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DAY TO DAY VARIATIONS OF INTER-ISLAND TRAFFICS AND PRICE ELASTICITY - TOWARDS CONGESTION CONTROL OF INTERCITY TRAFFICS -

Makoto OKUMURA
Associate Professor
Graduate School of Engineering
Hiroshima University
A2-446,1-4-1,Kagamiyama,
Higashi-Hiroshima,
739-8527, Japan
Fax: +81-82-424-7827
E-mail: mokmr@hiroshima-u.ac.jp

Makoto TSUKAI
Assistant Professor
College of Science and Engineering
Ritsumeikan University
1-1-1,Noji-Higashi,Kusatsu,
525-8577, Japan
Fax: +81-77-566-1111
E-mail: tsukai@ritsumeikan.ac.jp

Hajime JINNO
Master Course Student
Graduate School of Engineering
Hiroshima University
A2-446,1-4-1,Kagamiyama,
Higashi-Hiroshima,
739-8527, Japan
Fax: +81-82-424-7827
E-mail: jno@hiroshima-u.ac.jp

Abstract: Comparing to daily urban commuting traffics, intercity traffics are very intermingled with different purposes. Each of them may have different price elasticity for toll. Therefore, observed traffic flows must be carefully dissolved into several types of traffics, and price elasticity must be captured. In order to grasp the response of urban road traffics to price change, disaggregate behavioral model have been considered as an effective analytical tool. But in case of heterogeneous intercity traffics, survey on sampled individuals is very difficult to design and consumes much time and money. Fortunately in Japan, automatically detected traffic data have been gathered at many points along expressways and highways. This research is intended to analyze the cross-sectional traffic count of Honshu-Shikoku bridges. Specifically, influence of the fare change (10% discount in July 2003) is clarified by using the methods such as factor analysis and Vector Auto-Regression.

Key Words: Time series traffic data, Intercity traffic, Elasticity

1. INTRODUCTION

In order to provide data for a transportation planning, cross-sectional traffic census, person trip survey, etc. have been performed, and four step demand estimation method was developed to analyze average traffic flow based on data. Recently, in order to grasp not only quantitative traffic but also qualitative information, travel behavior surveys based on questionnaire have been performed, and travel behavior models were developed based on these data. However, to acquire sufficient samples in such survey becomes more and more difficult because the number of samples is restricted from severe survey budget or technical restrictions, decline of the effective respondent ratio due to increasing recognition of privacy.

On the other hand, at present, information, such as cross-sectional traffic count and the number of getting-on-and-off persons, becomes easy to be gathered owing to automatic detection equipments or the magnetic card system. And a lot of data containing exact measurement point and time information are stored every day. Analytical method corresponding to such automatic measurement data, however, has not yet well established.

For the Honshu-Shikoku bridges, cross-sectional daily traffic data of each bridge are acquired automatically, but at present, it is used only for the comparison of the annual traffics of each bridge, and for simple prediction of the traffic congestion on the consecutive holidays.

Total traffic which flows between Honshu (North Side) and Shikoku (South side) are constituted by several traffics with different purpose and quality. For example, the traffic which shuttle in one day for living purpose, wide area circulation for the sightseeing and so on are intermingled. These traffic have different fluctuation cycle needs of services and reaction to fare, weather and events. So it becomes important to raise customer satisfaction and awake demand by provision of services and detailed fare settings which fit each traffic. For that reason it is desired to grasp component ratio of these traffics with different temporal variation and behavioral characteristic. Especially, to grasp the effects of fare change (10% discount) which was done in July 2003 is an interesting problem.

The automatic detected data contains both spatial and temporal information but the method that is possible to treat the both at once, doesn't exist yet. This research then, start with factor analysis to see variations conducted over a wide area, and next factors of temporal variations are extracted. Furthermore, the temporal variations of traffics are investigated by time series analysis for the factor scores considering rain, fare change, weekday and holiday, etc.

