Memoirs of the Faculty of Engineering, Kyushu University, Vol.78, No.1, March 2018

Research on the Effect of P&R Facility Introduction to Bus Users

by

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(Received February 26, 2018)

Abstract

With the construction of the P&R facilities, people who used to have to travel by bus or taking bus from the residential area to the nearest railway station before taking to the city center, which can be named as bus-and-ride, will change their travel mode to P&R. However, this evidence will lead to a result which city planners and bus companies would not like to face: the utilization of bus will decrease; market sharing of public transportation in branch area of the city will be occupied by P&R facilities[1)]. This could make the operation of bus companies to a plight of collapse. It will turn to a big problem for the residents who cannot drive. This study used a hypothetical city to study the means of commuting traffic and analyzes the changes that have occurred since the introduction of P&R, by changing the parking price and the parking lot location, provided a proper P&R facility siting and pricing plan which will attract car drivers to change their travel mode to public transportation, at the same time, the P&R facility will not or have little effect on bus running in its sphere of influence.

Keywords: Park and ride, public transport, travel mode, location, pricing

1. Introduction

Park-and-ride (P&R) facilities are car parks with connections to public transport that allow commuters and other people to head to the city centers to leave their vehicles and transfer to a bus, rail system, or carpool for the remainder of the journey. The vehicle is stored in the car park during the day and retrieved when the owner returns. Park-and-rides are generally located in the suburbs of metropolitan areas or on the outer edges of large cities.

Park-and-ride facilities serve the needs of commuters who live beyond practical walking distance from the railway station or bus stop which offers service to the city centre. Park-and-ride facilities may suit for commuters with alternative fuel vehicles, which often have reduced range, since the facility may be closer to home than the ultimate destination. They also are useful as a fixed meeting place for those carsharing or carpooling or using kiss and ride (see below). Also,

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some transit operators use park-and-ride facilities to encourage more efficient driving practices by reserving parking spaces for low emission designs, high-occupancy vehicles, or carsharing. Most facilities provide services such as passenger waiting areas and toilets. Travel information, such as leaflets and posters, may be provided. At larger facilities, extra services such as a travel office, food shop, car wash, cafeteria, or other shops and services may be provided. These are often encouraged by municipal operators to improve the attraction of using park and ride[2)].

Though many researches have proved that the P&R facilities are effective in reducing congestion in city center, there are still many problems exist during the operation of the P&R facilities. G. Parkhurst found that the rate of provision of bus-based park and ride facilities on the fringes of UK urban areas have grown in recent years which leads to a reduction of the bus use in residential areas[3)]. But there is no further research focus on this issue.

Therefore, in this paper, we provide a P&R facility siting and pricing plan which will attract car drivers to change their travel mode to public transportation and keep the bus operation in a hypothesis linear city.

2. Residence Area Modeling and Travel Mode Analysis

2.1 Residence area modeling

2.1.1 Assumption

In this research, we mainly talk about the effect of P&R construction on bus users, so first we need to set a model which only focuses on the residents travel mode to analyze the change of travel behavior before the introduction of P&R and after.

There are many factors need to consider if the objective city is an existing one, some will influence the result of the calculation, therefore we set a supposed city to simplify the calculation.

There are several required assumptions:

1. Residents in the suburb area are random distribution;
2. Waiting time of bus and train is included in travel time;
3. Car ownership rate in this area is 50%;
4. Road between city center and residential area is parallel to railway, and congestible;
5. Residents' travel mode choices only depended on total general cost, that means, people only choose the travel mode of minimum cost, ignoring the individual preference;
6. Ignoring the distance between P&R parking lot and the railway station;
7. Ignoring the capacity of P&R parking lot;
8. All speed used in this research is average speed and changeless, that means, the level of congestion in road is the same in any random section;
9. Parking fee is monthly paid;
10. Purpose of all the trips is commuting;
11. There are 20 working days per month;
12. Ignoring travel by bikes and motorbikes.

2.1.2 Modeling

The image of the residential area is shown in Fig. 1. Taking the railway station in suburb area as the center of the circle; people live in a 3kilometer-radius-circle randomly. The railway station covered area is a 1kilometer-radius-circle and the center is the railway station, residents who can walk to the railway station are all live in this area. There are two bus routes running through the residential area heading to the railway station. Road connecting city center and suburb area is parallel with the railway and congestible. There are three methods for residents live in the target area to access this road.

