shinkansen is inversely proportional to the number of passengers; 3) LC-CO_2 per passenger-km for Shinkansen is lower than that for aviation for passenger volume of approximately 1,200 or more passengers per day; and 4) for eco-efficiency, the break-even point is more than 2,000 passengers per day. The second analysis considers the distance and travel demand for both aviation and Shinkansen. A possible shift from the current demand for aviation to Shinkansen is compared for each inter-prefectural Origin-Destination (OD) pair. It is found that Shinkansen is more advantageous for OD pairs with higher demand and shorter distance. An application to the inter-prefectural ODs in Japan shows the conditions that provide an advantage of lower CO_2 emission for Shinkansen or aviation.

Keywords: Aviation, Shinkansen high-speed railway, Eco-efficiency indicator, Carbon dioxide

BACKGROUND AND AIM

The share of CO_2 emissions from passenger transport in Japanese national man-made emissions was 11.6% in 2007. Aviation made up 6.1% of the transport sector (the share in the total man-made emissions was 0.7%) with a marked increase of 55%, compared to aviation emissions in 1990. The aviation sector has been quite late in replacing carbon fuels, and this is considered to be a major reason for relatively higher shares of CO_2 emissions from aviation (Fujisaki, 2007).

In Europe, the aviation sector is making progress in taking significant action against global warming and widely implementing carbon offset measures, by participating in emission trading scheme (ETS), or passing along costs of CO_2 reduction to passengers. In this context, Japan will enter an era in which the transport modes shall necessarily be selected and promoted by their environmental impact in development plans.

Japanese railways are an excellent alternative to the airways for long-distance journeys. National reports by the Ministry of Environment state that, on average, the railways prove their eco-efficiency for significantly less energy consumption and CO_2 emissions than the airways. However, these reports lack detail on the variations of such assessments among the different routes or origin–destination pairs and are limited to the environmental load only from the operation of transport systems. However, the improvement of new lines should be evaluated starting from the construction phase of such huge infrastructures. In addition, operational efficiency, namely capacity, and the degree of congestion are also other very important factors. The future infrastructure improvements will be different in that the capacities will be smaller and the design will be limited by more severe geographical conditions, and this will probably lead to a shift from the scope in which environmental concerns have had the high priorities. In the quantitative assessment of any shift of inter-regional demand from aviation to the new Shinkansen lines (either currently being constructed or included in future improvement plans) and the associated reductions in the energy use and CO_2 emissions, the construction phase should also be considered as an important parameter of environmental load (Kato et al., 2005).

To date, there has been a big difference in the progress of improvement plans between the new airports and Shinkansen lines. Figure 1 shows the location of existing and planned airports and Shinkansen lines in Japan. The number of existing airports over 35 prefectures is 84 and two new airports, one of which is on one of the remote islands, are included in future development plans (either being currently constructed or planned). However, compared to the airports, Shinkansen has less regional access as this system has stations only in 23 prefectures. After the enactment of the Act for Construction of Shinkansen Across the Country and the development of an improvement plan in 1973, the construction for some of the lines proposed here is still ongoing, with some still at the planning stage (shown as planned lines in Figure 1). The total length of Shinkansen lines in this plan was 6,853 km but only 31% of it was completed, and today the Japanese high-speed railway network constitutes 2,176 km Shinkansen lines across the whole country. In the prefectures, which are not connected by Shinkansen lines, the main modes of transport are aircrafts, buses, or personal cars, and the use of railways is notably low.

In a practical and useful assessment of the contribution of Shinkansen improvement projects to the reduction of national CO_2 emissions, this study aims to estimate the variations in the amounts of CO_2 emissions between two possible scenarios: current aviation passengers will again travel by airway, or they will shift to Shinkansen lines. For this purpose, the LCA method is mainly utilized. Additionally, the inter-prefecture passenger demand analysis is made by using the inter-prefecture observed trip data and the distances, and any possible changes in demand are examined through a sensitivity analysis. Finally, the environmentally best alternative for high-speed transportation is suggested based on the results obtained from this framework of analysis.

However, this study provides a more strategic evaluation because a more elaborate analysis in this given framework requires a huge data set and detailed scenario setting, which are neither practical nor fully available. Despite this, such a strategic approach provides a valuable assessment for supporting the main proposition of this study that the Shinkansen improvement projects do not always result in a reduction in the total amount of CO_2 emissions. Furthermore, the reductions gained by shifts to the Shinkansen are sometimes overwhelmed by the generation of CO_2 emissions in the construction phase of the infrastructures. Meanwhile, the road mode (e.g., coach and passenger car) is not considered for analysis here because this study focuses on high-speed passenger transport.