2. THE OUTLINE OF HONSHU-SHIKOKU BRIDGES AND TRAFFIC DATA

Honshu-Shikoku bridges are composed of three routes which link Honshu and Shikoku Islands. Those are shown in Figure 1: Kobe-Awaji-Naruto Expressway (Eastern Route), Seto-Chuo Expressway (Central Route), and Nishiseto Expressway (Western Route). Seto-Chuo Expressway (C) connected Honshu and Shikoku Islands for the first time in 1988. Nextly, Akashi Kaikyo Bridge (E1) and land portions of Kobe-Awaji-Naruto Expressway (E) was opened in 1998. Finally, all bridges in the Nishiseto Expressway (W) were opened in 1999, but several land portions have not yet opened on the Western Route.

This research is focusing on day to day cross-sectional detected traffic count data for south and north bound directions on each bridge shown in Figure 1: Akashi Kaikyo Bridge (E1), Ohnaruto Bridge (E2) on Kobe-Awaji-Naruto Expressway (Eastern Route), Seto Bridges (Honshu side (C1) and Shikoku side (C2)) on Seto-Chuo Expressway (Central Route), Shin-Onomichi Bridge (W1), Innoshima Bridge (W2), Ikuchi Bridge (W3), Tatara Bridge (W4), Ohmishima Bridge (W5), Hakata-Ohshima Bridge (W6), and Kurushima Kaikyo Bridges (W7) on Nishiseto Expressway (Western Route). The term that these data are used in this research is 1,858 days: from May 1st, 1999 to May 31th, 2004.

Since July 2003, toll of all bridges were 10% discounted. According to the comparison of traffic in 2002 and in 2003 which Honshu-Shikoku Bridge Authority provides information on the Web, traffics increased generally at all bridges excluding two exceptions; traffics decreased at Seto Bridges (C) and Kurushima Kaikyo Bridges (W7).

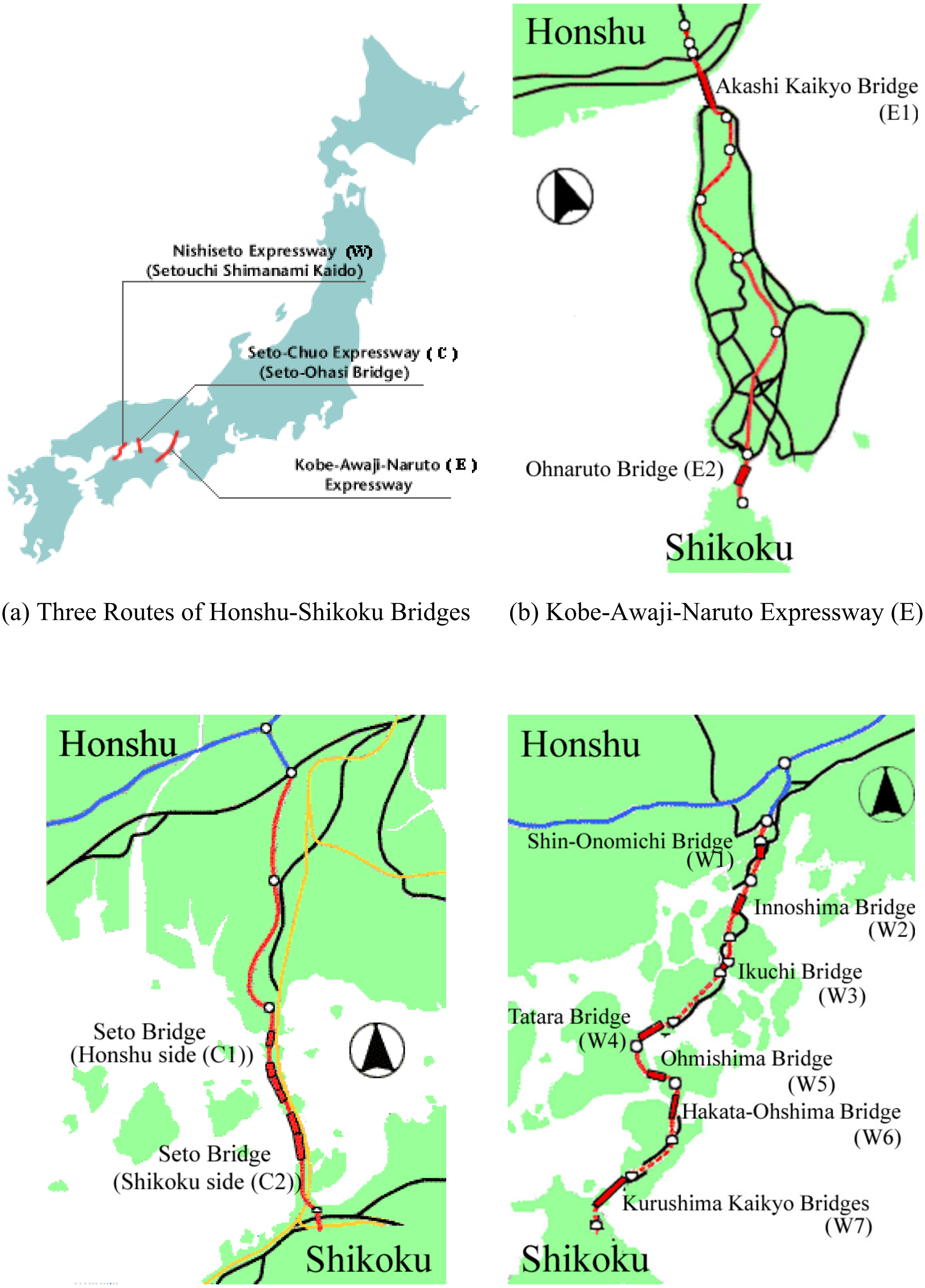
3. FACTOR ANALYSIS ABOUT TRAFFICS ON HONSHU-SHIKOKU BRIDGES

