


Direct and indirect effects of new high speed rail service: An empirical analysis using Japanese mobile phone location data

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1 **DIRECT AND INDIRECT EFFECTS OF NEW HIGH SPEED RAIL SERVICE:**
2 **AN EMPIRICAL ANALYSIS USING JAPANESE MOBILE PHONE LOCATION DATA**

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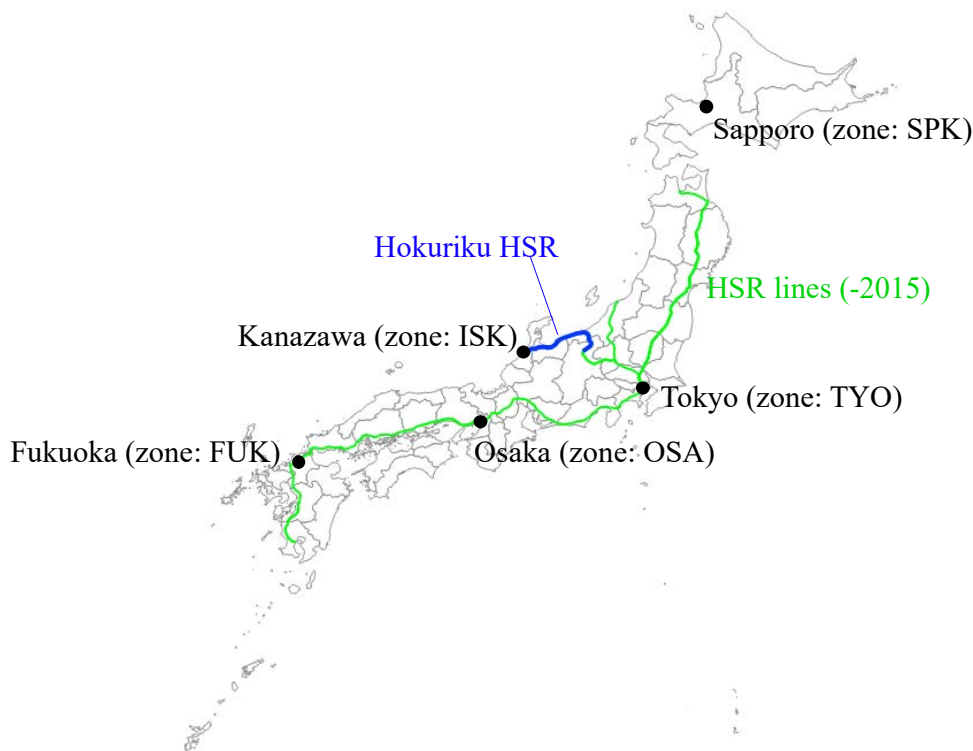
ABSTRACT

The development of high-speed rail (HSR) is expected to significantly change the long-distance travel structure and transportation patterns. The changes are expected to be not only the increase in the number of tourists who use HSR service (direct effect), but also the change in the regional travel structures by encouraging the growth of several zones as network hubs (indirect effect). In this paper, a methodology to understand the change in the residential - travel destination zone matrix derived from mobile phone location data is proposed. The developed methodology is applied to determine the effect of the Hokuriku HSR on the nationwide long-distance travel patterns. The proposed methodology decomposed the matrix into two meaningful matrices, which can be understood as the direct and indirect effects of HSR. The decomposed results indicate the following three features of the HSR effects: First, the changes before and after the development of the Hokuriku HSR on the residential - travel destination zone matrix are mostly explained by two patterns of change by direct and indirect effect. Second, the direct numerical effects are less significant than the indirect effects. Third, the changes are asymmetric in direction in several zone pairs, because of the indirect effects.

Keywords: High Speed Rail, destination choice, long-distance travel, mobile phone location data

1 INTRODUCTION

2 The development of High-Speed Rail (HSR) is expected to significantly change the long-
 3 distance travel structure and patterns. For example, the Hokuriku HSR's Nagano-Kanazawa
 4 section (228.4 km, shown as the blue line in Figure 1) has been operating since May. 14, 2015.
 5 This new HSR service reduced the travel time by railway between Tokyo and Kanazawa from
 6 230 min to 150 min. DBJ (1) reported that because of new HSR service, the cumulative number
 7 of overnight travelers to ISK zone, where Kanazawa is located, has increased to 8.2 million per
 8 year from 7.7 million.
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10
 11 **FIGURE 1 The Location of Hokuriku High Speed Rail (HSR) Service**

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 13 On the other hand, as the effect of new HSR, we expect not only the increase in the
 14 number of tourists to newly connected zones, but also the change in the regional travel
 15 structures. For example, Hokuriku HSR is expected to strengthen the “Japan sea side corridor”
 16 by encouraging the growth of several base (or hub) cities on the corridor. In order to evaluate this
 17 types of effect, it is required to analyze the change of the long-distance travel patterns throughout
 18 Japan (the entire origin-destination matrix) and to identify the effect of new HSR on the
 19 functions of the cities as network hub. However, the influence of the new HSR on the long-
 20 distance travel patterns is still unknown.

