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

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ABSTRACT

The carbon dioxide (CO2) emissions reduction policies for the inter-regional passenger transport system highlight on the 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 CO2 emissions is proposed. This study aims to explore the possible changes in Life Cycle CO2 (LC-CO2) per passenger-km and eco-efficiency indicator including considering travel speed as a result of a shift from aviation to the high speed railway system (Shinkansen). CO2 emissions both for Shinkansen and aviation are estimated by applying the Life Cycle Assessment (LCA) method and taking into account of dominant parameters such as passenger demand.

CO2 exhausted from aviation and Shinkansen during operation and the additional LC-CO2 from providing new infrastructure are estimated. First the sensitivity with the number of passengers for a 500km long corridor is analyzed. The main results are as follows: 1) CO2 per passenger-km from aviation hardly vary with the number of passengers; 2) LC-CO2 per passenger-km for Shinkansen is inversely proportional to the number of passengers; 3) LC-CO2 per passenger-km for Shinkansen is lower than that for aviation for the passenger volume of approximately 1,200 or more passengers per day; and 4) for eco-efficiency, the break-even point is more than around 2,000 passengers per day. The second 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 CO2 emission for Shinkansen or aviation.

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

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BACKGROUND AND AIM

The share of CO₂ 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 the aviation emissions in 1990. Aviation sector has been quite late in replacing carbon fuels and this is considered to be a major reason for relatively higher shares of CO₂ emissions from the aviation (Fujisaki, 2007).

In Europe, aviation sector is making progress in taking significant actions against global warming, and widely implementing carbon offset measures, by the ways in which aviation companies are participating in ETS (Emission Trading Scheme), or reflecting to the passengers a part of their costs for reducing the CO₂ amounts emitted from use of energy in the operation. In this context, Japan will enter an era in which the transport modes shall necessarily be selected and promoted by their impacts on the environment in the development plans.

Japanese railways are considerably serving for long-distance journeys besides the airways. In reference to the national reports by the Ministry of Environment, railways prove its eco-efficiency for significantly less energy consumption and CO₂ emissions than the airways at the national average. However, these reports lack in detailing 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. Additionally, operational efficiency, namely capacity, and the degree of congestion are also other very important factors. The future infrastructure improvements will be different in a way 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 for any shift of inter regional demand from the aviation to the new Shinkansen lines, (either currently being constructed or included in the future improvement plans) and the associated reductions in the energy use and CO₂ emissions, the phase of construction should also be taken in to account as an important parameter of environmental load (Kato et al., 2005).

Up 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, of which one is on one of the remote islands, are included in the 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 “Act for Construction of Shinkansen Across the Country” and development of “Improvement plan” in 1973, the construction for some of the lines proposed in this plan, is still ongoing and even some are at the planning stage (shown as planned lines in Figure 1). The total length of Shinkansen lines decided by this plan was 6,853 km, but only 31% of it was completed and today the Japanese high speed railway network constitutes of 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 share of railways are notably low.

In a practical and useful assessment of the contribution of Shinkansen improvement projects to the national CO₂ emissions, this study aims at estimating the variations in the amounts of CO₂ emissions between two possible cases of: current aviation passengers will again be carried by the airways; or will shift to Shinkansen lines. For this purpose, Life Cycle Assessment (LCA) methodology 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 the demand are examined through the sensitivity analysis. Finally, the environmentally best alternative for high speed transport mode is suggested based on the results obtained from this framework of analysis.

However, this study provides more strategic evaluation because; a more elaborate analysis in this given framework requires huge data set and detailed scenario setting which are neither practical nor fully available. Still, such a strategic approach provides a valuable assessment for proving the evidence to the main proposition of this study that the Shinkansen improvement projects do not always favor reduction in the total amount of CO₂ emissions and sometimes the reductions gained by shifts to the Shinkansen are overwhelmed by the generation of CO₂ emissions in the construction phase of the infrastructures.

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 CO₂ emissions generated from the energy use in the operation provides a useful tool for the comparison of the transport modes, but as earlier mentioned here, 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 CO₂ emissions more specifically through including the below characteristics of each mode in the analysis.
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.