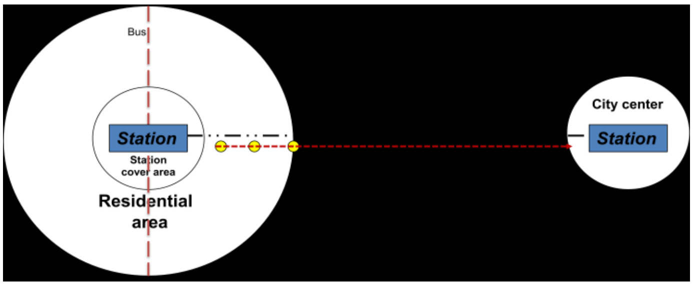

Fig. 1 Residential area model

2.2 Travel mode analysis

Since the research object is the effect of P&R facilities on bus users, we focus on the travel modes related to P&R facility and bus. There are four travel modes we need to consider: travel by car; travel by bus then transfer to train to the city center; park-and-ride; walk to the railway station then take a train to the city center.

The reason why we take the walk pattern into our research is that the residents are randomly distributed and some of them live very close to the railway station. As walking is a very common measure for travel, it is necessary for us to put the walking pattern into the travel mode analysis. On the other hand, it is impossible for all residents to walk from home to the railway station because the railway station has a cover area, people who live in the cover area have the possibility to go to the railway station, while other people will have a low motivation to choose this travel mode. Referring to the data from MLIT[7)] (Japanese Ministry of Land, Infrastructure, Transport and Tourism), the cover area of a railway station in Japan is a 1kilometer-radius-circle; the center of the circle is the railway station.

2.2.1 Travel by car

Travel by car is a very simple travel mode. People live in the suburb area would drive a car to the city center, then park the car in the parking lot near the destination in the city center. When they get off work, they pick the car from the parking lot in the city center then drive to the suburb area. Fig. 2 shows the image of the mode of travel by car.

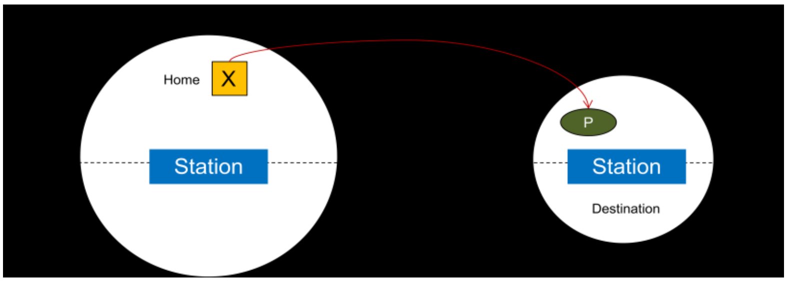

Fig. 2 Travel by car

The cost of the mode of travel by car is constituted in two parts: every kind of expenses, such as, the gasoline fee, the parking fee, etc; the other cost is the time value—time cost in traveling, which can be translated into money.

In travel by car pattern, the general cost includes:

1. Parking fee in the parking lot of city center (c_{pc});
2. Gasoline cost during the trip between residential area to the city center by car (c_{pg});
3. Time cost during the trip from residential area heading to the city center by car (t_c).

The total general cost of the pattern travel by car therefore:

$$f_c = c_{pc} + c_{pg} + t_c \cdot \omega \quad (1)$$

Where: f_c is the total cost of travel by car; ω is the value of time.

2.2.2 Walk to the railway station then taking a train

For this travel pattern, people walk from home to the nearest railway station, then take a train to finish the trip. As we mentioned in the beginning of the chapter, this travel mode have some requirements for the range of the place where residents live. The cover area is a 1kilometer-radius-circle, so people who live in this circle can walk to the railway station and no residents choose the same travel mode live in the outer place of the circle.

Fig. 3 shows the image of the mode of walk to the railway station then taking a train:

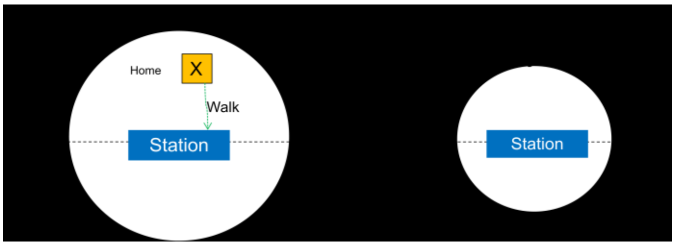

Fig. 3 Walk to the railway station then taking a train

Same as that of the mode of travel by car, the total general cost of the mode of walking to the railway station then taking a train also includes the expenses and the time value. This travel pattern is a little complicated than the mode of travelling by a car, so the cost therefore:

1. The cost of railway ticket (c_r);
2. Time of walking from home to the nearest railway station (t_w);
3. Time of taking a train from suburb area to the city center (t_r).

The total general cost of this mode is shown as follow:

$$f_w = t_w \cdot \omega + c_r + t_r \cdot \omega \quad (2)$$

Where: f_w is the total general cost of walking to the railway station then taking a train; ω is the value of time.

2.2.3 Take a bus to railway station then transfer by a train

Taking a bus to the railway station then transferring by a train is the most complicated mode in all the four travel modes, it can be separated into many small trips; and it is made by many kinds of travel modes.