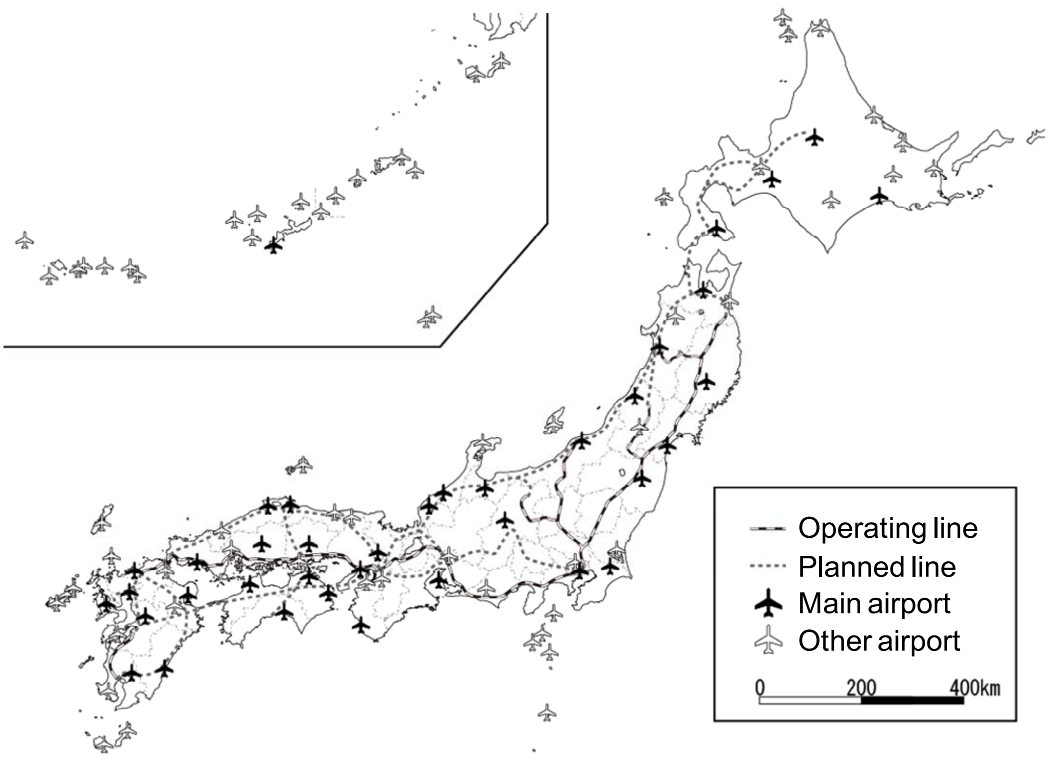

Figure 1 – Location of the airports and Shinkansen lines in Japan

ISSUES TO BE CONSIDERED IN APPLYING LCA TO REGIONAL HIGH-SPEED PASSENGER TRANSPORT SYSTEMS

National average CO_2 emissions generated from the energy use in the operation of transport modes provides a useful tool for their comparison, but as mentioned here earlier, some problems exist in this type of evaluation and the comparative analysis requires more special consideration of the transport improvements as a whole. Therefore, this study explores the modal CO_2 emissions more specifically by including the below characteristics of each mode in the analysis.

Aviation

- Infrastructure is not required between the origin–destination pairs
  -> It does not require as much maintenance as do the railways
- It can be operated through a route of straight connection between the origin–destination pairs
- The longer the route is, the lower the emissions generated per kilometer

Shinkansen

- Infrastructure is required between the origin–destination pairs
  -> Emissions generated by the infrastructure improvement per passenger is high for the routes with low passenger demand
- Geographical constraints do not allow a straight connection between the origin–destination pairs
  -> The length of the infrastructure is extended

The comparative analysis first provides insight into the extent of the life cycle environmental load by each abovementioned mode. The main components are the infrastructures, the vehicles, and their operation. Next, possible shifts of the aviation passengers to the newly constructed Shinkansen lines are estimated. The current state of the transport systems provides the starting point, and each alternative is analyzed by its impact the environmental load. In this context, an increase in the Shinkansen operations and relevant additional infrastructure and rolling stock requirements should necessarily be considered. In contrast, in the case that any of the airway routes are canceled, it is accepted that such a decrease in the number of routes will not have any effect of reductions in the aircrafts or airports in the short term and therefore is not included in the analysis. The scope of the analysis is limited to the newly constructed Shinkansen lines and manufactured rolling stock and does not necessarily take into account the existing infrastructures and aircrafts (Figure 2). The reasons for ignoring the emissions generated from the airports and production of aircrafts is explained later in this paper.

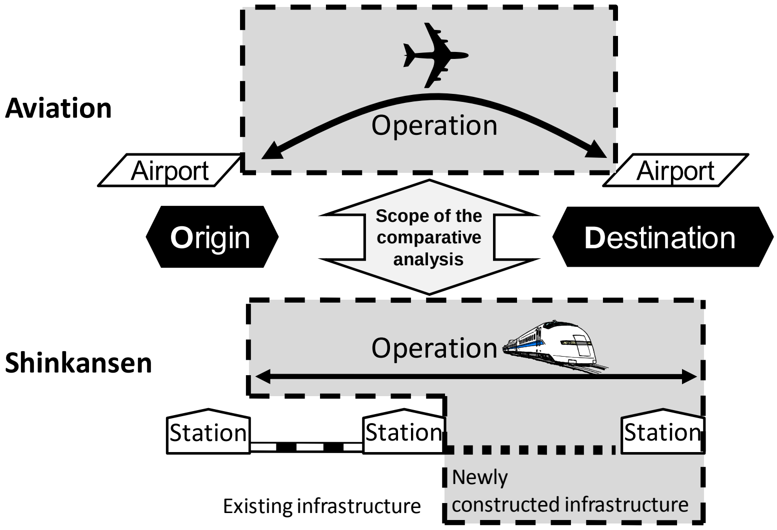

Figure 2 – Setting the scope of the comparative analysis (shown by the dotted lines)

