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REDUCTION IN VEHICLE COMMUTER TRIP LENGTHS IN SAPPORO URBAN AREA

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ABSTRACT

As part of low-carbon urban transport policy, the shortening of commute journeys has become a major consideration owing to temporal changes in the characteristics of long-term residences and workplaces. This study was conducted to clarify the changes in vehicle-related commuting behavior in Sapporo and to examine the effectiveness of efforts put in for shortening commutes on the basis of four previous central Hokkaido person–trip (PT) surveys. Potential commute reductions were calculated by applying the optimal commuting assignment problem on the basis of the changes in the number of attraction trips in each employment zone from an estimated preference curve that indicated commuting behavior. The transitions of annual distribution for commuting distances and potential commute reductions were also presented via cumulative distribution curves. The results revealed a recent downward trend in the number of vehicle-based commutes and a fixed distribution of commute lengths in Sapporo.

Keywords: commuting preference function, optimum commuting assignment

INTRODUCTION

Because commuting is a major part of urban transport, the consideration of commute reduction in transport/land-use measures is an important issue in supporting low-carbon urban logistics. Commuting involves the movement of traffic from residences to workplaces, which means that it is significantly affected by home/workplace distribution structures (e.g., the scale or geographical location of residences and workplaces) and by commuters' preference of the area to reside and work.

This study was conducted to clarify the changes in vehicle-related commuting behavior in Sapporo and to examine the effectiveness of efforts required to shorten commutes on the basis of four previous central Hokkaido person–trip (PT) surveys. We calculated potential commute reductions by applying the optimal commuting assignment problem on the basis of both the estimated preference curves that indicate the commuting behavior of workers and the adjustment of business operator numbers in individual employment zones. The transitions of annual distribution for commuting distances in each PT survey year were also presented via cumulative distribution curves to clarify the characteristics of vehicle-based commutes in Sapporo and to support the discussion of future measures for the promotion of low-carbon urban transport.

Chapter 2 reviews previous studies. Chapter 3 clarifies commute-related changes observed in the Sapporo metropolitan area between 1972 and 2006. Chapter 4 describes the method used to estimate preference curves at the beginning of each PT survey year and also formulates the optimization commuting assignment problem using these curves on the basis of (1) the changes in the number of workplace locations in each zone (i.e., commuter destinations) as the policy variable and (2) the total potential commute length reduction for the entire area as the objective function. In Chapter 5, the discrepancy between the calculated potential commute length reduction in the Sapporo metropolitan area and the actual total trip length in each PT survey year are compared and discussed. Chapter 6 presents our conclusions.

REVIEW OF PAST STUDIES

In this study, we used the trip distribution model for the optimal commuting assignment problem, which is based on an analogy of the Stouffer hypothesis applied to migration (Stouffer, 1940). Regarding this approach, the trip distribution model based on Stouffer's intervening opportunity hypothesis was applied in the 1956 Chicago Area Transportation Study (Stopher and Meyburg, 1975). Black and Conroy (1977) suggested a conceptual variation of this model that introduced zonal preference functions. Subsequently, Masuya and Black (1992) and Black et al. (1993) expanded the model to explain the preference of the employees' residence and employment place in each zone by introducing fitting mathematical functions to the shape of the preference functions. Then, Masuya et al. (2006) suggested that the model be expanded to include typical patterns of zone-specific travel behavior according to investigated zonal parameters. Masuya et al. (2008) also clarified preferences for places to reside and work in actual commutes using preference curves based on 1972, 1983, and 1994 PT survey data for the Sapporo urban area. The authors formulated the optimal commuting assignment problem by considering these preferences and examined the commute reduction potential by varying the number of residence/work locations. They also applied the preference functions for estimating the mean trip length of the journey to work in major four cites of Hokkaido, Japan (Masuya et al. 2010). Using a similar approach, Black et al. (2010) proposed that urban sustainability can be estimated in terms of both the environmental burden and accessibility using the optimal commuting assignment problem with the preference curves and functions incorporated into the problem. For the Sapporo metropolitan area (the target of this study), Miyamoto et al. (2007) established the random utility/rent-bidding analysis (RURBAN) model as a representation of land use/transport for decision support and ran simulations for several policy scenarios.

In this study, we identified the changes in commuting behavior from the past to the present by quantifying commutes in urban areas. This approach differed from that of Miyamoto et al. (2007) in terms of the analysis method used. Changes in commuting behavior in the Sapporo metropolitan area were then analyzed using preference curves proposed in previous studies by Masuya et al. (2010) and Black et al. (2010), and the commute reduction potential was examined. The novel characteristics of this study are (1) the use of data on vehicle-based commutes from four previous PT surveys, including the latest one conducted in 2006 for the Sapporo metropolitan area; (2) the calculation of potential commute reduction with workplace changes according to the workplace-based optimal commuting assignment problem; and (3) the time-series comparison of changes in the distribution structures of places of residence/work over the previous 34 years through the use of cumulative distribution curves.

POPULATION CHANGES IN CENTRAL HOKKAIDO METROPOLITAN AREA PT SURVEY YEARS

Changes in population distribution in the Sapporo metropolitan area

First, changes in population distribution in the Sapporo metropolitan area, commutes, and vehicle-based commutes were calculated for individual years, and the results were compared.