The mode of taking a bus to the railway station then transferring by a train includes three kinds of transportations: walking, taking bus and train. First, resident walk to the nearest bus stop, then take a bus to the railway station located in the suburb area; transfer by a train to go to the city center, and then finish the whole trip.

The image of the mode of taking a bus to railway station then transferring by a train shows as Fig. 4:

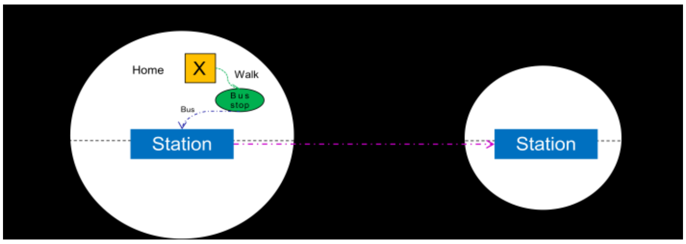

Fig. 4 Take bus to the railway station then transfer by a train

As the mode of taking a bus to the railway station then transferring by a train is complicated, the general cost of this travel mode is also made by many kinds of expenses:

1. The cost of bus fare (c_b);
2. The cost of train ticket (c_r);
3. Time of walking from home to the nearest bus stop (t_{wb});
4. Time of taking a bus from the nearest bus stop to the railway station located in the suburb area (t_b);
5. Time of taking a train from the railway station in the suburb area to the city center (t_r).

The total general cost of this mode is shown as follow:

$$f_b = t_{wb} \cdot \omega + c_b + t_b \cdot \omega + c_r + t_r \cdot \omega \quad (3)$$

Where, f_b is the total general cost of taking a bus to the railway station then transferring by a train, and ω is the value of time.

2.2.4 P&R

For the travel mode of P&R, there are two parts of travel behaviors: driving a car from home to the P&R parking lot near the railway station and parking the car, taking a train to the city center and finishing the trip.

Fig. 5 shows the image of the travel mode of P&R:

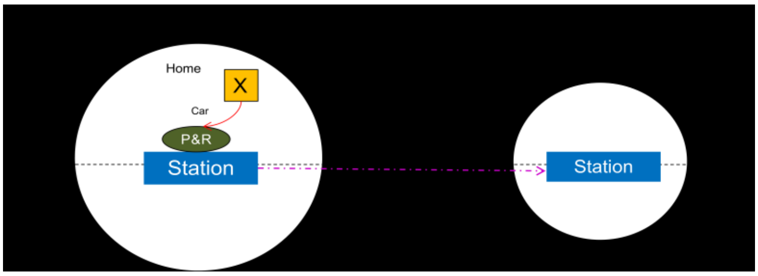

Fig.5 P&R

The total general cost of the travel mode of P&R includes a lot:

1. The gasoline cost from home to the nearest railway station in the suburb area by car (c_{gp});
2. Parking fee of the P&R parking lot (c_{pp});
3. The cost of train ticket (c_r);
4. Time cost from home to the nearest railway station in the suburb area by car (t_p);
5. Time cost from the railway station in the suburb area to city center by taking a train (t_r).

And the total general cost therefore:

$$f_p = t_p \cdot \omega + c_{gp} + c_{pp} + c_r + t_r \cdot \omega \quad (4)$$

Where, f_p is the total general cost of the travel mode of P&R; ω is the value of time.

2.3 Resident distribution

Since the residential area is a 3kilometer-radius-circle, we take the population density of Fukuoka City (4564person/km^2) into calculation and the number of residents in the target area is 714. Due to assumption 1, all the residents are randomly distributed in the residential area. Fig. 6 shows the location where each resident lives.

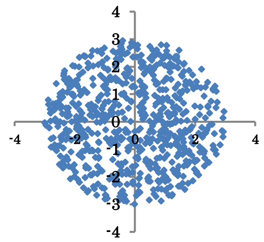

Fig. 6 Resident distribution

3. Estimation

The estimation of the effect of the P&R facilities introduction to bus users issue is related to the equations given in the previous sections. Since the number of residents is comparatively big, we use FORTRAN to program the whole calculation.

3.1 Individual Variability

Before the calculation, there are two individual variability need to be announced, the variability of time value and the variability of vehicle ownership.

3.1.1 Variability of time value

Since the income of each resident is different, the value of time is also different. The formula of the value of time given by Japanese Ministry of Land, Infrastructure, Transport and Tourism[8)] is shown as follow:

$$\text{Time value} = \frac{\text{Average monthly total income(Yen)}}{\text{Average monthly working time(min)}} \tag{5}$$

From the equation we can find that the value of time is related to income and total working time. Suppose that working time of the residents who live in the target area is the same, the decisive factor of the variability of time value is the total income. Referencing the private income survey[9)] carried out in 2011, the distribution of the revenue total income of Japan is shown as Fig. 7:

