Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 1987 - 2002, 2005

A STUDY ON THE SERIAL CHANGES OF TRAVEL BEHAVIOR ON WEEK AND WEEKEND DAYS IN A LOCAL CITY

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Abstract: This study aims firstly at examining the actual condition of travel behavior changes on both weekdays and weekend days in a local city of Japan by using a series of data from person-trip surveys conducted in 1977, 1991 and 2001. Secondly, it is to show that these travel behavior changes were determined by their factor attribute changes and their factor composition changes. Thereby, quantitative understanding of these temporal macro changes is attained, and it can find out direction of appropriate analysis required for future travel demand prediction. Consequently, the recent change of individuals' structures does not have as much effect on trip generation as the individuals themselves who reduce their trip generations. Dramatic modal split change such as car shift was caused by the change of traveler's mode itself rather than by the change of OD trip patterns, and trip attraction change was caused by the change of destination choice from other zones rather than that zone changed its trip generation.

Key Words: trip generation, trip distribution, modal split, factorization analysis

1. INTRODUCTION

In recent years many local cities in Japan have been facing problems such as chronic traffic congestion, relative decline of activities or city functions in urban central area which are caused by the rapid development of motorization, suburbanization, etc. Furthermore, economic activities and social structure have been changed and influenced greatly on travel behavior. Therefore, more importantly in urban transportation planning, appropriate prediction of these serial changes of travel behavior corresponding to the tempo-spatial changes of city structure or traveler characteristics is absolutely required (Hayashi *et al.*, 2000).

Thus far, concerning such changes of socio-economic situations and traffic characteristics, many researches have been conducted by using time-series Person Trip Survey data (PT data). For instance, Matsubara *et al.* (1993) had selected 46 prefectural capital cities for an analysis of the actual condition and transport policies. In this analysis, the main finding is that the share of private cars had risen and the primary reason for this was the growth of car ownership. So, if the car ownership is continuously rising and no countermeasures are taken, the condition of traffic congestion will be continually aggravated. Dealing with this, in its policy study it has concluded that comprehensive transportation planning was essential. Similarly, a variety of researches on particular travel behavior such as number of trips per

person (trip rates) and its change characteristics were examined in Sato *et al.* (1996), Nakata *et al.* (1995) and change characteristics of modal split were discussed in Nakata *et al.* (1995). Others, by concentrating on specific people, i.e. elderly people or women, time-series analysis of their travel behavior characteristic also have been discussed in Ito *et al.* (1996), Yamada *et al.* (1995), Fujii (2001), Kimura and Tokunaga (1999). Moreover, by using nationwide PT data, research on changes of travel behavior characteristics has also been done in Nagase (2000).

However those studies show time-series changes of travel behavior from various sides, the detailed information about structures or factor attributes of each change is not fully acquired. Furthermore, in reality, since there is a limited suitable accumulation of data that permit longitudinal study in a specific area, the temporal comparative analyses of travel behavior on either week and weekend days or only weekend days are very rare. Hence, the authors have conducted an analysis of change characteristics of travel behavior in Toyohashi city which includes both on weekdays and weekend days by using a series of data from person-trip surveys undertaken at four points in time between 1977 and 2001 (Hirobata *et al.*, 2003).

This paper, by recognizing the importance of factual accumulation in aiding the regulations of future urban transportation planning and policy, rearranges the above-mentioned results and advances the analysis by one more step through trying to indicate quantitatively that each amount of serial changes of trip rates, modal split and trip distribution can be decomposed into a function depending on factor characteristics and factor compositions which are subject to serial change. In this analysis, quantitative understanding of the temporal macro changes of travel behavior is attained, so that the direction of the appropriate analysis required for a future travel demand prediction can be given accordingly.

