Proposal and Application of a New Method for Bicycle Network Planning

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Abstract

Responding to the recent increase of cyclists, improvement and development of bicycle road network are being planned in many cities in Japan, and cycling environments are gradually being improved. The routes connecting facilities with many bicycles coming in and leaving are often selected as candidates in selecting suitable routes with high potential demand during the investigation of the bicycle network. There are, however, a lot of unexpected routes with large volumes of bicycle traffic because bicycles can pass through various types of routes from big roads to narrow streets. To create a bicycle road network with safety, consistency and immediacy, demand characteristics of bicycle paths including traffic demand of bicycles and route choice behavior of cyclists in the whole area need to be clarified accurately. This study proposes a way to do it precisely and easily (OLIVE method). This study also shows the panorama of the whole bicycle network and finds the problems in it by applying this method to downtown of Takamatsu City in Japan.

Keywords: bicycle network planning; traffic volume estimation; route choice behavior of cyclists; questionnaire survey

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1. Introduction

Recently, with the rapid increase of bicycle users as people become more environmentally and/or health conscious, bicycle is being regarded as an important part of urban transportation rather than just a supporting transportation tool. Responding to this change, development and improvement of bicycle networks are now planned in many places in Japan. Furthermore, the cycling environment is gradually being improved.

For an investigation of the bicycle network planning, a network candidate route is generally selected at first. The development method and its priority are then determined after examining the safety and travelling behavior of the selected route and assessing the current area. The routes highly demanded by bicycles are selected in many cases as the network candidate route, which will constitute the framework of the network.

Bicycles can pass through various types of roads from boulevards to narrow streets because of their size and flexibility. Cyclists would choose various types of route and it is possible that there are many bicycles driving in areas where pedestrians should have strong priority, such as an arcade and a shopping street. They often confuse pedestrians by congesting in an unexpected or unfavorable route. Meanwhile, Tolley et al. (2003) emphasize that bicycle networks need to include five requirements, that is, safety, consistency, immediacy, comfort and fun. To assure especially safety, consistency and immediacy out of these five requirements, understanding precisely the route choice behavior of cyclists and finding and solving the problems in the network is required, as shown in Fig. 1.

![Fig. 1. Image to find problems based on route choice behavior of cyclists](image)

In Takamatsu City, located in northern part of Shikoku Island, about 150km west of Osaka, for example, “the network development and improvement plan in central Takamatsu City” was developed in 2008. The bicycle paths on major roads with large traffic volume have been improved. As the next step, it is desirable to ensure a safe and comfortable environment from the view point of those residents who actually use bicycles. For this purpose, an improvement to the bicycle network based on the route choice behavior of cyclists is required taking the entire network into consideration.

Additionally, it should be considered the uncommon environmental situation of bicycle use in Japan. In Japan, a bicycle has been regarded one of a vehicle in law. Since 1970, a bicycle is allowed passing on
sidewalk as an exceptional rule in order to protect cyclists from fatal traffic accidents. Japan and Norway are only countries that had allowed sharing space between pedestrian and bicycle. Thus, there is no clarified definition, concept of keeping space for bicycle on road, and inadequate present level of service. Moreover, bicycles travel various levels of road, not only arterial road but also minor street, and it is difficult to understand the characteristics of bicycle travel behavior.

This means a traffic volume and route choice behavior of cyclists (quality) of bicycle in the entire network needs to be figured out precisely and effectively in order to select a network candidate route and assess the actual condition of each route in practice. However, there is no known method that clarifies the complex bicycle flow both quantitatively and qualitatively by link unit.

Therefore this study proposes a method to figure out precisely and easily and to find the problems in the whole bicycle network in the target area. This study also will endeavor to figure out both quantitatively and qualitatively the panorama of bicycle traffic by applying the method to central Takamatsu-city as the study area.

2. Literature review

For bicycle road network planning, it is essential to know the characteristics of travel demand for bicycle traffic. The previous study to know the characteristics is classified into aggregative and disaggregative approach. Aggregative approach focuses on volume of bicycle traffic on the roads that may compose the network. Sato, et al. (2010) estimated the relative scale of bicycle traffic volume on each link by overlaying the responded on-map travel route data obtained in the questionnaire survey conducted in Okayama, about one million population class city. The result indicates that bicycle traffic is concentrated arterial road in suburban, and dispersed in diverse streets in urban areas. However, the estimated scale of volume strongly depends on number of response, it means that the estimated value may not absolute volume. And also, the aggregate method is hard to know coherence and directness of characteristics of route choice behavior of bicycle users.