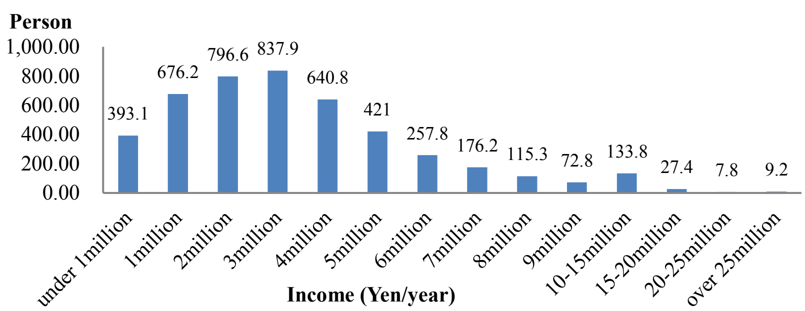

Fig. 7 Revenue income distribution

From Fig. 7 we can find that most people's revenue incomes are imploded in the 1-5 million Yen ranges. Other distribution ranges are also in the level which cannot be neglected. So using the equation (5), we can get the distribution of time value in different incomes. Fig. 8 shows the distribution of the value of time. Using the distribution of each value of time, we can get the variability on value of time.

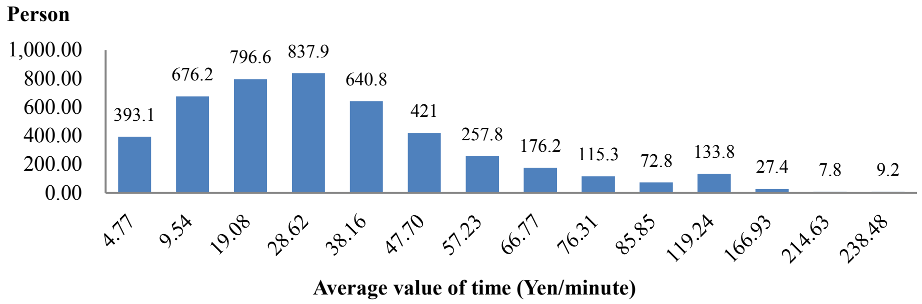

Fig. 8 Value of time distribution

3.1.2 Variability of vehicle ownership

In reality, it is impossible for every person to have a vehicle in a random residential area. In our research, it is necessary to bring the concept of vehicle ownership in our calculation. From the North Kyushu Person Trip Survey[10)] occurred in 2005, Fig. 9 shows the vehicle ownership of each age in Fukuoka city. And the distribution of the employment of each age is shown by Fig. 10.

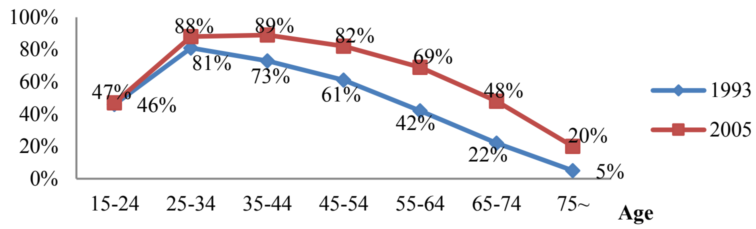

Fig. 9 Vehicle ownership in Fukuoka City

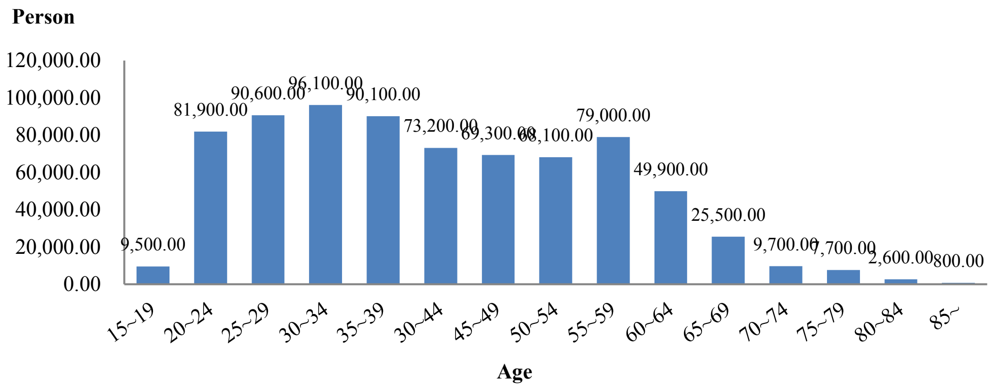

Fig. 10 Employment Distribution of Fukuoka City

Using the percentage of the employment in different ages and the distribution of the vehicle ownership, we concluded the vehicle ownership rate in Fukuoka City is 50%. The data is also applicable in our calculation.

3.2 Parameters

The related parameters in the calculation are referenced by the data of Fukuoka City and Japanese Ministry of Land, Infrastructure, Transport and Tourism. Some of the parameters do not have the existing data, so we need to obtain them from some related data at first.