Factor analysis is one of the multivariate analyses to search several mutually independent latent factors that lurk behind a lot of observed variables based on the correlations between those observed variables.

If there are some traveling cars which choose their route from the routes on the different bridges, or there are cars which make circulation via those bridges for longer than one day, some negative correlation appear between daily traffics of the bridges. That is to say, traffic pattern which choose different bridges or go through those bridges can be captured as the common variation factors. Therefore some latent components that lurk behind the phenomena are picked out by method of factor analysis, based on the temporal variations among a lot of observed variables.

In this study, factor analysis was performed to the traffic data on Honshu-Shikoku bridges.

Proportion of variance explained is shown in table 1, and the graph which showed relatively size of factor loadings is shown in figure 2.



(a) Three Routes of Honshu-Shikoku Bridges (b) Kobe-Awaji-Naruto Expressway (E)

(c) Seto-Chuo Expressway (C) (d) Nishiseto Expressway (W)

Figure 1. Honshu-Shikoku Bridges

Table 1. Proportion of Variance Explained and Cumulative Proportion of Variance Explained

Factor No.	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Proportion of variance explained (%)	86.5	6.1	4.8	1.2	0.6
Cumulative proportion of variance explained (%)	86.5	92.6	97.4	98.6	99.3

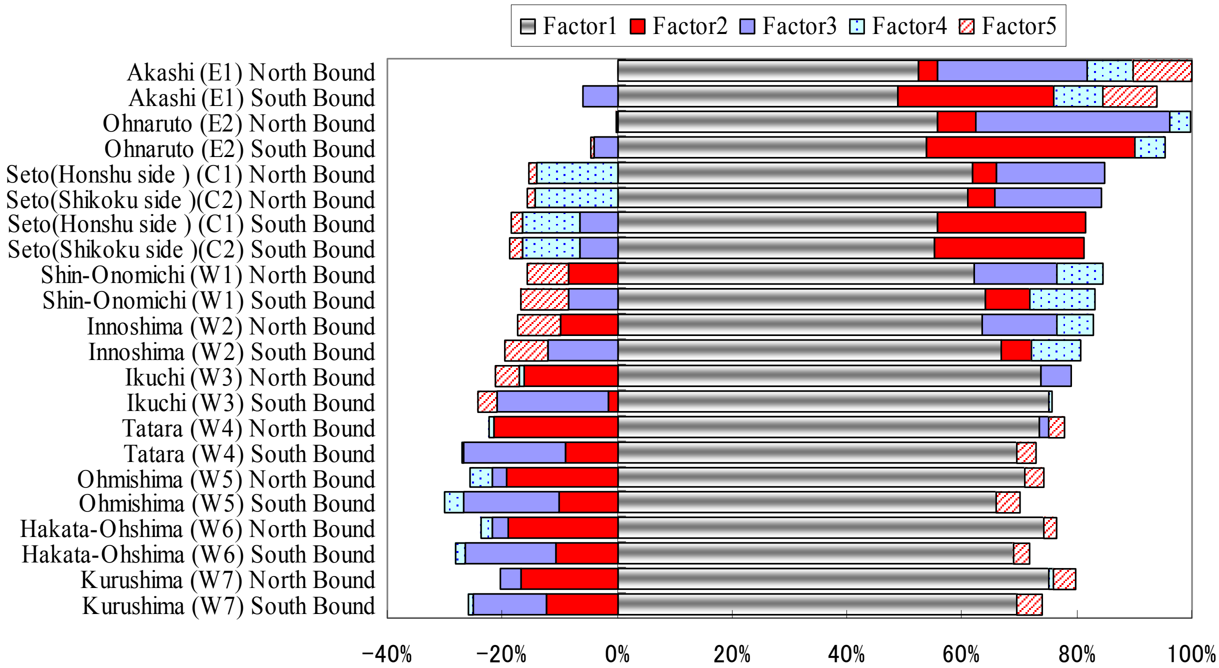


Figure 2. Factor Loadings

Proportion of variance explained by Factor 1 is as long as 85 % of total variance, and factor loadings mean positive strong influence on all bridges. Therefore, Factor 1 can be interpreted as overall traffic fluctuation.

