Method for Evaluating the Level of Convenience of Public Transportation Networks in Regional Small and Middle Sized Cities

Daiki OKUDA  Takuya WATANABE  Noriko FUKASAWA  Takamasa SUZUKI
Transport Planning and Marketing Laboratory, Signalling and Transport Information Technology Division

Hiroyuki SAKAKIBARA  Yushi NAKAMURA
Graduate School of Sciences and Technology for Innovation, Yamaguchi University

The object of this study is to develop a quantitative evaluation method of the convenience of public transportation networks in regional cities. In this paper, first, the theory of the quantitative evaluation method of the convenience of public transportation networks in regional cities is shown. Then, the findings concerning the way of public transportation actually used in the certain regional city obtained from the field survey in that city, and the development of the system for carrying out calculations of the convenience of transportation networks automatically are shown. Finally, the course of the development plan in the future is showed.

Keywords: regional small and middle sized city, method for evaluating the level of convenience, transportation network, accessibility

1. Introduction

As society evolves, with spreading motorization and a decreasing population, etc., the environment for continuing public transportation services in Japan is more unfavorable year by year. In regional cities, in particular, maintaining transportation services operated only by public operators is becoming increasingly difficult. Furthermore, even if a certain level of service is secured for each transportation mode, there are cases in regional cities where they do not function satisfactorily as an integrated public transportation network, for example with bus and railway services not connecting, and bus and railway services operating at parallel times. One reason for this is that in many regional cities in Japan, public transportation surveys such as person trip customer surveys are rarely implemented, and therefore there is a lack of sufficient data to have a clear picture of transportation conditions and customer needs in these regions. Each local transportation operator therefore only provide the necessary services separately in accordance with the limited transportation needs and conditions they have grasped in their management area [1]. However, were related parties such as transportation operators, local governments, and local residents ready to work together and build a network that functions efficiently across a whole region, it would be possible to improve the efficiency and user-friendliness of public transportation without requiring large-scale investments, or maintain current levels of service and reduce operating costs. To achieve this, however, the convenience of public transportation networks need to be quantitatively evaluated to help these stakeholders recognize the value of regional public transportation and the related responsibilities attached.

The purpose of this study is to develop a method for quantitatively evaluating the impact of changes in various transportation services on the convenience of public transportation networks in regional cities, even though the accumulation of data on the actual transportation condition is insufficient. Specifically, as shown in Fig. 1, if the bus-railway connection and the operation schedule are reviewed, the degree of change from the current state of the convenience of the public transportation network is quantitatively evaluated using the convenience evaluation value (CEV) and the convenience evaluation index (CEI) described later. This paper describes the theory of the evaluation method that have been built until now, outlines the data that needs to be collected to develop an evaluation method specifically for the purpose of this paper, examines the findings obtained as a result of analyzing this data, and gives an overview of a prototype system, currently un-
2. Method for evaluating the convenience of public transportation networks

2.1 Premises of the convenience evaluation method

When looking at a typical day, the trips of people who use public transportation in regional cities can be roughly classified into two groups: commuting (to work or school) concentrating in the mornings and evenings, and general trips (private or business) in the daytime. Hence, to evaluate the impact of the change in the transportation services on the convenience of public transportation networks, the different characteristics of each group needed to be distinguished. However, in the majority of regional cities in Japan, the percentage of people using private cars is overwhelmingly high [2] and the majority of public transportation users are those who, for various reasons, have difficulty in using private cars freely. This study therefore analyzed trips made by those commuting to and from school in the morning and evening, and general trips using the public transportations made by people who have difficulty in using cars freely (the trips by people who had no choice of cars) in the daytime.

2.2 Theory underlying the method for evaluating the convenience of public transportation networks

In this study, the impact of changes in various transportation services on the convenience of public transportation networks was quantified through the CEI based on the CEV under current conditions and changed conditions. The CEV was calculated by multiplying the three criteria listed below, and was developed with reference to past research on the same subject of evaluating the convenience of public transportations [3]. Figure 2 illustrates the process followed to develop the CEV. Details of each criterion are described later.

- Accessibility when tripping from point i to point j at departure time t
- Section importance when tripping from point i to point j at departure time t
- Timeframe importance when tripping from point i to point j at departure time t

Equation (1) was the route choice model derived by applying the disaggregate logit model to the discrete route choice of an individual ‘n’. Equation (2) and (3) gave the utility σ of the route from points i to j, and its observable part. Equation (4) was the accessibility ACCn(t) (=log-sum variable) when an individual ‘n’ tripped from points i to j.

\[ P_{ij}^n(t) = \frac{\exp(V_{ij}^n(\sigma(t)))}{\sum_{\sigma \in K} \exp(V_{ij}^n(\sigma(t)))} \] (1)

\[ U_{ij}^n(\sigma(t)) = V_{ij}^n(\sigma(t)) + \epsilon^n(t) \] (2)

\[ V_{ij}^n(\sigma(t)) = C + \sum_l \alpha_l X_{ijl}(t) \] (3)

\[ ACC_{ij}^n(t) = \frac{1}{n} \ln \left( \sum_{\sigma \in K} \exp\left( V_{ij}^n(\sigma(t)) \right) \right) \] (4)

