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Economical welfare maximisation analysis:

Assessing the use of existing Park-and-Ride services

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Abstract

This paper assesses travellers' responses to the use of existing Park-and-Ride (P&R) services based on an economical welfare maximisation approach. Specifically, the paper presents a modelling framework to estimate consumer surplus and producer surplus (business profits) on the basis of modal choice probabilities. The paper draws on evidence from Stated Preference surveys conducted around two P&R sites in Sapporo, Japan, where P&R services occupy a modest market space. Overall, the results suggest that business profit increases when economical welfare is maximised, as a consequence of increased demand. It is also shown that P&R choice is not only influenced by parking fees, but also by the fares and other attributes of alternative transportation modes. Accordingly, the interactions of P&R with alternative transportation modes should be taken into consideration in any strategic transportation policies oriented towards motivating sustainable transport mode choices.

Keywords

Park and Ride; Economical welfare; Public transport; Consumer surplus; Producer surplus.

1. Introduction

Growing concern worldwide over the use of private cars has led to the promotion of public transport, as well as interest in non-motorised modes and also alternative private-public interactions, as a means of making transportation systems more sustainable. For over 40 years, Park-and-Ride (P&R) services have been promoted within transportation plans, as several benefits are associated with its use. Such services motivate multimodal journeys and address issues of traffic congestion and emissions (Horner and Grubesic 2001; Griffin 2004; Vuchic 2007). Higher accessibility levels can be achieved through P&R systems, particularly in congested downtown areas (O'Flaherty 1997). The possibility of private-public partnerships play a strategic role in providing alternative transportation services, which benefit the user with the best features of both car and transit modes (Veras et al. 2012a). The implementation of P&R facilities alongside existing public transport networks is also suggested as a means to increase public transport ridership while leading to potential cost recovery improvements for such services (Reeven 2011). Accordingly, P&R is a potential agent towards achieving more sustainable and inclusive societies.

Research has been done on the propensity to park and ride, as well as on P&R policies and their implications for the user and for the environment. Enhancing public transport, along with implementing traffic control measures, appear to be most effective in motivating P&R choices (Hounsell et al. 2011; Friman et al. 2013). Parking availability and easy accessibility are also identified as important factors on influencing the behaviour of park and ride users (Hamid 2009). P&R has been correlated to a reduction in the generalised costs of travel through time and monetary savings (Meek et al. 2011). In turn, generalised costs are recognised as a determinant factor towards maximising P&R demand, particularly when kept lower than the auto-only alternative (Veras et al. 2012b). Moreover, the economic implications and perceived demand of P&R services have been indicated by governments as being the main elements

considered when determining whether or not to implement P&R facilities (Dijk and Montalvo 2011). Within urban centers, environmental benefits can be achieved by shifting a portion of car-based trips into public transport trips, while reducing the average distance travelled by car (Parkhurst 1994). However, previous research also highlights the main effects of P&R schemes being related to traffic redistribution, rather than to direct effects on traffic reduction when considering extra-urban areas (Parkhurst 2000). Several recommendations can be found in transportation literature towards successfully planning, implementing and evaluating P&R systems (AASHTO 2004; Wang et al. 2004; Farhan and Murray 2008).

Economical welfare is a key concept within transportation economics (Meyer and Miller 2001). Supplementing previous research, this paper extends the social welfare maximization model by addressing single public transport mode, while applied to the P&R problem. In this model, both parking fare and public transport fare influence the revenues of the companies. If no subsidy is paid by a local government to the public transport company, transport fare can be determined by maximizing the profit of the company. However, once subsidy is paid by the local government, the government does not allow the company to determine fare by maximizing the profits. This is true for general public transport problem including P&R.

The analysis looks at the needs of all actors involved with P&R services, the consumers, producers and local government, while discussing the likely reasons that motivate people to park and ride. Particularly, the modelling framework presented here focuses on maximasing consumer surplus and producer surplus, i.e. maximising economical welfare, while ensuring public transport service for the local community. Sensitivity analyses are also developed to investigate the influence of parking fees on mode choices. The interaction of P&R with other transportation modes is also taken into consideration.

This study focuses on P&R schemes in a Japanese context. In Japan, P&R shares are small, whilst public transit stations are predominantly accessed through walk or bicycle modes;

transit/transit links are also popular. This approach provides an interesting opportunity to further investigate the role of P&R services within contemporary multimodal transportation systems. The research findings provide insightful information to aid transport practitioners and policy makers in addressing issues of traffic management and in motivating behavioural change towards more sustainable transportation options.

The remainder of the paper includes a summary of P&R policies in Japan (Section 2); a description of the case study areas, the data sample and the modelling framework (Section 3); a discussion on the modelling outputs (Section 4) and on the numerical examples (Section 5); and conclusions (Section 6).

2. P&R within a Japanese Context

With significant increases in car share, car ownership and related problems over recent decades, all levels of government in Japan have intensified efforts in favor of more sustainable forms of transport. The outputs of the latest nationwide Person Trip Survey show increases of approximately 10% in the mode split of car during weekdays and 20% during weekends in between 1987 and 2005 (MLIT 2007). Also, a significant increase has been observed in household car ownership, while a greater number of car trips by female travellers have been noticeable over the same period. The car share among elderly people has also increased, despite a recent trend among elderlies within the three major metropolitan areas (Tokyo, Osaka and Nagoya) in shifting from car use towards using bicycles for short distance trips (MLIT 2005). Accordingly, local authorities have been focusing on projects which prioritise public transport and non-motorised modes. Expanding light rail transit systems and subway systems, improving bus services, and implementing traffic calming measures, particularly within residential districts, are among these projects. Turning urban environments more bicycle-friendly has also been

prioritised so as to attend to the great numbers of unimodal and multimodal trips involving bicycles especially within central urban areas (Andrade et al. 2011; Andrade and Kagaya 2012).