Factor 2 can be interpreted as the factor corresponding to the circulation around east and west routes, because Factor 2 has a positive influence on the bridges in the east route such as Akashi Kaikyo Bridge (E1), Ohnaruto Bridge (E2), and Seto Bridges (C) and negative influence on the bridges in Nishiseto Expressway (W).

Factor 3 can be interpreted as the factor corresponding to the traffics which does not shuttle between the Honshu and Shikoku Islands in a day, because Factor 3 tends to have a positive influence on the north bound direction traffics and negative influence on the south bound direction traffics for all bridges.

Factor 4 has a positive influence on Akashi Kaikyo Bridge (E1) and Ohnaruto Bridge (E2), but negative influence on Seto Bridges (C). There is little influence on the bridges in Nishiseto Expressway (W). Therefore, Factor 4 can be interpreted as the factor corresponding to the circulation between the eastern (E) and central (C) routes.

Factor 5 can be interpreted as the factor corresponding to the traffics in narrow range inside Nishiseto Expressway (W), because Factor 5 has a positive influence on the bridges which are situated on Shikoku side in the Western Routes such as Tatara Bridge (W4), Ohmishima Bridge (W5), Hakata-Ohshima Bridge (W6), and Kurushima Kaikyo Bridges (W7) while, negative influence on the bridges which are situated on Honshu side such as Shin-Onomichi Bridge (W1), Innoshima Bridge (W2), and Ikuchi Bridge (W3).

According to this analysis, main variation ingredients for traffics on the Honshu-Shikoku bridges are summarized as followings:

Factor 1: Overall traffic fluctuation
Factor 2: Circulation around east and west routes
Factor 3: Traffics which does not shuttle between the Honshu and Shikoku Islands in a day
Factor 4: Circulation between the eastern and central routes
Factor 5: Traffic in narrow range inside Nishiseto Expressway (W)

These five factors can capture 99% of the total variation.

