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Combinations of Transportation Policies to Promote BRT Usage Using Artificial Society Model

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Abstract: Various transportation systems have been developed in recent years. In this study, an artificial society model is developed to examine the combination of transportation policies in urban areas. In this model, each trip maker selects the primary and terminal transportation modes. An artificial society model is applied to the southeastern region of Osaka City, Japan. The effects of introducing BRT (bus rapid transit, primary transportation) and on-demand buses (terminal transportation) are investigated. The results confirm that BRT is used by a certain number of users. An increase in the use of BRT will increase the amount of walking, thus resulting in a healthy city. However, on-demand buses are rarely used as terminal transportation. Additionally, the development of bicycle parking stations near BRT stops is shown to be effective in the northern section of the BRT route.

Key words: Artificial society model, bus rapid transit, on-demand bus, transportation policy.

1. Introduction

Various transportation systems have been developed in recent years. For example, in Japan, electric scooters (kickboard) will be allowed to be driven without a driver's license by those over the age of 16 years from July 2023 onwards. In addition, sharing services such as cars, bicycles, and e-scooters are expanding by private companies, and the number of sharing ports is increasing in urban areas. Furthermore, public transportation systems such as LRT (light rail transit), BRT (bus rapid transit), and on-demand buses (which require reservation) are currently being operated. Various transportation modes exist, each with its own characteristics, and the appropriate combination of transportation modes may differ depending on the city.

In this study, combinations of transportation modes are analyzed in the southeastern region of Osaka City, Japan, where BRT social experiments are conducted. Because the transportation modal choice behavior of users is complex, utilizing a simple estimation model such as a disaggregate logit model is challenging. Therefore, an artificial social model that can express complex decision-making structures, including the effect of the surrounding users, is used. Measures to promote the use of BRT using on-demand buses and bicycles are examined using this model.

2. Significance of Using Artificial Society Models for Transportation Planning

This section presents the significance of using an artificial society model for examining of various transportation policies and summarizes existing studies that apply the artificial society model to transportation planning.

Transportation modal choice models typically employ logit models. Disaggregate logit models can account for various individual attributes, such as age, gender, and vehicle ownership. However, logit models alone cannot consider complex factors, such as the surrounding traffic conditions. For example, in the case of bicycle sharing, bicycles cannot be used unless they are available at a sharing port near the origin. Experience also influences modal choice behavior. In such cases,

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artificial society models may be useful.

Existing studies that used artificial society models are reviewed herein. Kagho et al. [1] summarized studies that applied agent-based models to transportation planning and indicated their future expectations. The significance of using agent models and an introduction to existing models were presented. Okushima [2] examined the promotion of clean-energy vehicles (battery electric vehicle, plug-in hybrid vehicle, hybrid vehicle and low emission gasoline vehicle) using an artificial society model, which comprises a small word network model and incorporates interactions with others. Their proposed system included vehicle choice, emission, and possession processes. Carbon dioxide emissions are estimated based on the efficiency of fuel consumption and the travel distance of agents. Gennady et al. [3] analyzed vehicle-collision prevention via agent-based microsimulation. An approach for establishing optical forecast time based on maneuverability maps that determine a vehicle's possible maneuvers is presented. The simulation results indicated that optimizing the forecast time in a conflict scenario can reduce the probability of an accident.

Several studies based on artificial social models have been conducted. However, few studies have considered the combinations of transportation modes. In this study, an artificial society model is used to examine combinations of transportation modes that are effective in promoting the use of BRT, with reference to existing studies.

3. Overview of Study Area

In this study, the southeastern region of Osaka City (Higashinari, Ikuno, and Higashisumiyoshi Wards), Japan, was selected as the target area. The target area is illustrated in Fig. 1. The railways operating in this area include JR (West Japan Railway Company), Kintetsu Railway, a subway (Osaka Metro), and a tramway (Hankai Tramway). In addition, the "Imazato Liner" BRT is being operated for a social experiment to assess its feasibility as an alternative transportation to subways. Two BRT routes are in operation: the Nagai and Abenobashi routes by the Osaka Metro. Additionally, on-demand buses are being operated in Ikuno Ward as a social experiment since March 2021, which features 177 pick-up and drop-off points by the Osaka Metro. To use the on-demand bus, you must make a reservation in advance via smartphone application or phone.