In this study, origin–destination (OD) trips for commuting and vehicle transportation were analyzed on the basis of the data from PT surveys conducted in 1972, 1983, 1994, and 2006 in seven cities and three towns (Sapporo, Kitahiroshima, the former city of Ishikari, Chitose, Eniwa, Otaru, Ebetsu, Nanporo, Naganuma, and Tobestu) in the central Hokkaido metropolitan area centered on Sapporo.

For time-series comparisons, the number of target zones in the OD table was adjusted to match the 1972 zone count (53 in total). Figures 1 and 2 show population shifts for each zone in Sapporo between 1983 and 1994 when the Toho subway line was opened, and between 1994 and 2006 when the Tozai subway line was partially extended. Between 1983 and 1994, when the Toho subway line was opened (Figure 1), the population in the suburbs surrounding the subway network substantially increased, whereas the population in city-center areas surrounding Zone 1, where workplaces are concentrated, decreased by 1,000–5,000. This decrease was thought to stem from a relative decrease in the number of residential areas owing to the limitations of zoning areas and living environments in city-center zones with numerous workplaces, despite the improvement in the public transport infrastructure. Meanwhile, the suburban area around Jozankei (Zone 53) stood out, with a population decrease of more than 20,000. Because the population of the entire city was increasing, this decrease was probably caused by a population shift to highly convenient areas around the city center, where employment opportunities were abundant, rather than by a population outflow to other cities. These data indicate the progression of suburban sprawl and an increased concentration of transportation to the city center.

Between 1994 and 2006 (Figure 2), a population return to the city center was observed, in contrast to the change observed between 1983 and 1994. In 2006, the residential area distribution pattern of suburban spread and city-center sparseness changed, presumably owing to a stronger tendency of people returning to the workplace-rich city center.

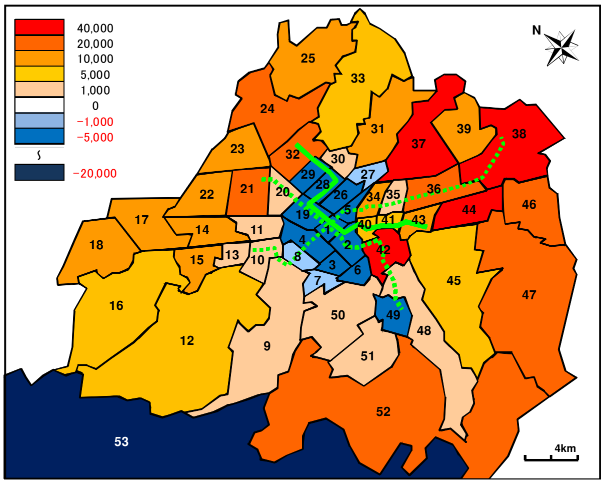

Figure 1 – Population shift (1983–1994)

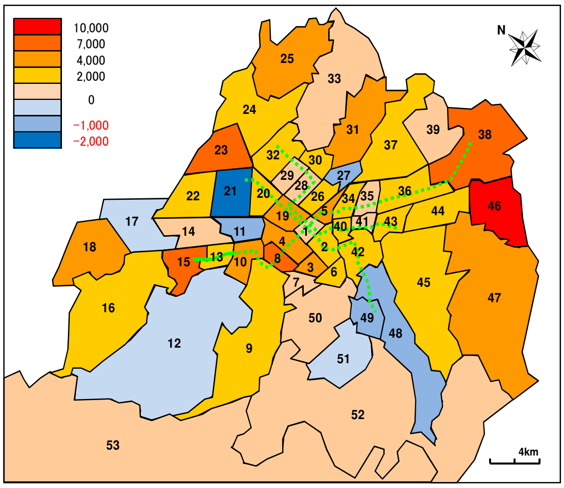

Figure 2 – Population shift (1994–2006)

Characteristics of commutes in the Sapporo metropolitan area

Next, analysis was performed with focus on commutes on the basis of the central Hokkaido PT surveys conducted in 1983, 1994, and 2006. The first PT survey, which was conducted in 1972, was excluded because the zoning used in this survey was much rougher than that used in other surveys. Figure 3 shows the PT survey zones (70 in total).

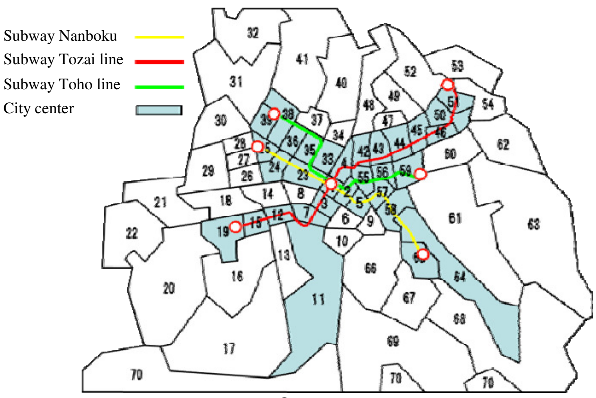

Figure 3 – Zoning in the Sapporo metropolitan area

On the basis of the commuting OD table, the trip length for each transport mode was calculated using the distance between zones (Table 1). Figure 4 focuses on the trip length and shows the results of calculations to find the number of trips for each mode in increments of 2 km. Although buses and railways that connect cities outside Sapporo represent different modes of transportation, they were treated as a single mode because the study focused only on the commuting OD in Sapporo, which resulted in a small number of trips.