4. CHANGE OF THE FACTOR SCORES BY THE FARE CHANGE

Since July 1st, 2003, toll of Honshu-Shikoku bridges were 10% discounted from the fares before. It might result in the changes of traffics and variation factor of them.

4.1 Comparison of Factor Score Mean by T-test

In order to clarify whether or not there was a significant difference in the mean factor score of each factor before and after the fare change, t-test was done. It used 336 days data from July 1st, 2003 to May 31st, 2004 as the factor scores after the fare change. While it used 730 days data from July 1st, 2001 to June 30th, 2003 as factor scores before the fare change.

A result of the t-test about the mean factor scores, before and after the fare change is shown in table 2.

Table 2. Comparison of Factor Score Mean before and after the Fare Change

from July, 2001

2 years before fare change	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Mean	-0.13	0.18	0.17	0.16	-0.28
Variance	0.64	0.51	0.69	0.61	0.39
Number of sample (day)	730	730	730	730	730

from July, 2003

After fare change	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Mean	-0.02	0.28	0.26	0.63	-0.54
Variance	0.71	0.55	0.82	0.49	0.37
Number of sample (day)	336	336	336	336	336

T-value	2.03	1.91	1.56	9.67	-6.33
Degree of freedom	621	632	602	723	667
	*			**	**

significance level * 5%, **1%

Table 2 shows that factor scores of the Factor 1 and 4 are significantly higher than them before the fare change, and factor scores of the Factor 5 are significantly lower than them before the fare change. In other words, the following changes are occurred due to the fare change:

Traffics increased generally after the fare change due to the influence on the Factor 1, because the factor loadings of Factor 1 are positive for all bridges.
Traffics of Kobe-Awaji-Naruto Expressway (E), increased but those of the Seto-Chuo Expressway (C) decreased after the fare change due to the influence on the Factor 4, because the factor loadings of the Factor 4 are positive about Kobe-Awaji-Naruto Expressway (E) and

negative about Seto-Chuo Expressway (C).

Traffics of Honshu side in Nishiseto Expressway (W) increased and those of Shikoku side decreased after the fare change due to the influence of the Factor 5, because the factor loadings of the Factor 5 are positive for the bridges which are situated on Shikoku side in Nishiseto Expressway (W) and negative for the bridges which are situated on Honshu side.

4.2 Time Series Analysis about Factor Scores

Not only the fare change but also weather, weekday and holiday arrangements and so on can be considered as the reasons affecting the traffic changes. Therefore, change of factor scores, before and after the fare change does not mean the influence of only the fare change. Then, how much among the change of factor scores would be caused by the fare change is grasped by the following method; time series analysis on the factor scores considering rainfalls and arrangement on weekday and holidays, and a dummy variable distinguish before or after the fare change.

Generally, traffic is fluctuated by weekday, holiday, consecutive holidays, etc., and waiting action up to the next consecutive holidays can be considered on holiday when consecutive holidays exist in the following week. Moreover, traffic changes also with differences that the day is situated in the first half or second half of consecutive holidays. Thus, holiday traffics change with previous and next holiday arrangement, and then it is necessary to incorporate such information of arrangement on weekday and holiday in the case to analyze.

In this research, following 10 types of dummy variable about arrangement on weekday and holiday are used;

- **Weekday;** during Monday to Friday which exclude holidays.
- **Holiday**; Saturdays, Sundays, public holidays, Golden Week holidays, year-end and new year holidays, and Bon holidays (Aug 13th-15th).
- **Consecutive holidays**; holidays which continue three days or more.
- **Holiday except the consecutive holidays**
- **Holiday which has consecutive holidays before itself**; holiday which has consecutive holidays in previous three weeks.
- **Holiday which has consecutive holidays after itself**; holiday which has consecutive holidays by in the following three weeks.
- **First day in the consecutive holidays**
- **Middle day in the consecutive holidays**
- **End day in the consecutive holidays**
- **Day after Holiday**

Furthermore, precipitation in surrounding cities of the Honshu-Shikoku bridges is used as the rainfall information, and the day when no less than 1 mm rainfall is observed in any city is considered as the rain day described with a dummy variable.