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 kilometre

On this ground, the comparative analysis first provides insight into the extent of the life cycle environmental load by each above mode. The main components are the infrastructures, vehicles and their operation. Next, possible shifts of the aviation passengers to the newly constructed Shinkansen lines are estimated. Current state of the transport systems provides the starting point and each alternative is analyzed by any of its impacts adding more to the environmental load. In this context, increase in the Shinkansen operations and relevant additional infrastructure and rolling stock requirements should necessarily be considered. On the other hand, in the case that any of the airway routes are canceled, it is accepted that such decrease in the number of routes will not have any effects 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 is not necessarily taking into account the existing infrastructures and aircrafts (Figure 2). The reasons for ignoring the emissions generated from the airports and production of aircrafts will be explained later in this study.

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

Data for estimation of LC-CO₂

Airports

a) Infrastructure
   The unit values to substantiate the amount of CO₂ emissions generated by the construction of an airport are extracted from the observed data belonging to the Chubu International Airport. The main parameters are the sources for landing field, 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]. By using these real figures, CO₂ emissions from the construction phase of an airport is estimated in terms of passenger-kilometer.

b) Aircraft
   Only the B777 type of aircrafts having a capacity of 500 passengers is assumed to be serving for 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 researches (JCMA, 2009) provide unit values for computations of total CO₂ emissions in respect of B777 type of aircraft having an average occupancy rate of 65 % (for materials 0.25 [g-CO₂/passenger-km]; for manufacturing, 1.34 [g-CO₂/passenger-km]; for operation 137.63 [g-CO₂/passenger-km]).

c) Operation (Flight)
   The CO₂ emissions generated from the aircrafts are calculated using the Equation 1 where;
   \[ Q_a = F(x) \times N_a \]  
   \( Q_a \): total daily CO₂ emissions generated from the flights of the aircrafts [t-CO₂/day]
   \( F(x) \): CO₂ emissions generated from one aircraft per one kilometer [t-CO₂/(flight-km)]
   \( x \): distance between the origin and the destination [km]
   \( N_a \): Number of flights by the aircrafts per day [flight/day]

   In this formulation, the CO₂ emissions from an aircraft per kilometer is defined on the basis that the largest energy consumption occurs at the taking off phase and the fuel consumptions decreases as the weight of the aircraft diminishes and therefore the longer the kilometers are travelled, the less CO₂ amounts are emitted per kilometer. In the same way, the IPCC Guide Book (IPCC, 1996) suggested that LTO (Land and Take Off) and the cruise phases should be separately evaluated when considering the environmental load generated by the aircrafts. In this context, rather than a constant unit value per kilometer, formulation of CO₂ emissions per kilometer but varying with the distances travelled is necessarily required. Bearing in mind such a requirement in environmental studies, this study suggests to compute the CO₂ amounts emitted from the aircrafts by an empirical formulation in which the distance...
is one variable and which is mainly derived from the Equation 2 that predicts the distance based fuel consumption of the jet aircrafts developed by using the real data obtained from the observations where:

\[ y: \text{CO}_2 \text{ emissions [t-CO}_2] \]
\[ J: \text{fuel consumption of jet aircrafts [l]} \]
\[ \alpha: 0.8767[\text{TOE/kl}] \]
\[ e: \text{unit value for the fuel consumption of jet aircrafts (estimated by using the 3EID,2000 data files)} \]

\[ y = J \alpha e \]  
(2)

The empirical formulation for the distance based CO\(_2\) emissions, given by the Equation 3, provides more accurate estimations in respect of the highly variable distances travelled in the aviation sector.

\[ F(x) = 1561 \ln(x) / x + 21.0 \]  
(3)

Here;

\[ F(x): \text{CO}_2 \text{ emissions generated from one aircraft per one kilometer [t-CO}_2/(\text{flight-km}]} \]
\[ x: \text{distance between the origin and the destination [km]} \]

The distance variable is defined by referring to the real airlines data. For the origin destinations pairs for which such data are not available, the distance is calculated by assuming a direct connection. The previous studies have shown that such an approach can only lead to a mistake which will not reach 10% of the total distance.

