PRELIMINARY ANALYSIS ON HOW TRIP SCHEDULE AND HOUSEHOLD ATTRIBUTES AFFECT EFFECTIVENESS OF CAR-SHARING SYSTEMS

Daisuke KIUCHI
Graduate Student, Graduate School of Environmental Studies, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603 JAPAN
TEL: +81-52-789-5728, FAX: +81-52-789-3738, E-mail: dai-k@trans.civil.nagoya-u.ac.jp
Mamiko YAGI
Ph.D. Candidate, Graduate School of Engineering, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603 JAPAN
TEL: +81-52-789-5728, FAX: +81-52-789-3738, E-mail: yagi@trans.civil.nagoya-u.ac.jp
Toshiyuki YAMAMOTO
Associate Professor, Department of Civil Engineering, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603 JAPAN
TEL: +81-52-789-5728, FAX: +81-52-789-3738, E-mail: yamamoto@civil.nagoya-u.ac.jp
Takayuki MORIKAWA
Professor, Graduate School of Environmental Studies, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603 JAPAN
TEL: +81-52-789-5728, FAX: +81-52-789-3738, E-mail: morikawa@civil.nagoya-u.ac.jp

ABSTRACT

This research investigates potential effectiveness of a car-sharing system for a mid-sized city in Japan. Sharing vehicles by a community is expected to reduce the total number of vehicles owned in the community and save the parking space and vehicle-owning costs. Trip diary data on both weekdays and weekends are analyzed in this paper to estimate the number of vehicles that can be reduced through car-sharing. We examined the household members' trip schedules in every household and in every community represented by a traffic zone in this study, and calculated the number of unused vehicles in a day. It is found that nearly 20% of vehicles become redundant by reorganizing trips in households and that more than 30% could be reduced by optimizing trip schedules and using shared vehicles in communities. We also developed regression models to identify the effects of household attributes on the possible reduction of car ownership by joining car-sharing.

INTRODUCTION

Despite many benefits offered by private vehicles, there is an increasing recognition of the negative social and environmental impacts of car dependence. Many policy measures have been implemented to reduce car use and dependence, but it is difficult to accomplish this goal. The acceptability of the measures should be strongly focused on. A car-sharing system can produce most of the benefits of private car usage at lower cost than privately owing a car, using a taxi, or renting a car. A few metropolitan areas in Japan have already introduced car-sharing systems. However, most of the systems are still in the experimental stage, and only adopt the station-car system in which only one-way usage is recommended between the depots deployed at rail stations and popular business destinations. On the other hand, most middle and small sized cities in Japan have severe difficulty in maintaining public transit due to the vicious circle of shrinking ridership, deteriorating service level, and losing patronage. Residents in these cities highly rely on private cars. Consequently, the car ownership in these cities is nearly one vehicle to each car license holder. Therefore, in these areas a second car type car-sharing system would be acceptable rather than the station-car system. The former system can reduce both the car ownership and vehicle mileage.

Although the car-sharing systems have already been introduced in Japan, it is difficult to increase their members. This is mainly because the car-sharing system is not well recognized among ordinary people. Also all the car-sharing systems in Japan are still in the experimental stage. It is reasonable for people who own cars to hesitate to join such an experimental system, which can be easily and suddenly closed. Therefore, it is difficult to grasp the potential demand of the car-sharing at the mature stage from the report of the experimental system (1-7). Most existing researches on the car-sharing are based on the car-sharing systems which have been already introduced, especially in Europe and the North America (8-12). Only a few papers forecast car-sharing demand before introducing. The objectives of this study are to investigate the number of vehicles that can be reduced through the car-sharing in a community by optimizing the car use in every household, and further to develop the model to estimate the appropriate size of the car-sharing system for the targeted communities (city).

This paper investigates the possibility of the second car type car-sharing in middle and small sized cities in Japan. We analyze how the household and zonal attributes affect the potential car ownership reduction through the car-sharing by using both weekdays and weekends person trip data of Toyota City.

OPTIMIZATION

TARGET AREA

Toyota City is used as a target area in this study. Toyota City is one of the mid-sized cities in Chukyo Metropolitan area, and located on the east of Nagoya City. The basic statistics of Toyota City is shown in Table 1.