METHOD OF ANALYSIS

Data for estimation of LC-CO_2

Aviation

a) Infrastructure

The unit values to substantiate the amount of CO_2 emissions generated by the construction of an airport are extracted from the observed data from the Chubu International Airport. The main parameters are the sources for the landing field, the guide path, design, and construction (boring and filling). The total number of arrivals and departures recorded in 2006 for the Chubu International Airport is 53,450, and the average passenger-km per flight is 99,313 [passenger-km/flight]. Using these real figures, CO_2 emissions from the construction phase of an airport is estimated in terms of passenger-kilometer.

b) Aircraft

It is assumed that only the B777 type of aircrafts having a capacity of 500 passengers serve the regional passengers. Obviously, for lower levels of demand, smaller types of aircrafts are used, but for the convenience of computations, this variation is excluded from the analysis. The trip times are taken from the time tables of the airway companies. The previous LCA research (JCMA, 2009) provided unit values for computations of total CO_2 emissions for B777 type of aircraft having an average occupancy rate of 65 [%] (for materials 0.25 [g-CO_2/passenger-km]; for manufacturing, 1.34 [g-CO_2/passenger-km]; for operation 137.63 [g-CO_2/passenger-km]).

c) Operation (Flight)

The CO_2 emissions generated from the aircrafts are calculated using Equation 1, where

Q_a: total daily CO_2 emissions generated from the flights of the aircrafts [t-CO_2/day]

$F(x)$: CO_2 emissions generated from one aircraft per one kilometer [t-CO_2/(flight-km)]

x: distance between the origin and the destination [km]

N_a: Number of flights by the aircrafts per day [flight/day]

$$Q_a = F(x) \cdot x \cdot N_a \tag{1}$$

In this formulation, the amount of CO_2 emissions from an aircraft per kilometer is defined on the basis that the largest energy consumption occurs at take off and that fuel consumption decreases with the weight of the aircraft, and therefore, the longer the distance traveled, the less CO_2 is emitted per kilometer. Similarly, the IPCC Guide Book (IPCC, 1996) suggested that land and take off and the cruise phases should be evaluated separately when considering the environmental load generated by the aircrafts. In this context, rather than a constant unit value per kilometer, the formulation of CO_2 emissions per kilometer must vary with the distances traveled. Bearing in mind such a requirement in environmental studies, this study suggests computing the CO_2 amounts emitted from the aircrafts by an empirical formulation. The formulation has the distance is one variable and is mainly derived from Equation 2 that predicts the distance-based fuel consumption of the jet aircrafts developed using the real data obtained from the observations by The Scheduled Airlines Association of Japan.

$$y = J \cdot \alpha \cdot e \tag{2}$$

Here,

y: CO_2 emissions [t-CO_2]

J: fuel consumption of jet aircrafts [l]

α: 0.8767 [TOE/kl]

e: unit value for the fuel consumption of jet aircrafts (estimated by using the 3EID, 2000 data files)

The empirical formulation for the distance-based CO_2 emissions, given by the Equation 3, provides more accurate estimations for highly variable distances traveled in the aviation sector.

$$F(x) = 1561\ ln(x) / x + 21.0 \tag{3}$$

Here,

$F(x)$: CO_2 emissions generated from one aircraft per one kilometer [t-CO_2/(flight-km)]

x: distance between the origin and the destination [km]

The distance variable is defined by referring to the real airline data.

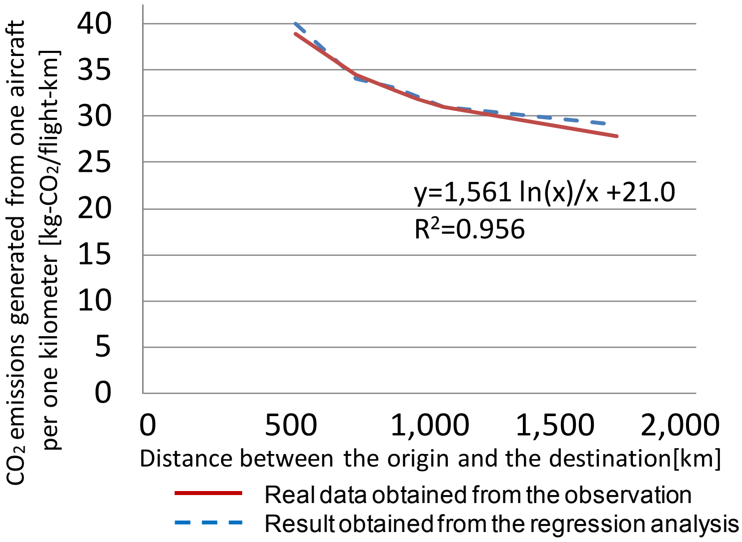

Figure 3 – Regression analysis for the CO_2 emissions emitted from the aircrafts

Shinkensen

a) Infrastructure

Similarly, the necessary unit values of CO_2 emissions are obtained from the previous works (RTRI, 2002) that provide results separately for the elevated track sections (7,550[t-CO_2/km]), tunnel sections (4,160[t-CO_2/km]), stations with an average interval of 50 kilometers (1,500[t-CO_2/station]); track works (507[t-CO_2/double line-km]).