3.2.1 Parking fee

There is no existing formula about parking fee, so we need to find some information or data related to the parking fee issue. First we investigated parking lots in Fukuoka City, and recorded the price of parking fee in city center and in suburb area; the distance between parking lot and the city center also need to be recorded. Using the data collected, we can draw a distance-price curve by Matlab. The curve is shown by Fig. 11.

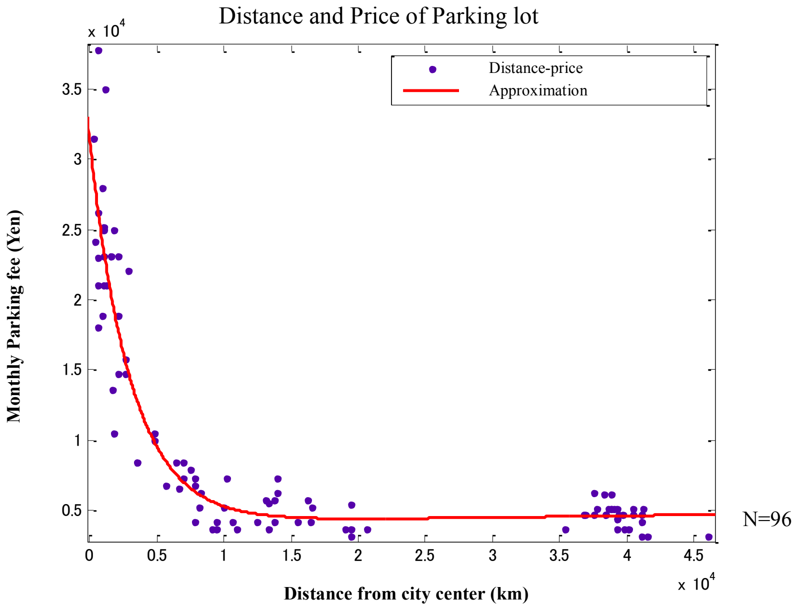

Fig. 11 Distance and Price of Parking lot

By analyzing the approximation curve in Fig.11, we can conclude the relationship between distance from city center and monthly parking fee therefore:

$$y = 2.704 \times 10^4 e^{-3.246x} + 4146e^{2.799\times10^{-3}x} \qquad \text{(Correlation coefficient =0.88)} \qquad (6)$$

Where: x is the distance between the parking lot and city center (km); y is the monthly parking fee (Yen/Month).

3.2.2 Price of railway ticket

The data of railway ticket price is an important parameter in our research. We seek the data from Kyushu Railway Company, and collect the charges of the lines running in Fukuoka City. By analyzing the price of railway ticket and mileage, we can get a linear relationship between them.

Fig. 12 shows the relationship between mileage and price of railway ticket.

And the equation of the relationship therefore:

$$y = 166.2 + 19.3x \qquad \text{(Correlation coefficient=0.80)} \qquad (7)$$

Where: x is the mileage the train running (km); y is the price of railway ticket (Yen).

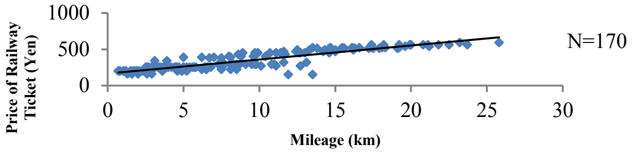

Fig. 12 Mileage and price of railway ticket

3.2.3 Price of Bus fare

Since most of the data we quoted are from Fukuoka City, the price of bus fare we collected also came from Fukuoka City. As the biggest bus company in Fukuoka City, Nishitestu Bus Company running a big amount of bus routes which running through most area in Fukuoka City. By collecting the mileage and the existing price of bus fare, we can get a relationship between them. Fig. 13 shows mileage and the price of bus fare.

The equation of the relationship between mileage and price of bus fare therefore:

$$y = 109.4 + 28.1x \qquad \text{(Correlation coefficient =0.94)} \qquad (8)$$

Where: x is the mileage the bus running (km); y is the price of bus fare (Yen).

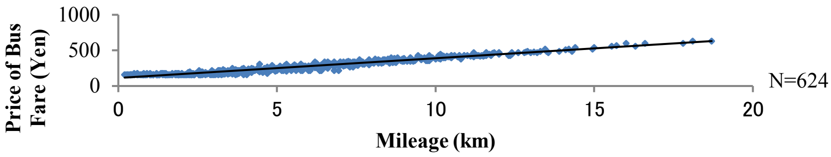

Fig. 13 Mileage and Price of Bus Fare

3.2.4 Other parameters

Except the parameters mentioned in the last sections, there are some other parameters related to the calculation.

As we mentioned in chapter 2, all the speed related with the research are changeless, so we selected the average speed for the calculation. Calculating the existing running speed of public transport, collecting walking speed and vehicle speed in rush hours, Table 1 shows all the speed related.

