CALCULATION OF SOCIAL COST OF ON-STREET PARKING IN RESIDENTIAL AREAS BASED ON TIME SPACE OCCUPANCY

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abstract: In the past 10 years, the number of motor vehicles in Seoul has increased tremendously. This has worsened the traffic condition in not only arterial roads but also residential streets. Especially, the environment of the residential areas has deteriorated due to on-street parking. So recently, some wards of Seoul Metropolitan Government started to apply the Residential Parking Permit Program (RPPP), however there seems to be no theoretical basis for setting the present fee. This paper proposes a charging scheme based on the social cost of on-street parking calculated based on Time-Space Occupancy (TSO) concept in Seoul and Tokyo. TSO is a concept that modifies and expands the ordinary occupancy concept in the traffic flow theory, and it shows TSO consumed by a transport vehicle/mode.

1.INTRODUCTION

Streets in residential areas are considered as not only space for people to walk on and vehicles to drive in but also spaces to provide a society with various functions such as access, accommodating public utilities, prevention of disasters and environment. However, on-street parking is such a serious problem in South Korea that it erodes the space on the streets to the extent of causing inconvenience for pedestrians, decreasing traffic capacity, increases traffic accidents, impeding access to the side roads, and degrading its function to prevent disasters. These negative effects are considered as social costs caused by on-street parking. Since it exclusively occupies a part of the street for a certain period of time, it is necessary to take up a notion of space in order to calculate this social cost.

In this paper, a new concept of 'Time-Space Occupancy' is proposed for the calculation. This concept derives from a notion of 'occupancy' which is often used in traffic engineering and is a unit to indicate a certain period of time and the space occupied by the mobile or stationary transport vehicles or modes. Also, we assume the social costs both in Seoul and Tokyo and compare the two cities. We also study effectiveness of parking control system such as a law of garage certification.

This study resulted in two findings: We were able to 1) propose a calculation method for social cost of on-street parking using TSO; 2) suggest validity of the approach based on this concept.

2.TIME SPACE OCCUPANCY

2.1 Existing Studies and Time- Space Occupancy

Since Tsukaguchi (1987) suggested the idea of Space Occupancy of streets in residential areas, this idea had studied by Nakagawa (1988) and Tsukaguchi (1989). But their studies related only to sense of danger and road maintenance in residential areas. Therefore the existing studies have not covered the social costs caused by on-street parking. Mark (1991) has calculated social costs of parking in relation to a traffic policy, but his calculation was only related to the facility cost of parking space.

On the other hand, in his study (1987), Tsukaguchi suggested that the traditional notion of occupancy of traffic engineering would be used to express occupancies of pedestrians (p), cars (c) and bicycles (b) on roads in residential areas.(See Table 1)

Table1 Comparison of space occupancy and time occupancy between each mode

Space occupancy	Time occupancy
$Qsi = 1/(L \cdot d) \sum_{j=1}^{Ni} Aij \cdots\cdots\cdots\cdots (1)$	$Qti = 1/T \sum_{j=1}^{ni} tij = 1/T \sum_{j=1}^{ni} L/vij \cdots\cdots (3)$
Where, formula (1) becomes the following formula (2) because of $ni = qi \cdot L/\bar{v}i$. $Qsi = qi \cdot \hat{A}i/(d \cdot \bar{v}i) \cdots\cdots\cdots\cdots (2)$	Where, formula (3) becomes the following formula (4) because of $ni = qi \cdot T$. $Qti = L \cdot qi/\bar{v}i \quad \cdots\cdots\cdots\cdots (4)$

Note: i: Transport modes (i= p, c, or b) T: Long enough time [seconds]
L: Long enough distance [m] d: Width of the street [m]
$\bar{v}i$: Average speed per transport mode i[m/second/veh]
qi: Transport volume [veh/second]
$\hat{A}i$: Average occupied area per transport mode i [m^2]
Aij: occupied area of jth vehicle(or person) of transport mode i [m^2]
tij: time required for jth vehicle(or person) of transport mode i to pass through the road section of L [seconds]
vij: jth speed of transport mode i [m/second]
Source: Tsukaguchi, H., Mori, M.(1987) Occupancy indices and its application to planning of residential streets, Journal of Civil Engineering and Planning 4-7.