b) Rolling Stock

One Shinkansen train, composed of the N700 type of rolling stock, has a seat capacity of 1,323. The emission factor of CO_2 in respect to the manufacturing and maintenance of Shinkansen rolling stock has been calculated in one of the earlier studies, assuming a life time of 20 years per vehicle, to be 150[t-CO_2/vehicle] for manufacturing; and 95[t-CO_2/vehicle/life time] (Tsujimura et al., 1998).

c) Operation (Running)

The total amount of CO_2 emitted from the energy use in the operation is formulated by Equation 4, where

Q_s: total daily CO_2 emissions generated from the operation of Shinkansen [t-CO_2/day]
R: CO_2 generated from one Shinkansen train per one kilometer [t-CO_2/(train-km)]
x: distance between the origin and the destination [km]
N_a: number of Shinkansen trains per day [train/day]

$$Q_s = R{\cdot}x{\cdot}N_s \tag{4}$$

CO_2 emissions per kilometer (*R*) are calculated by referring to the Central Japan Railway Company data base. The distance parameter is calculated by taking the distances of the existing lines. For the distances of planned lines, the existing designs are used and in the cases when such designs have not yet been completed, the length of the parallel conventional rail lines is used, as one very practical and correct way of filling such a gap in the data set.

Defining the Eco-Efficiency indicator

For the aims of this comparative analysis, an indicator to measure the CO_2 emissions from different type of relevant functions, namely one for Eco-efficiency, is necessary. Equation 5, below, is used to define a formulation that can be utilized better in the framework of this study.

$$\{\text{Eco-efficiency}\} = \{\text{Performance of the product}\} / \{\text{Environmental load from the production}\} \tag{5}$$

The number of total passenger-kilometers is an appropriate performance unit to represent the functioning of a transport system. However, in dealing with regional transport, besides the volume, the level of service parameters such as speed given by the rate of distance to trip time or comfort should necessarily be included in the performance parameters. Such a wider scope of indicator that contained the parameters of capacity and trip time was formulated by RTRI (2002) (Equation 6).

$$\{\text{Eco-efficiency of the train}\} = \frac{\{\text{Number of seats}\} \times \{\text{Total distance traveled}\} / \{\text{Total trip time}\}}{\{\text{Generated total environmental load}\}} \tag{6}$$

However, for an eco-efficiency assessment that better reflects the actual state of transport, it is necessary to use the real volume of transported passengers rather than the capacity generally given by the number of seats, which represents the potential of the system. Using this interpretation, this study defines the service-based eco-efficiency for the regional transport by Equation 7, below, which uses observed volumes of passengers instead of capacity.

$$\{\text{Service based eco-efficiency of the regional transport}\} = \frac{\{\text{Number of transported passengers}\} \times \{\text{Total distance traveled}\}/\{\text{total trip time}\}}{\{\text{Generated total environmental load}\}} \tag{7}$$

ANALYSIS IN THE CASE OF TRAVEL BETWEEN TOKYO AND OSAKA

A sensitivity analysis is performed to evaluate the relationship between LC-CO_2 and the volume of passengers between the two selected nodes, Tokyo and Osaka, which are connected by 515.4 kilometers of Shinkansen line and a 450.6 kilometer-long airline. The daily average number of passengers carried by these two transport systems along this corridor is 11,239 [passengers/day]. The load factor of these transport systems is 65[%] (MRIT, 2008).

Results of LC-CO_2 estimations

Figure 4 presents the results of LC-CO_2 estimations for Shinkansen and aviation. The amount of CO_2 emissions generated by the whole Shinkansen system through an assumed lifetime of 60 years equals to only 1/9 of the amount generated by aviation. The weight of each component in total estimated amount of LC-CO_2 clearly show that the contribution of the airport construction and the aircraft manufacturing to the environmental load is so small that it can easily be neglected alongside the emissions generated by the use of energy of an aircraft in its operation.