Table 1 Related speed values

Parameter	Value
Average speed of vehicle	35km/h
Average speed of walking	5km/h
Average speed of bus	15km/h
Average speed of train	60km/h

Except speed, there is an important parameter related to the cost of using cars—the gasoline fee. Referencing the data[11)] given by Japan Ministry of Land, Infrastructure, Transport and Tourism, the value of gasoline fee is 9.855Yen/km (2014).

3.3 Estimation

To investigate how the distance effects on the price of parking fee, the calculation has been separated into two patterns since we chose two residential areas and the distance to city center are 10 kilometer and 20 kilometer separately. On the other hand, half of the residents live in the target area do not have a car, so their travel behavior will not be affected by the introduction of P&R facilities. Therefore the non-vehicle residents and vehicle holders should be calculated separately.

3.3.1 Non-vehicle residents

For the residents who do not have a car, the only travel modes they can choose to the nearest railway station are walking then taking a train or taking a bus to the nearest railway station then transferring to a train. The total number of samples is 714; and the number of non-vehicle residents is 357.

People who can walk to the railway station—as mentioned in chapter 2, are all living in the railway station cover area. It is a 1kilometer-radius-circle of which the center is the railway station. Therefore we can get the number of residents who live in this area, and using the vehicle ownership rate, we can find that the number of residents who can choose this travel mode is 53. That means, 53 residents live in the railway station cover area, without having a vehicle, have a potential to choose the mode of walk to the railway station and take a train to go to city center.

3.3.2 Vehicle holders

For the residents who have a vehicle, they can choose all the travel modes mentioned in chapter 2. There are also some people who have the possibility to choose the mode of walking to the railway station then taking a train to the city center, and the number of the residents is 32.

3.4 Method of estimation

It is possible to program all the estimation procedures. The method of estimation is to calculate the cost of each sample in four travel modes using the equations (1), (2), (3), (4) mentioned in chapter 2, by comparing the cost we can find the minimum cost among four travel modes. Using the results of the estimation, it is easy to find the ratio of travelers in each travel mode.

4. Data Analysis

The results get from the estimation will be analyzed in this chapter. From data analysis, we can conclude the effect of P&R facilities construction on bus users and the influence in car users by introduction of P&R facilities.

4.1 Analysis on non-vehicle residents travel mode

Since in this pattern, all the residents don't hold vehicles, the calculations in 10kilometer and 20kilometer have the same answer. There are 357 residents in the target area without a vehicle, and the travel modes for them to choose are limited in walking to railway station then taking a train to city center or taking a bus to the railway station then transferring to a train. From the calculation, we know the number of the residents who have a possibility to choose the travel mode of walking to the railway station is 53. Comparing the total cost of two travel modes, all the residents living in the cover area of the railway station choose the travel mode of walking to the railway station since the cost is cheaper than that of the mode of taking a bus. Fig. 14 shows the ratio of two travel modes.

Since there is no effect on the ratio of each travel mode during the introduction of P&R facilities, it is unnecessary for us to discuss the change of travel behavior after the P&R facilities being introduced. In the following sections, we focus on the residents who have vehicles and find the change of the travel behavior before and after P&R facilities being introduced.

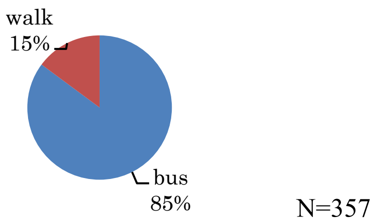

Fig. 14 Ratio of non-vehicle residents travel behavior

4.2 Analysis on vehicle holders travel mode

Residents who have a possibility to drive a car can choose the travel mode from all the four travel modes we mentioned in chapter 2. The analysis has been separated into two parts, the ratio of each travel behavior before the P&R facilities being introduced and the ratio of each travel behavior after the P&R facilities being introduced.

4.2.1 Residential area 10km away from city center

We analyze the residential area from the city center 10 kilometers away at first.

Before the introduction of P&R facilities, there are three travel modes provided: walking to the railway station then taking a train to city center; taking a bus to the railway station then transferring a train and driving to the city center. By comparing the total cost of each travel mode, we can obtain the ratio of each travel mode as Fig. 15 shows. From the figure, we can conclude that in the existing price, most people have a tendency to drive a car to the city center; 14.57% of residents take bus as their first choice.

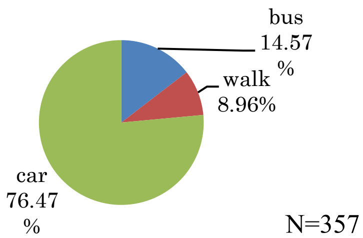

Fig. 15 Ratio of each travel mode before P&R introduced

After the introduction of P&R facilities, the ratio of each travel mode changes a lot, from Fig. 16 we can find that the P&R facilities occupied most trips from other travel modes. Since the existing price of the P&R fee is 266 yen per day, the total cost of travelling by P&R is the cheapest among all the travel modes. The introduction of P&R has a significant effect on reducing car use, and bus users are reduced at the same time.