Population			Household	Age			Area (km^2)	Density ($person/km^2$)
Total	Male	Female		0-14	15-64	Over 65		
358,027	187,033	170,994	131,805	56,854	259,589	41,584	290.12	1,234

Table 1. Toyota City (Feb.1.2004)

The rate of industries is Agriculture-2.3%, Manufacture-43.4%, and Service-54.3%. Mass transit network contains 2 lines of Nagoya Railways, 1 line of Japan Railway, and buses. There are 26 rail stations in the city.

The data used in this research are the Person Trip (PT) survey data collected in Chukyo Metropolitan Area on weekdays (weekdays PT data), and the PT survey data in Toyota on weekends in 2001 (weekends PT data) collected by Toyota City Hall and the Toyota Transportation Research Institute. According to the PT survey in 2001, 71% of all trips in the city are car trips. Also the average number of vehicles owned per household is 1.4 in Chukyo Metropolitan Area, which includes Toyota City, and 1.86 in Toyota City (Table 2).

Table 2. Car ownership in Chukyo Metropolitan area and Toyota City

	Chukyo Metropolitan Area (weekday PT survey)	Toyota City (weekday PT survey)	Toyota City (weekend PT survey)
Sample size (person)	264,573	25,070	3,217
Car ownership	136,639	16,801	1,999
Household	97,543	9,052	1,080
Driving license holder	167,539	17,309	2,104
Average number of car per household	1.40	1.86	1.85
Average number of car per person	0.52	0.67	0.62
Average number of car per license holder	0.82	0.97	0.95

OPTIMIZATION

In this section, we simulated to optimize car trip schedules under the introduction of car-sharing system, and investigate the possibility of reducing the number of vehicles in each household or zone (community).

Optimization considered in this study is divided into 1) optimization without shifting their original trip schedules and 2) with shifting their trip schedules. The images of optimization and shifting rules are shown in Figure 1. Also, the optimization is applied at both the household level and community level. At the household level, households are optimized to have the least number of cars to fill the travel needs of their own household, so cars are shared only among household members. On the other hand, households in a traffic zone are assumed to share the same fleet of shared cars in the optimization at the community level, so the cars are shared among households in the same traffic zone. This optimization at the community level assumes that all households in the zone become members of shearing system.