The Imazato Liner has been in operation since April 2019 and its number of users is approximately 3,700 on average per day on weekdays and 19.6 persons/trip (December 2022). The transportation capacity is sufficient, and efforts are required to increase the number of users.

The primary transportation for trips beginning from the home of residents in the target area is as follows: railway/BRT, 28%; car, 11%; bicycle, 34%; walking, 23%; motorcycle, 1%; and others, 3% (6th Kinki Area Person Trip Survey, 2021) [4]. In this study, we analyzed trips in which the primary modes of transportation were railway/BRT and the departure point is the home of residents.

Transportation facility and population data were obtained to develop an artificial society model. The transportation facility data comprised coordinate data for railway stations and BRT stops as the primary

Fig. 1 Overview of target area.

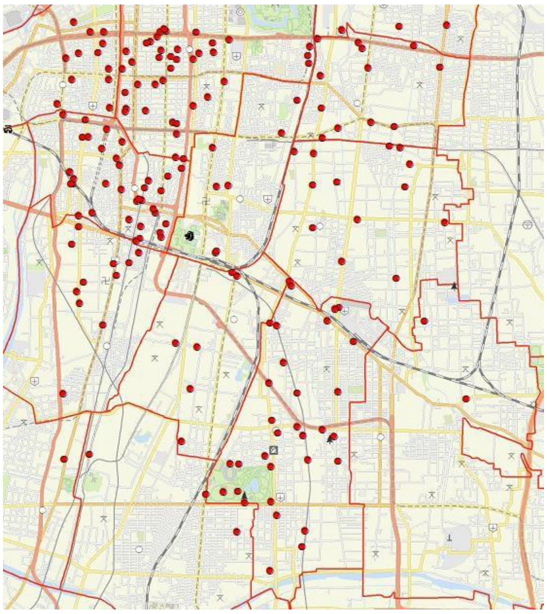

Fig. 2 Location of bicycle-sharing ports.

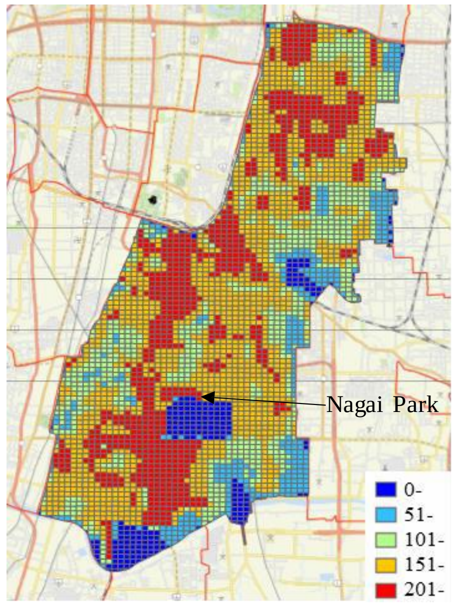

Fig. 3 Population density of target area.

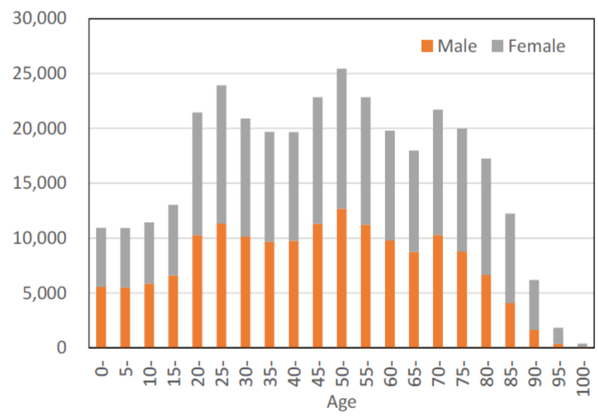

Fig. 4 Gender and age distribution in target area.

transportation modes. Additionally, for terminal transportation, coordinate data for bicycle/motorcycle parking stations, bus stops, bicycle sharing ports, and on-demand bus stops were constructed. As an example, Fig. 2 shows the locations of bicycle sharing ports. Many bicycle sharing ports are located in northwest region. However, only a few sharing ports exist near the BRT routes.