As the above formulas (2) and (4) show, each unit is same:[number of units]. It is difficult, however, to make a simple comparison between parked car, a source of stationary occupancy, and driving car, a source of mobile occupancy. But if we use TSO concept, we can easily distinguish these two forms of space use by car. So TSO of each transport mode can be expressed as the following equation (5). This concept can be called as the volume of TSO which occupies a space of the street and time within a certain period of time. (Note: Naturally, we can extend the TSO concept in 3-dimension space including street use above and below the surface level.)

$$Qtsi = \sum_{j=1}^{ni} Aij \cdot tij = \sum_{j=1}^{ni} Aij \cdot L/vij \cdots\cdots\cdots\cdots (5)$$

Where, formula (5) becomes the following formula(6) because of $ni = qi \cdot L / \bar{v}i \cdot \hat{A}i$.

$$Qtsi = qi \cdot (L / \bar{v}i) \cdot \hat{A}i[m^2 \cdot \text{seconds}] \cdots\cdots\cdots\cdots (6)$$

The formula (6) shows only the volume of TSO assessed on roads, but we need a unit which can compare with the level of TSO assessed on the roads whose width and length are different. Thus, the calculation in this paper is designed to overcome this difficulty by incorporating time in the concept of street itself. Let us take an example. Add an idea of time to <the length of the street> (L) · <the width of the street> d), and assume that a certain space of the road is available. This situation is expressed as (L)·(d)·(T). The formula (7) shows TSO level assessed on the roads whose width and length are different. It shows the same unit of formulas (1)-(4).

$$Otsi = Qtsi / (L \cdot d \cdot T) \cdots\cdots\cdots\cdots (7)$$

$$Otsi = (qi \cdot \hat{A}i) / (d \cdot \bar{v}i \cdot T) \cdots\cdots\cdots\cdots (8)$$

2.2 Calculation for TSO

Let us consider how much of the space one person occupies when a person goes through a given distance. This assumption is based on the following condition:

Vehicle unit of each transport mode: 1	Duration of time : 1 hour
Average speed of cars : 30km/h	Average speed of bicycles:12km/h
Average speed of pedestrians: 5km/h	Length of the street:100m

Table 2 shows the hourly TSO per capita and degree of the occupation of the objective streets. The TSO of on-street parking is as much as 54.5 times and 150 times as those of automobiles and pedestrians, respectively. Of course, if only one person uses the private car, the figure decreases to 300 times as that of pedestrian. It means TSO of on-street parking is the critical factor in streets.

Table 2 Comparison of characteristics of TSO per each mode

Modes	Space occupying of unit mode: A[m^2]	Assumed using persons[persons/veh]:B	Time occupying :C[secs]	TSO[m^2. secs] A*C/B	Efficiency[persons/hr]
Moving situation					
Car	(5+S.T.)×2.75=82.5	2	12	495	54.5
Bicycle	(2+S.T.)×1=5	1	30	150	180
Pedestrian	2.5	1	72	180	150
Stationary situation					
Car parking	3*5=15	2	3600	27000	1
Bicycle parking	1*2=2	1	3600	7200	3.75
Pedestrian talking	0.7* 1 =0.7	1	3600	2520	10.7

Note: S.T. = Stopping distance [m]

Efficiency i = (TSO(car parking)*using persons) /(TSO(mode i)*using persons)

3.CALCULATION OF THE SOCIAL COST CAUSED BY ON-STREET PARKING

3.1 Various Effects of On-Street Parking

There are many external effects of on-street parking. For example, Honma(1995) in his calculation, included speed loss of driving cars caused by on- street parking. Though the speed loss affects the volume of exhaust, this has not been studied much and it is difficult to calculate the volume of exhaust in cost. While, Hamada(1988a; 1988b) calculated loss from protruding cars due to on-street parking. Kataya(1994) suggested a model formula by the width of the street and traffic flow rate as an effect on the speed of driving cars caused by on-street parking. There are other studies that suggest on-street parking reduces safety of pedestrians and vehicles. But their measurements have not progressed much. This concept can be expressed by the following formula (9). However, in this paper, due to data availability we have calculated the social cost of major items only i.e.: the factor of TSO.

$$Cfd = \sum_{j=1}^{7} \sum_{k} \sum_{l} Pi \times Xj, k, l \quad \cdots\cdots(9)$$

Where, Cfd= Total social cost of factor f during the day d
Pi is unit cost.
X is TSO.
X1=Time-Space Occupancy Volume by on-street parking
X2=Increased exhaust caused by on-street parking
X3=Reduced speed caused by on-street parking
X4=Added occupancy caused by protruding cars
X5=Reduced safety
X6=Lowered ability of prevention of disasters
X7=Disturbance for landscape
k is a type of mode, l is a type of road