Disaggregative approach focuses on route choice behavior of each bicycle user. Chinzan, et al. (2007) formulated route choice model that represents bicycle users’ preference. The result shows that bicycle users prefer to proceed straight ahead, and to choose shortest path with sidewalk. Sener et al. (2009) also formulated route choice model, they obtained the date by web-based questionnaire survey. Mekuria (2011) proposed to develop a tool for evaluating bicycle networks that will estimate the number or fraction of a region’s trips that can be made by bike without subjecting to user to unacceptable levels of traffic stress or detour. Dill (2004) proposed connectivity index to evaluate for the potential of links to promote bicycling and walking, and analyze the relation between connectivity and level-of-service of links. The index consider detour distance ratio, number of intersections, nodes on route. The research substantiated that multiple routes and shortest distances are not the only factors that influence the attractiveness of bicycling on a network, and other factors that are related to the network include slope the presence of sidewalks, bike lanes, and bike paths, the amount of motorized vehicle traffic, aesthetics, and pavement or sidewalk quality. Moreover, some factors, such as stop signs, may be attractive to pedestrians but annoying to some cyclists.

The advantage of the above mentioned approaches are easy to obtain large number of responded data. And they have revealed general tendency of each characteristic of bicycle users’ route choice behavior. However, characteristics on entire trip of bicycle are not revealed.

In the viewpoint of characteristics of route choice behavior on entire trip, Fujii and Hato (2004) applied Person-trip Probe system. The advantage of this method is accuracy of obtained data and smaller sample bias. However, greater burden is on those who cooperate with the investigation for setting and returning probe devices.
As above reviewed, former studies identified relative scale of bicycle traffic volume or characteristics of route choice behavior. There are few studies that concern integrated method to figure out both characteristics.

3. Proposal of integrated method overviewing characteristics of bicycle travel on bicycle road networks - the OLIVE method

3.1. Component of the method

This study proposes the method that figures out characteristics of bicycle travel quantitatively and qualitatively, and extracts problematic points considering bicycle users’ travel behavior. This method is able to estimates traffic volume of bicycle in both peak hour and off-peak hour (daily traffic volume) for each link on entire network by integrating travel route record of respondents and observed number of bicycle traffic. And it also identifies the route and number of traffic that passes certain link. This method is able to overview bicycle traffic flow on entire network, and it is named as OLIVE (Obvious Line Of Vélo) method.

Fig. 2. Outline of OLIVE method

Fig. 3. Procedure of estimation of traffic volume
3.2. The procedure to estimate traffic volume of bicycle on each link – quantitative approach

Fig. 3 shows the procedure to estimate traffic volume of bicycle on each link. First, overlaying the responded travel routes of bicycle users obtained through questionnaire survey. And measure traffic volume of bicycle on several major roads. Then, multiple and adjust the number of responded bicycle travel up to counted traffic volume. By this way, estimate traffic volume of each link on the network area.

3.3. Identification of characteristics of bicycle travel behavior – qualitative approach

Identification of characteristics of bicycle travel behavior works continuously identifying origin and destination distribution and travel route distribution of cyclists that pass a certain link using obtained travel route records. To be concretely, analysts define choose a link that want to examine, and then extract the travel route data set that passed the defined link and draw the travel route, origin and destination of all extracted data using GIS. It means that characteristics of bicycle travelling, distribution of origin and destination, relative share of travel route distribution are identified. This result helps to extract roads to be avoided in the viewpoint of safety, coherence and directness.

![Fig. 4. Procedure of characteristics of bicycle travel behavior](image)

Fig. 4. Procedure of characteristics of bicycle travel behavior

![Fig. 5. Bicycle network plan of Takamatsu City](image)

Fig. 5. Bicycle network plan of Takamatsu City

4. Application of Proposed OLIVE method to downtown of Takamatsu City

4.1. Characteristics of downtown of Takamatsu City

In order to verify the effectiveness of proposed method, this paper applied it to analyze the characteristics of bicycle travel to downtown of Takamatsu City. Takamatsu City is located in northern part of Shikoku Island, about 150km west of Osaka. Its climate is often mild and sunny with flat land, it can be said to be a suitable environment for cyclists. Modal share of bicycle for commuting of Takamatsu City is twice as high as national average, bicycle has become a common transportation.

In 2008, the government and authority determined network development and improvement plan. Based on the plan, “Chuo-Doori”, the main boulevard that connects central station and “Ritsurin-Koen”, the
historical Japanese garden park, and several arterial roads have equipped space for bicycle travelling.

![Space for bicycle travelling](image)

**Fig. 6. Space for bicycle travelling**

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

**Table 1. Summary of the questions**

<table>
<thead>
<tr>
<th>Travel Purpose</th>
<th>Survey method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuting</td>
<td>Send questionnaire sheet to offices</td>
</tr>
<tr>
<td>School commuting</td>
<td>Send questionnaire sheet to high schools</td>
</tr>
<tr>
<td>Shopping, private and others</td>
<td>Interview survey in downtown 5 areas</td>
</tr>
</tbody>
</table>

**Table 2. Target and method of survey**

Newly developed bicycle roads have received high evaluation from citizens, especially easy-to-ride condition. However, some problems have been pointed out such as excessive concentration of passing bicycle on the arcade parallel to arterial cycling path, circumvention traffic due to underpasses intersections.