21 Most previous studies to identify the effect of new HSR lines (for example, 2, 3, 4) was
 22 not focused on the regional travel structures. They have been limited to the relationships between
 23 several zone-pairs or origin zones. Several demand models proposed by Yao and Morikawa (5),
 24 Fu et al. (6) and Kato et al. (7) are able to forecast the effect of new HSR on the entire origin-
 25 destination matrix. But their forecast results of the long-distance travel patterns depend on the

1 assumption of the model structure (nest structure or similarity patterns of choicesets). Especially,
2 these models do not incorporate the ‘indirect effects’ on the travel patterns by encouraging the
3 growth of several zones as network hubs.

4 These limitations of previous study are caused by the difficulty for questionnaire survey
5 to know the exact city-to-city travel pattern of the whole country. On the other hand, mobile
6 phone location data facilitates capturing of volume and time-series changes of nationwide long-
7 distance travel. Mobile phone location data constitutes records of the GPS data or
8 communication data of a mobile networks, for a substantial number of mobile phones at regular
9 time intervals. Thus, it is possible to obtain the population distribution data of a large number of
10 people without being bound by space or time. Therefore, these data are started to applied to
11 capture the spatio-temporal information of long-distance travel (8, 9).

12 In this paper, a methodology to understand the change in the residential - travel
13 destination zone matrix derived from mobile phone location data is proposed. In addition, the
14 developed methodology is applied to determine the effect of the Hokuriku HSR on the
15 nationwide long-distance travel patterns. The proposed methodology decomposed the matrix into
16 two meaningful matrices, which can be understood as the direct and indirect effects of HSR. The
17 decomposed results indicate the following three features of the HSR effects: First, the changes
18 before and after the development of the Hokuriku HSR on the residential - travel destination
19 zone matrix are mostly explained by two patterns of change by direct and indirect effect. Second,
20 the direct numerical effects are less significant than the indirect effects. Third, the changes are
21 asymmetric in direction in several zone pairs, because of the indirect effects.

22 The remainder of this paper is organized as follows: First, an explanation of the
23 Japanese mobile phone location data is offered and basic information directly obtained from the
24 data related to Hokuriku HSR is presented. Subsequently, the developed model and
25 decomposition methodology for understanding the change in the residential-travel destination
26 matrix is presented. Based on the decomposed results, the study findings on the effect of the new
27 HSR service is presented.

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1 DATA: “MOBILE SPATIAL STATISTICS”

2 This section presents the nationwide population distribution data to examine the Hokuriku HSR
3 effects. The data was obtained from the mobile spatial statistics (MSS), which is the aggregated
4 population distribution data estimated by the operations data from the mobile terminal network
5 of NTT DOCOMO. (The detailed estimation methodology is presented in Terada et al. (10)).

6 This data has three desirable characteristics for viewing HSR effects. First, the very
7 large sample size to estimate the population spatial density (60 million mobile phones served by
8 NTT DOCOMO). This sample size is almost half of the total Japanese population, which means
9 that MSS provides highly accurate population distribution data. The second feature is each
10 contract shows the residential address of the users. This can facilitate estimation of the
11 population of any residential and staying place (travel destination) zone pairs. The third feature is
12 the freedom of temporal information. Each mobile phone communicates with the near base
13 stations at regular intervals (typically: one hour) in order to efficiently connect at any time, and
14 this information is stored for long time. Therefore, the data can be obtained at any time.

15 In this study, the population in each residential – staying (travel destination) zone pair is
16 analyzed to examine the effect of Hokuriku HSR on the nationwide travel demand. Here, Japan
17 is divided into 50 zones, as shown in Figure 1 (most zones are consistent with prefectures).
18 Consider Z as the all zone set. Hence, the following two matrices ($\mathbf{M}_{s \in [\text{bef.}, \text{aft.}]}$), obtained from
19 MSS, are compared in this study.