Parking space relocation policies have been implemented so as to support the use of public transit modes (JFS 2012a). These measures have been emphasized in response to a situation where parking lots are randomly dispersed around the city centres of urban areas throughout Japan, which motivates the use of the car over public modes. P&R systems have also been explored in Japan. Parking facilities are owned and managed both by private sector and public sector groups without subsides. Parking lots provided by some suburban shopping centres are also used. Parking is usually paid, but public transport passes may be purchased at a discount by P&R users in a few cities. P&R services are often offered in major metropolitan areas, such as Tokyo, Yokohama and Nagoya, though several other regional urban areas have recently enhanced such services. Kanazawa city is one such example, where P&R services have been promoted within the city's Environmentally Sustainable Transport (EST) efforts (JFS 2012b). Sapporo city, which serves as the case study for this research, also offers a range of P&R facilities within its urban area (further described in Section 3.1).

In Japan, P&R services are implemented as a complementary service to the predominant walk/bicycle-transit links. The efficient links between bicycle and walk modes with other transit modes offers a replacement for car-based trips, particularly in densely inhabited districts. However, suburbanization and increase in the number of polycentric metropolitan areas has also resulted in longer distances to public transit stations, which in turn motivates car trips. In this context, P&R services offer a valuable alternative to unimodal car trips.

3. Data and methods

3.1 Case study areas within Sapporo city

Sapporo is the capital and the biggest city in the northern Japanese island of Hokkaido. The city has a population of 1.9 million, from which approximately 45% is a working population. It represents 1.5% of Japan's population and 34.8% of Hokkaido's population (Sapporo City 2011). With a regional and an international airport (46km from downtown Sapporo), one of the biggest universities in Japan (Hokkaido University) plus several private universities, and substantial shopping centres, the city is the major economic centre in the region. Sapporo station, Odori station and Susukino station areas (downtown Sapporo highlighted in Figure 1) compose the commercial hub of the city. On average, the Central, North and East wards generate 4 million trips per day, which accounts for approximately 36% of the total number of trips generated within Sapporo metropolitan area per day (Sapporo 2010). The city's person trip data indicates that approximately 52% of all daily trips are made by car, while public transport accounts for 19% of daily trips (Sapporo 2006). The municipal subway service, with its 380 cars, carries a daily average of 561 thousand passengers, while privately operated buses account for 289 thousand and Japan Railways (JR) Hokkaido accounts for 196 thousand passengers (Sapporo City 2011).

There are approximately 3 thousand parking spaces distributed amongst 14 P&R sites within Sapporo metropolitan area. Number of parking spaces and usage rates are very distinct among sites, as shown in Figure 2. Usage rates might be influenced by the level of service offered by each P&R site, e.g. monthly parking fee, accessibility, parking space availability, public transport links, snow removal service during the winter and availability of shopping areas in the surroundings of the parking site. Besides, the P&R sites can be as close as 1.5km and as far as 13.4km from the downtown area, which may also have certain influence on usage rates. Most of them are privately managed and fees are applied on a monthly basis, with only 14% of parking spaces made available on an hourly basis (Sapporo City 2011). Makomanai and Shin

Sapporo districts, also highlighted in Figure 1, were set as case study areas for this research as they are the districts which contain the P&R sites furthest from downtown Sapporo, yet these two P&R sites present very different characteristics and levels of service (see Table 1). Moreover, travellers who live in these areas frequently access downtown Sapporo either for working or shopping purposes.



Fig. 1 Location of Downtown Sapporo (Sapporo/Odori/Susukino Stations) and P&R sites (Makomanai/Shin Sapporo Stations) Source: Google maps