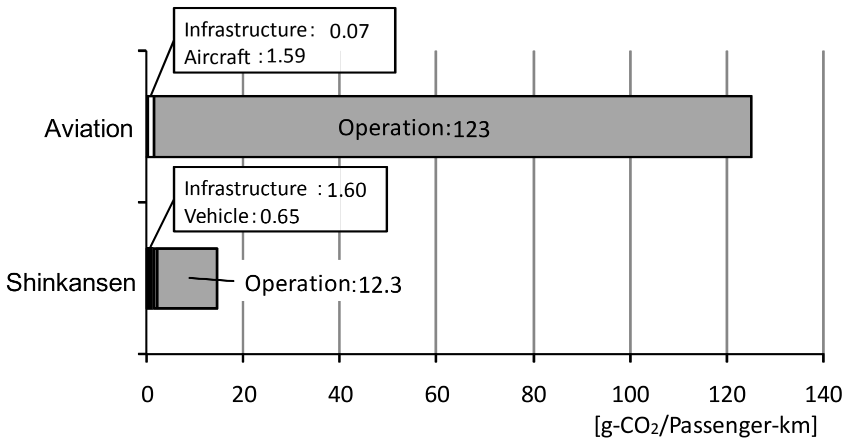

Figure 4 – LC-CO_2 by aviation and Shinkansen

Sensitivity analysis using the total volume of passengers and its evaluation

Figure 5 shows the graph plotted to represent the relationship between CO_2 emissions per passenger-km and the total volume of passengers, separately for both transport systems. In the case of Shinkansen, a strong relationship exists in such a way that as the number of passenger increases, the infrastructure-based CO_2 emissions are distributed among more passengers, and therefore, LC-CO_2 per passenger-km decreases. In the case of aviation, such an effect is so small that the environmental load per passenger-km is almost a constant value regardless of the number of passengers. However, in the low levels of aviation demand, i.e., a daily passenger demand less than 4,000 passengers, the relationship of CO_2 emissions per passenger-km and total volume of passengers is very slightly observed in a way similar to that revealed by the Shinkansen analysis.

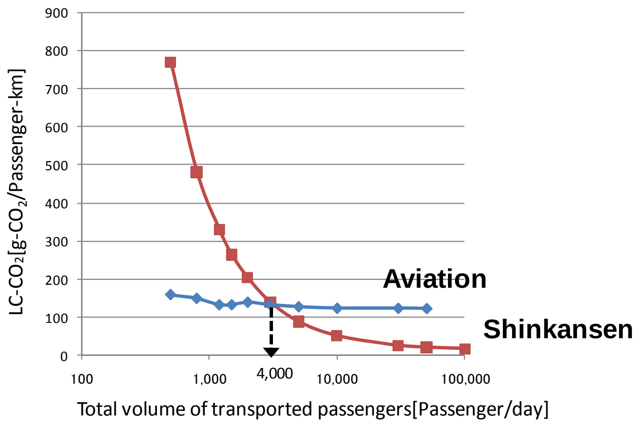

Figure 5 – Relationship between LC-CO_2 per passenger-km and total number of transported passengers

Next, service-based eco-efficiency is calculated for different volumes of passenger demand and presented in Figure 6. The average speed of an airplane is 450 [km/h], and that of Shinkansen is approximately 225 [km/h]. The total trip time by aviation is thus half of the time traveled by Shinkansen, and for this reason, the efficiency of aviation is initially higher than Shinkansen. However, after a point of intersection at a daily 10,000 passengers, Shinkansen's efficiency proves to be higher, showing a steep increase led by increasing passenger demand. As a result, Shinkansen proves its efficiency over aviation in terms of LC-CO_2 per passenger-km or eco-efficiency for the projected demand of the new Shinkansen lines, which is 4,000–32,000 [passengers/day].

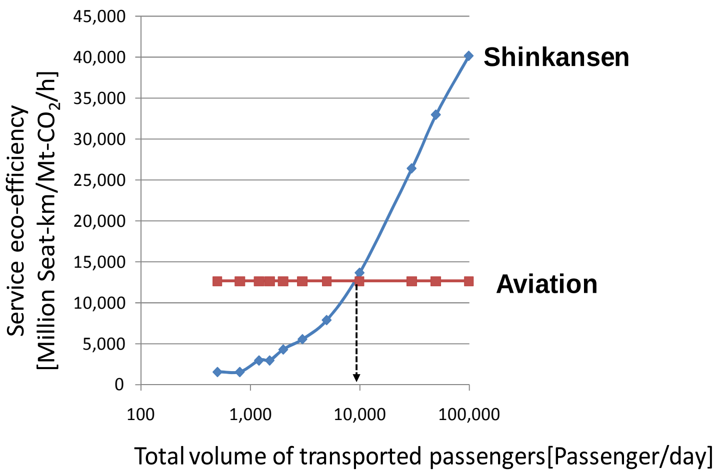

Figure 6 – Relationship between the service-based eco-efficiency and total number of transported passengers

ANALYSIS FOR EACH ORIGIN–DESTINATION PAIR OF PREFECTURES

This section discusses the possibility and the extent of CO_2 reductions by any modal shift from aviation to the newly added Shinkansen lines. For this analysis, the origin–destination pairs, in which at least one airport exists at both ends, are included in the analysis, and total amount of CO_2 emissions generated by aviation and rail transports are estimated separately by using the available distance and passenger demand data.

Table 1 presents the results estimated on the assumption that the new Shinkansen lines will replace aviation. This table is divided into two main parts by its diagonal; the right upper part shows the results for the service based eco-efficiency, and the left lower part gives the CO_2 emissions per passenger-kilometer. The letter **A** represents the significant environmentally advantageous position of the aviation and similarly, **S** represents the significant advantageous position of Shinkansen in that origin–destination pair. The cells for the origin–destination pairs where there is no available aviation data are left empty. This empirical study based on the estimation results of a model which is constructed by making some assumption. Therefore, the numerical results, which do not generate the necessary level of significance, are avoided and not presented here.

