A Study on the Practical Evaluation of Demand Change Caused by the Development of a Bicycle-Friendly Environment

Kiyoshi SUZUKI [a], Nobu TSUCHIZAKI [b], Yusuke KANDA [c], Kenji DOI [d]

[a] *Kagawa Road Work Office, Ministry of Land, Infrastructure, Transport and Tourism, 4-26-32, Fukuokacho, Takamatsu, Kagawa, 760-8546, Japan*
E-mail: suzuki-k8814@skr.mlit.go.jp
[b] *Oriental Consultants, Co., Ltd., 3-2-18, Nakanoshima, Kita-ku, Osaka, 530-0005, Japan*
E-mail: tsuchizaki@oriconsul.com
[c] *Graduate School of Engineering, Kyoto University, 4 Katsura Campus, Nishikyo-Ku, Kyoto, 615-8540, Japan; E-mail: kanda@trans.kuciv.kyoto-u.ac.jp*
[d] *Graduate School of Engineering, Osaka University, 2-1, Yamadagaoka, Suita, Osaka, 565-0871, Japan; E-mail: doi@civil.eng.osaka-u.ac.jp*

Abstract: In recent years, there have been efforts to develop bicycle-friendly environments across Japan. However, such development is conducted only where the road is wide enough, and thus efficient networks are not easy to develop. In this situation, it is essential to accurately evaluate the demand changes by development and to examine how to meet the needs as a network while developing the areas that are easier to proceed with. Therefore, to organize the information that is necessary to evaluate the demand changes, we build a route choice model using data of Takamatsu city and conduct verification using data from the actual implementation of measures. The study showed that bicycle route choice is mainly affected by discontinuity and presence of turns. Furthermore we have specified the need to note partial bottlenecks, and consider a measures under the assumption that routes would be chosen impromptu when we evaluate demand changes.

Keywords: bicycle network, routing model, bicycle demands, evaluating demand changes

1. INTRODUCTION

In Japan, with increasing environmental awareness and health consciousness, the use of bicycles has recently been expanding rapidly and is now considered as an important travel mode of urban transportation rather than a supplementary means. Bicycles can turn in a small radius and can be used in various types of routes from arterial roads to narrow alleys. In Japan, there has been introduced a legal rule since 1970 to allow bicycling to pass on sidewalks with the purpose of protecting bicycle users from traffic accidents. As far as the authors know, such rules exist only in a few countries, such as Japan, Norway and Australia, where pedestrians and bicycle riders share sidewalk space. Therefore, Japan still does not have enough bicycle lanes, and bicycle riders usually use the same spaces as pedestrians. Because of this situation, there are often an excessively large number of bicycle riders in local shopping streets and other spaces where pedestrians are supposed to be given priority, creating conflicts with pedestrians.

In response to such situation, network development plans are now being considered and the development of bicycle-friendly environments is actually being carried out in many cities across Japan for such purposes as ensuring safety. However, the result of evaluation and verification of 98 pilot areas across Japan conducted by the Committee for the Creation of

Safe and Comfortable Environments for the Use of Bicycles (2012) shows that only a small number of municipalities have established a bicycle network plan and that they tend to develop bicycle-friendly environments only where the road has enough width. This fact implies that much of the development work is carried out where the road has enough width, not where there are demands or issues.

For example, the city of Takamatsu in Kagawa Prefecture, one of the cities with the highest bicycle modal share rate in Japan, had a large number of bicycle users during commuting hours and the over-concentration caused issues of conflict in shopping avenues with arcades and arterial roads in the city center. To respond to such a situation, the "Policy for the Development of a Bicycle Network in the Center of Takamatsu City" was formulated in 2008 and Chuo-dori (National Route 11 and National Route 30), the street connecting the city center and the southern part of the city, and City Road "Goban-cho Saihou Line", the street connecting the city center and the western part of the city, have been improved.

Chuo-dori the main boulevard, is a parallel route adjacent to the arcade that has the largest number of bicycle riders. Although the user-friendliness of the road increased after improvement work, people cannot cross some intersections on the ground level due to structural reasons (underground passages have been built). Therefore, bicycle users do not use Chuo-dori, because they cannot continuously ride a bicycle along the route, and the issue of congestion in the shopping street has not been solved.

To address this situation, in April 2012, bicycles were banned from the shopping street, where there was the heaviest bicycle traffic. Since then, bicycle riders have started using Chuo-dori, parallel to the zone where bicycles are banned. However, it has caused new issues such as realizing the inadequate capacity of Chuo-dori and a concentration of bicycles in nearby narrow alleys.

Such issues often arise when trying to create a bicycle lane in road spaces in an existing urban area. Under such circumstances, it is essential to ensure that the environment for bicycles will be efficient and user-friendly by taking appropriate action to create a network that meets bicycle demands while carrying out development work according to the potential uses of the existing road space. To achieve this, it is necessary to determine the current needs and usage status and then to evaluate the effectiveness and consider additional measures while accurately evaluating the demand change caused by development.

In this study we analyze the relations between service level and demand, based on the data of actual bicycle utilization in the city center of Takamatsu obtained by the methods (2011,2012) developed by the authors et al. In addition, through evaluation and study of data from the actual implementation of measures (prohibiting bicycle riding in a shopping street), we also clarify the points to consider when evaluating demand change caused by development work.