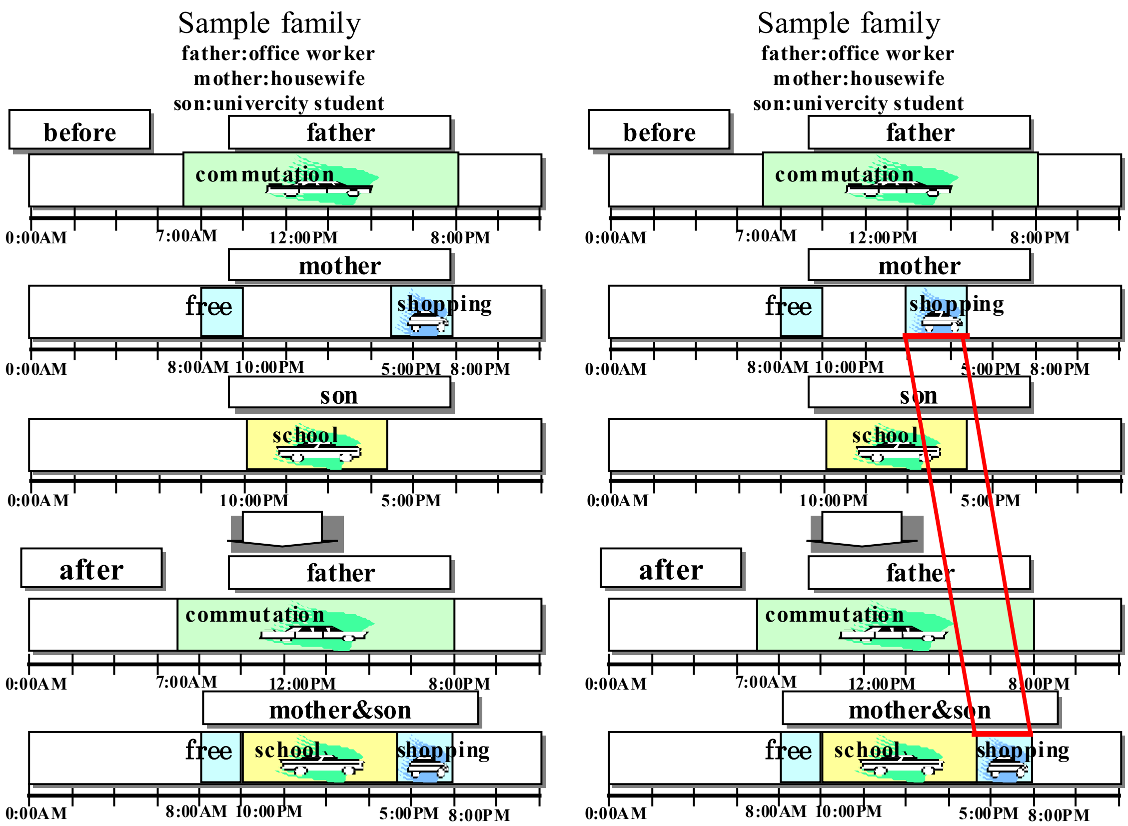


Figure 1. Images of Optimization (Left: w/o shifting, Right: w/ shifting)

OPTIMIZATION WITHOUT SHIFTING CAR TRIPS OF OTHER TIME ZONES

The number of vehicles per household is optimized without shifting the car trips to other time periods in a day. **Table 3** shows the distribution of the number of vehicles per household and the number of vehicles actually needed after the optimization at the household level. The shaded cells in the tables represent the rate of the number of households who own more vehicles than actually needed, called “over-own” vehicles.

weekday			number of actual car-need				
		households	0	1	2	3	4～
# of owned cars	0	8.61	7.83	0.42	0.24	0.07	0.04
	1	31.83	6.50	24.33	0.95	0.06	0.00
	2	37.13	2.04	12.47	22.16	0.42	0.03
	3	13.90	0.42	2.31	5.00	6.06	0.10
	4	6.24	0.20	0.62	1.54	2.23	1.66
	5	1.48	0.02	0.18	0.22	0.53	0.53
	6～	0.82	0.06	0.12	0.14	0.15	0.34
	total	100.00	17.07	40.44	30.26	9.52	2.71

holiday			number of car-need				
		households	0	1	2	3	4～
# of owned cars	0	8.69	8.59	0.10	0.00	0.00	0.00
	1	33.96	10.37	23.49	0.10	0.00	0.00
	2	37.22	4.74	22.80	9.67	0.00	0.00
	3	12.54	1.78	5.23	4.64	0.89	0.00
	4	5.53	0.20	1.18	2.57	1.28	0.30
	5	1.28	0.20	0.49	0.20	0.39	0.00
	6～	0.79	0.00	0.30	0.30	0.20	0.00
	total	100.00	25.86	53.60	17.47	2.76	0.30

Table 3. The rate of number of cars owned per household vs. number of cars actually needed per

OPTIMIZATION WITH SHIFTING CAR TRIPS TO OTHER TIME PERIODS

Car trips per household or per zone are optimized by shifting the car trips to other time periods. The optimization is conducted according to the following rules:

1. Only shopping trips and trips for discretionary activities are allowed to shift the trip timing. This is because trips for other purpose are assumed under restriction of trip schedule.
2. Those two types of trips are unshiftable to other time periods if the trip has a secondary purpose (e.g. picking up a family member at a station on the return trip from shopping.).

Two types of constraints are examined on the optimization process:

Optimization type 1) No restrictions on which time periods the trip is shifted to.

Optimization type 2) One day is divided into 3 time zones (8:00 ~ 12:00, 12:00 ~ 19:00, 19:00 ~ 8:00). Trips can be shifted only within the same time zone. If the trip stareted in mid-night (19:00 ~ 8:00) , the trip is unshiftable.