Table 1 – Commuting OD in Sapporo

	1983(2nd)			1994(3rd)			2006(4th)		
Mode	No. of trips	Ratio	Trip length (km/person)	No. of trips	Ratio	Trip length (km/person)	No. of trips	Ratio	Trip length (km/person)
Subway	125,496	25.2%	6.80	156,471	25.8%	7.06	169,450	26.3%	7.07
Bus/Train	72,431	14.5%	6.27	63,222	10.4%	7.08	62,498	9.7%	7.51
Vehicle	213,659	42.9%	6.19	286,732	47.3%	6.51	293,222	45.6%	6.49
Walking/Bicycle	86,852	17.4%	1.79	99,596	16.4%	1.83	118,524	18.4%	2.03
All modes	498,438	100%	5.59	606,021	100%	5.94	643,694	100.0%	5.92

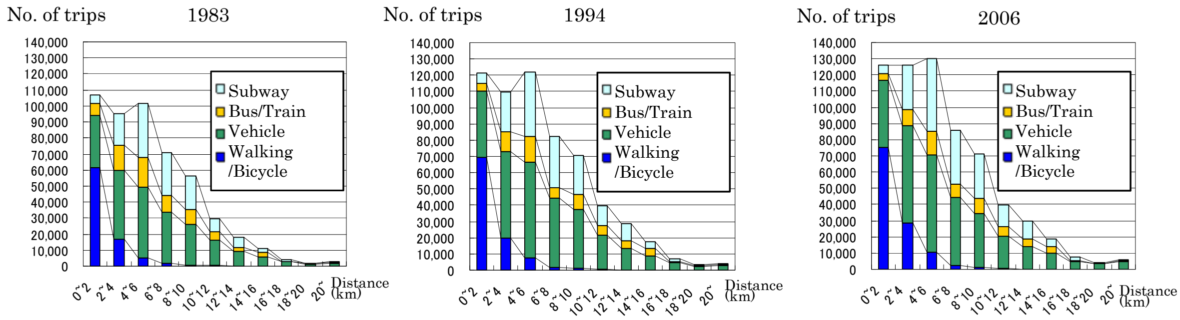

Figure 4 – Transport modes by commuting distance (1983, 1994, 2006)

As evident in Figure 4, the number of vehicle-based trips was the largest among the transport modes and accounted for a large proportion with all distances, indicating its significant effect on trip length for all modes. The distance for the largest number of vehicle-based trips was 4–6 km (approximately 44,000 in 1983, 59,000 in 1994, and 61,000 in 2006). The graph indicates that the total number of trips covering distances of 2–6 km increased over time. The number of trips covering distances of 2–4 km increased by approximately 14,000 between 1983 and 1994, and by 16,000 between 1994 and 2006, whereas those covering distances of 4–6 km increased by 21,000 and 7,000, respectively. These increases were thought to be owing to an increase in the number of trips on subway trains, which cover intermediate distances at high speeds, in addition to suburban sprawl caused by the proliferation of car usage. The high rate of increase in the number of walking and bicycle trips covering distances of up to 2 km between 1983 and 1994, and of 2–4 km between 1994 and 2006 highlights increased adoption of these modes of transport. These results indicate that short-distance zones were preferred by commuters with time restrictions because the number of trips decreased gradually with increased distance owing to the nature of commuting behavior (except in data on subway trips, which tend to be concentrated over medium and long distances).

Characteristics of vehicle-based commutes

Next, we performed a detailed analysis by focusing on the characteristics of vehicle-based commutes, which accounted for the majority of trip lengths for all transport modes.

The numbers and lengths of trips for all transport modes and vehicle-based trips in each PT survey year were divided into two groups: those involving city-center areas with subway stations (the blue zones in Figure 3) and those involving other (suburban) areas. Then, all trips were classified into four patterns: inside–inside trips from city-center to city-center areas, inside–outside trips from city-center to suburban areas, outside–outside trips from suburban to suburban areas, and outside–inside trips from suburban to city-center areas. Table 2 shows the inside–inside trips from city-center to city-center areas and outside–outside trips from suburban to suburban areas.

Table 2 – Trip characteristics by area

		1983(2nd)		1994(3rd)		2006(4th)	
		City center areas	Suburban areas	City center areas	Suburban areas	City center areas	Suburban areas
All modes	No. of trips	367561	130877	416763	189258	431805	211889
	Average Trip length (km)	4.76	5.42	5.17	5.51	4.99	5.87
Vehicles	No. of trips	137825	75834	163448	123284	153469	139753
	Average Trip length (km)	6.15	6.62	6.29	6.76	6.31	6.80
	Ratio of vehicle-based trips	37.50%	57.94%	39.22%	65.14%	35.54%	65.96%

Table 3 shows that the number of vehicle-based trips increased between 1983 and 1994, and decreased between 1994 and 2006. In contrast, the number of such trips in the suburbs increased drastically between 1983 and 1994, and was still increasing in 2006. The ratio of vehicle-based trips also continued to increase in the suburbs but decreased in city-center areas, and the gap between them widened. This widened gap suggests that vehicle use was widespread in the suburbs, whereas a modal shift to public transport, walking, bicycle, and other transport modes progressed steadily in city-center areas with well-established public transport services.
Average vehicle-based trips were not excessively longer in the suburbs than in city-center areas, although suburban zones were larger than those in the city center.