-\( P_{ij}^n(t) \): Probability that the route \( \sigma \) is selected out of K selectable routes when an individual ‘n’ trips from points i to j at departure time t
-\( U_{ij}^n(\sigma(t)) \): Utility of the chosen route \( \sigma \) when an individual ‘n’ trips from points i to j at departure time t
-\( V_{ij}^n(\sigma(t)) \): Observable part of the utility of chosen route \( \sigma \) when an individual ‘n’ trips from points i to j at departure time t

Accessibility means the level of ease in approaching destinations when tripping from point i to point j at departure time t
Parameter $\beta$ in (4) was estimated by maximum likelihood estimation, applying actual travel behavior data, such as data on people’s route choice behavior, to the route choice model. In principle, data for this model needs to be collected through surveys. However, since disaggregate discrete choice models can be built with relatively small amounts of data, and have high spatial and temporal transferability, if the difference in people’s route choice tendencies between regions or time points was not significant, it was considered that a more versatile model could be built that could be used even with data collected in a specific region or at a specific time point. Additionally, since public transportation in regional cities is not as dense as in urban areas, and there are fewer possible routes, necessary data for the estimation can be obtained from simple surveys that only gather information about the origin and destination of trips, the departure time and the transportation modes used. Consequently, only a small scale survey was considered necessary. Other data that was required about each mode of transportation such as required times and fares both for routes selected by people and other available routes was gathered from public transportation timetables and price charts.

Based on the concept described above, if the parameter $\beta$ in (4) were estimated, accessibility of trips between various points at various departure times can be calculated by using (1).

### 2.2.2 Section importance and timeframe importance

Since population distribution and use of land in regional cities are not uniform, the number and density of trips at each point and in each timeframe fluctuates. In this study, these fluctuations were defined as ‘section importance’ and ‘timeframe importance’. Section importance was calculated on the basis of population, working population, the number of school goers, and the number of hospital beds, etc. at each point in the region. In Japan, national population censuses are carried out regularly, and detailed data sets on the population etc. are published by administrative district units. The timeframe importance was based on the number of public transportation services operated per time zone from each section, and the operating hours of important facilities such as hospitals or schools.

### 2.3 Reducing the number of routes and simplifying the routes to which the regional mesh is applied

As the number of arbitrary points within a region is virtually infinite, the same is true for the number of routes having these points as origin or destination. For this reason, to estimate the convenience of public transportation networks in regional cities, it was necessary to reduce the number of routes for analysis down to a calculable level. In this study, the regional meshes defined by MIAC were applied, and all arbitrary points existing within each regional mesh were represented by the central point of the mesh, and trips between arbitrary points were replaced by trips between corresponding regional mesh center points, thus reducing the number of routes to be analyzed.

As the type of regional mesh to be applied, either the 1/4 regional mesh with a side length of about 250 m or the 1/2 regional mesh with a side length of about 500 m was considered to be appropriate. Furthermore, to simplify trip routes, itineraries between the center points of adjacent regional meshes, and those between center points of regional meshes and bus stops or stations within those meshes were all approximated by straight links. In Japan, the improvement of roads has been progressing in regional cities as well, and even if these routes were approximated by straight links, there was no major disparity between the approximate routes and the actual road routes. Figure 3 showed an image of a case when the actual railway route (blue line) from the point i to j was replaced by an approximate railway route (red line) form the central point of the regional mesh01 to the central point of the regional mesh11.

Figure 4 shows an image of the estimated CEV of public transportation networks with the regional mesh applied.

### 3. Travel behavior survey in urban area X

#### 3.1 Overview of the travel behavior survey

In this study, urban area X, with city X at its center, with a population of less than 200,000 located in a regional area in Japan was designed to be the target area for the
analysis. City X has a comparatively large number of important facilities, such as high schools and hospitals, and despite its small scale, there is a commercial district and there are trading streets. Although rate of private car use is overwhelmingly high like other regional cities in Japan, it is possible to trip between most areas within City X using public transportation. Additionally, City X is in an environment where trunk transportation such as high-speed railways is relatively easy to use, and there is also an extensive passenger flow into and from other city areas.

Travel behavior in urban area X was investigated using two types of survey: one on commuting to and from schools in the morning and the early evening (commuting survey), and the other on ordinary trips during daytime (daytime survey). Table 1 shows an overview of each survey. Although daytime surveys were also conducted on holidays at each station and at a bus stop, this paper, only presents the results of the weekday surveys. Additionally, the number of valid answers in the table 1 may change in the process of constructing the route choice model.