Population distribution data were obtained for the target areas. The population of the target area was 337,029, and the population density was 14,873 persons/km^2 (October 2015). As shown in Fig. 3, the population distribution was set in 100 m mesh units using data from the 2015 national census [5]. Some areas, such as Nagai Park, have a low population density.

A trip maker is generated based on the population density. Furthermore, the gender and age were set for the generated agent. Based on the age distribution of the target area (as of September 1, 2023) shown in Fig. 4, the age and gender in 5-year increments were determined probabilistically. Subsequently, the age in 1-year increments was determined using uniform random numbers from 0 to 4.

Based on these transportation facilities and population data, an artificial society model was developed.

4. Development of Artificial Society Model

This section describes the development of an artificial society model to examine the combinations of transportation policies in the target area.

4.1 Decision-Making Model of Trip Maker

Access terminal transportation modes for public transportation users to railway stations and BRT stops were analyzed in this study. Table 1 lists the terminal transportation modes considered in this study.

Seven types of terminal transportation modes were assumed. The usage fees shown in the table are the estimated parking fees and riding fares, which do not

Table 1 Terminal transportation modes.

Transportation	Features	Fees (Yen/trip)
Walk	- Low speed - Long distances are difficult to accomplish	0
Bicycle	- Must own the vehicle - Parking space required - Difficult to maneuver in rainy weather	75 (150 Yen/day)
Motorcycle	- Must own the vehicle - Parking space required - Can traverse relatively long distances - Difficult to maneuver in rainy weather - Driver's license required	100 (200 Yen/day)
E-scooter	- Must own the vehicle - Difficult to maneuver in rainy weather - Can be carried manually, albeit difficult - Cannot be used if luggage is involved - Age limit for driving	0
Bicycle sharing	- Requires a port nearby - Bicycle required at departure share-cycle port - A space must be implemented at the destination port - Difficult to maneuver in rainy weather	200
On-demand bus	- Advance reservation required - Require a stop nearby - Cannot be used unless user is within the operating area - Requires coordination with operating time - Involves a long detour in cases with many users	210
Route bus	- A nearby bus stop is required - Coordination with schedule is required	210

include vehicle purchase, maintenance and fuel costs. Additionally, bicycles, motorcycles, and e-scooters cannot be used unless they are privately owned the vehicle. Whether each trip maker owns a vehicle was determined using a random number based on the ownership rate. Furthermore, because no facilities exist currently that allow e-scooters to be parked, we assumed that e-scooters will be transported to railways or the BRT. Therefore, the fee of e-scooter was set at JPY 0.

To select a transportation mode, the following steps are performed: (1) Select the nearest railway station and BRT stop, (2) calculate the generalized cost (time costs and fees) of each terminal transportation mode to the railway station and BRT stop, (3) select the terminal transportation mode to the railway station and BRT stop, and (4) select the primary transportation mode (railway or BRT).

(1) When selecting the nearest railway station or BRT stop, the shortest distance (straight-line distance between coordinates) from the departure point (home location) is selected.

(2) For the generalized cost of each terminal transportation mode, in the case of bicycle sharing for example, availability and walking to the sharing port were considered. Specifically, as shown in Fig. 5, we searched for sharing ports within a 200 m radius from the departure point, railway station, or BRT stop.

If multiple ports were present, then the closest port was selected. In addition, bicycle sharing cannot be used if no port exists near the departure point, railway station, or BRT stop.