Equation of Vector Auto-Regression model is shown as follows.

$$F_i(t) = \sum_k \alpha_{ik} F_i(t-k) + \sum_{j \neq i} \sum_l \beta_{jl} F_j(t-l) + \sum_m \gamma_{im} x_m(t) + \varepsilon_i(t) \qquad (1)$$

Here, F describes the factor scores, i and j describes index of factor. l and k shows lug. x_m shows dummy variables such as rainfall, fare change, and information of weekday and holiday. α, β and γ are parameters. ε is error term.

Estimated result of the Vector Auto-Regression model to each factor are shown in table 3.

When focus on the fare change dummy, parameter for the Factor 4 is significant positive and of that for the Factor 5 is significant negative; these results are consistent with the results of the t-test. As for the Factor 1, it is more strongly influenced from the factor score in the previous day, consecutive holidays, and rainfall than the fare change. It is possible to get the following rule from the estimated result: Since the rainfall dummy is significant negative and rainfall dummy (-1) is significant positive, factor score of Factor 1 decreases on rainy day and increases on the following day.

Table 3. Result of Vector Auto-Regression Model

(a) Result of Applying Vector Auto-Regression Model to Factor 1

Factor 1 Explanatory variable	Estimate	T-value	
Factor 1 (-1)	0.71	38.60	**
Factor 1 (-7)	0.03	1.96	*
Rainfall dummy	-0.13	-5.66	**
Rainfall dummy(-1)	0.08	3.72	**
Weekday	-0.06	-3.29	**
Holiday	0.17	3.99	**
Holiday which has consecutive holidays before itself	0.02	0.60	
Holiday which has consecutive holidays after itself	0.09	2.40	*
First day in the consecutive holidays	0.69	11.45	**
Middle day in the consecutive holidays	0.87	18.09	**
End day in the consecutive holidays	-0.22	-3.19	**
Day after Holiday	-0.56	-17.30	**
Fare change dummy	0.04	1.75	
Coefficient of Determination	0.85		

significance level * 5%, **1%

(b) Result of Applying Vector Auto-Regression Model to Factor 2

Factor 2 Explanatory variable	Estimate	T-value	
Factor 2 (-1)	0.66	19.09	**
Factor 2 (-7)	0.04	2.06	*
Factor 1	0.77	17.24	**
Factor 1 (-1)	-0.89	-17.76	**
Factor 3 (-1)	0.28	9.21	**
Rainfall dummy	0.03	0.90	
Rainfall dummy (-1)	-0.01	-0.47	
Weekday	-0.06	-2.00	*
Holiday except the consecutive holidays	-0.14	-3.92	**
First day in the consecutive holidays	0.89	9.89	**
Middle day in the consecutive holidays	-0.01	-0.17	
End day in the consecutive holidays	0.00	-0.04	
Day after Holiday	0.25	4.86	**
Fare change dummy	0.01	0.35	
Coefficient of Determination	0.64		

significance level * 5%, **1%

(c) Result of Applying Vector Auto-Regression Model to Factor 3

Factor 3 Explanatory variable	Estimate	T-value	
Factor 3 (-1)	0.46	16.10	**
Factor 3 (-2)	-0.10	-5.58	**
Factor 3 (-7)	0.02	1.67	
Factor 1	0.50	12.48	**
Factor 1 (-1)	0.18	3.75	**
Factor 2	-0.62	-23.42	**
Factor 2 (-1)	0.02	0.55	
Factor 2 (-2)	0.08	2.75	**
Factor 2 (-3)	0.00	0.15	
Rainfall dummy	0.00	-0.01	
Weekday	0.40	15.92	**
First day in the consecutive holidays	0.05	1.24	
Day after Holiday (+1)	0.83	23.94	**
Day after Holiday	-0.76	-17.10	**
Fare change dummy	0.04	1.80	
Coefficient of Determination	0.82		