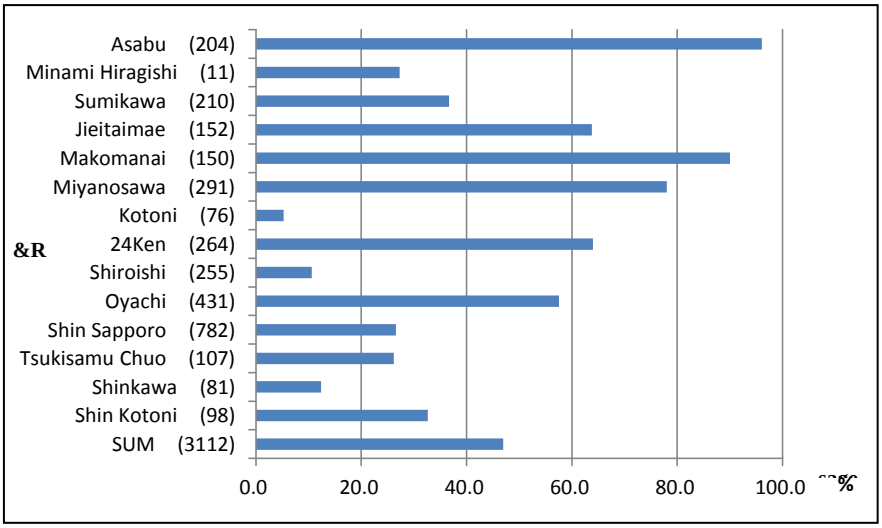


Fig. 2 P&R sites and usage rates in Sapporo

Table 1

Characteristics of the study areas

Characteristics	Makomanai	Shin Sapporo
Distance to downtown (km)	10.5	13.4
Location (with respect to downtown)	South	Southeast
Parking spaces (cars)	150	782
Daily Usage Rate (%)	90	28
Management	Municipal	Private
Hourly-based parking availability	Yes	No
Available public transport link	Subway	Subway/Japan Railway
Snow removal in winter	Yes	Yes

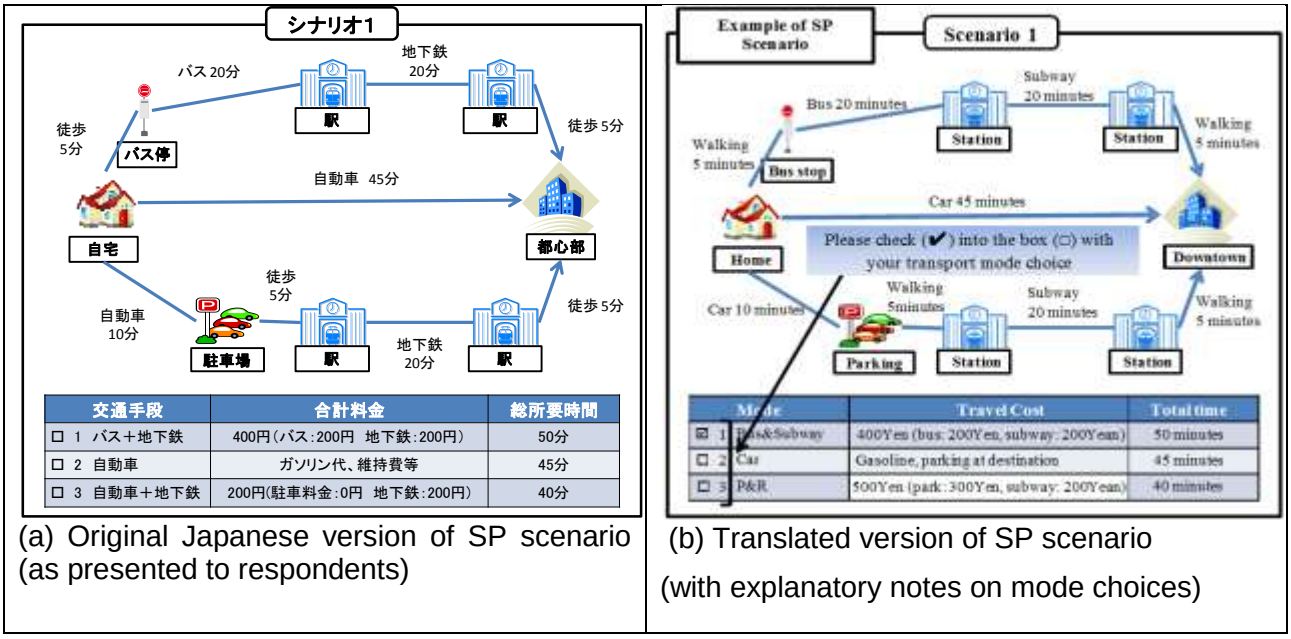
3.2 Data sample

A questionnaire survey was carried out in December 2011 to collect primary data for the analysis. The questionnaires were distributed among residents living within the districts of Makomanai and Shin Sapporo, where the P&R sites furthest from downtown Sapporo are located (as described on Section 3.1). In order to increase the participation of car users, P&R users and Bus&Ride users, the questionnaires were delivered to households located at least 2km from public transit stations. Large residential buildings with a potentially large number of travellers were randomly selected for the study. The questionnaires were distributed via residents' mailboxes, along with a paid-reply envelop; and a pen, which was included as a symbolic incentive. Also, respondents were given the option of requesting a survey output report in an attempt to increase response rates. A pilot survey was conducted one month prior to the actual survey, where a few households from each study area were visited by research team

members. The pilot survey was used to check to what level respondents would understand the questions, particularly the hypothetical mode choice scenarios, thus allowing for adjustments to be made in the format and the length of the questionnaire.

The survey focused mainly on P&R-related issues and on travellers' views and attitudes towards P&R services. However, it also included other transportation aspects both in order to gather responses from potential P&R users and to investigate the extent to which other transportation alternatives influence P&R choices. The initial part of the questionnaire was based on Revealed Preference (RP) information. Respondents were asked about their mode choices and trip frequency to downtown Sapporo, trip purpose, and the main factors when choosing a mode of transport. The core of the survey included several P&R-related questions, such as awareness about P&R parking lots, P&R costs and limiting factors to the use of P&R services. In the second part of the questionnaire, hypothetical scenarios were then presented in a Stated Preference (SP) format. The Orthogonal Array procedure (SPSS 1997) was applied to generate combinations of SP questions with independent effects, and a total of 8 scenarios were included in the questionnaires. Through these scenarios, travellers' responses to changes in in-vehicle travel time, walking time and travel costs were captured. Socio-demographic information complemented the survey.