$$21 \mathbf{M}_{\text{bef.}} = \sum_{d \in [\text{May.1.2014} \sim \text{Feb.28.2015}]} \mathbf{Q}_{d,t=13:00} / 365, \quad (1)$$

$$23 \mathbf{M}_{\text{aft}} = \sum_{d \in [\text{Apr.1.2015} \sim \text{May.31.2015}]} \mathbf{Q}_{d,t=13:00} / 366, \quad (2)$$

$$25 \mathbf{Q}_{d,t} = \begin{pmatrix} q_{1,1,d,t} & \cdots & q_{1,j,d,t} & \cdots \\ \vdots & \ddots & & \\ q_{i,1,d,t} & & q_{i,j,d,t} & \\ \vdots & & & \ddots \end{pmatrix}, \quad \mathbf{M}_s = \begin{pmatrix} m_{1,1,s} & \cdots & m_{1,j,s} & \cdots \\ \vdots & \ddots & & \\ m_{i,1,s} & & m_{i,j,s} & \\ \vdots & & & \ddots \end{pmatrix} \quad (3)$$

26 where, $q_{i,j,d,t}$ is the estimated number of people who live in zone $i \in Z$ and stay in zone $j \in Z$ at
27 period t on date d . $\mathbf{M}_{\text{bef.}}$ is the average population density at 13:00 for one year before the beginning of
28 Hokuriku HSR operation, while \mathbf{M}_{aft} is the population density after the beginning of HSR operation.
29 Since 2016 is the leap year, average values are calculated from 366 days, as shown in equation (2). Here,
30 these average values for one year are compared, in order to exclude the influence of seasonal fluctuation
31 and the day of the week.
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1 **BASIC CHANGES IN MAJOR ZONE PAIRS**

2 This section discuss the part of the difference between $M_{\text{bef.}}$ and $M_{\text{aft.}}$. Table 1 shows the two
 3 features of the travel volume changes in the two major zone pairs. First is the asymmetric change
 4 in the TYO – ISK zone pair which is the starting - end zone of the Hokuriku HSR. Although, the
 5 number of travelers in both directions (“TYO to ISK” and “ISK to TYO”) increased since the
 6 beginning of HSR operation, the increased volume was asymmetric in direction. The number of
 7 travelers to ISK from TYO increased by 1,875 (1.6 times), and, the number of traveling to TYO
 8 from ISK was increased by only 440 travelers (1.1 times). Second, the number of travelers from
 9 OSA to ISK also increased, despite almost no change in the service level in this zone pair. This
 10 number increased by 327 travelers (1.1 times), since the beginning of HSR operation, and this
 11 increase volume was almost similar to that from ISK to TYO.

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TABLE 1 The Changes in the Average Number of Travelers Before and After the Beginning of HSR Operation

Residential zone	Staying zone at 13:00	(1) 2014.3.1 – 2015.2.28 (Before the beginning of HSR operation) $m_{i,j,\text{bef.}}$	(2) 2014.3.1 – 2015.2.28 (After the beginning of HSR operation) $m_{i,j,\text{aft.}}$	(2) – (1) $m_{i,j,\text{aft.}} - m_{i,j,\text{bef.}}$
TYO	ISK	3,311	5,186	+ 1,875
ISK	TYO	3,452	3,892	+ 440
OSA	ISK	3,710	4,037	+ 327
ISK	OSA	2,433	2,456	+ 23

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18
19

1 PATTERN DECOMPOSITION OF RESIDENTIAL - STAYING ZONE MATRIX

2 In this section, the detected differences in travel patterns are analyzed. Accordingly, a
3 methodology to explain the changes in the inter-prefectural distribution matrix, by decomposing
4 the matrix into two types of spatial patterns, referred as “direct effect” and “indirect effect”, is
5 proposed.

7 Model for Estimating Direct and Indirect Effects

8 The inter-prefectural distribution matrices $\mathbf{M}_{s \in [\text{bef.}, \text{aft.}]}$ are analyzed as the result of destination (or
9 staying zone) choice behavior. Assuming the multi-nomial logit model, the probability to stay at zone j
10 in period s for residents of zone i is expressed as follows:

$$12 \quad p_{i,s}(j) = \frac{\exp(V_{i,j,s})}{\sum_{j \in Z} \exp(V_{i,j,s})} \quad , \quad (4)$$

13 where, $V_{i,j,s}$ is the fixed utility at zone j in period s for residents of zone i . Then, the difference in
14 fixed utility between zone $j \in Z$ and residential zone i can be calculated from MSS data $m_{i,j,s}$ by
15 Equation (5):

$$18 \quad V_{i,j,s} - V_{i,i,s} = \log\left(\frac{p_{i,s}(j)}{p_{i,s}(i)}\right) = \log\left(\frac{m_{i,j,s}}{m_{i,i,s}}\right) \quad (5)$$

19 The matrix of fixed utility difference \mathbf{B}_s can be denoted as follows.

$$22 \quad \mathbf{B}_s = \begin{pmatrix} b_{11,s} & \cdots & b_{1j,s} & \cdots \\ \vdots & \ddots & & \\ b_{i1,s} & & b_{i,j,s} & \\ \vdots & & & \ddots \end{pmatrix} = \begin{pmatrix} 0 & \cdots & V_{1j,s} - V_{11,s} & \cdots \\ \vdots & \ddots & & \\ V_{i1,s} - V_{i,i,s} & & 0 & \\ \vdots & & & \ddots \end{pmatrix} \quad . \quad (6)$$