3.2 Calculation of TSO According to Traffic Modes

Table 3 Basic assumptions for accounting

Approach		Parking fees based approach	Land prices based approach
Seoul	Basic assumption	Parking fees 250yen／hr or 10,000yen／month	Average land price:100,000 yen／㎡、interest rate is 5%／year
	Unit cost	0.0021yen／㎡・second	0.00016yen／㎡・second
Tokyo	Basic assumption	Parking fees: 280yen／hr or 13,000yen／month	Average land price:300,000 yen／㎡、interest rate is 3%／year
	Unit cost	0.0023yen／㎡・second	0.0003yen／㎡・second

Note: Won : yen = 1 : 8

Source: Nishimura, T.(1975)、A study for survey in residential environment areas、A thesis of University of Tokyo.

There are two ways to include TSO into the cost: 1) approach based on parking fees; 2) approach based on land prices. First of all, the average parking fees for regular users in Tokyo are: 1) an hourly parking lot costs 280 yen; 2) a monthly parking lot costs 13,000 yen. If we calculate based on this condition, the cost will be 0.0023yen/㎡·seconds. If the land price of 300thounds yen per square meters and interest rate of the bank is 3%, it will be 0.0003 yen per square meters. But Korea's numbers will be 0.0021 and 0.00016, respectively.

3.3 Comparison of The Characteristics for Different Districts by TSO

Although, it is quite difficult to compare districts if their characteristics, population density, economy, and traffic patterns are different from one another. In this paper, however, we will make a comparison among the districts in TSO level, number of cars per capita, daily social costs per capita, and economic standards.

1) Comparison by TSO Level
=TSO by on-street parking ／TSO of the streets in the study area.[%]･･･(10)

2) By the number of cars = TSO ／ Number of cars owned by 1,000 people
[K ㎡ · seconds／car／1,000people]･･･････(11)

3) Calculation of the social cost = Total daily social cost by on-street parking
／ Population[yen／person／day]･････(12)

4) Comparison by economic standards = Total daily social cost by on-street parking ／Daily GNP[%／GNP／day]･･･(13)

3.4 The Method of Assessment

It is possible to charge the assessed fee evenly for each mode, but the traffic volume or the flow of pedestrians affects it differently even on the same street. Therefore, in this paper, the methods to charge the assessed fee will be different according to the 24 hour TSO by each transport modes and by state (moving/stationary). The assessment fee will be calculated by the formula (14) and (15).

$$Yt = \alpha \cdot \text{Unit cost} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(14)$$

$$\alpha = \sum_{i=\text{mode}} si \;/\; \sum_{i=\text{mode}} Si \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(15)$$

Where, Yt is the assessed fee for a certain period of time t.
Unit cost is the assessed fee by TSO only without a weight parameter.
α is a weight parameter by TSO.
si is the total TSO for a certain period of time.
Si is the total TSO for 24 hours.

4. APPLICATION TO SEOUL AND TOKYO

4.1 Seoul in The 1990s and Tokyo in The 1970s

In Seoul where there is no obligation to possess a garage for vehicle owner, problems concerning on-street parking in residential areas are far more serious than in Japan. The number of registered automobiles is more than two million as of August 31st, 1995. But there are only 1.09 million parking lots including on-street parking lots, so after eight at night, the people struggle to acquire a parking space for that night. This kind of illegal on-street parking and the lack of parking space cause degradation of living environment in the residential areas in various dimensions. Urgent measures to improve and solve it are necessary in terms of environmental policies for the city.

Table 4 Comparison of the number of owned cars per 1,000 people

	No of the cars owned by 1,000 people(cars/1,000people)			
Nations	1960	1970	1980	1990
USA	—	437	534	560
Germany	90	220	378	490
U.K	83	211	262	340
Japan	—	85	203	261
ROK(Seoul)	—	—	16	89

Source: Lee,K. and Jin,J.(1994)、Transportation improvement livable neighborhoods in Seoul、Proceedings ISCP、Fukuoka and Kitakyushu，Japan.

As Table 4 shows, it is interesting that the current number of possessed cars per 1000 people in Seoul is almost the same as that of Europe in the 1960s and that of Japan in the 1970s. This similarity is seen not only in a quantitative dimension but also in a phenomenal dimension. Just as Japan introducing traffic calming measures (e.g. community zone) when the environment of residential areas were jeopardized due to rapidly increased number of cars, Seoul has just started to take those kind of measures. Given this background, we will use the data from Tokyo in the 1970s and those from Seoul in the 1990s that had been taken in general residential areas.