Figure 3 shows an example of the SP scenarios used in the survey. Figure 3(a) shows the original version of Scenario 1 (in Japanese), while Figure 3(b) shows its translation. In order to ensure that respondents understand the contents and how to answer the SP scenarios, an explanatory note was included in the questionnaire. In this note, explanations about each mode were made, and an example of how to answer each scenario was presented (as indicated in Figure 3(b)).



(a) Original Japanese version of SP scenario (as presented to respondents)

(b) Translated version of SP scenario (with explanatory notes on mode choices)

Fig. 3 Example of SP scenario included in the questionnaire survey

The final sample included responses from 468 individuals, which represents a 23.4% response rate. The diversity within the Sapporo population is well represented in the sample, as shown in Table 2. Employment data shows comparable labor force distribution between respondents and Sapporo rates. Car ownership and driving license rates are higher among the sampled travellers than the averages in Sapporo. Makomanai and Shin Sapporo districts are suburban areas relatively far from downtown Sapporo, from where travellers often access the downtown area for working and shopping purposes (as described in 3.1). These districts include large residential areas with a high incidence of family-based households. These factors contribute to increased numbers of drivers and car owners.

Table 2

General characteristics of the data sample and Sapporo demographics

Characteristic	Sample (%)	Sapporo (%)
Gender		
Male	52	47
Female	48	53
Age Range		
0-17	--	14
18-29	7	14
30-44	27	22
45-60	43	23
60 plus	23	27
Employment Status		
Student	2	7
Employee	53	55
Self-employed	9	5
House-wife	16	17
Unemployed	14	5
	6 (others or no reply)	11 (others)
Car Ownership (Household)		
Yes	86	78
No	14	22
Driving License		
Yes	87	60
No	13	40

3.3 Modelling framework

The modelling exercise performed in this study focused on the likely reasons that motivate people to park and ride, as well as on the potential interactions of P&R with other transport options, in a context where unimodal car trips have increased over recent decades. A discrete choice modelling framework is used to estimate transport mode choice models in the forms of Nested Logit (NL) models (Bierlaire 2011). Random utility theory is assumed in order to enable these models to be derived. This theory suggests that choice preferences towards a certain alternative can be shown through its utility. Also, it is assumed that the alternative with the highest utility is chosen by the decision maker (Meyer and Miller 2001). The utility of a certain alternative is composed of observed and unobserved (random) terms. The observed term of the utility includes a set of observed variables related to the alternative and the decision maker; and a vector of alternative coefficients. The random term includes the uncertainties related to the analyst's limited information on individual preferences (Ben-Akiva and Lerman 1985). In the NL structure, the alternatives are grouped in different nests according to their similarities.

The two-level NL model estimated in this study includes a set of three alternatives: private car, bus&subway and car&subway, which represents the P&R alternative (Figure 4). In order to maximise the number of car-only and P&R users, the data survey was performed reasonably far from the public transit station, thus reducing the incidence of subway-only trips. Accordingly, this alternative was not included in the analysis. Following the broad literature on this topic (Bierlaire 2011; Meyer and Miller 2001; Ben-Akiva and Lerman 1985; Ortuzar and Willumsen 2001), the utility gains by using car and subway are respectively given by

$$V_c = \alpha_c + \alpha_1 \cdot t_c^2 \tag{1}$$

$$V_s = \alpha_1 \cdot t_s + \alpha_2 \cdot f_s + \alpha_3 \cdot w_s + \lambda \cdot ln\left(exp(V_b/\lambda) + exp\left(V_{pr}/\lambda\right)\right) \tag{2}$$

where

$$V_b = \alpha_1 \cdot t_b^1 + \alpha_2 \cdot f_b + \alpha_3 \cdot w_b \quad (3)$$

$$V_{pr} = \alpha_c + \alpha_1 \cdot t_c^1 + \alpha_2 \cdot f_{pr} \quad (4)$$

t_m^d in (1), (3) and (4) is in-vehicle time from home to destination $d \in \{1: \text{subway station}, 2: \text{final destination}\}$ using transport mode $m \in \{c: \text{car and } b: \text{bus}\}$. α_c in (1) and (4) is the alternative specific constant of car. α_1, α_2 and α_3 are parameters, and λ in (2) is scale parameter. (1) expresses the utility gain obtained from a trip by car from home to the final destination. f_m in (2), (3) and (4) is mode fare of transport mode $m \in \{s: \text{subway}, b: \text{bus}, \text{and } pr: \text{P\&}R\}$. w_m in (2) and (3) is walking time required to access to transport mode $m \in \{b: \text{bus}, \text{and } s: \text{subway}\}$. (3) expresses the utility gain obtained from a trip by bus from home to the subway station. (4) expresses the utility gain obtained from a trip by car from home to the subway station. t_s in (2) is in-vehicle time of subway. (2) expresses the utility gain obtained from a trip by subway to the final destination in which transport mode bus or car is used as access mode from home to the subway station. These form the bus&subway and P&R alternatives.

It is highlighted that mode transfer penalties were not considered as part of the modelling exercise in this paper. However, it should be considered for future analysis, as travellers negatively value any mode transfer, which could influence model outputs.