Next, we conducted an analysis by focusing on the points to which vehicle-based trips were concentrated. Figure 5 shows the results of our processing to extract zones within the top 60% of the cumulative ratio of concentrated vehicle-based trips for each PT survey year. The results show that although the ratio of trips concentrated to the city center was high in 1983, dispersion was seen in and after 1994. However, average trip lengths in suburban areas did not increase significantly, as shown in Table 3, which indicates that commuters formed short-distance commute zones centered around several areas even in suburbs rather than commuting long distances in a disorderly manner.

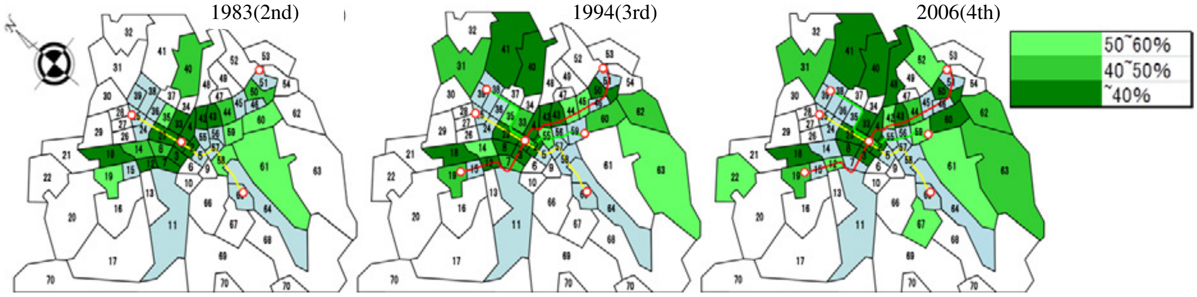

Figure 5 – Cumulative ratio of trip concentration

Following this summary of commuting in the Sapporo metropolitan area between 1972 and 2006, the next chapter outlines our analysis of the optimal commuting assignment problem using commuting preference curves.

OPTIMAL COMMUTING ASSIGNMENT PROBLEM WITH CHANGES IN WORKPLACES

Travel preference curves

In this study, travel preference curves proposed by Masuya et al. (2003) were used to examine the effect of reducing overall commute lengths by varying the number of workplace locations.

Commute preference curves are based on Stouffer's intervening opportunity model (Stouffer, 1940) on the assumption that the number (ratio) of trips between a certain origin to a certain destination is proportional to the number of opportunities at the destination and inversely proportional to the number of intervening opportunities in between the origin and destination. Such curves show the relationship between the cumulative ratio of concentrated trips (indicating workplace distribution) and generated trips (indicating the generation of workers in places of residence).

We estimated preference curves for each zone on the basis of non-linear regression with a quadratic curve by sorting concentrated trips from all zones to each zone in ascending order from the zone closest to the target. The cumulative ratio of the concentrated trips normalized to the total number of trips was plotted on the horizontal axis, and the cumulative ratio of trips from the target zone to the sorted zones was plotted on the vertical axis.

Commute preference curves shift to the *y*-axis side when the ratio of short-distance trips (including that of trips within a certain zone) is high and shift to the right when the ratio of long-distance trips is high. The estimation of a curve for each zone highlights the preference ratio of workplaces commuted to by workers who live in certain zones.

Quadratic curve regression is conventionally used to estimate preference curves. In this study, the following quadratic curve crossing the coordinates (1, 1) was used for regression of the cumulative ratios of concentrated and generated trips (Eq. 1):

$$Y = a_i(x-1)^2 + b_i(x-1) + 1 \tag{1}$$

a_i, b_i : Regression coefficient for Zone *i*

As an example, Figure 6 shows preference curves for all zones estimated from 2006 PT survey data.

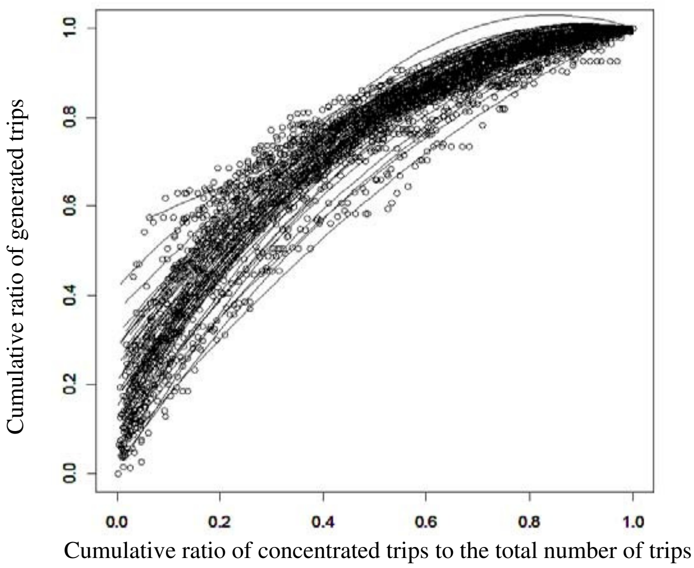

Figure 6 – Preference curves (2006, all zones)

Workplace-based optimal commuting assignment problem

In this study, the potential commute reduction for each PT survey year was calculated on the basis of the optimal commuting assignment problem proposed by Masuya et al. (2010). Preference curves were used to represent the characteristics of the preference ratio for workplaces commuted to each zone with the number of trips concentrated to workplaces as variables.