significance level * 5%, **1%

(d) Result of Applying Vector Auto-Regression Model to Factor 4

Factor 4 Explanatory variable	Estimate	T-value	
Factor 4 (-1)	0.33	11.59	**
Factor 4(-7)	0.24	8.87	**
Factor 1	-0.18	-4.79	**
Factor 2 (-1)	0.38	10.87	**
Factor 2 (-2)	-0.25	-6.72	**
First day in the consecutive holidays	0.51	10.38	**
Day after Holiday (+1)	0.31	5.85	**
Day after Holiday	0.05	0.95	
Weekday	-0.17	-5.17	**
Fare change dummy	0.21	5.19	**
Coefficient of Determination	0.50		

significance level * 5%, **1%

(e) Result of Applying Vector Auto-Regression Model to Factor 5

Factor 5 Explanatory variable	Estimate	T-value	
Factor 5 (-1)	0.29	10.44	**
Factor 5 (-7)	0.25	9.25	**
Factor 1	-0.35	-7.03	**
Factor 1 (-1)	0.29	4.68	**
Factor 1 (-2)	-0.01	-0.30	
Holiday except the consecutive holidays	0.10	2.68	**
First day in the consecutive holidays	0.56	5.34	**
Middle day in the consecutive holidays	0.27	3.01	**
End day in the consecutive holidays	0.26	2.36	*
Day after Holiday	-0.25	-4.08	**
Weekday	-0.25	-7.98	**
Fare change dummy	-0.11	-3.17	**
Coefficient of Determination	0.33		

significance level * 5%, **1%

4.3 Consideration of the Effects of the Fare Change

The following results were obtained from the above analysis:

- Traffics of all bridges increased after the fare change due to the influence of the Factor1.
- Traffics of Kobe-Awaji-Naruto Expressway (E) increased but those of Seto-Chuo Expressway (C) decreased due to the influence of the Factor 4.
- Traffics of Honshu side in Nishiseto Expressway (W) increased but those of Shikoku side decreased due to the influence of the Factor 5.

As the reason why traffics of Kobe-Awaji-Naruto Expressway (E) increased and traffic of Seto-Chuo Expressway (C) decreased, the feeling of comparatively high price for the former route was suppressed by the following causes: since this fare change was implemented at the same rate of 10 % discount, the amount of discount was larger in the former route (Kobe-Awaji-Naruto Expressway (E)) whose conventional toll was high, than in the latter route (Seto-Chuo Expressway (C)).

These results are consistent to the tendency of actual traffic changes which was described in chapter 2. They also show where fare elasticity is enough large for the possible traffic promotion through further fare reductions, which would help to improve profitability of the Honshu-Shikoku Bridge Authority.

However, our findings are derived from the one shot fare change with the constant reduction rate of 10% then, it is not clear whether similar effects will occur with different fare change rate. One practical way to scrutinize the effect of fare change is a temporal social experiment with help of flexibility of the Electric Toll Collection System at small number of bridges with large elasticity, which can be selected using the results of this study.

5. CONCLUSION

This research aimed at the proposal of a method which analyzes temporal and spatial structure of inter-city traffics variations, using multivariate time series data, and analyzed the cross-sectional traffic count of Honshu-Shikoku bridges. Specifically, influence of the fare change at July 1st, 2003 was clarified by using the methods such as factor analysis and Vector Auto-

Regression.

Although emphasis was put on developing the model which describes the already occurred phenomenon in this research, the time series analysis is the method to be used originally for prediction. It is necessary to develop the model which can be used for future prediction of traffics from now on.

Finally, although variation pattern of factors was analyzed in this research, correspondence between individual attributes and the change of factors has not been analyzed. Development of surveying technique and analyzing method for this relation are issues to be solved in the future.

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