23 Figure 2 shows the following two features of the matrix \mathbf{B}_{bef} . First, the values close to
24 the diagonal element are large, and the values far from the diagonal element are small. In this
25 figure, spatially close zones are located near to each other. Therefore, this feature means that
26 travelers basically choose near place as the travel destination. Second, the log ratio of travel
27 destination TYO and OSA are exceptionally large for almost all residential zones. Thus, TYO
28 and OSA are exceptionally chosen by high ratio of travelers, regardless of their residential
29 locations.

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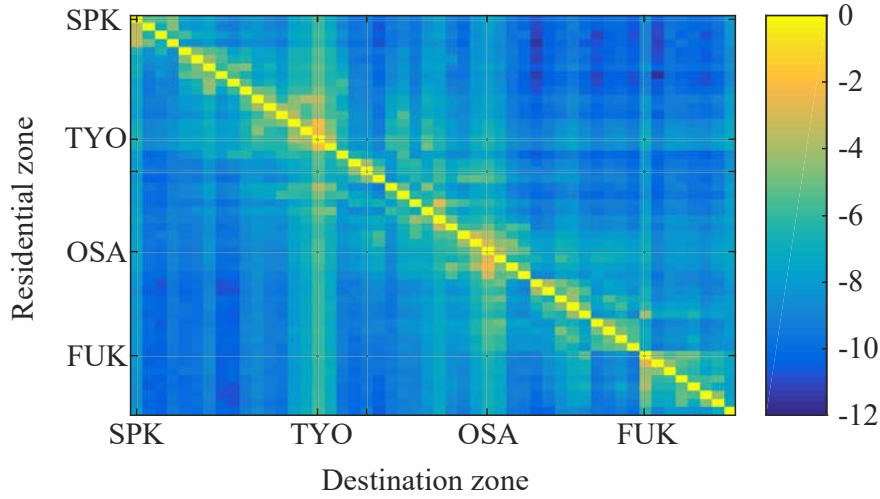


FIGURE 2 Calculated difference of fixed utilities \mathbf{B}_{bef}
(period: “Before the beginning of HSR operation”)

In this paper, the change in matrices \mathbf{B}_s is decomposed into three simple components:

$$\mathbf{B}_{\text{aft}} - \mathbf{B}_{\text{bef}} = \mathbf{D}_{\text{diff}} + \mathbf{C}_{\text{diff}} + \mathbf{E}_{\text{diff}} \quad (7)$$

\mathbf{E}_{diff} is the residual matrix. \mathbf{C}_{diff} is assumed to be the symmetric matrix which satisfies the condition that all-diagonal elements are equal to zero as follows:

$$\mathbf{C}_{\text{diff}} = \begin{pmatrix} 0 & c_{1,2,\text{diff}} & c_{1,3,\text{diff}} & \cdots \\ c_{1,2,\text{diff}} & 0 & c_{2,3,\text{diff}} & \\ c_{1,3,\text{diff}} & c_{2,3,\text{diff}} & 0 & \\ \vdots & & & \ddots \end{pmatrix} \quad (8)$$

And \mathbf{D}_{diff} is assumed to satisfy the two following conditions: all-diagonal elements are equal to zero, and all off-diagonal elements in the same column are equal. This matrix is written as follows:

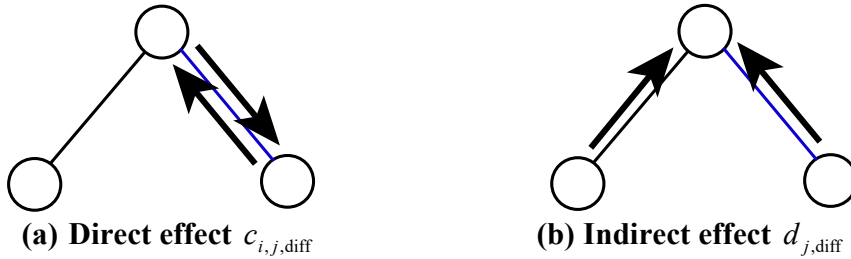
$$\mathbf{D}_{\text{diff}} = \begin{pmatrix} 0 & d_{2,\text{diff}} & d_{3,\text{diff}} & \cdots \\ d_{1,\text{diff}} & 0 & d_{3,\text{diff}} & \\ d_{1,\text{diff}} & d_{2,\text{diff}} & 0 & \\ \vdots & & & \ddots \end{pmatrix} \quad (9)$$