2. REVIEW OF PREVIOUS STUDIES

Regarding the characteristics of bicycle riders' route choice, Suzuki et al. (2011,2012) developed methods using GIS to analyze route data collected through a questionnaire and analyzed characteristics of routes with high bicycle demand and points to consider when identifying candidate routes for a network. However, there has been no information concerning demand change caused by prohibition of bicycles and road improvement and no quantitative analysis has been conducted.

On the other hand, there are some cases of quantitative analysis using models or the like. Shizuyama et al. (2007) built route choice models based on data collected from plotted maps and showed that bicycle users prefer going in a direct route and tend to choose a short-distance link with a sidewalk. Mekuria et al. (2011) estimated bicycle traffic after clarifying the characteristics of bicycle users' route choice, examining streets, narrow alleys and bicycle lanes. The result of the study shows that bicycling is not selected as a transportation means if the detouring rate from a straight route exceeds 50%. Dill (2004) studied network shapes favorable for bicycles and pedestrians. He analyzed directness of routes using such indicators as intersection density and number of nodes to pass between certain CDs and clarified that bicycle riders do not always choose the shortest route but avoid signalized intersections more than pedestrians. From the result of a street survey of bicycle users, Krizek et al. found that the travel distance had increased by about 67% to use bicycle lanes bikeways with higher traveling performance.

Although these studies have clarified the general characteristics of routes preferred by bicycle riders, such as a small number of turns, short distance, a small number of signals, and higher traveling performance, they do not show information concerning demand change caused by development work. Moreover, although factors identified in such model analysis are important points to consider when considering development, there are other points to be considered in real situations.

Therefore, in this study we first build a route choice model based on data about bicycle users' route choice in the city center of Takamatsu. Then, using this model, we forecast how the demand will change when bicycle riding is prohibited in the above-mentioned shopping street and verify the consistency with the actual measurements taken after bicycle riding was prohibited. Through examination of the results, we also summarize information concerning tendencies of expected demand change and points to consider at the time of development.

3. CHARACTERISTICS OF BICYCLE UTILIZATION IN TAKAMATSU CITY AND STATUS OF THE DEVELOPMENT OF A BICYCLE-FRENDLY ENVIRONMENT

3.1 Local Characteristics in Takamatsu City

Located roughly in the center of Kagawa Prefecture in the northeast of Shikoku, Takamatsu is the economic center of Shikoku with a population of about 420,000. Facing the Seto Inland Sea, it has a warm climate and low rainfall. The region is rather flat and the flat area stretching from the city center to the southeast is especially suitable for bicycle riding.

Thanks to such bicycle-friendly environment, the rate of commuters using bicycles is 21%, much higher than the national average (Figure 1).

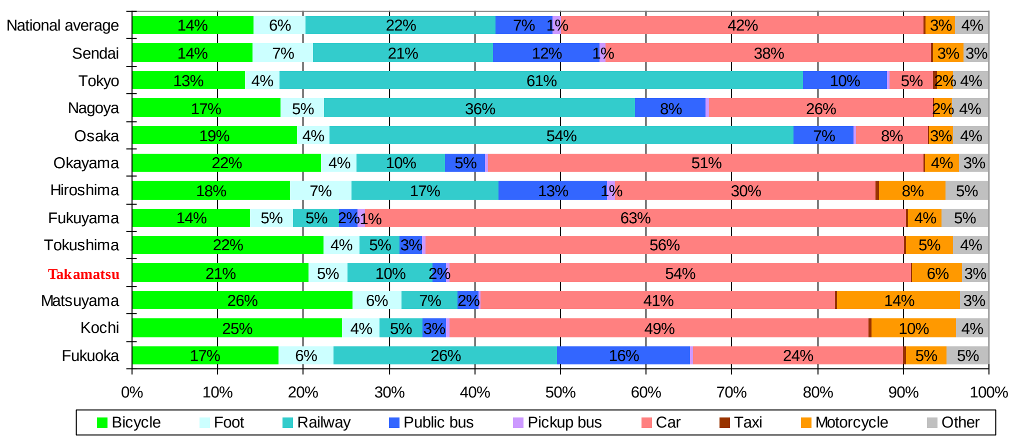

Figure 1. Rate of bicycle utilization for commuting

3.2 Characteristics of Bicycle Utilization in the City Center of Takamatsu

Suzuki et al. determined and analyzed the status of bicycle utilization in the city center of Takamatsu based on the route data obtained through a questionnaire carried out in 2010 and the result of bicycle traffic observation in multiple locations.

Figure 2 shows bicycle link traffic flows in the whole city center determined through the data described above. It shows concentrations of bicycles in arterial roads from the east and south including Hama-kaido, National Route 11, Kankou-dori, Marugame-machi Ritsurin Line, Marugame-machi Shopping Street and Chuo-dori. Heavy bicycle traffic is seen not only in these arterial roads but also in narrow alleys in the city center, where there are a large number of bicycle riders.

Marugame-machi Shopping Street has the most bicycle users, while Chuo-dori, an arterial road parallel to the shopping street, has a decreased number of bicycle users in the north of Nakajin-cho Intersection. Marugame-machi Shopping Street seems to attract a large number of bicycle riders because it has a wide arcade to keep out wind and rain, and Chuo-dori has underground passages to cross the Nakajin-cho Intersection and Ban-cho Intersection. Heavy bicycle traffic is also seen in another arcade stretching east to west.