4.2 A Survey Conducted in Residential Areas in Seoul and Tokyo

Study areas in both cities has chosen because of the availability of basic data collected by an extensive survey of the Government Agencies which are the Seoul Development Institute in Korea and the Metropolitan Police Board in Japan. The land area of the block in Tokyo is twice as that of Seoul, but they are very similar in the population density and density of houses. With respect to the number of cars owned, the level in Soul is 3.5 times higher than in Tokyo.

There are two types of data: 1) Social and economic attributes and 2) traffic volumes of cars and pedestrians on one weekday. As for parked cars, data collecting in Seoul was conducted 6 times a day through the June 20th, 1996 supplementary survey, while the collection was conducted only 3 times a day in Tokyo. (See Table 5, Table 6)

Table 5 Outlines of each area in Seoul and Tokyo

Name of areas / Contents	Seoul Daejo area (Seodaemun-Ku)	Tokyo Tokumochi area (Ohta-Ku)
Area of block	0.48k ㎡	0.9k ㎡
Rate of road area	19.6%	16.5%
Population	16,614 peoples	28,916 peoples
Density of population	34,613 peoples／k ㎡	32,129 peoples／k ㎡
No of households	5,943h.h.s	9,512h.h.s
No of cars	2,563 cars	1,178cars
Income	8,000 $ ／capita	4,000 $ ／capita
Date of survey	February 14, 1995	April 28, 1974

Source: the Report of Seoul Development Institute(1995), A study on Design and Operation Guide for District-Level Road(Seoul Daejo area); Nishimura, T.(1975)、A study for survey in residential environment areas、A thesis of University of Tokyo.(Tokyo Tokumochi area)

Table 6 Contents of survey

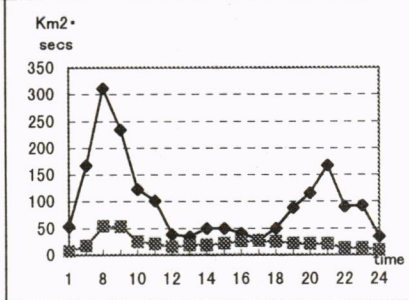
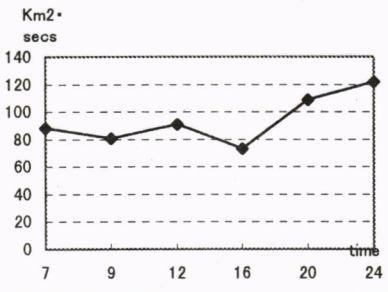
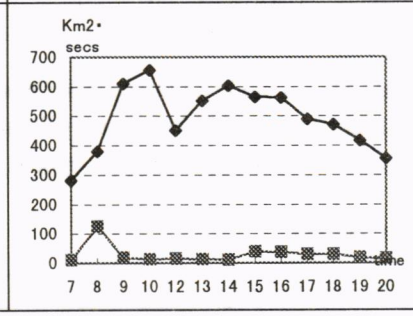
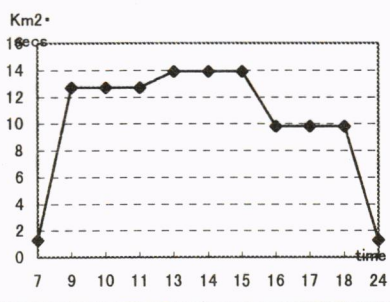
Area	Contents of survey
Seoul Daejo area	Socio-economic data; personal route and mode data of residents in 736 households (sample ratio,12.4%) and 189 commuters(sample ratio,23%) who work in the area; parking data
Tokyo Tokumochi area	Socio-economic data and travel data are similar with Seoul's case. But parking data are collected for 3 times in a day.

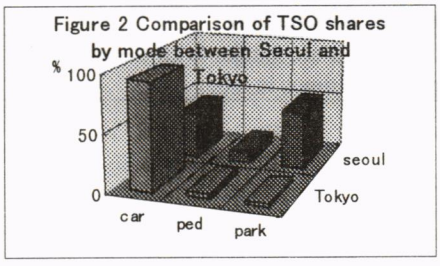
4.3 Traffic and Parking Patterns

One way to charge for on-street parking is to base with the market price, i.e. the charge of the nearby private parking space. Another way is to charge different to workers or visitors. In other words, based upon the different level of pedestrian flows, the parking fee maybe charged. For example, while at night, the less pedestrians use the street, the less you pay. Making a clear distinction in parking payments based on the social cost is an effective measure in Seoul where any parking lots cannot be increased in the existing residential areas.