The optimal commuting assignment problem with the number of concentrated trips as a variable can be used to find the assignment pattern for the minimum total commuting distance with a fixed volume of traffic generated in each zone (for the number of residence locations) and a variable traffic volume concentrated (for the number of workplace locations). Here we assumed that the relative ratio of the OD traffic volume from each residential zone could be found on the basis of the preference curve in order to represent commuting behavior in the zone. The OD traffic volume and total commute length thus varied with changes in the number of workplace locations in each zone (for the number of concentrated trips).

Figure 7 shows preference curves regressed with a quadratic curve to represent commuting behavior in a certain zone. With changes in the number of locations in each zone, the cumulative and relative ratios for the number of concentrated trips in the *k*-th zone of Zone *i* changed from cg^b_{ik} and ug^b_{ik} (broken lines) to cg^a_{ik} and ug^a_{ik} (solid lines), respectively, resulting in a change in the relative ratio of the *k*-th OD traffic volume for Zone *i* from f^b_{ik} to f^a_{ik}. The *k*-th zone in Zone *i* is related to the order after the sorting of Zone *j* on the basis of the distance from Zone *i* and is expressed as k_i. Using these OD traffic volume changes with variations in the number of workplace locations in each zone, we quantified the total reduction in the commute length. The problem can be formulated in consideration of commuting behavior (i.e., preference curves) for each zone, as shown in Eqs. 2–13.

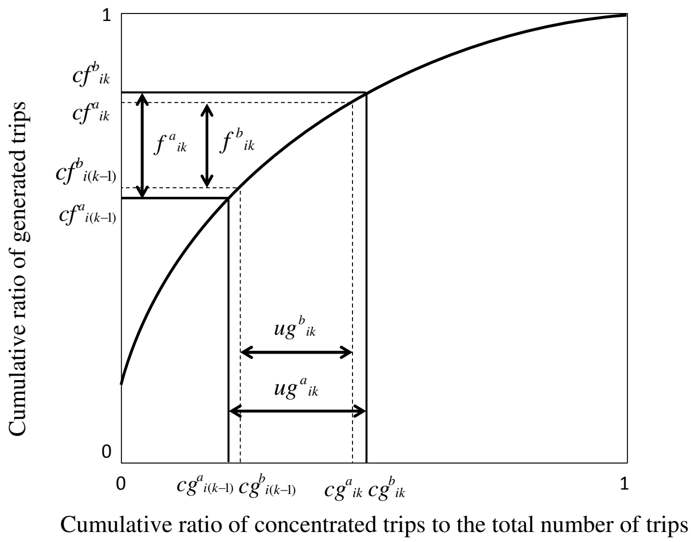

Figure 7 – Changes in the concentrated trip ratio on a preference curve

$$\sum_{i=1}^{n} G_i^a = T \qquad (i = 1, \cdots, n) \tag{2}$$

$$G_i^a = G_i^b + \Delta G_i \qquad (i = 1, \cdots, n) \tag{3}$$

$$\Delta G_i : \textit{free variable} \qquad (i = 1, \cdots, n) \tag{4}$$

$$\sum_{i=1}^{n} \Delta G_i = 0 \tag{5}$$

$$\Delta G_i^L \le \Delta G_i \le \Delta G_l^U \tag{6}$$

$$ug_i^a = G_i^a / T \tag{7}$$

$$cg^a_{ik_i} = cg^a_{i(k_i-1)} + ug^a_{ik_i} \qquad (i = 1, \cdots, n), (k_i = k_1, \cdots, k_n) \tag{8}$$

$$cf^a_{i(k_i-1)} = a_i (g^a_{i(k_i-1)} - 1)^2 + b_i (cg^a_{i(k_i-1)} - 1) + 1 \qquad (i = 1, \cdots, n), (k_i = k_1, \cdots, k_n) \tag{9}$$

$$cf^a_{ik_i} = a_i (g^a_{ik_i} - 1)^2 + b_i (cg^a_{ik_i} - 1) + 1 \qquad (i = 1, \cdots, n), (k_i = k_1, \cdots, k_n) \tag{10}$$

$$f^a_{ik_i} = cf^a_{ik_i} - cf^a_{i(k_i-1)} \qquad (i = 1, \cdots, n), (k_i = k_1, \cdots, k_n) \tag{11}$$

$$X^a_{ik_i} = F_i \cdot f^a_{ik_i} \tag{12}$$

$$\sum_{i=1}^{n}\sum_{k_i=1}^{k_n} X_{ik_i}^a \cdot d_{ik_i} \to \min \tag{13}$$

where

G_i^a, G_i^b	:	Number of locations in Zone *i* before (*b*) and after (*a*) the change in the number of locations for business establishments, etc. (quantities of concentration)
T	:	Total number of trips
ΔG_i	:	Variation in the number of locations for business establishments, etc. in Zone *i* (free variable)
$\Delta G_i^L, \Delta G_l^U$	:	Upper and lower limits of the number of locations for business establishments, etc. in Zone *i*
ug_i^a	:	Relative ratio of the changed number of locations associated with the change in the number of locations for business establishments, etc. in Zone *i*
k_i	:	Zone number in ascending order based on the distance from Zone *i* $(k_i = k_1, \cdots, k_n)$
a_i, b_i	:	Regression coefficients for the preference curve
$ug_{ik_i}^a, cg_{ik_i}^a$	:	Relative and cumulative ratios for the number of locations in the k_i-th zone in Zone *i* after the change in the number of locations
$cf_{i(k_i-1)}^a, cf_{ik_i}^a$	:	Cumulative ratios of the k_i*-1*-th and k_i-th zones in Zone *i* determined using the quadratic curve regression coefficient
$f_{ik_i}^a$	:	Relative ratio of the number of generated trips with the k_i-th zone in Zone *i* after the change in the number of locations
F_i	:	Number of generated trips in Zone *i*
$X_{ik_i}^a$	:	OD traffic volume with the k_i-th zone in Zone *i* after the change in the number of locations
d_{ik_i}	:	Distance to Zone ik_i (trip length)