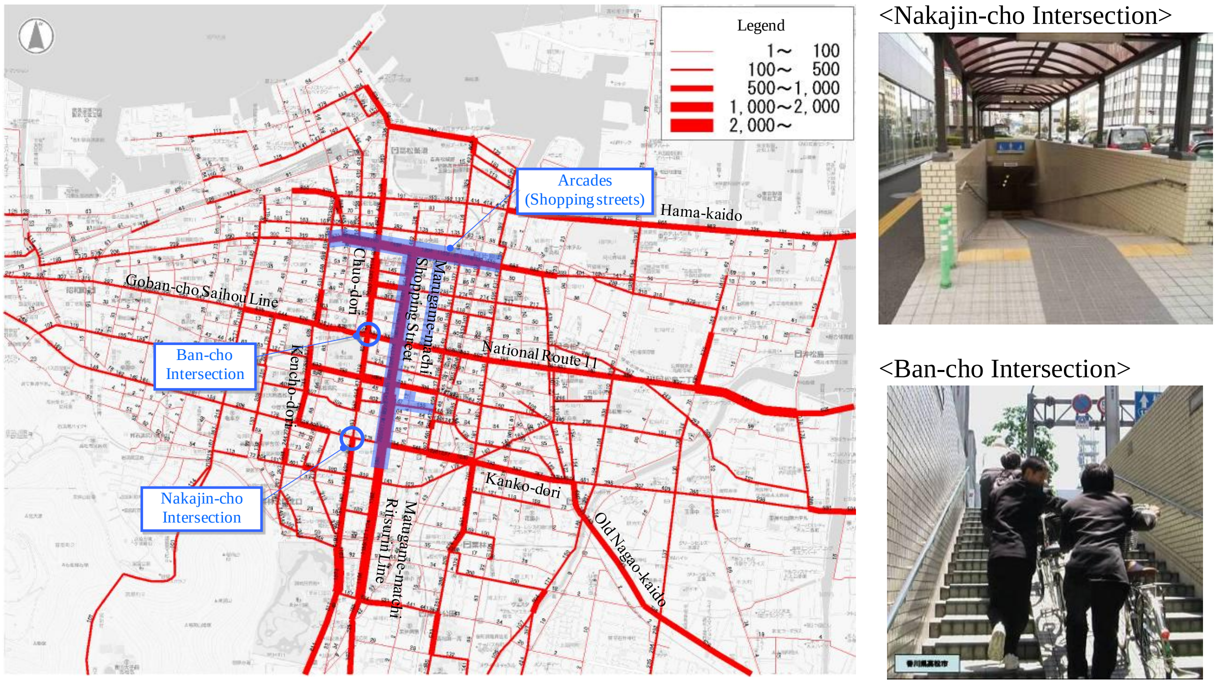

Figure 2. Bicycle utilization in the city center of Takamatsu (commuting)

3.3 Outline of the Previous Measures

3.3.1 Previous Conditions

To respond to the situation described in the previous section, in 2008, Takamatsu City formulated the Policy for Maintenance of a Bicycle Network in the City Center of Takamatsu (Draft), based on which systematic development work has been carried out (Figure 3). Recently, the focus has been put on such work as the structural separation of sidewalks into a pedestrian lane and a bicycle lane in Chuo-dori (2008) and conversion of car lanes into bicycle lanes on Goban-cho Saihou Line, a city road (2011). Both are well received by users and the framework of the bicycle network is being formed. However, it has been developed in an unsatisfactory manner with improved streets left unconnected with each other and the remaining underground passages.

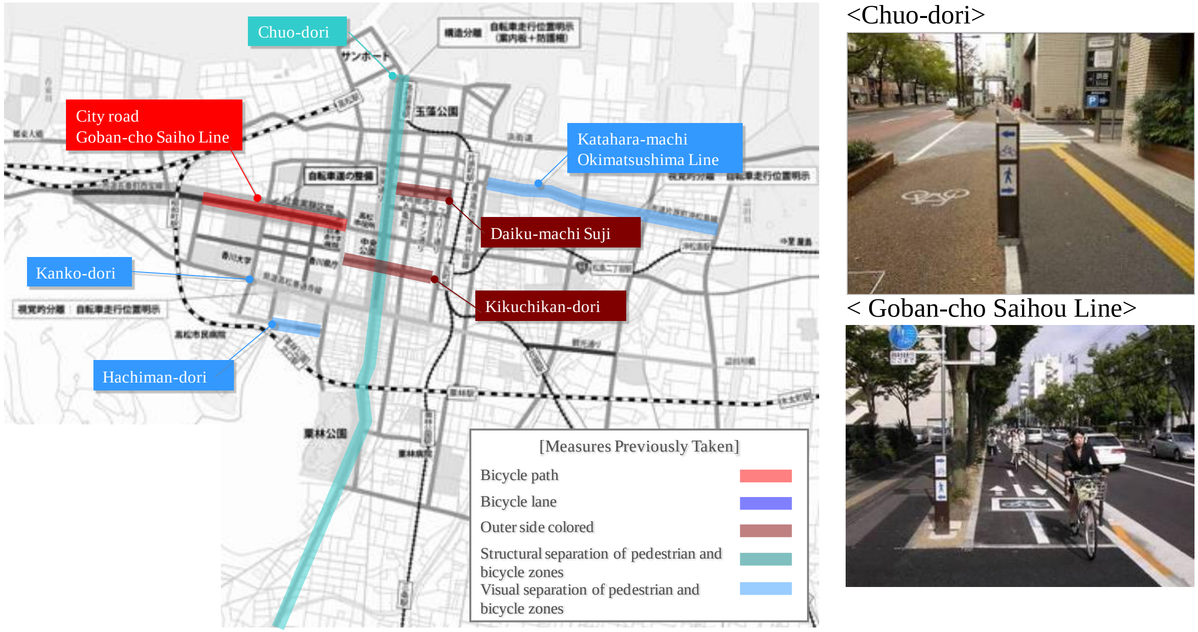

Figure 3. Development of a bicycle-friendly environment in the city center of Takamatsu