2. STUDY AREA AND DATA

Toyohashi city, which was selected as a case study area, is situated at the southeastern edge of Aichi prefecture in Japan. By the end of January 2001, its population was around 370,000 with city area of about 261 km^2. It also serves as the central city of East Mikawa metropolitan area. In this analysis, based on the zoning of East Mikawa Metropolitan Area by person-trip survey and on the basic of two standards, i.e. the historical development of the urban area and the spatial distance from the city center, this object city was divided into four zones as shown in Fig.1.

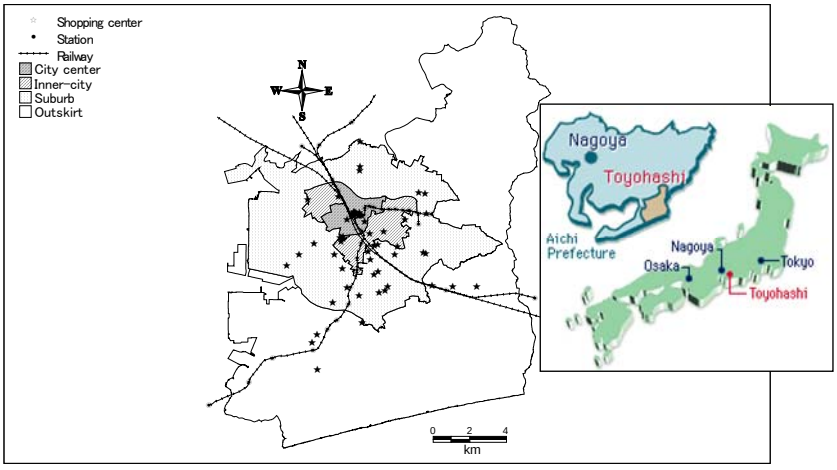


Figure 1. Location of the Study Area and Zoning

Table 1. Trends of Inhabitants, Establishments, Industrial and Commercial Employees

	Year	City center	Inner-city	Suburb	Outskirt	Total	Density (*/km^2)
Inhabitants	1975	56132 (100)	55706 (100)	107042 (100)	65717 (100)	284597 (100)	1108
	1990	45730 (81)	43932 (79)	154871 (145)	93449 (142)	337982 (119)	1300
	2000	41067 (73)	49823 (89)	180232 (168)	93746 (143)	364868 (128)	1397
Establishments	1978	6697 (100)	3380 (100)	4502 (100)	2172 (100)	16751 (100)	65
	1991	5879 (88)	3198 (95)	6483 (144)	2804 (129)	18364 (110)	71
	2001	4758 (71)	2770 (82)	6661 (148)	2841 (131)	17030 (102)	65
Industrial employees	1977	6563 (100)	6149 (100)	9285 (100)	12094 (100)	34091 (100)	133
	1990	3891 (59)	4450 (72)	10874 (117)	17717 (146)	36932 (108)	142
	2000	2298 (35)	3378 (55)	8705 (94)	19468 (161)	33849 (99)	130
Commercial employees	1976	17600 (100)	6166 (100)	8866 (100)	2334 (100)	34966 (100)	136
	1991	13854 (79)	6280 (102)	14856 (168)	4234 (181)	39224 (112)	151
	1997	10842 (62)	4722 (77)	15084 (170)	4466 (191)	35114 (100)	135

Source: Population Census, Japan Statistical Yearbook
( ): in % compared to the first year as 100%

Table 2. Outline of Person Trip Surveys

	1977 PT survey	1991 PT survey	1992 PT survey	2001 PT survey
Responsible organization	Aichi prefecture	University lab	Aichi prefecture	University lab
Target area	Higashi Mikawa	Toyohashi city	Higashi Mikawa	Toyohashi city
Respondent	5 years and over	18 years and over	5 years and over	15 years and over
Distribution/collection method	postal method	postal method	visiting method	postal method
Effective collection rate	35.0%	53.4%	87.6%	42.3%
Effective sample	48633 (16368)*	1459	18308 (7162)*	1642 (1614)*
Target day: weekdays	○	○	○	○
weekend days	×	○	×	○

* : respondents over the age of 18

Each zonal change trends of inhabitants, establishments, and commercial/industrial employees are shown in Table 1, where they clarify that economic activities at central area have been declining and the suburbanization is on the way of progressing.