Next, the distance from the departure point to the origin bicycle sharing port, and that from the destination bicycle sharing port to the railway station/BRT stop were determined. Subsequently, the walking time was calculated for those distances. The generalized cost of bicycle sharing for trip maker i is calculated as shown in Eq. (1).

$$C^{i}_{sharecycle} = \left(D_{access}/2/3 + D_{cycle}/2.5 + D_{igress}/2/3 \right) \times 50 + 200 + u^{i} + \varepsilon^{i} \quad (1)$$

Fig. 5 Calculating generalized cost of bicycle sharing.

where D_{access} is the walking distance from the departure point to the departure sharing port (in units of 0.1 km), D_{cycle} is the cycling distance from the departure sharing port to the arrival sharing port (in units of 0.1 km), D_{igress} is the walking distance from the arrival sharing port to the railway station or BRT stop (in units of 0.1 km), and ε is a uniform random number from 0 to 100. In addition, the walking speed was assumed to be 4 km/h, and the walking time was calculated by dividing it by 40/60 (×0.1 km/min). The travel speed of the bicycle was assumed to be 15 km/h, which was then divided by 150/60 (×0.1 km/min). The value of time was 50 (yen/min), and the travel time was converted into cost, where 200 is the usage fee (yen) for bicycle sharing.

Bicycle sharing cannot be used if no rental bicycles are available at the departure sharing port. In this study, we assume that if another trip maker uses bicycle sharing at the departure sharing port, then bicycle sharing cannot be used, and the user must walk to the nearest railway station or BRT stop. In this case, we speculate that the user will likely refrain from using bicycle sharing in the future; therefore, 50 was added to u for each experience. In addition, considering that the memory of the experience decreases over time, the value was set to 0.98 times per step.

In addition, if no sharing ports exist within a 200 m radius, then the generalized cost is set to infinity and no ports are selected.

Generalized costs for other transportation modes, such as on-demand buses and route buses, are calculated by considering factors such as access time, egress time, and usage fees in the same manner as bicycle sharing. If an individual does not own a bicycle, motorcycle, or e-scooter, then the generalized cost of that mode of transportation is set to infinity.

(3) Calculate the generalized cost for each terminal mode of transportation to the railway station and select the lowest one as the terminal mode of transportation to the railway station. In addition, transportation to the BRT stops is calculated in the same manner, and the terminal transportation modes to the BRT stops are determined.

(4) Select whether to use the railway or BRT. At this time, if Eq. (2) is satisfied, then select the BRT; otherwise, select the railway.

$$C^{i}_{BRT} + \alpha < C^{i}_{railway} \tag{2}$$

where C^{i}_{BRT} is agent i's generalized cost to reach the BRT stop, and $C^{i}_{railway}$ is agent i's generalized cost to reach the railway station. In addition, transfer time is required in the case of BRT; therefore, a uniform random number between 0 and 200 is set for α.

4.2 Development of Multi-agent System

In this study, a multi-agent system was developed using the "Artisoc Ver. 4.2.1" software developed by Kozo Keikaku Engineering Inc. [6]. Artisoc can define the agent and variable types on the GUI ((graphical user interface; model structure can be defined solely through use of a mouse), set behavior rules in a visual basic-like simple language, and support various input/output formats (text files, graphs, maps, etc.) [7]. Therefore, it is suitable for analyzing complex traffic behavior. Fig. 6 shows the display screen of the developed artificial society model.

The left side of the screen shows the usage status of each railway station, BRT stop, bus stop, bicycle parking station, and the size of the mark changes depending on the number of users. In addition, the center of the screen shows each trip maker's terminal transportation mode based on color. The graph on the right side of the screen shows the changes over time in