3.3.2 Outline of Prohibition of Bicycle Riding in Marugame-machi Shopping Street

In such situation, the concentration of bicycle traffic in Marugame-machi Shopping Street was not eased and there were still such issues as conflicts frequently arising between pedestrians and bicycles, and shops having difficulty attracting customers. Therefore, it was decided that bicycles would be banned from Marugame-machi Shopping Street starting in April 2012 (Figure 4). Although it was originally planned as a two-month social experiment, it continued after June 2012 as it was well received by pedestrians and the shop owners in the shopping street.

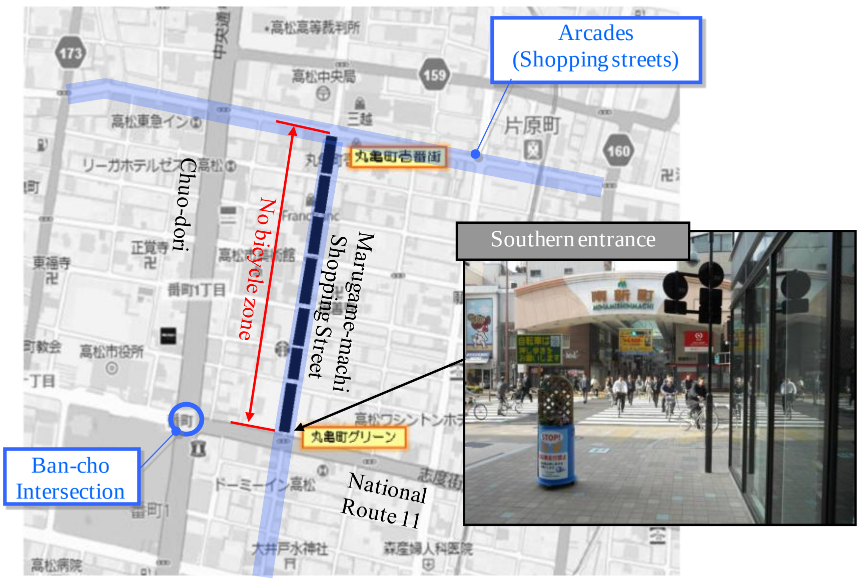

Figure 4. Prohibition of bicycle riding in Marugame-machi Shopping Street

4. CONSTRUCTION OF ROUTE CHOICE MODEL

4.1 Concept for Route Choice Model

The purpose of this study is to clarify information concerning the tendency of possible demand change caused by changes made to the service level in a certain section of a bicycle network and points to consider. First, we build a route choice model for the purpose of quantitative analysis of changes in service level and demand. For this, we built a multi-nominal logit model showing expected route choice behaviors in the Marugame-machi Shopping Street, where bicycle riding is prohibited, and other possible alternate routes.

4.2 Data Collection

In order to build a multi-nominal logit model, this study conducted a questionnaire survey asking cyclists in the downtown area about travelling routes and other issues. A summary of the questions is shown in Table 1.

Table 1. Summary of the questions

Viewpoint	Questions
Individual attribute	- Age, Gender
Travel pattern	- Purpose of bicycle travel - Origin, Destination, Stop-off point
Route choice behavior	- Travel route　(written detailed route directly on map) - Main factors affecting route choice
Level of service	- Potentially unsafe point - Hard place to travel - Evaluation of developed/improved link

In Takamatsu, bicycles are used especially by workers and students (mostly high school students) who commute to the city center. Thus, this study conducted two forms of questionnaire survey as shown in Table 2. The questionnaire for commuting workers was conducted at the business establishments located in the bicycle network planning area. The questionnaire for commuting students was conducted in all the high schools in the bicycle network planning area. This survey has obtained 717 replies from high school students (22% of all bike-commuting students) and 158 replies from commuting workers (Table 3, Figure 5).

Table 2. Target and method of survey

Travel Purpose	Survey method
Commuting	Send questionnaire sheet to offices
School commuting	Send questionnaire sheet to high schools

Table 3. Targets of questionnaire and number of samples

Purpose	Targets	No. of Samples Obtained
Commuting to work	Employees of business establishments in the city center	158
Commuting to school	Students of high schools in the city center	717
Total		875

Figure 5. Companies and High Schools of the Questionnaire Respondents

4.3 Model Formulation

4.3.1 Setting of Alternate Routes

When bicycle riding is prohibited in Marugame-machi Shopping Street, possible alternate routes should be parallel to the shopping street and easy to access through an arterial road. Based on these conditions, we selected five arterial routes that cross arterial roads stretching east to west including National Route 11 and Kankou-dori, from among those stretching south to north parallel to the shopping street (Figure 6).