The outline of person-trip surveys that had been conducted in Toyohashi city both by the government and the authors' laboratory in the university is shown in Table 2. Since there is a constraint in data analysis, this research includes only the travel behavior of residents above eighteen years old, and uses the data of surveys undertaken in 1977, 1991 and 2001 after considering the surveys' method and the direction of analysis. In this stage, the 1992 PT data are excluded even if the sample size is good and considered to be reliable because it is conceivable that differences in extraction rate or survey method lead to the variation of trip characteristics aggregation as shown in Table 3 and 4. It is clear that the aggregate value in 1991 differs from that in 1992, i.e. in 1992 PT data the activity rate is low and the share of discretionary trips is relatively small compared to 1991 PT data. Moreover, differences in transport mode such as public transport, motorcycle and on foot also arose. These differences can also be inferred from the collection rate (Table 2) or the breakdown of discretionary trip share by job (Table 4, lower berth). This is because the 1992 PT survey is based on the visiting distribution/collection method, for which the responses from non-activity and shorter-distance traveling people can be collected with a high rate. In this meaning, it is clear that the 1992 PT data is more reliable than the 1991 PT data; however, those data were collected almost at the same time and it cannot be said that the necessity of using these 2 points-in-time data simultaneously for the purpose of analyzing the long-term changes of travel behavior is high. Then, it is rather more desirable to eliminate differences of trip characteristics, which are originated from different survey methods. Furthermore, since the weekend days data is available only in 1991 PT data, for the comparative analysis between

Table 3. Comparison of Daily Trip Frequency and Modal Split in 1991 and 1992

(a) Trip frequency

Frequency	1991	1992
0	7.1	19.7
1	0.0	0.6
2	49.4	45.1
3	11.5	7.9
4	17.5	14.8
5	7.2	3.9
≥6	7.3	8.0
Activity rate (%)	92.9	80.3
Net trip rates (trips/person)	3.10	3.07

(b) Modal split

Transport mode	1991	1992
Public transport	8.3	5.9
Car	67.1	68.0
Motorcycle and on foot	24.7	26.1
Total	100.0	100.0

Table 4. Comparison of Trip Purpose in 1991 and 1992

Year	Work	School	Discretionary	Business	Home	Total
1991	20.5	2.2	28.1	11.8	37.5	100.0
1992	18.1	1.5	22.8	19.5	38.2	100.0

Breakdown of discretionary trip share by job

Year	Worker	Student	Housewife and non-worker	Total
1991	12.5	1.1	14.4	28.1
1992	12.6	0.8	9.4	22.8

Unit: %

weekdays and weekend, it is more desirable to use them as well as the survey method is the same as the 2001 PT data. From these viewpoints, in this research, it has been decided to give priority to analyzing the long-term time-series changes of travel behavior and then excluding the 1992 PT data in the subsequent analysis in spite of its reliability.

3. ACTUAL CONDITION OF TIME SERIES CHANGES OF TRAVEL BEHAVIOR

3.1 Activity Rate and Trip Frequency

Table 5 shows the daily trip frequency at each temporal point on both weekdays and weekend. On weekdays in the 24-year period (1977-2001), the share of trip frequency up to four trips had increased steadily which led to the decrease of activity rate and gross trip rates. That is, net trip rates changed with 3.41 -> 3.10 ->3.12 (trips/person) which shows the tendency of stop declining, the gross trip rates and activity rate were changed with 3.27->2.88->2.77 (trips/person), 95.7->92.9->88.9% indicating that both are on downward trend. On weekend days in the 10-year period (1991-2001), in contrast to weekdays, people who do not have trip had decreased significantly which was a reason that the share of trip frequency up to four trips decreased and the activity rate increased, but the net trip rates was decreasing.