Here, each of the elements $(c_{i,j,\text{diff}}, d_{j,\text{diff}})$ in matrix $(\mathbf{C}_{\text{diff}}, \mathbf{D}_{\text{diff}})$ refer to the changes of fixed utility in different spatial patterns, as shown in Figure 3. $c_{i,j,\text{diff}}$, are defined in each zone pair (i, j) and equal in both directions, as expressed in Equation (8). These patterns are similar to the change in travel service qualities (fare, required time, frequency of operation, etc.) which are “directly” changed

1 by the new HSR service. For example, Hokuriku HSR reduced the 80 min travel time between TYO and
 2 ISK. This service improvement is beneficial for all travelers between TYO and ISK in both directions as
 3 described in Figure 3(a).

4 $d_{j,diff}$ are defined in each destination zone $j \in Z$, and equal to all residential zones $i \in Z$, as
 5 described Figure 3(b). This spatial pattern can be considered as a centripetal force of zone j , and this is
 6 similar to the utility change caused by the construction of new attractive facilities, such as amusement
 7 parks. When building new HSRs, there is a potential to change the pattern via improvement of the value
 8 of zone as the destination (ex. through accumulation of business facilities). As a result of this effect, the
 9 behavior of people who do not directly use the HSR service also changes. Therefore, in this paper, the
 10 effect in \mathbf{D}_{diff} is referred to as an indirect effect, compared to the direct effect in \mathbf{C}_{diff} .

11 These indirect effects were not considered in the studies by Yao and Morikawa (5) and Fu et
 12 al. (6), because the pattern of \mathbf{D}_{diff} was described by socio-economic factors such as zone population and
 13 economic scale. Thus, the relationship between the existence of HSR services and socio-economic factors
 14 were not described in their models. In this paper, both the direct and indirect effects of Hokuriku HSR are
 15 estimated based on the MSS data, and the significance of the direct and indirect effects are compared.
 16



18 **FIGURE 3 Two decomposed patterns of change**

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21 **Estimation Methodology**

22 By rewriting the matrices $(\mathbf{B}_{aft} - \mathbf{B}_{bef})$, \mathbf{D}_{diff} , \mathbf{C}_{diff} , and \mathbf{E}_{diff} as vectors, Equation (7) can be
 23 rewritten as follow:
 24

25
$$\mathbf{b}_{diff} = \mathbf{K} \begin{pmatrix} \mathbf{d}_{diff} \\ \mathbf{c}_{diff} \end{pmatrix} + \boldsymbol{\varepsilon}_{diff}, \quad . \quad (10)$$

26
27 where, $\mathbf{b}_{diff} = \begin{pmatrix} b_{1,2,aft} - b_{1,2,bef} \\ b_{1,3,aft} - b_{1,3,bef} \\ \vdots \\ b_{50,49,aft} - b_{50,49,bef} \end{pmatrix}$, $\mathbf{d}_{diff} = \begin{pmatrix} d_{1,diff} \\ \vdots \\ d_{50,diff} \end{pmatrix}$, $\mathbf{c}_{diff} = \begin{pmatrix} c_{1,2,diff} \\ \vdots \\ c_{50,49,diff} \end{pmatrix}$, $\boldsymbol{\varepsilon}_{diff} = \begin{pmatrix} \varepsilon_{1,2,diff} \\ \varepsilon_{1,3,diff} \\ \vdots \\ \varepsilon_{50,49,diff} \end{pmatrix}$.

28 These vectors are composed of non-diagonal components of matrices $(\mathbf{B}_{aft} - \mathbf{B}_{bef})$, \mathbf{D}_{diff} , \mathbf{C}_{diff} ,
 29 and \mathbf{E}_{diff} . Further, \mathbf{K} is the binary matrix satisfying Equations (8) – (10).

30 Then, the $(\mathbf{d}_{bef}^*, \mathbf{c}_{bef}^*)$ minimize the residual sum of squares $\sum_{(i,j)} (\varepsilon_{1,2,diff})^2$ are estimated. Here,

31 Equation (7) can be rewritten as follow:
 32

$$b_{i,j,\text{aft}} - b_{i,j,\text{bef}} = d_{j,\text{diff}} + c_{i,j,\text{diff}} + \varepsilon_{i,j,\text{diff}} = (d_{j,\text{diff}} + e) + (c_{i,j,\text{diff}} - e) + \varepsilon_{i,j,\text{diff}}, \quad \forall e \in \mathfrak{R}, \forall (i,j) \in Z \times Z. \quad (11)$$

Therefore, there exists a vector $\mathbf{a} \neq \mathbf{0}$, which satisfies Equation (12):

$$\mathbf{K} \begin{pmatrix} \mathbf{d}_{\text{diff}} \\ \mathbf{c}_{\text{diff}} \end{pmatrix} = \mathbf{K} \left(\begin{pmatrix} \mathbf{d}_{\text{diff}} \\ \mathbf{c}_{\text{diff}} \end{pmatrix} + e\mathbf{a} \right), \quad \forall e \in \mathfrak{R}. \quad (12)$$

This means that \mathbf{K} is the rank-deficient matrix and we cannot estimate unique $(\mathbf{d}_{\text{bef}}^*, \mathbf{c}_{\text{bef}}^*)$ only minimizing the residual sum of squares.