![Regression analysis for the CO\(_2\) emissions emitted from the aircrafts](image)

**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 unit values of CO\textsubscript{2} emissions in respect of manufacturing and maintenance of N700 series have already been calculated in one of the earlier studies, assuming a life time of 20 years per vehicle: 150[t-\text{CO}_2/\text{vehicle}] for manufacturing; and 95[t-\text{CO}_2/\text{vehicle}] - life time for maintenance (Tsujimura et al., 1998).

c) Operation (Running)

The total amount of CO\textsubscript{2} emitted from the energy use in the operation is formulated by the below Equation 4 where;

\[ Q_s: \text{total daily CO}_2 \text{ emissions generated from the operation of Shinkansen} \ [t-\text{CO}_2/\text{day}] \]
\[ R: \text{CO}_2 \text{ generated from one Shinkansen train per one kilometer} \ [t-\text{CO}_2/(\text{train-km})] \]
\[ x: \text{distance between the origin and the destination} \ [\text{km}] \]
\[ N_s: \text{number of Shinkansen trains per day} \ [\text{train/day}] \]

\[ Q_s = R \times N_s \]

(4)

CO\textsubscript{2} emissions per kilometer (\(R\)) are calculated by referring to the Central Japan Railway Company database. 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 unit CO\textsubscript{2} emissions from different type of relevant functions, namely an indicator for “Eco-Efficiency” is necessary and the below Equation 5 is basically used to define a formulation that can be utilized better in the framework of this study.

\[ \{\text{Eco-Efficiency}\} = \frac{\{\text{Performance of the product}\}}{\{\text{Environmental load from the production}\}} \]

(5)

The total passenger-kilometers is an appropriate performance unit to represent the functioning of a transport system. However, in dealing with the 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 which contained the parameters of capacity and trip time was formulated by (RTRI, 2002) in respect of Shinkansen (Equation 6).

\[ \{\text{Eco-efficiency of the train}\} = \frac{\{\text{Number of seats}\} \times \{\text{total distance travelled}\}}{\{\text{total trip time}\}} \]
\[ \{\text{Generated total environmental load}\} \]

(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 representing more potential of the system. On this interpretation, this study defines the service based eco-efficiency for the regional transport by the below Equation 7 which uses the observed volumes of passengers instead of capacity.

\[
[\text{Service based eco-efficiency of the regional transport}] = \frac{\{\text{Number of transported passengers}\} \times \{\text{total distance travelled}\}}{\{\text{total trip time}\}} \div \{\text{Generated total environmental load}\}
\] (7)

ANALYSIS IN CASE OF BETWEEN TOKYO AND OSAKA

A sensitivity analysis is performed to evaluate the relation between LC-CO\textsubscript{2} and the volume of passengers between the two selected nodes, Tokyo and Osaka, which are connected by 515.4[km] long Shinkansen line and 450.6[km] long airline. The daily average number of passengers carried by these two transport systems along this corridor is 11,239[passengers/day]. The road factor of these transport systems is 65[%].

Results of LC-CO\textsubscript{2} estimations

Figure 4 presents the results of LC-CO\textsubscript{2} estimations for Shinkansen and aviation. The amount of CO\textsubscript{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 the aviation. The weight of each component in total estimated amount of LC-CO\textsubscript{2} clearly show that the contribution of the airport construction and the aircraft manufacturing to the environmental load is so small that can easily be neglected besides the emissions generated by use of energy of an aircraft in its operation.
Sensitivity analysis by the total volume of passengers and its evaluation

Figure 5 shows the graph plotted to represent the relation between CO₂ emissions per passenger-km and the total volume of passengers, separately for both transport systems. In the case of Shinkansen, a strong relation exists in such a way that as the number of passengers increases, the infrastructure based CO₂ emissions are distributed among more passengers and therefore LC-CO₂ per passenger-km decreases. In the case of aviation, such an effect is so small that the environmental load per passenger-km proves almost a constant value regardless of the number of passengers. However, in the low levels of aviation demand, that is a daily passenger demand less than 4,000 passengers, the relation of CO₂ emissions per passenger-km and total volume of passengers is very slightly observed in the similar way to that revealed by the Shinkansen analysis.