3.2 Trip Purpose

Table 6 shows the time-series changes of trip purposes at each point in time. On weekdays in those 24 years, trip purpose had been changed remarkably, especially the largest relative increase of discretionary trips and decrease of business trips. This resulted from the extreme decrease in workers' business trips and a gradual increase in discretionary trips of workers, non-workers and housewives (Table 6, lower berth). At the same time, on weekend days in those ten years, in contrast to weekdays, discretionary trips decreased (-3.6%) while working trips and business trips were increased.

Table 5. Changes of Daily Trip Frequency and Activity Rate (all purposes, all modes)

	Weekdays			Weekend days	
Trip frequency	1977	1991	2001	1991	2001
0	4.3	7.1	11.1	30.8	27.1
1	0.3	0.0	0.6	0.0	2.0
2	39.9	49.4	47.0	34.7	40.5
3	11.3	11.5	12.8	13.7	10.5
4	21.7	17.5	14.8	12.0	10.1
5	8.9	7.2	4.8	4.0	4.3
≥6	13.6	7.3	9.0	4.9	5.4
≤4	77.6	85.5	86.3	91.2	90.2
≥5	22.4	14.5	13.7	8.8	9.8
activity rate (%)	95.7	92.9	88.9	69.2	72.9
Net trip rates (trips/person)	3.41	3.10	3.12	3.05	2.92

Table 6. Changes of Trip Purpose (all modes)

	Weekdays			Weekend days	
	1977	1991	2001	1991	2001
Work	14.4	20.5	17.6	1.7	3.5
School	1.2	2.2	1.3	0.3	0.1
Discretionary	25.7	28.1	33.4	58.2	54.6
Business	21.0	11.8	7.6	0.8	1.8
Home	37.6	37.5	40.0	39.0	39.9
Total	100.0	100.0	100.0	100.0	100.0
Breakdown of discretionary trip share by job					
Worker	9.6	12.5	13.3	42.9	34.8
Student	0.6	1.1	0.4	3.1	0.6
Housewife and non-worker	15.6	14.4	19.7	12.2	19.2
Total	25.7	28.1	33.4	58.2	54.6

Unit: %

3.3 Trip Generation and Attraction

Time-series changes of trip generation and attraction by zone at each point in time are shown in Fig. 2. On weekdays in those 24 years, the share of trip generation and attraction in the suburbs increased by 12.1%, while in the city center it decreased by 13.6%. At the same time, on weekend days in those ten years, the share on of trip generation and attraction in the suburb has increased by 4.8% whereas in the city center it has decreased by 2.8% showing that their change rates are almost the same level as on weekdays (i.e., change rates in ten years at the city center and suburb are 0.78 and 1.12 for weekdays, 0.79 and 1.13 for weekend days, respectively).

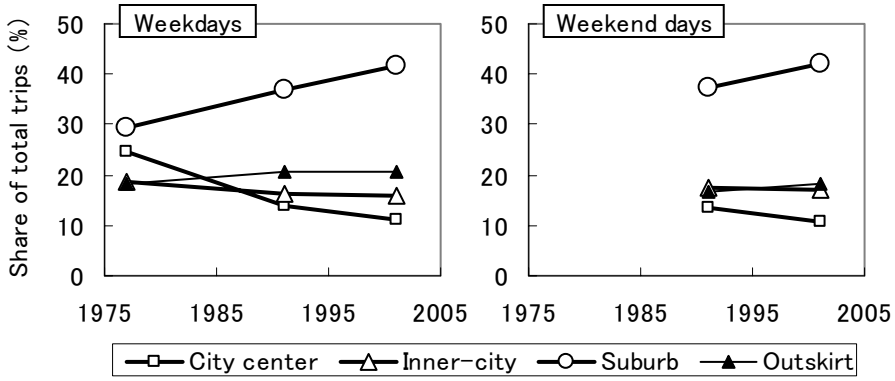


Figure 2. Changes of Trip Generation and Attraction by Zone (all purposes, all modes)