In the optimization type 1, all shiftable trips are moved into any time zones if there is enough blank time. So an early morning shopping may be shifted into evening. In the optimization type 2, such an unusual shift is avoided. But the stronger restriction makes it difficult to obtain higher reduction of the fleet.

The target households for optimization with shifting car trip is the households who need 2 or more cars after the optimization without shifting car trips in **Table 3**.**Table 4** shows the results of the optimization, the number of households who could reduce their owning cars (hereafter called as reduced households). **Table 4** also shows total number of reduced cars. The results indicate that there are few households who could reduce more than one owning cars. The results suggest that nearly 20% of vehicles become redundant by optimizing trips in households by optimization type 1.

		weekdays	weekends
household actually need 2 or more cars		3846	208
type1	reduced households	771	109
	reduced cars	775	113
type2	reduced households	271	50
	reduced cars	271	51

Table 4. Number of vehicle reduced

Figures 2 and **3** show the results at the community level on the map of Toyota City for weekdays and weekends in optimization type 1. The results of community level optimization are supposed to be provided by car-sharing system. **Figure 2** suggests that the effectiveness of the optimization to reduce the number of vehicles for households is large in central parts of the city. Nearly 20% vehicles in each zone are reduced by the optimization at household level. And over 15% vehicles are additionally reduced by the community level optimization. So, more than 30 % cars are reduced by the optimization at both household and community level. **Figure 3** shows the results for weekends. This figure indicates the higher rate of the number of reducible vehicles than that of weekdays in both household and community.