In this paper, $(\mathbf{d}_{\text{bef}}^*, \mathbf{c}_{\text{bef}}^*)$ are estimated by following two step calculations. In the first step, we consider the vector \mathbf{z} defined as follows:

$$\begin{pmatrix} 0 \\ \mathbf{z} \end{pmatrix} = \mathbf{L}\mathbf{z} = \begin{pmatrix} \mathbf{d}_{\text{diff}} \\ \mathbf{c}_{\text{diff}} \end{pmatrix} - d_{1,\text{diff}}\mathbf{a}, \quad \text{where } \mathbf{L} = \begin{pmatrix} 0 & 0 & \dots & 0 \\ 1 & & & 0 \\ & 1 & & \\ & & \ddots & \\ 0 & & & 1 \end{pmatrix} \quad (13)$$

Then, using Equations (12) - (13), Equation (10) can be rewritten as follow:

$$\mathbf{b}_{\text{diff}} = \mathbf{K}\mathbf{L}\mathbf{z} + \boldsymbol{\varepsilon}_{\text{diff}}, \quad (14)$$

Here, $[\mathbf{L}^T \mathbf{K}^T \mathbf{K} \mathbf{L}]$ is the regular matrix, therefore the \mathbf{z}^* which minimize the residual sum of squares can be estimated by following equations:

$$\mathbf{z}^* = \arg \min (\boldsymbol{\varepsilon}_{\text{diff}}^T \boldsymbol{\varepsilon}_{\text{diff}}) = [\mathbf{L}^T \mathbf{K}^T \mathbf{K} \mathbf{L}]^{-1} \mathbf{L}^T \mathbf{K}^T \mathbf{b}_{\text{diff}}, \quad (15)$$

In second step, we estimate unique $(\mathbf{d}_{\text{bef}}^*, \mathbf{c}_{\text{bef}}^*)$ from following equation:

$$\begin{pmatrix} \mathbf{d}_{\text{diff}}^* \\ \mathbf{c}_{\text{diff}}^* \end{pmatrix} = \begin{pmatrix} 0 \\ \mathbf{z}^* \end{pmatrix} + e^* \mathbf{a}. \quad (16)$$

Hence, in order to determine e^* , it is assumed that most components of $\mathbf{c}_{\text{bef}}^*$ are close to zero. This assumption is reasonable because there were no major changes in travel service quality in most zone pairs, excluding pairs related with the Hokuriku HSR. Then, e^* is estimated as follows:

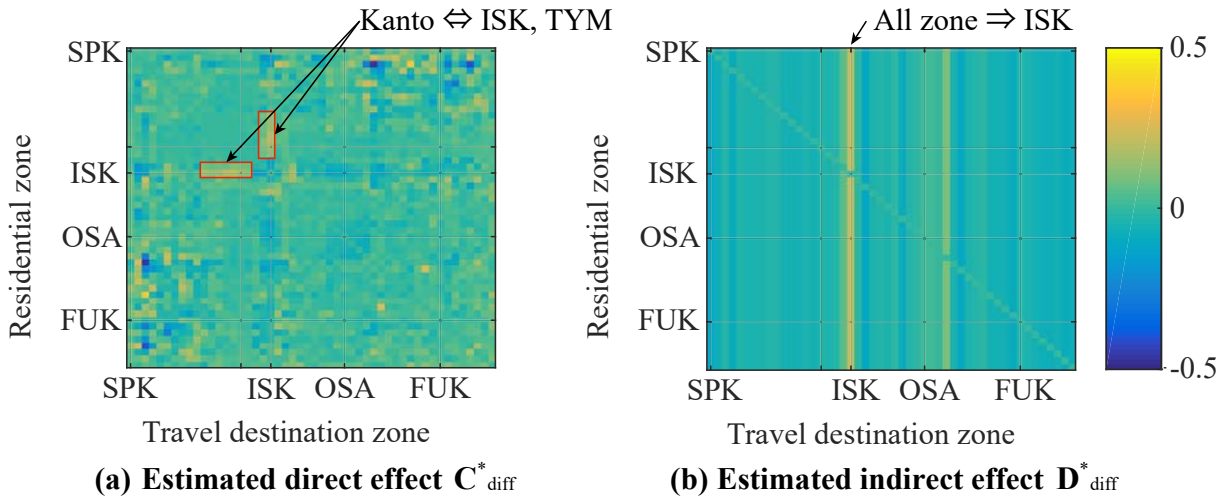
$$e^* = \arg \min \sum_{(i,j)} |c_{i,j,\text{diff}}^*|. \quad (17)$$

Finally, $(\mathbf{d}_{\text{bef}}^*, \mathbf{c}_{\text{bef}}^*)$ can be estimated using Equation (15), (16) and (17).