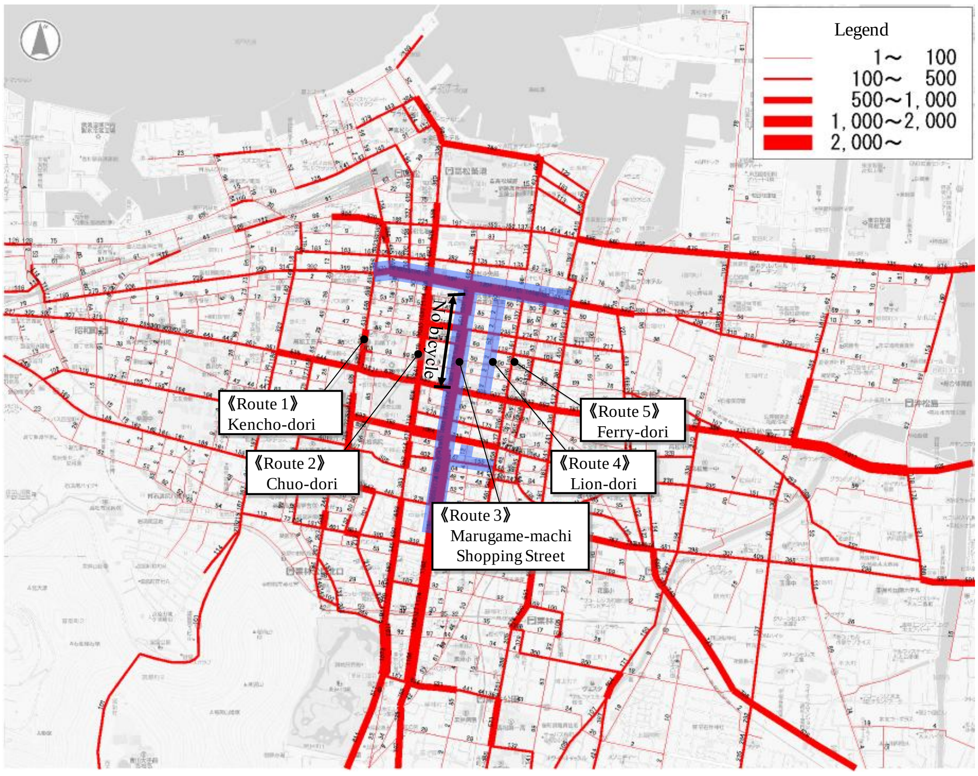

Figure 6. Routes for model construction

4.3.2 Model Forms

We used multi-nominal logit models for formulation on the assumption that each user of the above five routes selects the most desirable route after considering the conditions of each route. Considering the factors shown in the above-stated studies, we used distance from the point of departure to the destination, number of turns, number of underground passages to go through, and whether there are any arcades (difference in distance, 30% or above), as explanatory variables. The model formulas based on such conditions are as follows:

$$P_i = \frac{\exp(V_i)}{\sum_{j=1}^{5} \exp(V_j)} \quad (1)$$

$$V_i = \beta_{dist} X_{idist} + \beta_{turn} X_{iturn} + \beta_{under} X_{iunder} + \beta_{arcade} X_{iarcade} \quad (2)$$

In these formulas,

X_{idist} : Distance of Route i

X_{iturn} : Number of turns on Route i

X_{iunder} : Number of underground passages on Route i

$X_{iarcade}$: Whether there are any arcades on Route i

β_{dist} : Parameter for distance

β_{turn} : Parameter for number of turns

β_{under} : Parameter for number of underground passages

β_{arcade} : Parameter concerning whether there are any arcades

4.3.3 Data Setting

Next, we prepared data to be used for model estimation, using the route data collected from a questionnaire. Concerning the 81 samples (out of about 900) passing any of the 5 streets, we set virtual routes in case they use the other 4 streets that are not actually taken by the respondents based on the following concepts:

- Take the shortest route from the starting point to the target point on each route.
- Mainly choose routes favored by bicycle riders such as routes currently taken by many bicycle riders and arterial roads.
- Avoid underground passages whenever possible unless the distance is much increased.

Concerning these routes, we obtained data for the variables listed in the previous section for each sample.

4.4 Result of Model Estimation

Table 4 shows the result of estimation of route choice parameters based on the data described in the previous section. The likelihood ratio of the model is 40.6, it can be evaluated as good. Parameter coding is appropriate because the selection rate decreases when the values of distance, number of turns and number of underground passages increase and the selection rate increases when there is an arcade.

Table 4 Result of Estimation of Parameters for Route Choice Model

Explanatory variable	Estimated value	(t value)
Distance (m)	-0.00418*	(-3.175)
No. of turns	-0.517 *	(-3.641)
No. of underground passages to take	-1.02 *	(-2.986)
Presence of an arcade	0.752 **	(1.966)
Initial log-likelihood		-130.36
Final log-likelihood		-77.61
Log likelihood ratio		40.6
Accuracy		64%
No. of samples		81

** 1% significance, * 5% significance

Looking at the balance of parameter estimation, an underground passage corresponds to a distance of about 250 meters and two turns. Routes with an underground passage are not chosen even if there is an arcade. This implies that an underground passage has a significant impact on route choice. A turn also has a large impact on route selection, corresponding to a distance of about 100 meters. It is probably because turns are often required when crossing an intersection, and waiting time at a red light also has an influence.