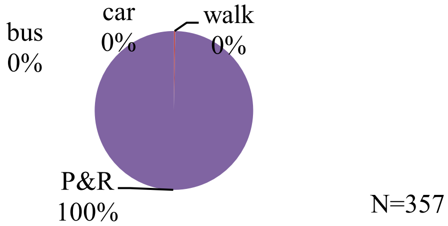

Fig. 16 Ratio of each travel mode after the introduction of P&R facilities

Since the effect of P&R introduction to bus users in existing price of parking fee, it is necessary to take action to make sure the number of bus users remains in a normal level. Because of the value of other related parameters are abiding, the only method for us to change the residents' travel behavior is to increase the parking fee. The target is to find a price which the number of bus users is exactly in the same level before the introduction of P&R facilities. When the price of the parking fee is increased to 1526 Yen per day, the goal can be achieved. The result is shown by Fig. 17.

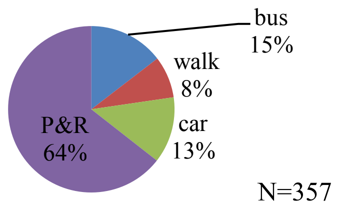

Fig. 17 Ratio of each travel mode when P&R parking fee is 1526 Yen/Day

4.2.2 Residential area 20km away from city center

The calculation of 20km pattern is similar to that of 10km.

Before the introduction of P&R facilities, the ratio of each travel mode is the same as that of 10km away from the city center. However, due to the distance between residential area and city center, it is more adverse for people who drive to city center, so the number of bus users increased into 55. Fig. 18 shows the details.

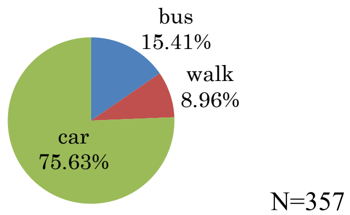

Fig. 18 Ratio of each travel mode before P&R introduced

After introducing the P&R facilities, all the residents change their travel behavior into P&R. For the existing price of parking fee in this area is 215Yen per day, the total price is the cheapest among all the travel modes. Fig. 19 explains the details.

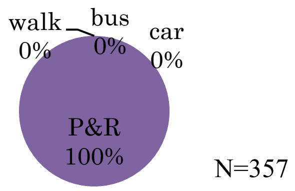

Fig. 19 Ratio of each travel mode after the introduction of P&R

It has been found that increasing the price of P&R parking fee is the way to find balancing situation, when the price of P&R parking fee reaches 1535 Yen per day, the number of bus user can remain in the normal level. Fig. 20 shows the details.

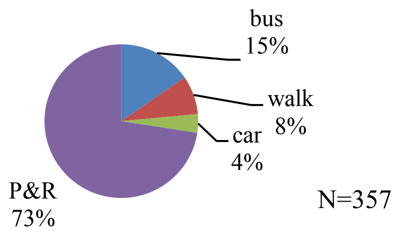

Fig. 20 Ratio of each travel mode when the price of P&R parking fee is 1535Yen/Day

4.3 Relation between P&R price and total general cost

From searching the balance situation by increasing the price of P&R parking fee, we obtained many patterns and the proportions of each travel mode that are different when P&R parking fee is different. The proportions of each travel mode with different P&R parking fee are shown by Fig. 21 and Fig. 22 which represents the residential area 10km away from city center and the residential area 20km away from city center. We also noticed that the general cost of the total residents live in the target area. The relationship between the price of P&R parking fee and total general cost in 10km area and 20km area are shown by Fig. 23 and Fig.24. The total general cost includes gasoline cost, time cost and railway ticket. The figure shows that the total general cost is not in the lowest level when the price of P&R is 1526Yen/day in 10km area and 1535Yen/day in 20km area. The lowest point of the two curves in the figure appear when the price of P&R parking fee is at the lowest level—the existing price of P&R parking fee.

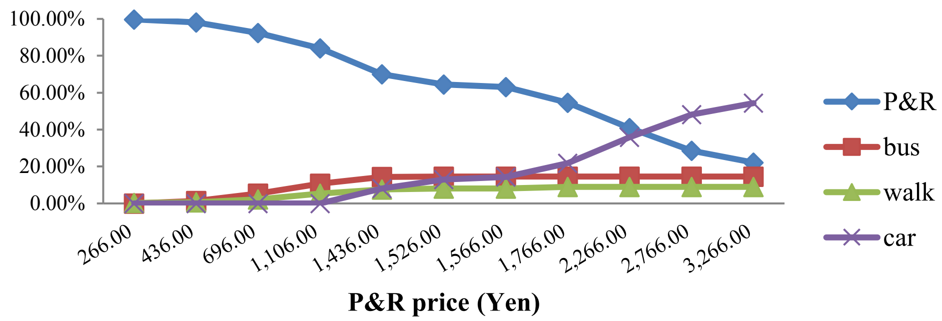

Fig. 21 Proportion of each travel mode in different prices of P&R parking fee in the area 10km away from city center