3.4 Trip Distribution

Table 7 shows the time-series changes of OD trips at each point in time. On weekdays in those 24 years, the share of OD trips between each OD pair had changed significantly. A greatly varied one is between OD pair "city center-city center" which decreased by 8.0%, and between OD pair "suburb-suburb", "suburb-outskirt" which increased by 7.6% and 6.2%, respectively. On weekend days in those ten years, in comparison to weekdays, it is remarkable that although their change trends are almost the same, the amount of change in OD pair which had changed dramatically on weekdays is small (i.e., change rates in ten years of OD pair "city center-city center" and "suburb-suburb" are -1.2% and +5.1% for weekdays, -0.7% and +4.3% for weekend days).

Table 7. Changes of OD Trip (all purposes, all modes)

	Weekdays			Weekend days	
	1977	1991	2001	1991	2001
City center – City center	12.5	5.7	4.5	4.1	3.4
City center – Inner city	7.9	4.8	3.4	7.1	3.8
City center – Suburb	9.5	7.7	6.4	6.8	6.7
City center – Outskirt	3.6	3.0	1.8	2.1	1.9
Inner city – Inner city	7.6	5.2	5.8	5.8	6.1
Inner city – Suburb	8.3	9.9	10.3	9.0	11.0
Inner city – Outskirt	2.8	4.2	3.2	3.4	3.3
Suburb – Suburb	15.6	18.1	23.2	18.7	23.1
Suburb – Outskirt	5.3	11.5	11.4	9.4	10.4
Outskirt – Outskirt	11.0	8.8	9.9	5.8	8.4
Exchange trips, Crossing trips	15.8	21.2	20.1	27.9	21.8
Total	100.0	100.0	100.0	100.0	100.0

unit: %

Table 8. Changes of Trip Destination Choice by Zone Origin (all purposes, all modes)

		Weekdays			Weekend days	
Zone origin	Destination zone	1977	1991	2001	1991	2001
City center	City center	51.0	40.7	40.8	31.9	32.3
	Inner-city	16.0	15.9	15.9	23.9	17.1
	Suburb	19.4	29.1	28.7	29.1	32.7
	Outskirt	7.5	10.0	8.5	6.8	8.5
	Ouside city	6.1	4.3	6.1	8.3	9.3
	Total	100	100	100	100	100
Inner-city	City center	21.3	15.9	10.5	22.4	11.9
	Inner-city	41.0	31.6	36.3	32.6	35.8
	Suburb	22.5	29.9	32.5	23.5	31.4
	Outskirt	7.5	11.8	10.0	9.0	9.6
	Ouside city	7.7	10.7	10.6	12.6	11.3
	Total	100	100	100	100	100
Suburb	City center	16.1	9.8	7.7	8.1	7.6
	Inner-city	14.1	13.5	12.1	12.9	13.5
	Suburb	52.9	48.6	55.9	50.0	54.6
	Outskirt	9.0	16.1	13.7	13.1	12.4
	Ouside city	7.8	12.0	10.5	16.0	12.0
	Total	100	100	100	100	100
Outskirt	City center	10.0	7.7	4.0	7.1	5.5
	Inner-city	7.9	10.7	7.9	10.8	8.9
	Suburb	14.4	26.5	28.0	27.2	28.2
	Outskirt	60.6	42.4	48.1	35.2	45.9
	Ouside city	7.1	12.7	12.0	19.7	11.6
	Total	100.0	100.0	100.0	100.0	100.0

Unit: %

Moreover, time-series changes of trip destination choice by zone origin are shown in Table 8. On weekdays in those 24 years, destination choice to “city center” from every zone origin decreased dramatically whereas destination choice to “suburb” except for intrazonal trips increased significantly. Among these, especially in zone origin “suburb” where change of destination choice is great, the destination choice to “city center” decreased more than half while to “suburb” increased twice. At the same time, on weekend days in those ten years, although the change of destination choice to “city center” from every zone origin is in the same tendency as on weekdays, the destination choice of trips, which mostly are discretionary trips, to suburb from every zone origin is on upward trend.