Next, service based eco-efficiency is calculated for different volumes of passenger demand and presented in Figure 6. The total trip time by aviation is half of the time travelled by Shinkansen and for this reason; the efficiency of aviation is initially higher than Shinkansen but after a point of intersection at a daily 10,000 passengers, Shinkansen proves higher efficiency which shows a steep increase led by the increasing passenger demand. As a result, Shinkansen proves its efficiency over the aviation in terms of LC-CO₂ per passenger-km or eco-efficiency for the projected demand of the new Shinkansen lines, which is 4,000-32,000 [passenger/day].
ANALYSIS FOR EACH ORIGIN-DESTINATION PAIRS OF PREFECTURES

This section discusses the possibility and the extent of CO\(_2\) reductions by any modal shift from the 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 the aviation. This table is divided into two main parts by its diagonal where 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 provides policy discussions 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).

\[
\text{Distribution of infrastructure generated CO}_2\ [\text{t-CO}_2]\ \text{to one pair of origin destination in corridor A} = \\
\{\text{Total infrastructure generated CO}_2\ \text{emissions [t-CO}_2]\} \times \\
\{\text{Volume of trips on one origin destination pair in corridor A [passenger]}\} / \\
\{\text{total trip volume in corridor A [passenger]}\} \\
\text{(8)}
\]

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 which 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 the aviation. However, among the origin destination pairs linked by Shinkansen, between the closer prefectures having shorter distances of airlines the gap between Shinkansen and aviation diminishes (for example, Osaka-Iwate section).

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 the current aviation passengers prefer the planned Shinkansen improvements proves environmentally advantageous position of Shinkansen in terms of both CO₂ emissions per passenger-kilometer and service based Eco-Efficiency particularly for the regions Douo.

Table 1 - Comparison of the origin destination pairs of prefectures by LC-CO₂ (left lower part) and service based eco-efficiency (right upper part)

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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 aviation shares generally increase for the longer distance journeys. However, in comparing the mode shares of aviation and rail (Shinkansen) transport by 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, which is mainly because of far longer out of vehicle time composed of waiting, access and egress times for the aviation.

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Bearing in mind the significance of out of vehicle time in modal choices, this study defines the “real trip time” which attempts to include out of vehicle time in the total trip time for the aviation but does not seek to substantiate such out of vehicle time in a common way of estimating each of its three component for different lines. 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 (Narita Airport).

By using these relations, the out of vehicle time in aviation is estimated at approximately 2.5 hours. For this, first the trip distance at 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 others at this distance. This shifted line represents the relation between the distance and the real trip time for the aviation and the difference between the previous and this new lines gives the estimated out of vehicle time. However, it should be strongly noted 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.

**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 the aviation. Also, by applying the service based efficiency, the point at which Shinkansen exceeds aviation in eco-efficiency drops from approximately 10,000 daily passengers to 2,500 passengers.
ANALYSIS FOR EACH ORIGIN DESTINATION PAIRS OF PREFECTURES

In the same way to that discussed earlier by Table 1, each origin destination pair of all prefectures are compared by CO₂ emissions and service based eco-efficiency but this time by the real trip time in Table 2. Both the efficiency and CO₂ analysis yield the same result of which of the modes 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 applying the real trip time.

Table 2 - Comparison of the origin destination pairs of prefectures by LC-CO₂ and service based eco-efficiency (using real trip time for aviation)
CONCLUSIONS

In designing the national policies to control the contribution of regional transport to the global warming, improvement of Shinkansen as 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:

1) In the preliminary analysis which only considers the trips between Tokyo and Osaka, Shinkansen proves its environmental advantageous 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 which has not yet been connected by Shinkansen, policy discussions are made on future Shinkansen improvements along these corridors by using the available aviation data. The main assumption in this assessment is that the 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 favour 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 which uses the real trip times containing the out of vehicle time (composed of waiting, access and egress times) only for the 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\(_2\).

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