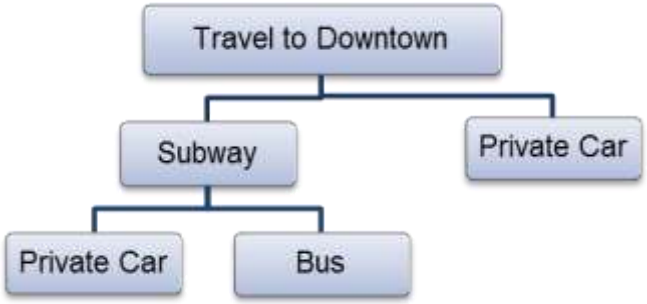


Fig. 4 Structure of the Nested Logit mode choice

3.4 Economical Welfare Analysis

A public transport sustainability analysis is developed in this study with the objective of maximising the economical welfare associated with P&R services, while ensuring public transport service provision. This analysis is meant to address consumer needs, producer needs and the local government's needs. Producer surplus and consumer surplus are estimated on the basis of mode choice probabilities. Initially, fare revenues for a bus company, P&R company and subway company are respectively calculated as:

$$R_b = f_b \cdot P_s \cdot P_{b/s} \cdot N \tag{5}$$

$$R_{pr} = f_{pr} \cdot P_s \cdot \left(1 - P_{b/s}\right) \cdot N \tag{6}$$

$$R_s = f_s \cdot P_s \cdot N \tag{7}$$

where

$$P_s = \frac{exp(V_s)}{exp(V_s) + exp(V_c)} \tag{8}$$

$$P_{b/s} = \frac{exp(V_b/\lambda)}{exp(V_{pr}/\lambda) + exp(V_b/\lambda)} \tag{9}$$

N in (5), (6) and (7) is Population. Their business profits are then estimated as:

$$PF_m = PS_m + S_m \qquad \forall m = \{s, pr, b\} \tag{10}$$

where S_m is subsidy from the local government to company operating transport mode m. PS_m in (10) is the producer surplus of company operating transport mode m, given by:

$$PS_m = R_m - OC_m \qquad \forall m = \{s, pr, b\} \tag{11}$$

where $OC_m(\forall m = \{s, pr, b\})$ is operation cost of company operating transport mode m.

Consumer surplus is given by:

$$CS = \sum_{k=1}^{N} CS_k \tag{12}$$

where CS_k is the consumer surplus of individual k calculated by using $-\alpha_2$, which is the marginal utility of income, given by (Williams, 1977; Small and Rosen, 1981):

$$CS_k = -\frac{1}{\alpha_2}\left(ln\left(\sum_{m\in\{c,s\}} exp(V_m)\right) + \gamma\right) \tag{13}$$

where $\gamma = 0.577$ is Euler's constant. Finally, the economical welfare maximization problem is formulated as:

$$\begin{aligned} \max EW &= CS + \sum_m PF_m - \sum_m S_m \\ &= CS + \sum_m PS_m \end{aligned} \tag{14}$$

with respect to f_m $(\forall m = \{s, pr, b\})$ subject to

$$S_m \cdot (PS_m + S_m) = 0 \tag{15}$$

$$PS_m + S_m \geq 0 \tag{16}$$

$$S_m \geq 0 \tag{17}$$

Note that, since the subsidies paid by the local government are received by the operating companies, they were cancelled out in the economical welfare in (14). The constraints of the economic welfare maximization problem mean that $PS_m + S_m$ which is the profit of the company is more than 0 if no subsidy is paid by the government to the operating company m, and 0

otherwise. Therefore, the optimal subsidy is calculated such that the profit is zero if a company runs in red. Otherwise, the optimal subsidy is calculated as zero.

The economical welfare maximization problem formulated above plays an important role in managing public transport systems. In general, the behaviour of the public transport operating company and the passenger is assumed as profit maximization and utility maximization respectively. As a result, economic welfare can be maximised. Utility maximization behaviour can be reflected in the passenger's modal choice behaviour. The public transport company's controllable variable may be the fare, in response to which the passenger's modal choice behaviour can change. If the public transport operating company runs a deficit, the company exits the public transport market, based on profit maximization behaviour. Such a situation may be troublesome for the local community if there are no other transportation options. Therefore, we introduced the subsidy from the local government. In the economical welfare maximization problem, the local government is factored in, with the purpose of maintaining the public transport company in the market, even if it is operating in red. However, the local government may be unnecessary if the market is efficient, i.e., the public transport company is in profit.

In this initial study, externalities, e.g. congestion, were not added to the economical welfare maximisation framework. However, further research has been planned to extend the welfare framework to include congestion, by considering that congestion is an important argument towards public transport subsidisation.

4. Discussion of the model's outputs

Table 3 summarises the results of the best-fit NL model. Alternative specific constant for mode car; and the attribute variables of in-vehicle time, mode fare and walking time are included in the final structure of the model. Whilst demographic control variables were initially tested in the model, they were not included in the final model structure because of the constraint of

modelling responses only from travellers who can choose between car and transit alternatives. Accordingly, the model is limited to respondents who are over 18 years old, have a car available at home and possess a driving license.

The summary of statistics suggests that the model is well fitted to represent the sample. Moreover, all coefficients are sign-coherent and significant at the 0.99 confidence level (critical value is 2.58). Mode car appears as less attractive than the P&R alternative, which is set as the comparison case. As other medium sized cities in Japan, parking fees are significantly high within urban areas. Also traffic policies prioritise non-motorized travel within downtown Sapporo, which slows down car traffic. Moreover, subway links are convenient between most suburban areas and downtown. These factors contribute to attractiveness of the P&R alternative compared to private car.