Based on the above, we need to consider the possibility that bicycle users do not use the expected route if the route has a feature like an underground passage that prevents bicycle riders from crossing a road in an uninterrupted manner or/and forces them to wait at a stoplight or make turns even though the prepared route is shorter. Moreover, in case there is an arcade where wind and rain can be avoided or a wide lane for pedestrians and bicycle riders is nearby, it is important to improve the user-friendliness of the route and smoothly connect it to other nearby streets.

5. SUMMARY OF POINTS TO CONSIDER WHEN CONSIDERING MEASURES THROUTH MODEL VERIFICATION

5.1 Verification of Route Choice Model

5.1.1 Forecast of Demand When Bicycles Are Banned from Marugame-machi Shopping Street

We forecasted demand change caused by the prohibition of bicycle riding in Marugame-machi Shopping Street, using the route choice model created in the previous section. Figure 6 shows the forecast made with the model in the case study that, of 81 samples (corresponding to 2,939 people when expanded) used for the model construction, 27 samples (corresponding to 1,603 people when expanded) who used the shopping street cannot take the shopping street any more.

As a result, we forecasted that Chuo-dori would have the heaviest bicycle traffic, chosen by 47% of the bicycle riders, followed by Lion-dori, chosen by 21%, Kencho-dori and Ferry-dori by 16% each.

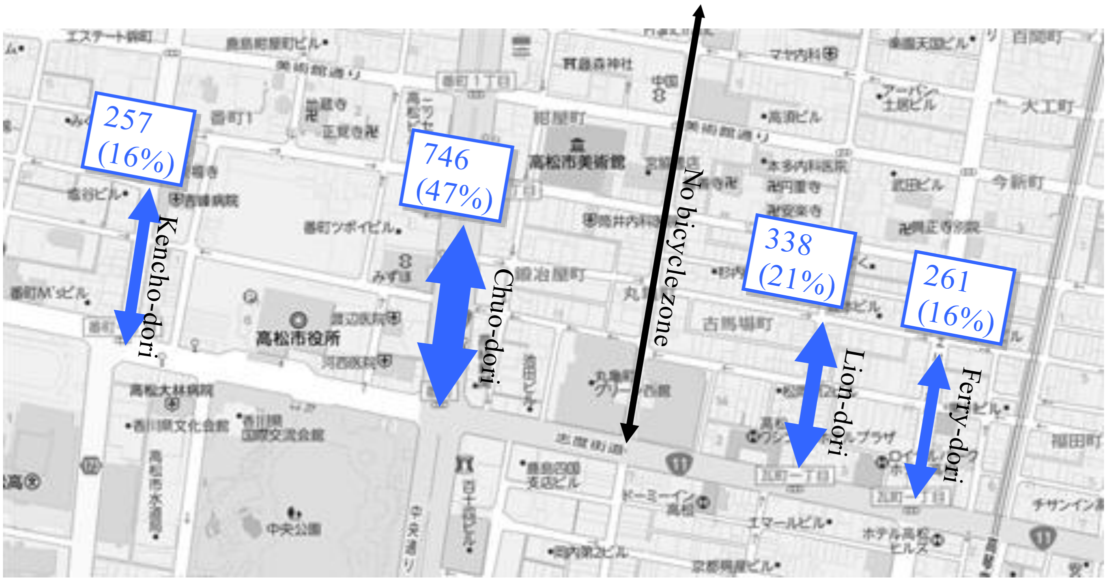

Figure 7. Forecast of traffic when bicycles are prohibited in Marugame-machi Shopping Street based on route choice model

5.1.2 Changes at the Time of Actual Bicycle Prohibition in the Shopping Street

In order to understand the changes in actual traffic volume, we summarized the changes in traffic volume on the 5 target roads, using the result of the traffic volume survey conducted in adjacent streets a month after bicycle riding was prohibited in Marugame-machi Shopping Street (Figure 8). The result shows that Chuo-dori was used by the majority, 52% (including those who used the narrow alleys on the east), followed by Lion-dori (31%), Kencho-dori and Ferry-dori (slightly less than 10% each).

Changes in spot traffic volume
(increase/decrease before and after the prohibition of bicycle riding)

Before: Measured on Tue., March 13, 2012, 7:30-9:30
After: Measured on Tue., May 29, 2012, 7:30-9:30

Expected changes (Increased volume on nearby routes)