In the case of a transport corridor through which more than one origin destination–pairs are linked, the infrastructure-generated CO_2 emissions are distributed by the trip volumes on each pair, for a better representation of environmental load in terms of passenger kilometers (Equation 8).

{Distribution of infrastructure generated CO_2 [t-CO_2] to one pair of origin destination in corridor A} =

{Total infrastructure generated CO_2 emissions [t-CO_2]} x
{Volume of trips on one origin–destination pair in corridor A [passenger]} /
{Total trip volume in corridor A [passenger]} (8)

The infrastructure-generated emissions are not considered in the corridors through which the given means of transport is currently providing services and not requiring new infrastructure developments that would definitely add more to the environmental load.

The results for CO_2 emissions per passenger-km indicate that the origin–destination pairs either starting or ending at Tokyo carry high passenger demand, and for this reason, Shinkansen is advantageous nearly in all of these routes. Similarly, in some of the other large metropolitan areas (for example, Aichi or Fukuoka), Shinkansen generates less CO_2 emissions per passenger-km than the airways. In contrast, the regions, which have not yet been connected to Shinkansen system (for example, Shikoku or Kyushu), due to the large environmental load from the infrastructure construction phase, the advantageous position of the railways is replaced by aviation.

Service-based eco-efficiency results show a similar trend to that of CO_2 emissions, but the number of origin–destination pairs yielding aviation efficiency against Shinkansen is higher, and such a trend is particularly observed in the origin destinations pairs from Aichi and Osaka to Shikoku and Kyushu. Aviation between Tottori and Tokyo also turns out to be more environmentally advantageous.

The assumption that current aviation passengers prefer the planned Shinkansen improvements proves the environmentally advantageous position of Shinkansen in terms of both CO_2 emissions per passenger-kilometer and service based eco-efficiency, particularly for the regions Douou.

Table 1 – Comparison of the origin–destination pairs of prefectures by LC-CO_2 (left lower part) and service based eco-efficiency (right upper part)

	Douhoku	Douou	Dounan	Aomori	Iwate	Miyagi	Akita	Yamagata	Fukushima	Tokyo	Niigata	Toyama	Isikawa	Nagano	Aichi	Osaka	Hyogo	Tottori	Shimane	Okayama	Hiroshima	Yamaguchi	Tokushima	Kagawa	Ehime	Kouchi	Fukuoka	Saga	Nagasaki	Kumamoto	Ooita	Miyazaki	Kagoshima
Douhoku		S	S		S					S					A	A					A			A					A				A
Douou	S		S	S	S	S	S	S	S	S	A	A	A	A		S	A		A	A	S		A	A	A		S			A		A	A
Dounan	S	S				S				S					S	S																	
Aomori		S								S					S	S					A				A		A						
Iwate	S	S													S	S		A	A								A			A			
Miyagi		S	S										S		S	S	S			S	A			S			S						A
Akita		S								S		S			A	S					A			A									
Yamagata		S								S					S	S																	
Fukushima		S													S	S											S						A
Tokyo	S	S	S	S			S	S				S	S			S	S	A	S	S	S	S	S	S	A	S	S	S	S	S	A	A	A
Niigata		S													S	S											S						
Toyama		S								S																	S						
Isikawa		S				S				S																	S						
Nagano		S														S											A						
Aichi	S	S	S	S	S	S	S	S	S		S	S											S		A	S	S		S	S	A	A	S
Osaka	S	S	S	S	S	S	S	S	S	S	S			S			S		S						A	S	S	S	S	S	A	A	S
Hyogo		S				S				S	S					S														S			S
Tottori				S						S					S																		
Shimane		S		S						S					S	S											A						S
Okayama		S				S				S						S																	S
Hiroshima	S	S	S	S	S	S	S			S	S								S													A	S
Yamaguchi	S									S																							
Tokushima		S								S					S												A						
Kagawa	S	S				S	S			S					S	S																	S
Ehime		A								A					A	A											A						A
Kouchi										S					S	S					S						S					A	
Fukuoka		S		S	S	S			S	S	S	S	S	S	S	S		S	A				A	S	A	S			S	S		A	S
Saga										S					S	S																	
Nagasaki	S									S					S	S											S					A	S
Kumamoto	S	S								S					S	S	S								A		S						
Ooita										A					A	A																	
Miyazaki		S								A					A	A				S	A				S	A	A		A				
Kagoshima	S	S				S			S	S					S	S	S		S	S	S			S	A		S		S				

SERVICE BASED ECO-EFFICIENCY DEFINED IN TERMS OF REAL TRIP TIME

The concept of real trip time

The modal split in the regional trips indicates that the longer the distance of the journey, the more travelers choose aviation. However, in comparing the mode shares of aviation and rail (Shinkansen) transport only in vehicle-time, even if the trip time is shorter for aviation, rail transport sometimes gains higher share between the same origin and destination, mainly because of far longer out-of-vehicle time composed of waiting, access, and egress times for aviation.