In the workplace-based optimal commuting assignment problem using preference curves, the OD pattern among 53 zones with which the total commute length is the shortest is generated from preference curves estimated for each zone depending on the variation in the number of workplace locations in each zone, which is a free variable.

If the number of actual workplace locations is substituted into the preference curve as is, the trip length is different from that found using the actual commuting OD pattern, which is the difference between the commute length in the current residential–employment distribution and that in the optimum distribution based on Stouffer's intervening opportunity model. The commute length can thus be reduced by changing the destination of each commute without changing the current number of workplace locations. In this study, commute lengths were calculated for a case in which the upper and lower limits of the number of concentrated trips expressed by Eq. 5 were not changed from the current values for each zone (±0%) and for cases in which they were changed by ±10% and ±20%.

The excess percentage was also calculated on the basis of the solution of the optimal commuting assignment problem. This value is found by dividing the difference between the actual and minimum values of the total commute length by the actual value. The index value is 0 when the actual total commute length is equal to the minimum value and moves closer to 1 as the total trip length is increased compared to the minimum value. The difference between the commute length and the minimum trip length in each PT survey year is standardized using this value, which can be formulated as Eq. 14 using the actual trip length T_{act} and the minimum value T_{min} of the commute length based on the optimal commuting assignment problem.

$$\text{Excess percentage} = \frac{T_{act} - T_{\min}}{T_{act}} \qquad (14)$$

CALCULATION RESULTS AND DISCUSSION

In this study, preference curves for vehicle-based commutes were estimated using PT data for four points between 1972 and 2006. The minimum distance between the representative centroids was used as the trip length between zones, and the distance of a trip ending in a single zone was assumed to be half the distance to the closest zone instead of 0. Table 3 shows the frequency of significant levels for the p values of parameters a_i and b_i estimated for a total of 53 zones.

Table 3 – Parameter significance levels

	PT survey year: 1972	PT survey year: 1984	PT survey year: 1994	PT survey year: 2006
Coefficient *a*				
Significance level	No. of parameters	No. of parameters	No. of parameters	No. of parameters
0.001	51	52	53	52
0.01	1	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
P>0.1	1	1	0	1
Coefficient *b*				
Significance level	No. of parameters	No. of parameters	No. of parameters	No. of parameters
0.001	37	35	28	18
0.01	2	3	3	3
0.05	4	0	5	5
0.1	1	3	3	4
P>0.1	9	12	14	23

Figure 8 shows the results obtained when the workplace-based optimal commuting assignment problem for each year was solved. Table 4 shows the optimum value, the difference in the mean top length of the actual and minimum values, and the excess percentage calculated for a case in which the actual values of the total and mean trip lengths and the upper and lower values of the number of concentrated trips, as expressed by Eq. 5, were unchanged (±0%) and for cases in which they were changed by ±10% and ±20% from the current value for each zone.

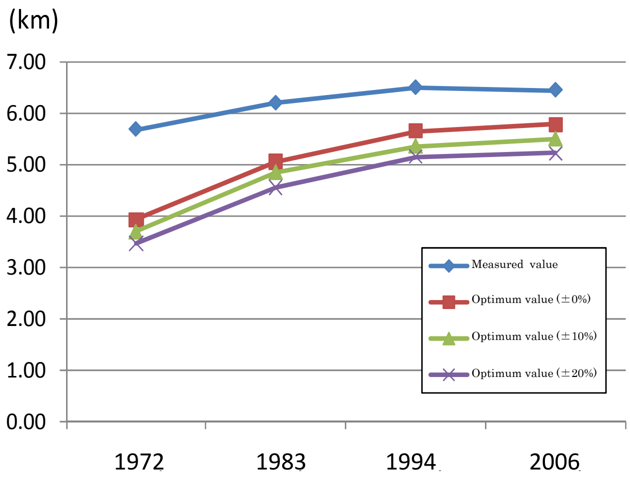

Figure 8 – Mean trip length for each PT survey year

Table 4 – Results of workplace-based optimal commuting assignment problem

		1972(1st)	1983(2nd)	1994(3rd)	2006(4th)
Total trip (km)	Mesured value	559,823	1,322,735	1,861,173	1,889,194
Total no.of trips	Mesured value	98,584	213,706	286,794	293,283
Mean trip (km)	Mesured value	5.68	6.19	6.49	6.44
	Optimum value	3.93	5.05	5.65	5.78
	Optimum value	3.69	4.84	5.35	5.49
	Optimum value	3.46	4.56	5.15	5.22
Difference between actual value and mean trip length (km)	±0%	1.75	1.14	0.84	0.66
	±10%	1.99	1.34	1.13	0.95
	±20%	2.22	1.63	1.34	1.22
Excess percentage	±0%	0.31	0.18	0.13	0.10
	±10%	0.35	0.22	0.17	0.15
	±20%	0.39	0.26	0.21	0.19