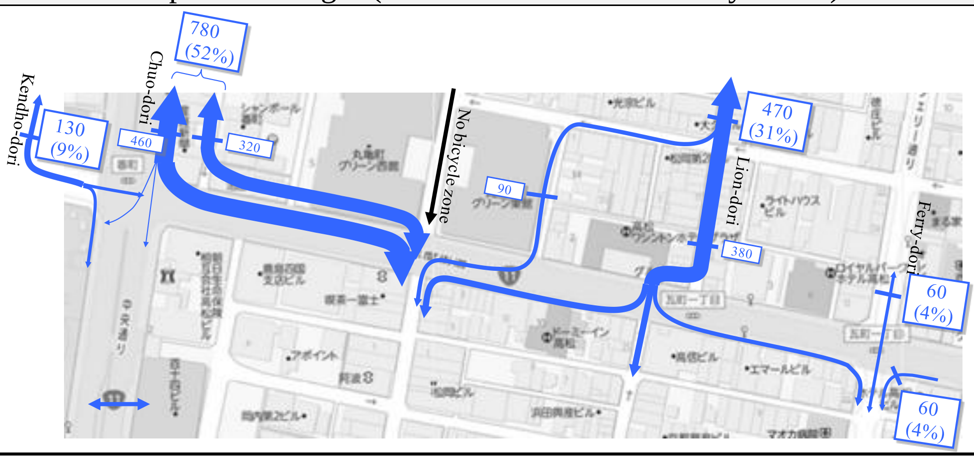

Figure 8. Changes in actual spot traffic volume

5.1.3 Comparative Verification of Forecasts and Actual Measurements

Table 5 shows the summary of the model-based forecasts and the actual measurements. Both in forecast and actual measurement, Chuo-dori has the highest percentage of bicycle riders (about 50%) diverted from the shopping street. The second most popular choice is Lion-dori, and Kencho-dori and Ferry-dori are the least popular choices, chosen by a similar percentage of bicycle riders. The forecast based on the route choice model is approximately equal to the actual state and it seems that the route choices presented in the model are actually made.

On the other hand, the differences are that bicycle riders enter nearby narrow alleys when taking Chuo-dori or Lion-dori; that more traffic actually turned into Lion-dori than forecasted; and that Kencho-dori and Ferry-dori have less traffic than forecasted.

Table 5 Comparison between Forecasts and Actual Measurements

	Kencho-dori	Chuo-dori (including narrow alleys)	Marugame-machi Shopping Street	Lion-dori (including narrow alleys)	Ferry-dori
Forecast	257 bicycles (16%)	746 bicycles (47%)	—	338 bicycles (21%)	261 bicycles (16%)
Actual measurement	130 bicycles (9%)	790 bicycles (52%) ※320 bicycles entered narrow alleys on the east	—	470 bicycles (31%) ※90 bicycles entered narrow streets on the west	120 bicycles (8%)

5.2 Summary of Points to Consider When Evaluating Demand Change

Regarding the three differences mentioned in the previous section, we discuss the causes and the identified points to consider when evaluating demand.

5.2.1 Entry into Narrow Alleys from Chuo-dori and Lion-dori

Pedestrian/bicycle lanes get extremely narrow in several locations, including the intersection of Chuo-dori and National Route 11 (Ban-machi Intersection) and a part of National Route 11 on the west of Lion-dori (Figure 9). It seems that some bicycle riders enter narrow alleys before these locations because of the much decreased user-friendliness caused by heavy bicycle traffic diverted from Marugame-machi Shopping Street and increased risk of accidents with bicycles coming from the opposite direction. We think such differences arose because the forecast model covered only 5 streets and road width and bottlenecks were not considered.

Therefore, it is believed that evaluation should not be solely based on the standard structure but we need to consider measures to eliminate bottlenecks, etc., while conducting evaluation in consideration of the presence of partial bottlenecks and dangerous spots and the positional relation of such spots in the network.