Coefficients of in-vehicle time, mode fare and walking time are negative, which are sensible outputs. Travellers are likely to choose modes that present the least time and fare if all else is equal. However, it is interesting to note that the coefficient related to in-vehicle time is considerably higher in magnitude than that related to walking time. The higher coefficient for in-vehicle time suggests that travellers' decision towards choosing P&R services are more sensitive to any time reductions in the public transit leg of the trip than to reductions in transfer time. Moreover, this output indicates that reductions in bus travel time would motivate bus&subway trips. Bus&subway trips are most common among commuters (approximately 60% share); while P&R is the second most used mode (approximately 28% share). The coefficient related to the walking time attribute is also statistically significant. This output is consistent with previous research and confirms that transfer time is highly significant on whether or not multimodal trips are chosen (Veras et al. 2012b).

The coefficients related to mode fare and in-vehicle time were used (in combination with actual public transit fare and travel time) to estimate the monetary value of time for trips between

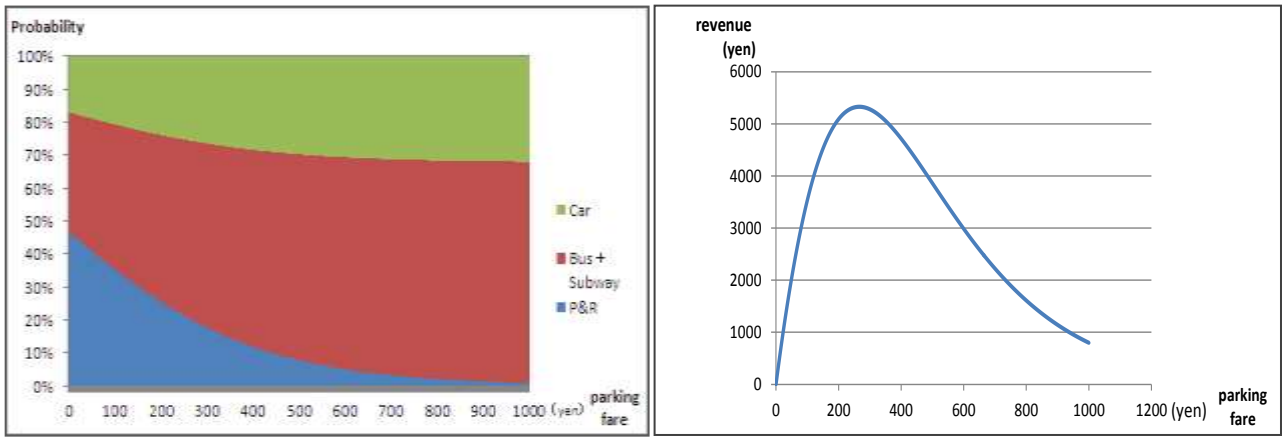
the P&R sites and downtown Sapporo by public transport. The analysis suggests a value of time of 1,980JPY/hour or 25.74USD/hour (1JPY equals to 0.013USD at the time of the study). This preliminary output gives an indication on the value of time, which may be used as an indicator for comparison with values of time from different modes on a local basis. However, values of time may vary greatly according to the users, while this variation relies on several external attributes (Wardman 2004), so they are likely to vary across places. Therefore, further analysis is required so as to produce values of time indicators that could be used in different locations.

Table 3

Outputs of the NL model

Attribute variable	**Coefficient**	**t-statistics**
ASC car*	-2.320	-6.19
In-vehicle time	-0.162	-5.31
Mode fare	-0.005	-7.31
Walking time	-0.078	-4.55
λ**	0.921	4.19
Summary of statistics		
Number of observations: 468		
Likelihood ratio: 0.45		
Predictive ratio: 65.9%		
* Alternative Specific Constant for mode car		
** Scale parameter: $0 \leq \lambda \leq 1$		

Sensitivity analysis was carried out so as to investigate the influence of parking fees on mode choices; as well as on usage rates and service revenue. For this analysis, bus fare, subway fare and time attributes were assumed constant. The analysis emphasised the strong correlation between parking costs and P&R choice. In accordance with previous research, this output suggests that parking fees should be kept at a minimum to motivate the use of P&R services (Hamer 2010). As shown in Figure 5(a), P&R share reduces to minimum levels as a result of increasing parking fees. A preliminary simulation based on 1 thousand travellers (including travellers from both Makomanai and Shin Sapporo P&R sites) was then developed to evaluate current P&R fees. This simulation suggested a monthly fee of 5,874JPY (267JPY/day, assuming 22 working days/month) as the optimal parking fee in order to achieve the highest usage rate, while achieving the highest service revenue (see Figure 5(b)). This output is closer to the actual monthly fee for the Makomanai P&R (7,000JPY) than that for the Shin Sapporo P&R (9,100JPY). The lower monthly fee applied by the Makomanai P&R is likely to contribute to its considerable higher usage rate when compared to the Shin Sapporo P&R site (see Figure 2).