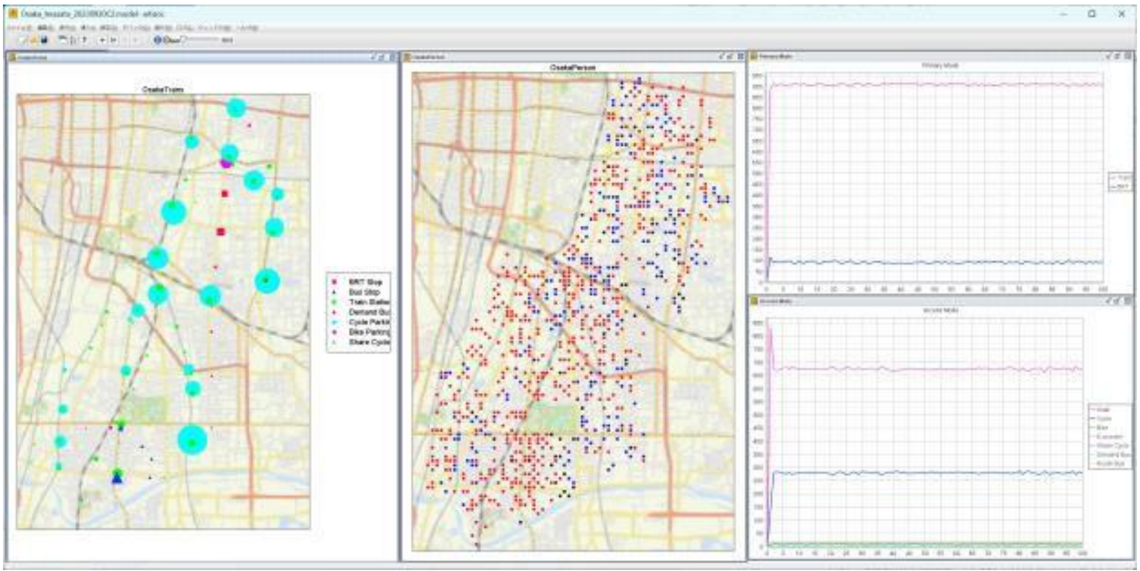

Fig. 6 Display screen of artificial society model.

the number of users of the primary transportation mode (railway, BRT) and terminal transportation mode (walking, cycling, on-demand buses, etc.). By observing these screens, one can understand the status of local transportation usage.

The simulation was repeated 100 steps, and the results for the number of users of each transportation mode were aggregated at the 100th step. In addition, to reduce the effects of variations due to the use of random numbers in the modal choice model, the results of five replicates were used as the average.

5. Analysis of Effects of Introducing BRT/On-Demand Buses

5.1 Setting of Study Cases

The artificial society model developed in this study was used to analyze the changes in transportation modes when various transportation policies were implemented. Specifically, we compared whether the "Imazato Liner" BRT, which is a primary transportation mode, and the on-demand bus (Ikuno Ward/Hirano Ward), which is a terminal transportation mode, were introduced. Table 2 lists the cases considered in this study.

For each case, 1,000 trip makers were generated to select the primary and terminal transportation modes.

Table 2 Case setting of transportation policies.

Case	BRT	On-demand Bus
Case 1	No introduction	No introduction
Case 2	With introduction	No introduction
Case 3	No introduction	With introduction
Case 4	With introduction	With introduction

5.2 Results of Primary Transportation Modal Choice

This section focuses on the results of the modal choice for primary transportation. Fig. 7 presents the modal choice results of the primary transportation modes for each case. In Cases 1 and 3, BRT was not introduced; therefore, railways were selected for all trip makers. However, in Cases 2 and 4, the choice rate for BRT was approximately 10%. In Cases 2 and 4, the BRT choice rate was similar, and the presence or absence of on-demand bus introduction was assumed to minimally affect the choice of primary transportation mode.

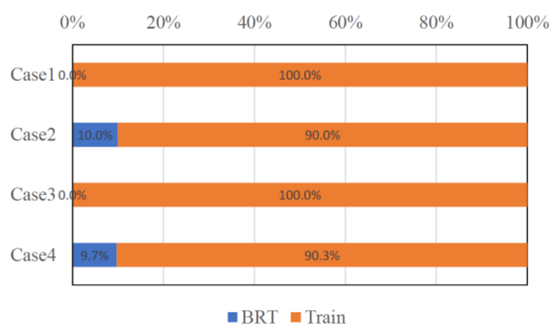

Fig. 7 Results of modal choice of primary transportation.

5.3 Results of Terminal Transportation Modal Choice

The modal choice of terminal transportation to railway stations and BRT stops was analyzed. Fig. 8 presents the results of the modal choice of terminal transportation.

The ratio of walking was 66%-70%, which was high. The next most typical mode of transportation was bicycle, with a ratio of 25%-27%. The ratios of on-demand buses were 0.7% and 0.1% in Cases 3 and 4, respectively, and on-demand buses were barely used as terminal transportation. In particular, users of on-demand buses were fewer in cases where BRT was introduced than in cases where BRT was not introduced.