A comparison of vehicle-based commute data by PT survey year in time-series form indicated that although the actual total trip length and total number of trips increased over the previous 34 years, the mean trip length became roughly constant in 2006. As is evident in Figures 1 and 2, the progress of motorization and suburbanization between 1972 and 1994 and a subsequent population return to the city center can be inferred even from the simple aggregate results. The difference between the actual commute lengths and optimum trip lengths calculated from preference curves decreased with the passage of time. For example, on the basis of the cumulative ratio for the current number of concentrated trips (rate of variation ±0%), the difference was 1.75 km in 1972, 1.14 km in 1983, 0.84 km in 1994, and 0.66 km in 2006. Although the mean trip length becomes shorter than the actual value if the number of concentrated trips to workplaces changes from the current value, this difference will decrease over time. Because the excess percentage showed a similar tendency, places of residence and work can be concluded to have become more closely distributed than in 1972.

Figures 9–12 show the workplace location variation when the upper and lower limits for the number of concentrated trips to each zone were set within the range of ±20% for each PT survey year. The figures show an increasing tendency in the number of workplace locations at the times of all PT surveys with a location pattern in which vehicle-based commutes became the shortest.

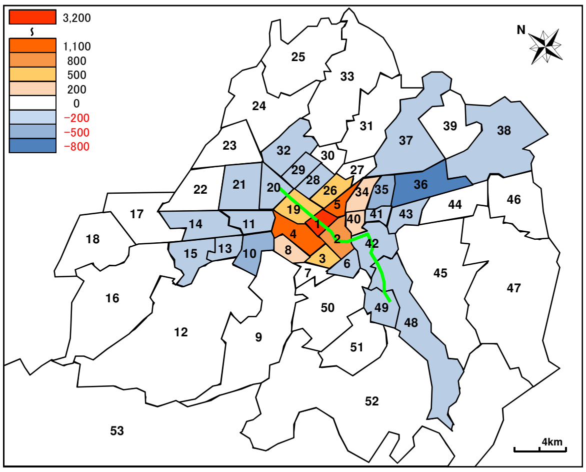

Figure 9 – Number of workplace locations
(first survey, 1972; variation: 20%)

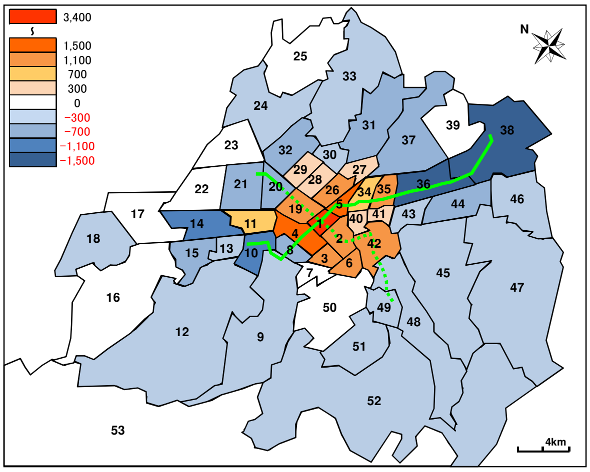

Figure 10 – Number of workplace locations
(second survey, 1983; variation: 20%)

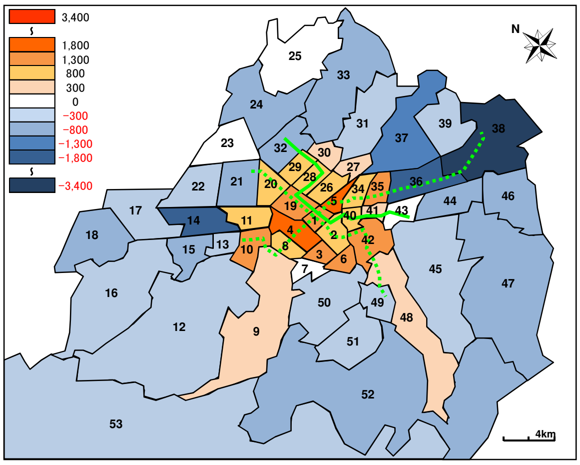

Figure 11 – Number of workplace locations
(third survey, 1994; variation: 20%)

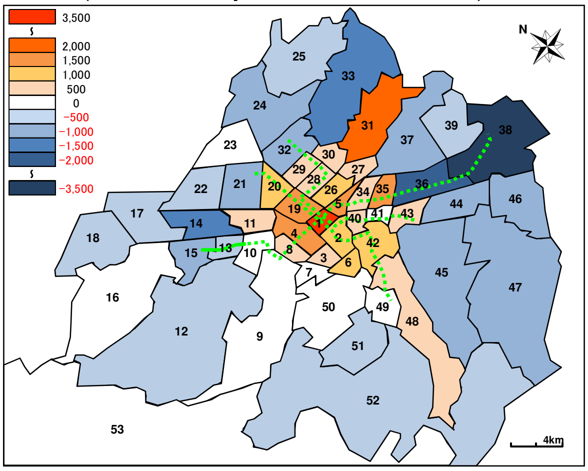

Figure 12 – Number of workplace locations
(fourth survey, 2006; variation: 20%)

A tendency for the number of suburban workplace locations to decrease over time since 1972 is also observed, and a similar tendency was seen for a ±10% ratio of variation.