4.2. Data collection for application

In order to understand the characteristics of bicycle transportation and route choice behavior on entire network in downtown Takamatsu City, This study conducted questionnaire survey that inquire of cyclists in downtown about travelling route and others. Summary of the questions is shown in Table 1.

Purpose of using bicycle is not simple, citizen use for not only commuting, but also going shopping, private trip and so on. Moreover it has been expected that characteristics of bicycle travel and route choice behavior are depend on travel purpose. Thus this study conducted three ways of questionnaire survey as shown in Table 2. Questionnaire survey for school commuting was conducted in all high school within bicycle network planning area. Interview survey in downtown was conducted in five areas considering less bias of sampling and obtained almost same number of samples. This survey has obtained 717 respondents by high school students (22% of all bike-commuting students), 107 respondents by commuting workers, and 595 respondents by downtown interview survey (2% of all bike-commuters in
Bicycle traffic volume was counted in fifteen points as shown in Fig. 7. It was conducted in daytime of weekday.

Fig. 7. Bicycle traffic count survey points

4.3. Estimation of traffic volume on each link of network

Based on the procedure as shown in Fig. 2, traffic volume of each link in morning commuting hours is estimated. Detail procedure is as follows; first, estimate traffic volume of each link for school commuting purpose(3) by multiplying responded travel route date of high school students(1) considering number of students commuting by bicycle in each school(2). Then, estimate traffic volume of bicycle for work commuting purpose on fifteen point where bicycle traffic was counted (5) by subtracting estimated traffic volume of each link for school commuting purpose(3) from counted traffic volume of each counted point. Next, magnifying responded based traffic volume of work commuters on counted fifteen points (6) up to estimated traffic volume of bicycle for work commuting purpose (5), and multiplying volume of other links referring the magnifying ratio (8). By Summing estimated traffic volume of school commuters and work commuters, traffic volume of each link in morning commuting hours is estimated.

Fig. 8. Procedure of estimating link traffic volume
<table>
<thead>
<tr>
<th>Estimated Traffic volume</th>
<th>Overlaid responded travel route</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Work and school commuting</strong></td>
<td></td>
</tr>
<tr>
<td><img src="image1" alt="Map" /></td>
<td></td>
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<tr>
<td><img src="image2" alt="Map" /></td>
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<tr>
<td><strong>Work commuting Only</strong></td>
<td></td>
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<td><img src="image3" alt="Map" /></td>
<td></td>
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<tr>
<td><img src="image4" alt="Map" /></td>
<td></td>
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<tr>
<td><strong>School commuting Only</strong></td>
<td></td>
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<td><img src="image5" alt="Map" /></td>
<td></td>
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<tr>
<td><img src="image6" alt="Map" /></td>
<td></td>
</tr>
<tr>
<td><strong>Holyday cyclists</strong></td>
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<td><img src="image7" alt="Map" /></td>
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<tr>
<td><img src="image8" alt="Map" /></td>
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</table>

Fig. 9. Result and comparison of estimated traffic volume of bicycle
Fig. 9 shows estimated traffic volume of each link for commuting purpose, and aggregated responded value of each link just overlaid. Bicycle traffic is concentrated on arterial roads directing west-east and north-south, and in central area, traffic is dispersed plenty of links. For work commuting purpose, focus on “Chuo-doori” boulevard, much bicycle traffic is confirmed in northern section but less traffic in southern section. Relatively bicycle traffic of arcade is relatively larger than that of “Chuo-doori” in southern area. For school travelling purpose, much traffic concentration is seen on links around high school.

On the other hand, for holiday shopping/private purpose on weekday, difference of traffic volume among sections on “Chuo-doori” is not confirmed like commuting purpose.

4.4. Clarification of characteristics to select the cycling routes

a) Influence of intersections with underpass

As shown in Fig. 9, a certain number of bicycles are relatively concentrated in arterial roads of east-west direction or north-south direction and it is not clear tendency to take a detour. However, the arterial road in the south area, “Chuo-doori” has smaller amount of bicycles traffic, comparing than arcade which is parallel to the Chuo-doori. It is considered that cyclists want to avoid underpass of Chuo-dori. Since passing the underpass forces cyclists for vertical movement with getting off their bicycles, cyclists may avoid due to psychological and physical factors. To understand impacts of the factors above with the characteristics to choose routes, the flow of bicycles through Chuo-doori coming from the south was analyzed. Fig. 10 shows travel flow of bicycles through “Nakajincho Intersection” on Chuo-Doori, which has underpass for pedestrian and cyclists crossing, Most of the cyclists passing Chuo-doori from south bounds to Nakajincho Intersection do not go straight at the intersection. They choose to pass “Kencho-doori” or arcade which are parallel to Chuo-doori.