Furthermore, in cases where BRT was introduced, the ratio of walking was approximately 3% higher than in cases where BRT was not introduced. Walking promotes health, and the introduction of BRT is effective for creating a healthy city.

Fig. 9 shows the usage status of each BRT stop, bicycle parking station, etc. for Case 2.

Bicycle parking stations near railway stations are used frequently (light blue circles). Additionally, motorcycle parking stations are observed around the Imazato railway station (purple circles). Meanwhile, bus users were observed in the southern region of the target area (blue triangles). However, the use of bicycle parking stations or bicycle sharing ports was not indicated near BRT stops (red square). BRT users were few in the southern region (Nagai route).

Thus, although a certain number of BRT users were observed, the combination of BRT and on-demand buses was less effective.

5.4 Using Bicycles to Promote Use of BRT

This section examines the promotion of BRT use by improving the environment for bicycle use. Currently, as shown in Fig. 2, bicycle parking stations exist around railway stations but not around BRT stops. Therefore, a case in which bicycle parking stations are provided around BRT stops is examined. In addition, a case in which bicycle sharing ports are provided around BRT stops and in residential areas is examined.

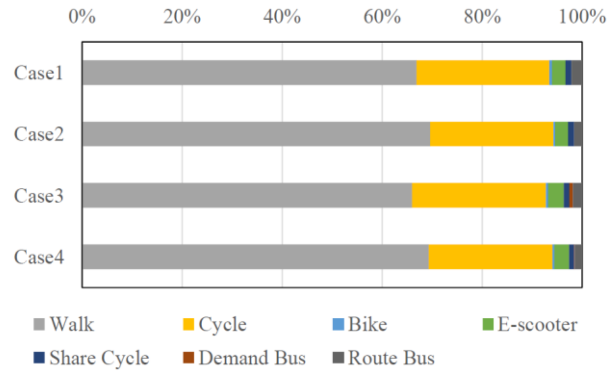

Fig. 8 Results of modal choice of terminal transportation.

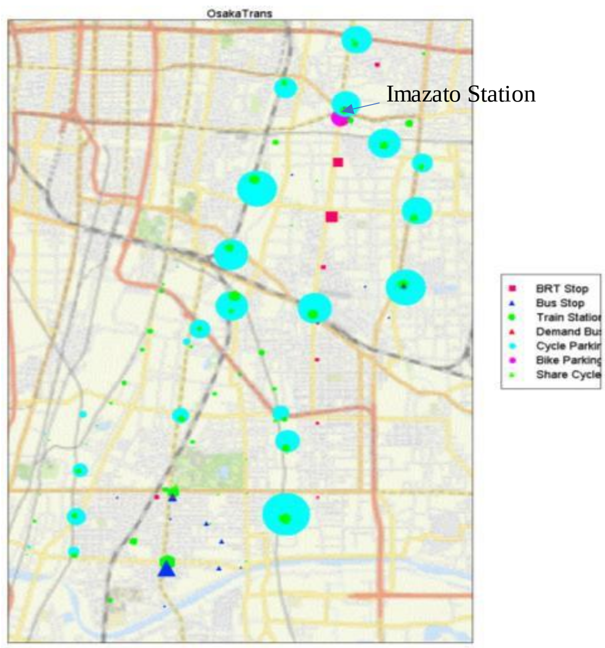

Fig. 9 Transportation usage status (Case 2).

Bicycle parking stations near BRT stops are established at seven BRT stops where no nearby railway stations are available. This may encourage people who ride bicycles to railway stations to use the BRT, and people who walk to BRT stops to use bicycles to arrive at BRT stops.

In addition, bicycle sharing requires ports to be installed near BRT stops, as well as at the starting point. Therefore, the installation of sharing ports in parks in the target area and BRT stops is considered in this study.

Fig. 10 shows the locations of the bicycle sharing ports. The red dots in the map indicate the existing ports (175 ports) and the blue dots indicate newly established ports (134 ports).