Based on this idea, Figure 1 shows pattern of 24 hour TSO by transport modes in residential areas. Tokumochi area in Tokyo is represented by the data on points which has the largest traffic volume in the network. As Figure 1 shows, the patterns of cars and pedestrians are similar to each other, but the pattern of parking is just opposite. In Tokyo, the darker it gets, the less the traffic volume gets; while in Seoul, the traffic volume hits the peak at midnight and decreases at four in the afternoon. This reflects the seriousness of the lack of parking lots in Seoul.

Figure 1 Patterns of 24hours TSO of each area and mode

	Patterns of car and pedestrian	Patterns of on-street parking
Seoul		
Tokyo		



As Figure 2 shows, the streets in Tokyo are occupied by driving cars by 92.3%, parked cars by 2.4%, while those of Seoul are occupied by parked cars by high rate of 50.3%, by driving cars by 40.6% and by pedestrians by 9.1%. It means that streets in residential areas in Seoul mostly have lost their original function.

4.4 Comparison of Characteristics for Each Area by TSO

Table 7 shows the characteristics of social costs of each area by the TSO calculated based on Formulas (10)-(13). The social cost calculated by hourly parking lot fees in Seoul is 292.6 yen/day per capita. That of Tokyo is 81.8 yen/day per capita. In an economic term, in Seoul it is 13.3% of GNP while in Tokyo it is only 7.5% of GNP. So we see how serious the situation is in Seoul. If we make a comparison based on the number of cars per 1,000 peoples, Seoul' s number marks 3.34 times higher than that of Tokyo.

In comparison by level of TSO, 28.4% of the streets are used for on-street parking in average per day in Seoul. Since it is 1.3% in Tokyo, Seoul's number is 21.8 times higher than Tokyo's. This difference results from the difference in obligation to possess a garage for vehicle owner. So in Seoul, those who own a car and possess their own garages currently have to pay for 292.6 yen a day regardless of their intention. In order to introduce a fair measure and protect environment in the residential areas, it is necessary to assess the charge fee to 'free riders' who use spaces of the street freely.

Table 7 Comparison of the characteristics for each area by TSO

Comparison by each index	Daejo area: A	Tokumochi area: B	A/B(times)
TSO(k ㎡ · seconds)	2315	167	11.6
Percents of TSO(TSO%)	28.4	1.3	21.8
No. of cars(k ㎡ · seconds／car／1000peoples)	16.3	4.4	3.34
Social costs(yen／person／day)	292.6(22.3)	8(1.6)	3.6
Economic standard(%／GNP／day)	13.3(4.7)	7.5(0.15)	1.8

Note:1)Price is adopted by present value(1 : 8 : 8)
2)Value of ( ) is adopted by land prices.

4.5 Calculation of Fees of RPPP

Making a distinction in the cost according to the situation how much the extent of street use is one way. In this case, it might become difficult to give up cars due to daytime parking fees. If so, we come up with another idea that this measure is accompanied by the RPPP in the residential areas. Table 8 shows the assumed fees of RPPP based on the idea of making distinctions.

Table 8 Assumed charge fee of RPPP by traffic patterns

Contents	Seoul	Tokyo
Percentages of TSO in a daytime(%)	77.6	73.4
Percentages of TSO in a nighttime(%)	22.4	26.6
Assessment fee of daytime(yen／hr／car)	211(31)	411(29)
Assessment fee of nighttime(yen／hr／car)	61(9)	149(10)

Note: 1) Daytime means from 8 AM to 8 PM.
2) Fees in ( ) are in cases using monthly parking lots as a standard.

5. POLICY SUGGESTION AND FUTURE STUDY

In Seoul, the lack of parking space caused by reckless on-street parking in existing residential areas erodes original function of the streets. As the first step to solve social economic problems, we tried to calculate the social costs caused by on-street parking based on TSO, making a comparison between Seoul and Tokyo. Due to insufficient materials, we could not measure external economic negative aspect such as traffic jam caused by on-street parking, safety issues, and appearance damage due to lack of materials,. However, this study is significant in a sense that the issues nobody has studied earlier were taken up. The external economic effects of on-street parking in the dimension of TSO was also studied.

Further, We discussed how much we should have the users pay for the RPPP. For the future, it is necessary to analyze the above mentioned external economic effect including others already addressed.

Note:1) Main social report of Chosun Daily Newspaper(Sept 19, 1995)、「A very serious violence because of parking problem -fight to neighborhood with a knife ,Sometimes suicide

also- : New social diseases」
Source: Lee, J.(1996)、A study on traffic demand analysis and evaluation methods for district-level transportation planning 、A P.H.D. thesis of University of Dankook.

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