Bearing in mind the significance of out-of-vehicle time in modal choices, this study defines “real trip time.” which attempts to include out-of-vehicle time in the total trip time for aviation but does not seek to substantiate such out-of-vehicle time in a common way by estimating each of its three components for different lines. A real-trip-time approach assumes that at the distances where the mode shares of aviation and rail are equal, the real trip times are also equal. Figure 7 presents the relationships between the observed trip times and the distances for Shinkansen along Tokaido and Sanyo lines and similarly for the airlines in the same corridor and starting from the Tokyo International Airport (Haneda Airport).

By using these measures, the out-of-vehicle time in aviation is estimated at approximately 2.5 hours. For this, that the trip distance for both rail and aviation are nearly equal is extracted from the observations and found on the line drawn for aviation (600 km). Then, in order to equate the real trip time for the airport to the observed trip time of Shinkansen at 600 km, this line is shifted upwards until such a point that the lines of aviation and Shinkansen intersect each other at this distance. This shifted line represents the relationship between the distance and the real trip time for aviation and the difference between the only in-vehicle time and this new lines gives the estimated out-of-vehicle time. However, it should be emphasized here that this study does not intend to prove the validity of this method but only aims to provide a reference number for the further analysis.

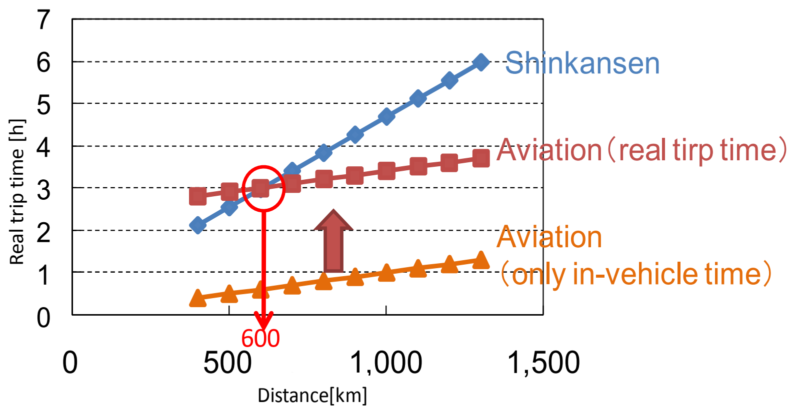

Figure 7 – Computation of real trip time

Analysis between Tokyo and Osaka

Similar to the previous computations in LC-CO_2 and eco-efficiency assessments, a sensitivity analysis is conducted between Tokyo and Osaka to represent the relationship between the volume of passengers and service-based eco-efficiency given in terms of real trip time (Figure 8). This type of eco-efficiency defined by the real trip time proves smaller figures than the previous nominal eco-efficiency given in terms of the only in vehicle time for aviation. Also, by applying service-based efficiency, the point at which Shinkansen exceeds aviation in eco-efficiency drops from approximately 10,000 daily passengers to 2,500 passengers.

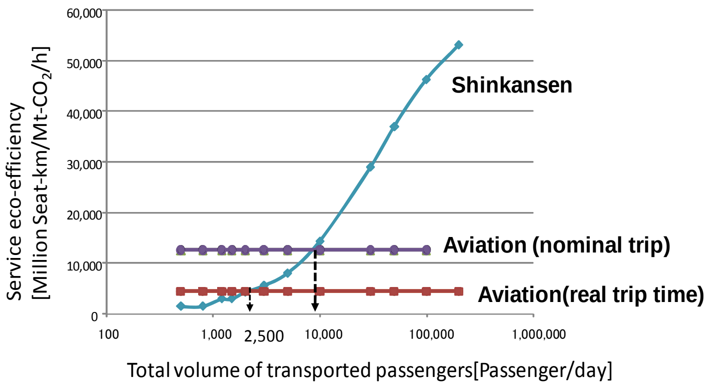

Figure 8 – Relationship between service-based eco-efficiency and total volume of transported passengers

Analysis for each origin–destination pairs of prefectures

Similar to Table 1, Table 2 compares each origin–destination pair of all prefectures by CO_2 emissions and service based eco-efficiency, but this time by real trip time. Both the efficiency and CO_2 analysis yield the same determination of which mode is advantageous for the same origin–destination pair in most of the cases. This is clearly because of more origin–destination pairs in which trip times for Shinkansen and aviation are equal or closer in real trip time.