In this analysis, Case 2, which introduces the BRT and does not introduce on-demand buses, is considered as the reference case. In this reference case, the following cases were established: installation of bicycle parking stations (Case 5), installation of bicycle-sharing ports (Case 6), and installation of both facilities (Case 7).

Fig. 11 presents the results of the modal choice of primary transportation.

In Case 5, where bicycle parking stations were provided, the choice ratio of the BRT was 4.6% higher than that in Case 2. By contrast, the increase in the BRT choice ratio was only 0.8% when bicycle sharing ports were established (Case 6). In Case 7, where both facilities were installed, the increase was 4.2%, which was lower than that in Case 5. Providing bicycle parking stations at BRT stops will increase the number of BRT users. However, because bicycle sharing ports are installed not only near BRT stops but also near residential areas, the use of bicycle sharing to arrive at railway stations is expected to increase.

Fig. 12 presents the results of the modal choice of terminal transportation for each case. In Case 5, bicycle use increased by 3.5% compared with Case 2 because of the provision of bicycle parking stations. In addition, because of the installation of bicycle sharing ports in Case 6, the amount of bicycle sharing increased by 3.3%. By contrast, walking decreased by 2.9% and 3.2% in Cases 5 and 6, respectively, thus indicating a significant shift from walking. In Case 7, where both were provided, the use of bicycles increased by 3.8%, the use of bicycle sharing increased by 3.2%, and walking decreased by 6.5%.

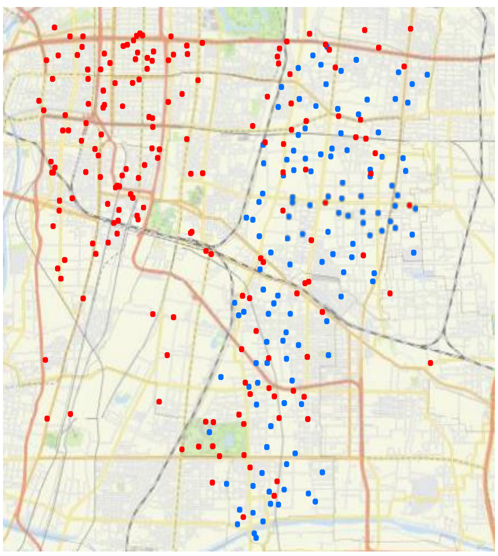

Fig. 10 Location of bicycle-sharing ports.

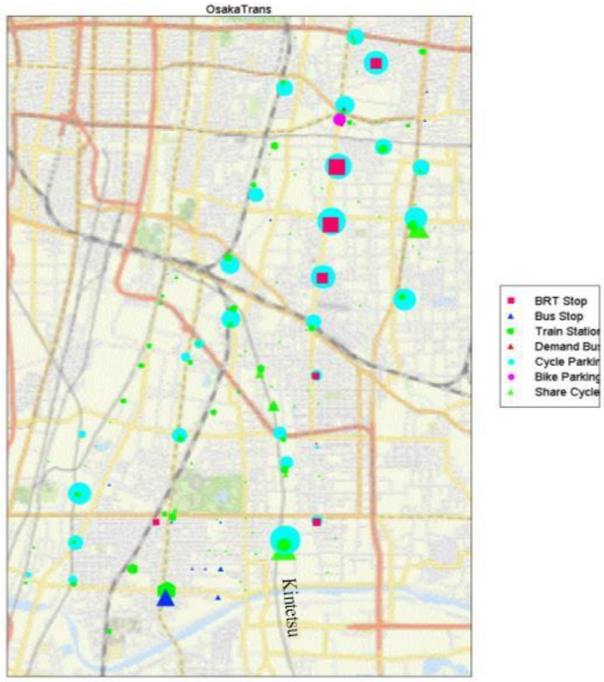

Fig. 11 Results of modal choice of primary transportation.