3.5 Modal Split

Fig. 3 shows the time-series changes of modal split. On weekdays, public transport changed with 12.9->8.3->7.3%, car changed with 45.7->67.1-> 70.3%, and motorcycle and on foot changed with 41.4->24.7->22.4%. That is, in those 24 years, share of car had increased dramatically while in contrast shares of public transport, motorcycle and on foot had decreased sharply. In detail, compared to share of public transport which had decreased by about 5.6%, share of motorcycle and on foot had decreased by about 19.0% which clarified that modal shift to car from motorcycle and on foot is progressing rather than from public transport. On the other hand, on weekend days in those ten years, share of car had increased and shares of public transport, motorcycle and on foot had decreased showing the same tendency as on weekdays but the amount of change of car, motorcycle and on foot is comparatively small.

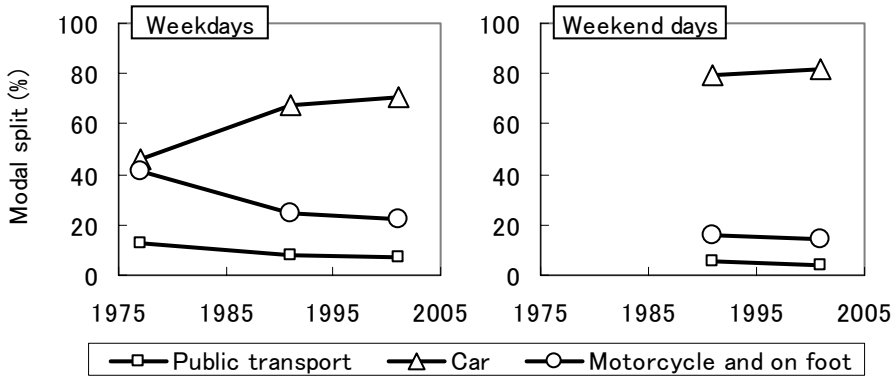


Figure 3. Changes of Modal Split (all purposes)

Furthermore, time-series changes of modal split by zone origin are shown in Table 9. On weekdays in those 24 years, share of car increased greatly in every zone origin while share of other transport modes decreased significantly. In detail, by comparing to the change of public transport, share of motorcycle and on foot had decreased significantly especially in zone origin “outskirt” where its decrease rate was high. At the same time, on weekend days in those ten years, while mode choice at zone origin “inner-city” and “suburb” show the same tendency as on weekdays, at zone origin “city center” where on weekdays car choice had decreased, motorcycle and on foot had increased slightly, is contrasted to the one on weekend days as well as the change is also large. However, both on weekdays and weekend days, as reflecting to the differences in level of service of the relevant transport modes, the farther distance from central area, the larger the share of car and the smaller the share of public transport, motorcycle and on foot.

Table 9. Changes of Modal Split by Zone Origin (all purposes)

		Weekdays			Weekend days	
Zone origin	Transport mode	1977	1991	2001	1991	2001
City center	Public transport	14.9	7.0	9.1	4.8	5.4
	Car	34.3	55.1	52.3	60.7	70.6
	Motorcycle and on foot	50.8	38.0	38.5	34.6	24.0
	Total	100.0	100.0	100.0	100.0	100.0
Inner-city	Public transport	11.4	6.0	5.7	7.8	2.3
	Car	39.7	58.5	66.6	71.6	86.0
	Motorcycle and on foot	48.9	35.5	27.7	20.6	11.7
	Total	100.0	100.0	100.0	100.0	100.0
Suburb	Public transport	8.8	6.9	5.8	3.6	2.9
	Car	48.4	70.2	69.6	83.4	78.3
	Motorcycle and on foot	42.8	22.9	24.6	13.0	18.8
	Total	100.0	100.0	100.0	100.0	100.0
Outskirt	Public transport	9.9	9.0	2.8	3.6	2.2
	Car	53.0	74.6	81.3	90.7	88.8
	Motorcycle and on foot	37.1	16.4	15.9	5.7	9.0
	Total	100.0	100.0	100.0	100.0	100.0