![Fig. 10. Travel flow of bicycles through Nakajincho intersection (Work Commuting)](image)

“Bancho Intersection” in Chuo-doori is also underpass intersection. To confirm the influence of Bancho Intersection, bicycle flow analysis is examined at the intersection through east and west bound, as shown in Fig. 11. Despite an increase in the number of left and right turns for avoiding to pass there, it is confirmed that many cyclists flow into a shopping arcade or Kikuchi-Kan-doori.

These results indicate that existence of underpass in a network force to decrease of coherence of travelling and to choose a less direct detour.

The characteristics mentioned above are not stronger for cyclists on holidays. It seems that commuter has higher sensitivity because of frequent receiving of time limitation and physical factors.

b) Characteristics of bicycles passing shopping arcade

As mentioned in previous section, many cyclists tend to pass the arcade which parallel to the main boulevard in order to avoid barriers in the intersections. As there are many pedestrians in the arcades,
excessive concentration of bicycle travelling passing through arcade decrease safety due to conflict between pedestrians and bicycles. In order to understand the characteristics of the bicycles passing through the arcade, the flow was analyzed as shown in Fig. 12.

![Fig. 11. Travel flow of bicycles through Bancho intersection from east bound (Work Commuting)](image1)

![Fig. 12. Travel flow of bicycles through the arcade from south bound (Work Commuting)](image2)

![Fig. 13. Factors for choosing traveling route](image3)

The difference of relative traffic volumes of arcade is lower among sections. It means that cyclists run linearly and continuously through the arcade to around their destinations. It seems that the arcade has better safety, consistency and immediacy than other route. These functions should be served by the main road originally.

c) Characteristics of bicycles passing shorter routes with low level of service

Shorter distance and shorter travelling time is important factors for cyclists to choose travelling routes as shown in Fig. 13.
The road network in Takamatsu is set out in a grid, and there are relatively moderate spaces for the bicycles and the pedestrians on east-west and north-south arterial roads. However there are a few diagonally shorter routes and not have enough space for bicycle travelling. Bicycles often concentrate the routes.

Fig. 14 shows estimated traffic volume of each link for school commuters. It seems that the bicycles through the shorter route seem to be continuous northbound. However, as shown in Fig. 15, most of cyclists continue to travel east-west directions.

As shown below, such diagonally shorter route is often insecure but many cyclists pass, bicycle network planning should focus such travel characteristics.

5. Conclusions

This study applied the OLIVE method, which makes it possible to figure out precisely and easily “planar estimation of bicycle traffic volume” and “route choice status of cyclists” and to find the problems in the bicycle network by comparing them to the route choice behavior of cyclist, required in an investigation of the bicycle network, with central Takamatsu-city as the study area.

More specifically, the bicycle route choice information was obtained from a questionnaire survey
where each subject wrote their route choice on the map directly. The bicycle traffic demand in the entire area was defined by estimating the obtained information through each link based on the results from the traffic volume census. As well, the actual route choice status of cyclists was analyzed by extracting, counting and schematizing the passages on a random section using GIS.

The result presented the bicycle traffic volume in the entire network planarly, which was not possible with the conventional methods. It also presented the characters of the routes with high demand. For example, each route including the narrow streets in the city center is used to travel within the area, while the major roads are mainly used to go from a suburb to the city center, and relatively more cyclists choose “Shopping Streets” than “Central Streets” in the area below Route 11.

The OLIVE method, which analyzes an actual route choice in a random section, revealed problems in the bicycle network of central Takamatsu City. That is, the riding space in the intersections needs improvement. It also revealed the problems that people tend to choose a detour, which has low immediacy, on Central street due to its low consistency because the underground passages need to be passed in the intersections. As well, “Shopping streets” functions as the route with higher safety, consistency and immediacy than other routes, which is supposed to be a role for the major roads. There are several areas where the short-cut routes with low safety are used because those areas lack the network immediacy against the demand.

A bicycle is an easy vehicle and gives people a high degree of freedom for riding, which can cause a disordered transport situation on the other hand. To create a safe and smooth bicycle traffic environment, not only progress on the cyclists’ manner is required. But also this study shows that the bicycle network plan needs to be developed by selecting a candidate route based on the bicycle traffic volume and the route choice status of the cyclists, assessing the current area, and the planned path needs to be carried out. From this point of view, this study concludes that the method built by this study, which figures out the panorama of the charactalistics of the bicycle flow in a relatively easy manner, is very practical and can contribute to the development of a bicycle path network plan with a higher feasibility.

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