(a) Modal split (b) Revenue

Fig. 5 Outputs of the parking fee sensitivity analysis

5. Numerical Examples

The sustainability analysis developed in this study looked at maximising economical welfare related to the use of P&R services, while ensuring public transport service. In this analysis, an optimization function was built to estimate optimal subway fares, parking fees and subsidies from the local government, while taking into account characteristics of the car and bus&subway alternatives. Modal choice probabilities are the basis for the estimation of business profit and consumer surplus, further leading to the estimation of maximum economical welfare (formulation described in Section 3.4).

We assumed that P&R is operated by the subway company and that the fares and subsidies of P&R and subway are optimised whereas the bus fare is fixed at 200JPY. Therefore, the constraints of the economical welfare maximization problem shown in section 3.4 are:

$$\left(S_s + S_{pr}\right) \cdot \left(PS_s + PS_{pr} + S_s + S_{pr}\right) = 0 \tag{18}$$

$$PS_s + PS_{pr} + S_s + S_{pr} \geq 0, S_s + S_{pr} \geq 0 \tag{19}$$

$$S_b \cdot (PF_b + S_b) = 0 \tag{20}$$

$$PF_b + S_b \geq 0, S_b \geq 0 \tag{21}$$

We assumed further that $OC_b = \hat{f}_b \cdot P_s \cdot P_{b/s} \cdot \widehat{N}$, $OC_{pr} = \hat{f}_{pr} \cdot P_s \cdot \left(1 - P_{b/s}\right) \cdot \widehat{N}$ and $OC_s = \hat{f}_s \cdot P_s \cdot \widehat{N}$ in which we set $\hat{f}_b = 200$JPY, $\hat{f}_{pr} = \hat{f}_s = 250$JPY, and $\widehat{N} = 1000$. Thus, we have assumed only the variable operational costs because of the difficulty in setting realistic ones. In public transport, however, the fixed operational cost plays important role in expressing the relationship of the decreasing average cost. However, this assumption does not mean a restriction of the model since the fixed operational cost can be addressed in the model without any model modifications. Note that, the optimal fare and fee are estimated independent from the introduction of the fixed operational cost, and that the maximized economical welfare decreases by the summation of the fixed operational costs compared with the one calculated without the fixed cost. The optimal

subway fare and parking fee are estimated respectively 251JPY and 192JPY/day at which the maximized economical welfare is calculated as – 1,733JPY/person for trips between the investigated P&R sites and downtown. In this example, no subsidy was required. The deficit of P&R was calculated as 3,100JPY and the profit of subway was calculated as 3,100JPY, thus covering the deficit. However, the calculated fares are considerably lower than the actual fares and fees applied in Sapporo. Subway fares from Makomanai and Shin Sapporo stations to downtown Sapporo (Sapporo station) are respectively 280JPY and 310JPY at which the economical welfare is calculated as –1758JPY/person. In this case, an increase of 1.4% in welfare is gained at the optimized fare and fee compared to the present welfare. The estimated parking fee is also lower than the parking fees applied by both P&R sites (see Section 4). Moreover, it is lower than the parking fee suggested in Section 4, which was estimated without taking into account characteristics of other transportation modes. Figures 6 and 7 show the profit fluctuation for modes bus and P&R according to changes in subway and parking fees. These figures highlight that changes in subway fares and parking fees will directly influence business profits not only for the P&R alternative, but also for the bus&subway alternative.