In the optimization model used for this study, the commuting OD was optimized to minimize the commute length while reflecting the actual commute behavior characteristics of each zone. Accordingly, the characteristics of zones with large numbers of concentrated trips from nearby zones became predominant, and the number of workplace locations increased in these zones. Conversely, the characteristics of zones with large numbers of trips from distant zones were suppressed, and the number of locations decreased in these zones. These results suggest that if the number of workplace locations can be changed from the current value, the total commute in the Sapporo metropolitan area can be reduced by facilitating the placement of locations in areas around the city center while controlling the establishment of locations in suburban zones.

Next, cumulative distribution curves were created on the basis of the results of the optimal commuting assignment problem to clarify the relationship between the number of generated trips and travel distances in more detail. The horizontal and vertical axes of the curves represent the distance between zones and the OD traffic volume that can be reached within a certain range from the target OD traffic volume, respectively. Figure 14 shows cumulative distribution curves based on actual commuting OD traffic and those based on commuting OD traffic to which the optimal commuting assignment problem (±0%) was applied.

The actual values of cumulative distribution curves (the broken lines in Figure 13) indicate that most trips finished within a commuting distance slightly longer than 10 km in 1972. In 1983, the number of vehicle-based commutes increased owing to suburbanization; however, the residential/work-related trip ratio approached the optimum value. In 1994 and 2006, the rate of increase in the number of vehicle-based commutes slowed, and the residential/work-related trip ratio for the actual value was almost equal to the optimum ratio according to the intervening opportunity model (±0%).

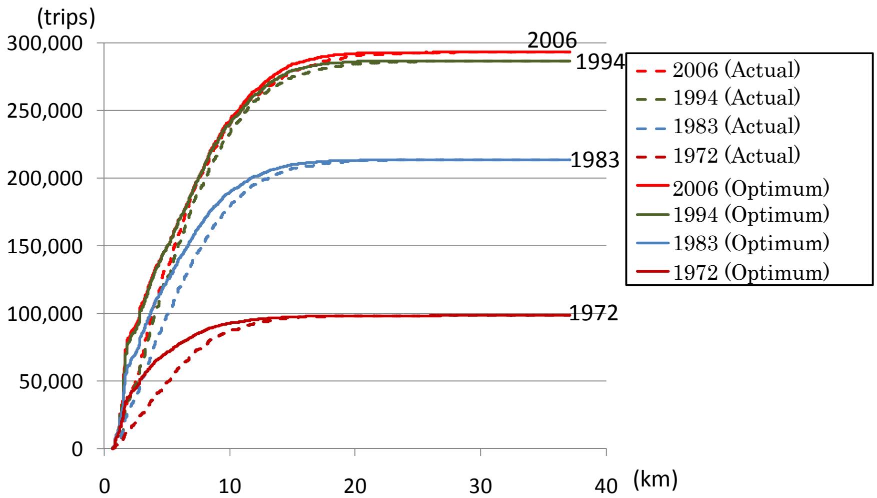

Figure 13 – Cumulative distribution curves

The previously presented results indicate that generated and concentrated traffic volumes between places of residence and work were distributed almost evenly within a 10-km radius irrespective of commuting distances in 1972, and that there was room for improvement. However, the distribution of vehicle-based commute lengths in Sapporo in current patterns of residence and workplace locations is largely consistent with the optimum value found using commuting preference curves, indicating that the distribution is approaching conversion.

Such factor analysis is outside the scope of the present study; however, it can be assumed that although the number of trips increased with the progress of suburbanization, cross-commuting was reduced as places of residence eventually became concentrated in zones close to workplaces with the selection of new residences and relocation; it can also be assumed that the number of factors that increase commuting distances has decreased in the last 34 years (e.g., fewer detours owing to improvements in road networks).

On the basis of the examination of various measures to support the establishment of future low-carbon urban transportation with vehicle-based commutes as variables, action involving a shift to the use of low-pollution vehicles and other lower-emission transport modes is considered more realistic in the short run compared to the implementation of measures to reduce travel distances in Sapporo, especially in suburban areas with high number of vehicle-based commutes.

CONCLUSIONS

In this study, the changes in vehicle-based commutes in the Sapporo metropolitan area between 1972 and 2006 were summarized, the extent to which commute lengths that could be reduced were calculated, and the results were compared in time-series form on the basis of the optimal commuting assignment problem using preference curves. The findings of the study can be summarized as follows:

1. The rate of increase in the number of vehicle-based commutes in Sapporo has decreased since 1994. Excess percentage and cumulative distribution curves indicate that vehicle-based commute lengths became more closely distributed and that the distribution approached conversion between 1994 and 2006.

2. Even when the number of concentrated trips to current workplace zones was varied by ±20% by facilitating the establishment of workplace locations and implementing other measures, the mean trip length reduction effect was only approximately 1.2 km in 2006.

3. In consideration of future low-carbon urban transportation with focus on vehicle commuting, the introduction of transport modes with low-emission factors in addition to measures for reducing commuting distances should be considered because vehicle commuting distances in Sapporo already show a shorter tendency.

This study did not consider public transport commuting nor did it examine the commuting distance reduction effect associated with significant changes in land-use patterns (e.g., TOD) because certain upper and lower limits were applied to variations in the number of concentrated trips to each workplace zone. The estimation of an efficient number of locations for each workplace zone is an important factor in determining the structure of low-carbon urban transportation and should be addressed in future studies.

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