1 Estimated Decomposed Results

2 Figure 4 shows the estimated results of \mathbf{D}^*_{diff} , \mathbf{C}^*_{diff} . Figure 4(a) indicates that $c_{i,j,diff}$ are increased
 3 in the zone-pair which are connected by new HSR (red blocks in Figure 4(a); Kanto – ISK, TYM which
 4 are directly connected by the Hokuriku HSR). In the other words, the new HSR increased the number of
 5 travelers between Kanto and Hokuriku areas (ISK, TYM zones). This change is directly anticipated
 6 because of the time reduction effect of the new HSR service.

7 Figure 4(b) indicates that the indirect effect $d_{j,diff}$ was increased in the ISK zone. As
 8 discussed in the previous section, these changes are similar in all residential zones including OSA zone,
 9 which is in the opposite direction to the new HSR line. On the other hand, asymmetric effect was detected
 10 in on direction, in the TYO – ISK pair.



14 **FIGURE 4 Two decomposed matrices.**

15
16

17 In order to confirm the validity of this decomposition, $(\mathbf{B}_{aft} - \mathbf{B}_{bef})$ and $(\mathbf{D}^*_{diff} + \mathbf{C}^*_{diff})$
 18 are compared, as shown in Figure 5. Figure 5(a) illustrates $(\mathbf{B}_{aft} - \mathbf{B}_{bef})$ calculated from MSS
 19 data directly, while Figure 5(b) shows $(\mathbf{D}^*_{diff} + \mathbf{C}^*_{diff})$, which are the estimated components in this
 20 study. The comparison between Figure 5(a) and (b) indicates that $(\mathbf{D}^*_{diff} + \mathbf{C}^*_{diff})$ succeed in reproducing
 21 most of the features of $(\mathbf{B}_{aft} - \mathbf{B}_{bef})$. In the other words, most changes that occurred before and after the
 22 beginning of the new HSR service were patterns of \mathbf{C}^*_{diff} and \mathbf{D}^*_{diff} .

23

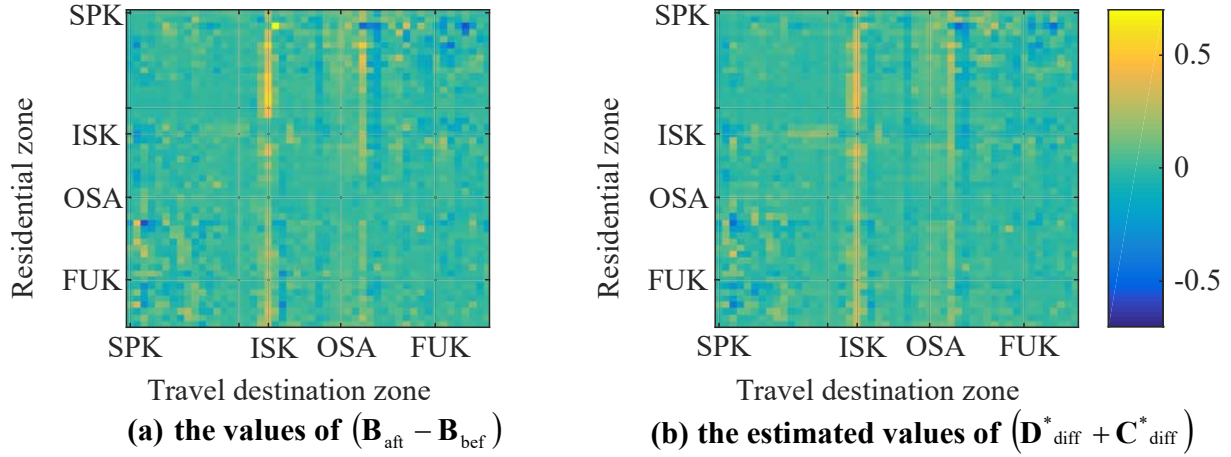


FIGURE 5 Comparison between $(\mathbf{B}_{\text{aft}} - \mathbf{B}_{\text{bef}})$ and $(\mathbf{D}_{\text{diff}}^* + \mathbf{C}_{\text{diff}}^*)$