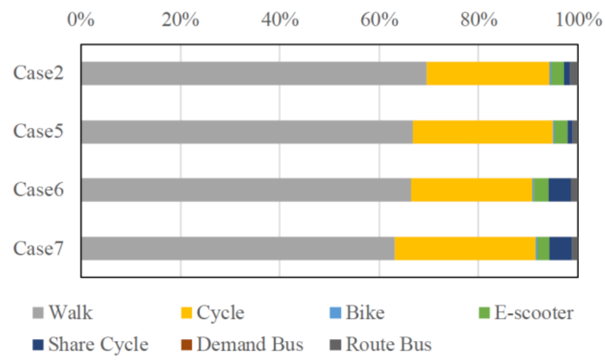

Fig. 12 Results of modal choice of terminal transportation.

Fig. 13 shows the usage status of transportation in Case 5.

Bicycle parking stations are typically used at the northern stops of BRT lines, and the number of BRT users is increasing. However, bicycle parking stations are rarely used at southern BRT stops. A railway (Kintetsu) operates along the western side of the BRT route. Hence, even if the environment for using the BRT is improved, many trip makers are believed to continue traveling to railway stations.

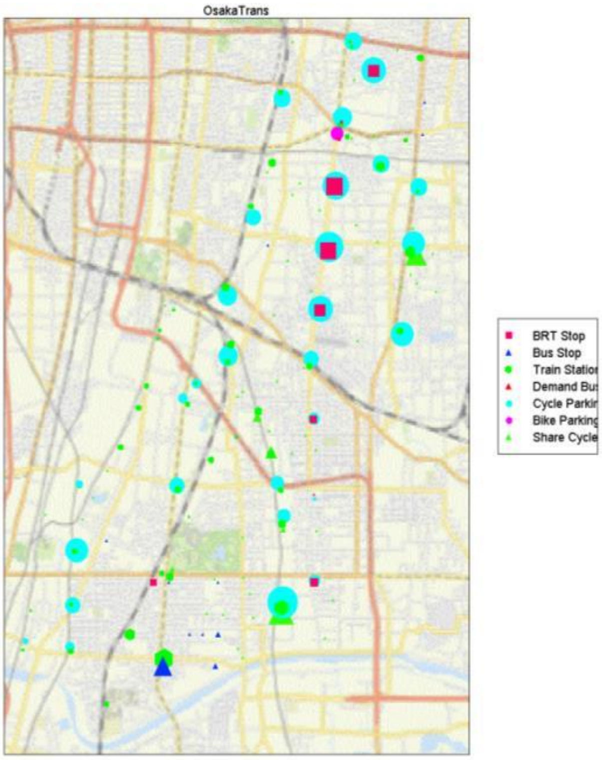

Fig. 13 Transportation usage status (Case 5).

6. Conclusions

In this study, an artificial society model was developed to examine combinations of transportation policies in urban areas. The main results of this study are summarized as follows.

(1) Targeting urban areas (southeastern Osaka City, Japan), a modal choice model of primary and terminal transportation was developed using an artificial society model software (Artisoc). This model is unique in that it incorporates factors that are difficult to consider in normal logit models, such as experiences that cannot be considered when selecting a bicycle sharing option. Additionally, the modal choice status can be visually understood via maps and graphs, thus allowing various transportation policies to be considered.

(2) The introduction of the "Imazato Liner" BRT and the introduction of on-demand buses in Ikuno Ward were examined. The result showed a certain number of BRT users but few users of on-demand buses as a terminal transportation mode. Among the terminal transportation modes, the choice ratio for walking was high, and the introduction of BRT increased the amount of walking. Therefore, the introduction of BRT effectively created a healthy city.

(3) To promote the use of BRT, the installation of bicycle parking stations near BRT stops and bicycle sharing ports in parks and near BRT stops was examined. The results showed that the provision of bicycle parking stations was associated with the use of the BRT, whereas the provision of bicycle sharing increased the use of railway stations. In addition, in the southern region of the BRT route, a railway line was available nearby. Therefore, even if bicycle parking stations are provided, the usage of BRT will likely remain low.

The model developed in this study did not sufficiently consider the effects of traffic behavior. In future studies, situations involving fully occupied bicycle parking stations and bicycle sharing ports should be considered. Additionally, we plan to consider weather, walking speed, maximum walking distance for each trip maker and other factors when performing modeling.

Acknowledgments

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