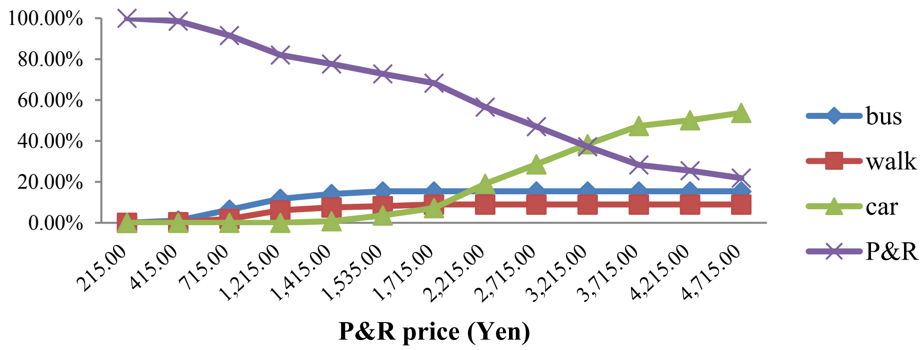

Fig. 22 Proportion of each travel mode in different prices of P&R parking fee in the area 20km away from city center

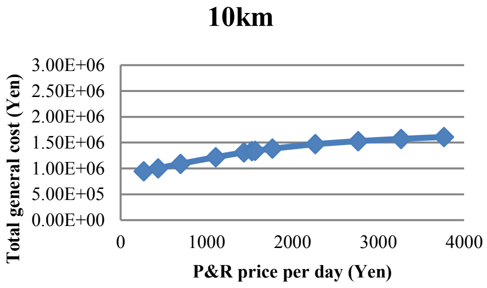

Fig. 23 P&R price and total general cost in the area 10km away from city center

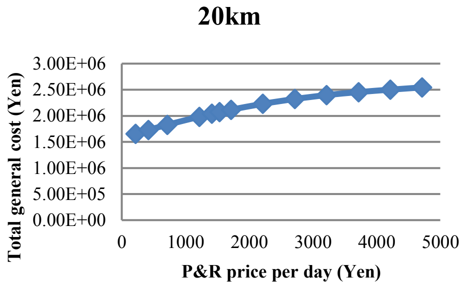

Fig.24 P&R price and total general cost in 20 km away from city center

5. Discussion and Summaries

From the data analysis in previous chapter, we find it is difficult for the policymakers to set a proper plan to maintain the bus operation and ensure the total general cost in the lowest level. In the section of discussion, several solutions will be proposed to achieve the goals.

5.1 The effect of P&R facilities construction on bus users

Form the estimation and data analysis we can conclude that the introduction of P&R facilities will assault the operation of bus. Since the existing price of P&R parking fee is at a very low level, when P&R is introduced, people will choose the cheapest travel mode by the method of price-oriented. Though car users are also significantly reduced, however, when the introduction of P&R facilities affect the operation of bus, it is possible for the bus company to abolish the route which is not profitable. At the position of the residents who cannot drive a car, the only way of travel they can choose is walking. For the residents who live far away from the railway station, it is very inconvenient to walk to the railway station.

To avoid the situation, we increased the price of P&R parking fee to find a balancing situation where the bus user can remain in the previous level as the time the P&R facility is not introduced. Finally we found that when the price of P&R is 1526Yen/day in 10km area and 1535Yen/day in 20km area bus users are exactly in the normal level.

5.2 Measures of maintain bus operation

Since the relationship between the price of P&R parking fee and total general cost given in the last chapter shows that in the balancing situation the total general cost is not in the lowest level, the measures of this issue have two starting points: maintaining the bus users and keeping the total general cost in the lowest level.

To maintain the bus operation, the measure of the P&R pricing issue is to increase the price of P&R parking fee until the bus users reach to the normal level.

To keep the total general cost in the lowest level, the measure of the P&R pricing issue is to keep the price of P&R parking fee at the existing level. Since the measure of keeping the P&R parking fee will lead the bus operation to a negative situation, other measures are needed to keep the bus operation. An effective measure is that the local government subsidy helps the bus company to keep the route running. Since the total general cost of all residents who live in the target area is cheaper than that of the bus users in the normal level, the social general cost will be decreased by setting the price of P&R parking fee in the existing price level.

5.3 Further research plan

The object we studied is a simple hypothesis model in which the target area and samples are all assumed; there are still many issues remained in the P&R pricing problem.

In further research, it is necessary to initiate an investigation in an area in reality. By listening to the residents who live in the area we can get real data and that will make the result different.

Individual preferences in the further research may also have some effects on the result and it is possible to add this factor into the further research.

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