3.2 Findings obtained from the travel behavior survey

3.2.1 Findings obtained from the commuting behavior survey

The main modes of transportation used by students to commute to and from school were walking or bicycle, buses, and trains, with choice of mode influenced mainly by distance between home and school. This relationship is illustrated in the schema in Fig.5. When the distance between home and school was less than approximately 3 km, the majority of the students chose walking or riding a bicycle. In the short-to-middle distance zone of 3 km to 5 km, a competitive relationship was seen between walking or riding a bicycle, and taking the bus. In terms of bus competitiveness, the level of service, such as speed or bus frequency were important, and the probability that students chose a bus was low in areas where only routes of a bus whose service level was low were available. Therefore, despite the advantage of speed offered by the bus for such short-to-middle distances compared to walking and the bicycle, this benefit alone was not enough to form a serious competitive alternative. From the responses to the virtual questions a competitive alternative. From the responses to the virtual questions
questions asking about student’s attitude towards changes in the level of transportation services of a bus, it was understood that the sensitivity of students was competitively high; it seemed to be the evidence that a bus tended to build competitive relationships with walking and a bicycle.

A railway were superior to a bus in speed and punctuality, but because of not easily to trip between their home or school and stations due to the long distance between stations, and the low frequency of operation, etc., the probability that students chose railways was low as far as the zones of up to short-middle distance were concerned, and a competitive relationship with other commuting modes was not built. However, the probability increased in the 5–7 km middle-long distance zone, and was even higher in the long-distance zone over 10 km. It seemed that as the distance to the school increased, the importance of speed and punctuality was more prevailing than the low accessibility between their home or school and stations. Moreover, in the long distance zone, it appeared that there were many students for whom railways were practically the only commuting modes. From the responses to the virtual questions asking about student’s attitude towards changes in the level of transportation services of a railway, it was understood that the sensitivity of students was low; it seemed to be the evidence that the probability that students choose a railway was high especially in the long-distance zone.

These findings suggest that students made rational choices about their chosen modes of transportation, based on a comparison of level of service offered by each mode, ease of trip to and from bus stops or stations, and frequency of operation. Therefore, it could be concluded that it is possible to build a route choice model for students commuting to and from school based on the obtained data. Nevertheless, it was necessary to take into account that the effect of fares on student route-choice behavior was small and unstable, as most students using public transportation to commute had their travelcards purchased by their parents.

3.2.2 Findings obtained from the daytime survey

Whereas all bus users only tripped within urban area X, approximately 60% of railway users tripped outside urban area X, (of these, about 20% made middle-distance trips to and from other adjacent cities, about 40% made long-distance trips over prefectural boundaries). These results suggested that railway users surveyed in the daytime, like commuting students, made rational decisions about their choice of transportation mode based on the level of service provided, such as speed and punctuality of buses and trains. Regarding the relationship between gender or age group and public transportation modes used, overall, more women used the bus than men, and the proportion of women over 70 was very high. The reason for this appeared to be linked to the very small number women over 70 holding a driving license, which meant that they had limited use of private cars: it was considered unlikely that elderly women specifically favored using the bus. Another reason underlying the high proportion of elderly women over 70 using the bus, was the availability of courtesy passes (discount bus fare) to people over 70 living in city X. Of male users, about 60% were over 70. The reason for the high proportion of women of other age groups using the bus, was thought to be most likely linked to the fact that even if they had a driving license, the car was probably used by their spouse preferentially to commute, so they did not readily have access to a private car.

The gender and age group distribution among railway users was diverse, but as mentioned above, most of them were moving middle-to-long distances to other cities or prefectures, with the majority using the railways as a mode to access connections to the trunk transportation network. The reason for this would seem to be that for these people, accessing these connections was difficult: either because of parking issues or because of cost. In addition, railway users were often from other cities and prefectures, so it would be difficult for them to have ready access to a car in urban area X.

These findings suggest that people in the daytime chose their mode of transportation based on a rational decision arrived at by comparing speed and punctuality of available public transportation services, in the knowledge that they would not have ready access to a car. Therefore, it could be concluded that it is possible to build a route choice model for public transportation users in day time, based on the obtained data. In addition, at stations that had good connections with bus stops, some of them transferred directly from the bus to the railway and vice versa. Consequently, it was necessary to take into account this kind of route when building a route choice model.

4. System for evaluating the convenience of public transportation networks

A prototype system was developed combining the method for evaluating the convenience of public transportation networks and GIS, in order to automate series of tasks related to the evaluation process. The route search function of this system has already been completed. The purpose of this function is to extract bus routes, railway routes, and routes connecting buses and trains between two arbitrary points selected on the system screen, and various transportation service data such as the required time for each route can be automatically preconfigured. Figure 6 shows the system screen when the route search function is
5. Conclusion

The purpose of this study was to develop a method for quantitatively evaluating the impact of changes to various transportation services on the convenience of public transportation networks in regional small and middle-sized cities, despite an insufficient amount of data on actual transportation conditions.

This paper describes the theoretical outline of the method for evaluating the convenience of public transportation networks, presents findings from an analysis of the data obtained from travel behavior surveys, and introduces the system for evaluating the convenience of public transportation networks which is under development.

Research on this topic will continue to develop the methods and the system for evaluating public transportation, by building prototypes, and checking their validity through case studies on the convenience of the public transportation network in urban area X. Further research will then be conducted to help plan measures to improve regional public transportation networks to make them more attractive in their respective regions.

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