Table 2 - Comparison of the origin–destination pairs of prefectures by LC-CO_2 and service-based eco-efficiency (using real trip time for aviation)

	Douhoku	Douou	Dounan	Aomori	Iwate	Miyagi	Akita	Yamagata	Fukushima	Tokyo	Niigata	Toyama	Isikawa	Nagano	Aichi	Osaka	Hyogo	Tottori	Shimane	Okayama	Hiroshima	Yamaguchi	Tokushima	Kagawa	Ehime	Kouchi	Fukuoka	Saga	Nagasaki	Kumamoto	Ooita	Miyazaki	Kagoshima
Douhoku		S	S		S					S					S	S					S			S					S				A
Douou	S		S	S	S	S	S	S	S	S	S	S	S	S	S	S	S		S	S	S		S	S	A		S			S		A	S
Dounan	S	S				S				S					S	S																	
Aomori		S								S					S	S					S				S		S						
Iwate	S	S													S	S		S	S								S			S			
Miyagi		S	S										S		S	S	S			S	S			S			S						S
Akita		S								S		S			S	S					S			S									
Yamagata		S								S					S	S																	
Fukushima		S													S	S											S						S
Tokyo	S	S	S	S			S	S				S	S			S	S	S	S	S	S	S	S	S	A	S	S	S	S	S	A	A	S
Niigata		S													S	S											S						
Toyama		S								S																	S						
Isikawa		S				S				S																	S						
Nagano		S														S											S						
Aichi	S	S	S	S	S	S	S	S	S		S	S											S		A	S	S		S	S	A	A	S
Osaka	S	S	S	S	S	S	S	S	S	S	S			S			S		S						A	S	S	S	S	S	A	A	S
Hyogo		S				S				S	S					S														S			S
Tottori				S						S					S																		
Shimane		S		S						S					S	S											S						S
Okayama		S				S				S						S																	S
Hiroshima	S	S	S	S	S	S	S			S	S								S													A	S
Yamaguchi	S									S																							
Tokushima		S								S					S												S						
Kagawa	S	S				S	S			S					S	S																	S
Ehime		A								A					A	A											A						S
Kouchi										S					S	S					S						S					A	
Fukuoka		S		S	S	S			S	S	S	S	S	S	S	S		S	A				A	S	A	S			S	S		A	S
Saga										S					S	S																	
Nagasaki	S									S					S	S											S					A	S
Kumamoto	S	S								S					S	S	A								A		S						
Ooita										A					A	A																	
Miyazaki		S								A					A	A				S	A				S	A	A		A				
Kagoshima	S	S				S			S	S					S	S	S		S	S	S			S	A		S		S				

CONCLUSIONS

In designing the national policies to control the contribution of regional transport to global warming, improvement of Shinkansen as an alternative mode to the airways is one of the main discussions in Japan. At this stage, this study first develops a systematic but strategic level of analysis within the framework of LCA and further explores the eco-efficiency of such a modal shift in the regional transport. In the context of environmental policy discussions concerning the regional transport systems, the main results obtained from this study are as follows:

1) In the preliminary analysis, which only considers the trips between Tokyo and Osaka, Shinkansen proves its environmental advantage in terms of LC-CO_2 per passenger-kilometer and service based eco-efficiency for the given volumes of passenger demand (Shinkansen connecting Tokyo and Osaka already exists and therefore the environmental load in respect of the infrastructure development is not included in the model).

2) In each origin–destination pair of prefectures that has not yet been connected by Shinkansen, policy discussions focus on future Shinkansen improvements along these corridors by using the available aviation data. The main assumption in this assessment is that current aviation passengers will choose to travel by the newly constructed Shinkansen and in such a case of modal shift, LC-CO_2 results tend to favor the environmental advantage of the aviation over Shinkansen only at low levels of passenger demand.
3) In some of the origin–destination pairs where Shinkansen proves its environmental advantage in terms of LC-CO_2, aviation turns out to be more advantageous in the service-based eco-efficiency assessment for the same pairs.
4) In the assessment of service-based eco-efficiency that uses real trip times including the out-of-vehicle time (composed of waiting, access, and egress times) only for aviation, Shinkansen is advantageous in most of the sections, and similar results in favor of Shinkansen are also obtained from the comparison of LC-CO_2.

REFERENCES

Fujisaki, N.T. (2007). US aviation, demand, capacity and climate change - Can it all be fixed in time?, Proceedings of International Symposium for Climate Change and Transport Strategy 19, The Institution for Transport Policy Studies.

Kato, H., Shibahara, N., Osada, M., Hayashi, Y. (2005). A life cycle assessment for evaluating environmental impacts of inter-regional high-speed mass transit projects, Journal of the Eastern Asia Society for Transportation Studies 6, 3211-3224.

Intergovernmental Panel on Climate Change (1996). Revised 1996 IPCC Guidelines for National Greenhouse Gas inventories: Reference Manual (Volume 3), IPCC-NGGIP publications, Available at: <http://www.ipcc-nggip.iges.or.jp/public/gl/invs6.html>.

The Japan Carbon Fiber Manufacturers Association (JCMA) (2009). Substantiation of environmental improvement effects of carbon fiber uses.

Tsujimura, T., Kunai, H., Nagatomo, T., Hashimoto, J. (1998). Eco-efficiency and the case of rolling stock of Shinkansen, Proceedings of the Symposium for Japan Railway Technology Association, 601-604.

Railway Technical Research Institute (RTRI) (2002). Report of RTRI.

Ministry of Land, Infrastructure, Transport and Tourism (MRIT) (2008). Survey on Air Transport.

Ministry of Land, Infrastructure, Transport and Tourism (MRIT) (2008). Survey on Railway Transport.