Table 10. Changes of Average Trip Distance

	Year	Public transport	Car	Motorcycle and on foot	Total	Discretionary
Weekdays	1977	4.42 (82)	3.60 (93)	1.55 (72)	2.69 (78)	1.99 (75)
	1991	5.38 (100)	3.86 (100)	2.17 (100)	3.44 (100)	2.65 (100)
	2001	4.32 (80)	3.69 (96)	1.84 (85)	3.20 (93)	2.57 (97)
Weekend days	1991	3.75 (100)	3.38 (100)	1.78 (100)	3.09 (100)	3.45 (100)
	2001	4.98 (133)	3.46 (102)	1.70 (95)	3.19 (103)	3.25 (94)

Unit: km; ( ): in % compared to 1991 as 100%

3.6 Average Trip Distance and Time

Time-series changes of average trip distance of OD trips in the whole region are shown in Table 10. In this calculation, each internal trip distance is defined as the distance in straight line between two centroids of PT zones (there are 30 PT zones in the study area). Simultaneously, each intrazonal trip distance is defined as one-haft of the minimum distance between the relevant zones to all other zones in the area. As shown in Table 10, both on weekdays and weekend days, in response to city's suburbanized activities growth, the average trip distance had increased, which on weekdays in those 24 years it was lengthened from 2.7km to 3.2km and on weekend days in those ten years it was lengthened from 3.1km to 3.2km. In detail, by examining from the transport mode, on weekdays in those 24 years, car trip distance had increased slightly whereas motorcycle and on foot had increased dramatically; however, the average trip distance of public transport in 1991 became longer which may be caused by its small sample size. Examining from the trip purpose, it revealed that the average trip distance of discretionary trip on weekdays in those 24 years increased from 2.0km to 2.6km, but in the last ten years it was decreasing and smaller than the one on weekend days. Additionally, time-series changes of average trip distance by zone origin are shown in Table 11. On weekdays, although there was a slight decrease in every zone origin during the last ten years, the overall trend of those 24 years is significantly increased. At the meantime, on weekend days in those ten years, the average trip distance had increased in zone origin "city center" and "inner-city", but decreased in zone origin "outskirt" as on weekdays. However, the farther from city center, the longer the average trip distance, which is twice as long as in "suburb" compared to "city center".

Table 11. Changes of Average Trip Distance by Zone Origin (all purposes, all modes)

	Year	City center	Inner-city	Suburb	Outskirt	Total
Weekdays	1977	2.13 (81)	2.20 (82)	2.71 (81)	3.89 (81)	2.69 (78)
	1991	2.64 (100)	2.68 (100)	3.34 (100)	4.81 (100)	3.44 (100)
	2001	2.51 (95)	2.50 (93)	3.00 (90)	4.54 (94)	3.20 (93)
Weekend days	1991	2.51 (100)	2.40 (100)	2.94 (100)	4.74 (100)	3.09 (100)
	2001	2.69 (107)	2.61 (109)	2.92 (99)	4.63 (98)	3.19 (103)

Unit: km; ( ): in % compared to 1991 as 100%

Table 12. Changes of Average Trip Time by Transport Mode (all purposes)