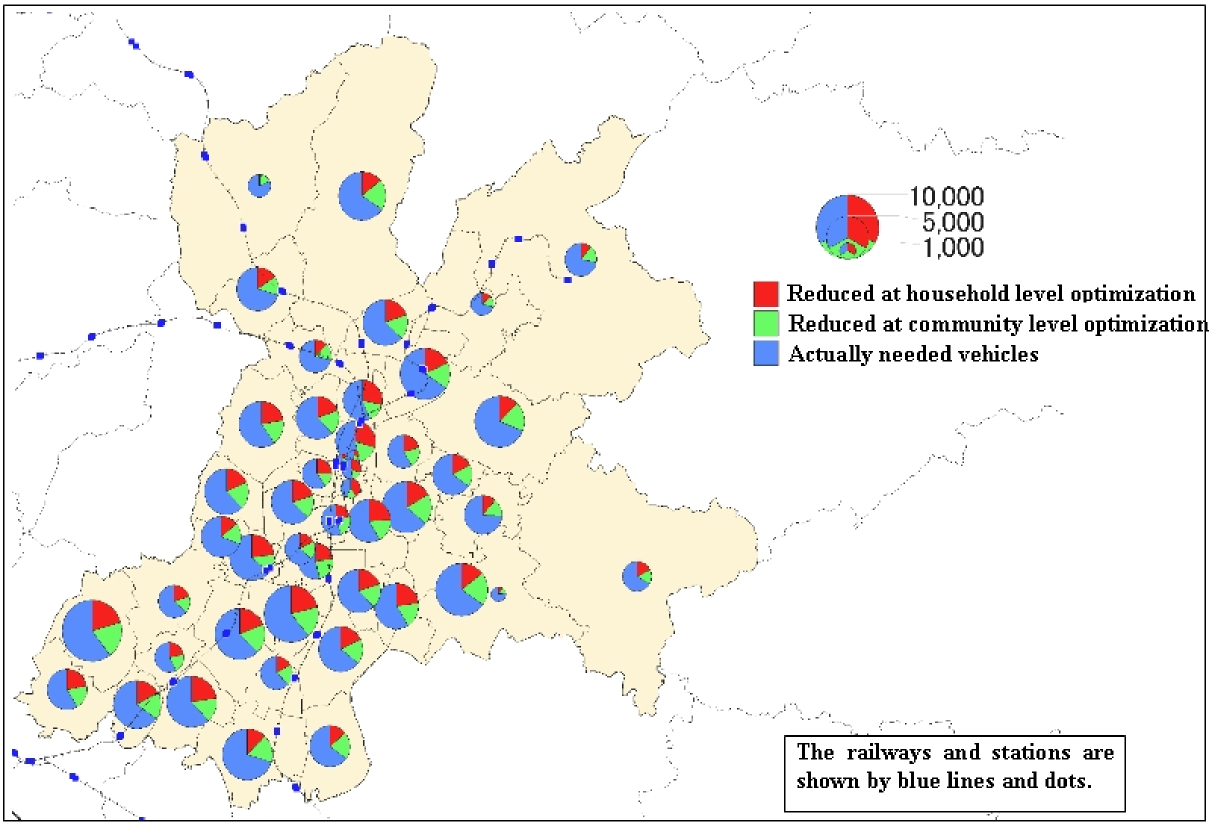
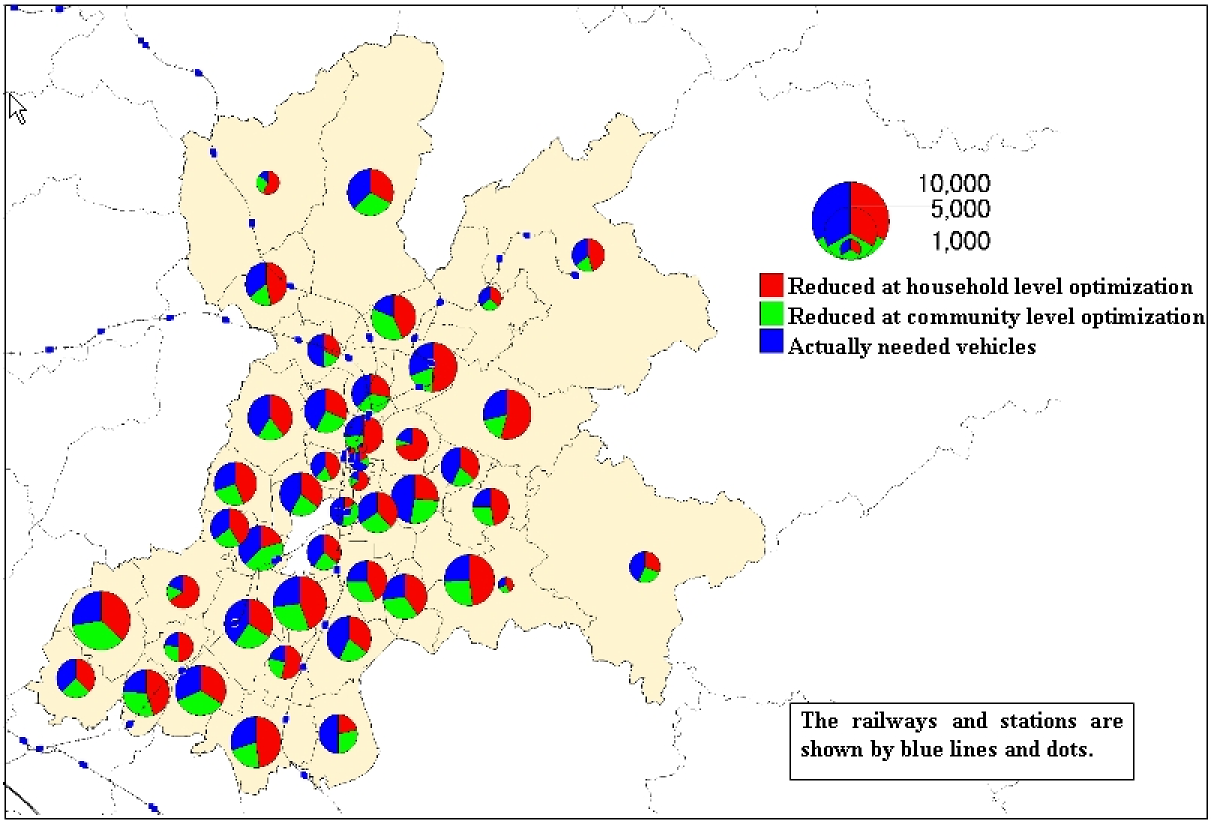


Figure 2. Number of vehicle reduction by zone (weekdays)