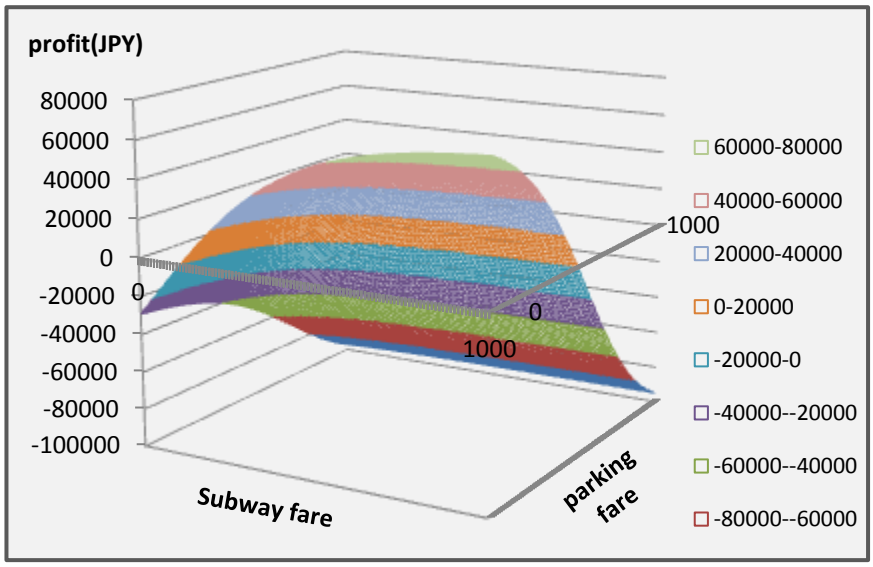


Fig. 6 Profit of bus company based on the subway and parking fares

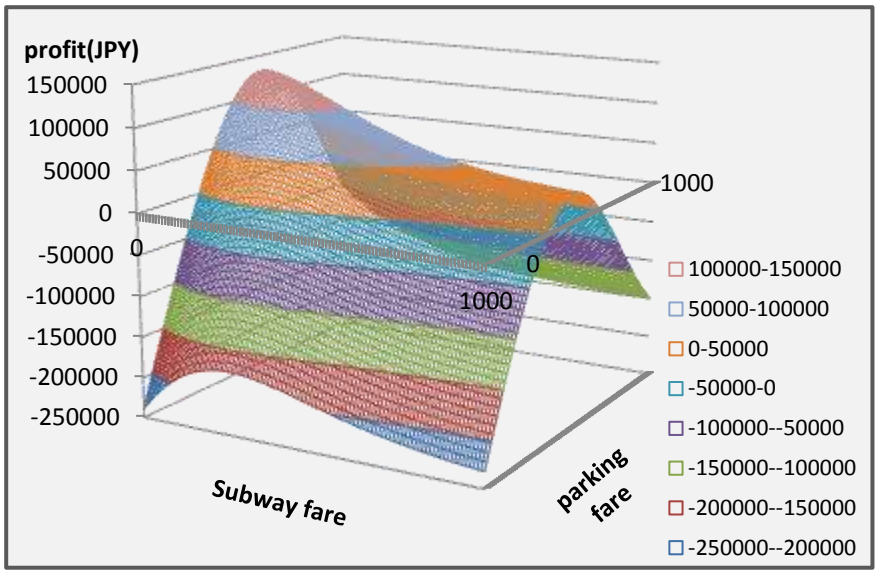


Fig. 7 Profit of P&R company based on the subway and parking fares

The example described above may be an unrealistic scenario considering the public transport system in Sapporo. Like most of the cities in Japan, Sapporo faces the difficulty of ensuring public transport profitability without subsides. We consider then a second scenario, where operational costs of bus, P&R and subway are assumed as one and a half of the respective operational costs in the first example. This scenario leads to the need of subsidies while being more realistic. The optimized variables which maximise the economical welfare were calculated as $f_{pr} = 200$ JPY, $f_s = 320$ JPY, $S_b = 61{,}000$ JPY and $S_{pr} + S_s = 95{,}000$ JPY. The subsidies cover the deficits of bus, P&R and subway systems which were calculated as 61,000JPY, 35,000JPY and 60,000JPY, respectively. Both fares of P&R and subway increase compared with the first example. Figure 8 shows the maximum welfare as a function of total subsidy.

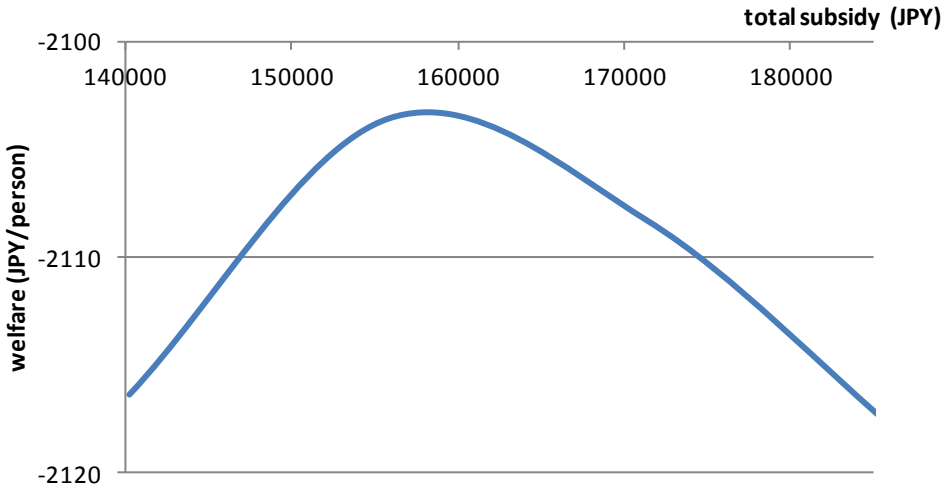


Fig. 8 Maximum welfare as a function of total subsidy

These are case specific estimations, which cannot be directly transferred to other cities either within Japan or worldwide. However, the formulation presented in this paper can be used to estimate new coefficients and cost indicators in different places after necessary adjustments to account for economic differences.

6. Conclusions

The economical welfare analysis presented in this paper has sought to maximise economical welfare associated with P&R services, while taking into consideration local community need for a public transport service. Ensuring maximum economical welfare is a challenge directly associated with the success of P&R systems. The Japanese context is investigated in this study, where P&R trips complement the common non-motorised/transit trips or transit/transit trips. A recent trend towards unimodal trips by car has also been observed. P&R economic efficiency is achieved by maximising economical welfare, which in turn motivates demand increases. The analysis in this study suggests that the current costs imposed to P&R

users in Sapporo are considerably higher than the optimal cost for increasing usage rates. Consequently, reduced usage rates lead to negative effects on business profit. An increase in P&R share would potentially supplement the multimodal transportation network of Sapporo, while replacing unimodal trips by car.

Model outputs indicate that the probability of choosing P&R is not only influenced by P&R fees and times, but also by attributes of alternative transportation modes. Particularly, characteristics of the bus&subway alternative (transit/transit link) appeared to be correlated with P&R choices. The interactions of P&R with alternative transportation modes are essential and should be taken into consideration in any strategic transportation plans envisaging to motivate changes in choice behaviour. With necessary adjustments, the modelling framework presented in this paper may be used by government bodies in Japan and elsewhere when evaluating P&R services.

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