Direct vs. Indirect Effects of the New HSR

In this section, the amount of direct effect of \mathbf{C}_{diff} and indirect effect of \mathbf{D}_{diff} in Hokuriku HSR are compared. First, the change volume by both effects $n_{i,j,\text{Both}}$ (residential and staying zone pair:

$(i, j) \in Z \times Z$) can be calculated using the following equation:

$$n_{i,j,\text{Both}} = \text{POP}_i \frac{\exp(b_{i,j,\text{bef}} + c_{i,j,\text{diff}} + d_{j,\text{diff}})}{\sum_{j \in Z} \exp(b_{i,j,\text{bef}} + c_{i,j,\text{diff}} + d_{j,\text{diff}})} - m_{i,j,\text{bef}}, \quad (16)$$

where POP_i is population of zone $i \in Z$, which is equal to $\sum_{j \in Z} m_{i,j,\text{bef}}$. Second, the amount of

change by only the direct effect $n_{i,j,\text{Direct}}$ (residential and staying zone pair: $(i, j) \in Z \times Z$) can be calculated using the following equation:

$$n_{i,j,\text{Direct}} = \text{POP}_i \frac{\exp(b_{i,j,\text{bef}} + c_{i,j,\text{diff}})}{\sum_{j \in Z} \exp(b_{i,j,\text{bef}} + c_{i,j,\text{diff}})} - m_{i,j,\text{bef}}. \quad (17)$$

This $n_{i,j,\text{Direct}}$ indicates the amount of change before and after the Hokuriku HSR, without the indirect effect \mathbf{D}_{diff} .

Table 2 lists part of estimated results of $n_{i,j,\text{Both}}$ and $n_{i,j,\text{Direct}}$. The following features of direct and indirect effects of Hokuriku HSR can be recognized. First, the increase volume of travelers to ISK from TYO due to the direct effect is smaller than the volume by “both” effects. The ratio of the direct effect to the total of both effects was only 34%. This is attributed to the large increase in value of the zone as travel destination (indirect effect) in the ISK zone seen in Figure 4(b). On the other hand, in the reverse direction (traveler to TYO from ISK), the direct effect accounts for majority of the increase, because the value of TYO zone as travel destination was not increased. Hence, the direct effects are almost similar in both directions of the zone pair. Therefore, the total increase amount was asymmetric between directions

of travel because of the difference in the indirect effects. Furthermore, in the result of the total increase of travel volume to the ISK zone, the direct effect was very limited, and 93% of the increase was due to the indirect effect. This reflects the increase in inflow from other zones connected by the new HSR service, such as OSA.

Accordingly, when the changes before and after the beginning of Hokuriku HSR operation are compared, it is found that the indirect pattern effects, which are described in Figure 3(b), were more significant than the direct pattern effects.

TABLE 2 Estimated Direct and Indirect Effects of the Hokuriku HSR

Residential zone	Staying zone at 13:00	(1) Direct effect only	(2) Direct + indirect effects	(1) / (2)
TYO	ISK	+ 551	+ 1,617	0.34
ISK	TYO	+ 583	+ 647	0.90
46 zones ^{**}	ISK	+ 555	+ 8,097	0.07

^{**} '46 zones' means all zones except four zones in Hokuriku regions (Nigata, Toyama, Ishikawa and Fukui).

SUMMARY

In this study the direct and indirect effects of Hokuriku HSR on the residential - travel destination matrix data are analyzed. The matrix was decomposed into two matrices corresponding to direct and indirect effects, in order to understand the matrix difference. The decomposed results indicate the following three features of the HSR effect: First, the change before and after the beginning of the Hokuriku HSR operation in the residential - travel destination matrix are mostly explained by two change patterns (direct and indirect effects). Second, the direct numerical effects are smaller than in-direct effects on the travel volume. Third, the changes are asymmetric on the flows for several zone pairs because of indirect effects.

The current study findings reveal the importance of predicting the indirect effects, while forecasting the effects of the new HSR lines. However, most long-distance travel demand models are similar to those developed by Yao and Morikawa (5) and Fu et al. (6), which cannot predict these indirect effects. Therefore, in order to understand the value of the HSR services for the national-scale travel structure or patterns, and to estimate the benefits of the new HSR services, it is necessary to model and incorporate the indirect effect of new HSR service. For modeling the indirect effects, it is required to compare the indirect effects of several HSR services. Moreover, it may be important to discuss the long-term and short-term effects of the service, because the indirect effects are expected to reflect long-term changes, such as the future economic development of the region (location of companies). The focus of this paper is only on the short-term effect (1 year). However, the long-term effects can also be discussed by applying a similar methodology to long-term data.

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