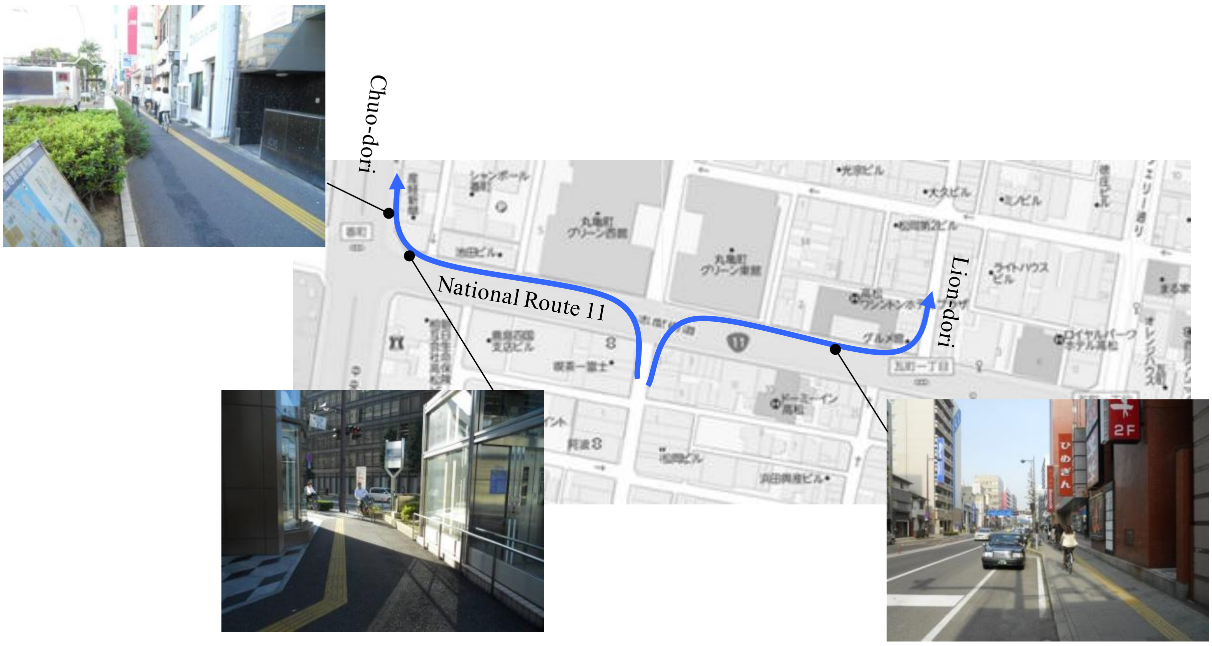

Figure 9. Conditions of detours (National Route 11) to Chuo-dori and Lion-dori

5.2.2 Concentration of Diverted Traffic on Lion-dori

Lion-dori is an arcade like Marugame-machi Shopping Street. It seems the gap arose because the parameters of the presence of an arcade are smaller than the actual impact on the route choice although the presence of an arcade was considered when the model was built. If there had been heavier traffic in Lion-dori before bicycles were banned from Marugame-machi Shopping Street, the parameters would be larger. However, it seems that Lion-dori was not really considered as an option and had low traffic because the wide and user-friendly Marugame-machi Shopping Street is just next to it and Lion-dori does not continuously stretch from south to north like Marugame-machi Shopping Street. However, after the bicycle ban, Lion-dori has become an option for bicycle riders to consider because it has an arcade; this probably created the gap between the forecast and the actual state.

Based on the above, it is believed that we need to consider the possibility of users changing their options when changes are made to a network. It is not enough to focus on the routes that are currently used by many users, but we need to envision concrete changes from the user's point of view and reflect them in consideration of the positional relation of target streets and destinations. Moreover, we also need to keep in mind that bicycle riders especially like arcades.

5.2.3 Small Traffic Diversion to Kencho-dori and Ferry-dori

Kencho-dori and Ferry-dori, far from Marugame-machi Shopping Street, are alternate routes in a rather wide area. Therefore, bicycle riders choose these routes if they make objective judgments with a broad view of such conditions as distance and turns. However, many bicycle users do not choose these routes because they remain on the shopping street till they get just before the zone where bicycles are banned and only at that point do they detour to available routes. The possible reason for this is that, in addition to the above-mentioned preference of arcades, bicycle users do not have objective information and make impromptu decisions, heavily affected by their previous behavior.

Based on the above, we consider it necessary to pay attention to the movements of bicycles at the ends of the improved section of a street and points where the street connects with another major street. Moreover, if the movements are not desirable, it is also necessary to carry out improvement work and PR activities using a network map, etc., to encourage desirable route choices.

6. CONCLUSION

In this study, we built a route selection model with the data concerning routes taken by bicycle riders in the city center of Takamatsu to evaluate demand change caused by the development of a bicycle-friendly environment. We also studied the differences between the forecasts and the actual changes that occurred when bicycle riding was prohibited in Marugame-machi Shopping Street. Based on these, we identified the following points to consider when evaluating demand change and considering measures.

<Basic Factors to Consider When Evaluating Demand Change>

- Bicycle route choice is mainly affected by the "presence of a feature that creates discontinuity such as an underground passage", "presence of turns", "route distance", and "presence of a highly user-friendly zone such as an arcade".
- Bicycle riders tend to avoid features that prevent uninterrupted riding such as an

underground passage, stoplights and turns even if they have to take a slightly longer route.

- In some cases bicycle riders especially prefer user-friendly routes such as an arcade.

<Other Points to Consider at the Time of Evaluation>

- When evaluating demand change, not only the standard structure but partial bottlenecks should also be considered. Factors like the positional relation of bottlenecks have to be considered when evaluations and studies are conducted.
- Development work may affect users' route choice. Evaluation of demand change should not focus solely on the routes that are heavily used now, but assumptions and reflections have to be made in consideration of the positional relation of routes and destinations from the user's point of view.
- Without objective information, bicycle riders may make impromptu choices. When developing a new bicycle lane, attention has to be paid to the movements of bicycles at the ends of the lane and the connection points with arterial roads. When necessary, wide-area development and PR activities should be conducted to encourage desirable route choice.

The prohibition of bicycle riding in Marugame-machi Shopping Street has diverted a large amount of bicycle traffic to Chuo-dori, causing such issues as heavy bicycle traffic in the bottlenecks at the intersections with National Route 11 and bicycle traffic flowing into nearby narrow alleys. The reason for this is that bicycle riders want to avoid an underground passage when entering Chuo-dori from the shopping street. A possible fundamental measure to resolve this is to allow bicycle riders to cross the Ban-machi Intersection and the Nakajin-cho Intersection on the ground level.

A forecast of the route choice model shows that, if this is done, the number of bicycle riders in Chuo-dori will further increase by 152. Based on the above-stated knowledge, the following points should be noted:

- If sidewalks or/and intersections do not have sufficient capacity when bicycle traffic becomes heavy in Chuo-dori, some bicycle riders choose to enter nearby narrow alleys.
- If bicycles are not banned from the whole arcade (if the zone of bicycle prohibition remains the same), it is expected that many bicycle riders will prefer to stay in the arcade as much as possible and will not change the route.
- It is considered necessary to take such actions as the improvement of the user-friendliness of Chuo-dori, elimination of bottlenecks, coordination with measures for other nearby routes including arcades, reservation of access roads in consideration of wide-area moves, and PR activities.

We believe that, by taking measures in consideration of these points, we can achieve an efficient network that meets bicycle demand while efficiently using the existing road space.

We also believe that continuous measurement and analysis of demand change and influence on nearby routes caused by such development will lead to the summary of systematic and more useful information.

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