THE EFFECTS OF HOUSEHOLD ATTRIBUTES

OPTIMIZATION AT HOUSEHOLD LEVEL

In this section, binary probit models are developed to analyze the possibility of household car ownership reduction through travel schedule optimization. The results for weekdays and weekends are shown in **Table 5**. In the table, if the coefficient is positive, the probability of household car ownership reduction increases along the value of the variable. The results indicate that not only the attributes of households but also the attributes of zones in which the households are located affect the possibility of reducing the number of vehicles. The results suggest that the household who owns bicycles, and motorcycles has a higher probability of reduction. But the results also suggest that if someone aged over 60 or attending school is in the household, the household would have lower probability of reduction. Compared the models for weekdays and weekends, the model for the weekends includes fewer explanatory variables, implying that the activity schedules in weekends have more variations than in weekdays.

Table 5. Binary probit models of car ownership reduction in household

	weekday		holiday	
	coefficient	t	coefficient	t
const	−1.531	−29.1	−1.605	−9.51
familly size	0.138	5.54	−	−
# of workers	−0.550	−18.2	−	−
# of students	−0.243	−8.55	−	−
# of retained cars	1.098	33.8	1.913	14.7
# of license holder	−0.250	−7.69	−0.458	−4.82
dummy of possessing motorcycle	0.142	3.67	−	−
dummy of possessing bicycle	0.153	3.50	−	−
dummy of possessing compact car	0.072	2.10	−	−
dummy of housewife	0.108	3.06	−	−
dummy of age over 60	−0.108	−2.51	−	−
dummy of self−employed	−	−	0.354	2.17
shop density per km^2	1.178E−05	3.33	−	−
the population density per km^2	4.477E−05	3.61	−8.903E−05	−2.50
ρ^2	0.267		0.434	
	9052		1013	

OPTIMIZTION AT COMMUNITY LEVEL

In this section, the necessary number of vehicles in a zone in weekdays is investigated by the regression analysis. The results are shown in **Table 6.** The results indicate that the number of vehicles needed by a zone increases with the size of households in the zone, the average number of license holders in the zone, the rate of households with mini-size cars, and the distance between the center of the zone and the closest station. Moreover, the number of vehicles needed by a zone decreases if the number of households whose head works at home increases, or if the number of households owning a moped or bicycle increase.

weekday	optimizing of car use		optimizing of time in use	
	coefficient	t	coefficient	t
constant	-0.216	-2.00	-0.335	-1.73
average familly size	0.0743	1.55	0.0386	0.24
average # of license holder	0.704	7.23	0.795	12.03
rate of home worker(house holder)	-0.621	-2.67	-0.684	-2.54
rate of mini-size car possessing house holds	0.569	3.71	0.464	2.46
rate of moped or bicycle possessing house holds	-0.520	-3.89	-0.384	-3.05
distance of nearby station from center of zone	0.0104	1.34	0.0189	2.19
R^2	0.905		0.876	
number of sumple	62		62	

CONCLUSION AND FUTURE WORK

The following are the results of the possibility of the applicable car-sharing system under the conditions of weekdays and weekends in Toyota city.

-Most of the shopping trips and trips for discretionary activities are made during daytime. Consequently, the second-car type car-sharing should be applied only to daytime.

-According to the PT data, a number of households “over-own” vehicles.

-The analysis of weekend travel is difficult due to the dispersion of travel patterns compared with those of weekdays.

-From the results of the probit model, households who have many members, vehicles, bikes, and other mobility have a higher probability of reducing the number of owing cars.

-Similarly, the regression analysis shows that the number of vehicles owned by a household is affected by the zone attributes where the household is located.

-The results on the possibility of introducing car-sharing by zone show that the zone-oriented optimization can reduce the number of necessary vehicles in the zone whose average number of household members is large.

We could not obtain many significant variables in the models for weekends. It might be caused by the fact that the travel behaviors taken in weekends have larger heterogeneity among households and variability along the time. Further research, therefore, would be highly recommended to investigate the car usage in weekends with additional data such as probe-car data, by which more detailed profiles of travels, such as elemental destinations and routing, could be identifiable. Also we could not consider about how the decrease in convenience affects for customers to join membership of car-shearing system, which calls for a further research on individuals’ perceptions about the inconvenience of the car-sharing system.

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