	Year	Public transport	Car	Motorcycle and on foot	All modes
Weekdays	1991	37.2 (26.0)	18.6 (20.0)	14.1 (16.4)	18.2 (19.9)
	2001	32.5 (19.8)	17.8 (17.6)	15.5 (20.4)	17.7 (18.6)
Weekend days	1991	25.4 (12.4)	18.1 (16.4)	16.4 (22.3)	18.1 (17.5)
	2001	26.9 (14.3)	17.7 (15.5)	16.3 (26.3)	17.7 (17.6)

Unit: mn; ( ): standard deviation

Table 13. Changes of Average Trip Time by Trip Purpose (all modes)

	Year	Work	Discretionary	Business	All purposes
Weekdays	1991	18.9 (17.6)	19.1 (22.9)	19.7 (27.2)	18.2 (19.9)
	2001	19.3 (11.9)	17.9 (23.3)	19.2 (17.5)	17.7 (18.6)
Weekend days	1991	16.2 (8.7)	20.0 (19.5)	23.6 (28.8)	18.1 (17.5)
	2001	15.0 (10.5)	18.6 (19.7)	22.5 (28.4)	17.7 (17.6)

Unit: mn; ( ): standard deviation

Time-series changes of average trip time of OD trips in the whole region by transport mode are shown in Table 12. Since the 1977 PT survey has no data on trip time, only two points in time of average trip time are compared here. First, by viewing from the transport modes it was found that in those ten years, the average trip times of all modes on both weekdays and weekend days were decreasing. In detail, the average trip time of motorcycle and on foot on weekdays and the average trip time of public transport on weekend days had increased. Other modes beside these modes had decreased on both weekdays and weekend days. Secondly, by examining from the trip purpose as shown in Table 13, on weekdays in the last ten years while the average trip time of commuting trips was increasing, the average trip times of discretionary trips and of business trips were increasing. At the same time, on weekend days the average trip time were decreased in all trip purposes.

In conclusion, from the viewpoints of global environmental problems, etc., it is important to make these mean trip lengths shorter, and it is assumed that the lesser these values, the higher the convenience level and the more saving in transportation energy.

4. FACTORIZATION ANALYSIS OF THE TIME SERIES CHANGE

4.1 Method and Definition of Factorization

It is considered that the overall trip rates generally change by time-series change of trip rates classified by individual attribute and time-series change of individual attribute composition.

The overall modal split in the whole region generally changes by time-series change of modal split between OD pairs and time-series change of OD trip compositions. Furthermore, trip attraction rate to a particular zone generally changes by time-series change of destination choices to that zone of trips generated from every zones and time-series change of trip generations of those zones.

This paper, in order to describe them in general, the value of trip characteristics *A* such as trip rates, modal split, etc. at time *t* is expressed as follows:

$$a_A^t = \sum_i a_{A/B_i}^t \cdot P_{B_i}^t \quad \cdots\cdots (1)$$

where,

a_A^t : the value of trip characteristic *A* at time *t*

a_{A/B_i}^t : the value of trip characteristic *A* classified by factor B_i at time *t*, and

$P_{B_i}^t$: the factor composition B_i at time *t*.

In addition, at time $t+\Delta t$, the value of trip characteristic *A* and factor composition B_i can be expressed as:

$$\begin{cases} a_{A/B_i}^{t+\Delta t} = a_{A/B_i}^t + a_{A/B_i}^{\Delta t} \\ P_{B_i}^{t+\Delta t} = P_{B_i}^t + P_{B_i}^{\Delta t} \end{cases} \quad \cdots\cdots (2)$$

Then, the value of trip characteristic A at time $t+\Delta t$ is given as follows, showing the decomposition of time series change quantitatively by factors.

$$\begin{aligned} a_A^{t+\Delta t} &= \sum_i a_{A/B_i}^{t+\Delta t} \cdot P_{B_i}^{t+\Delta t} \\ &= \sum_i (a_{A/B_i}^t \cdot P_{B_i}^t + a_{A/B_i}^{\Delta t} \cdot P_{B_i}^t + a_{A/B_i}^t \cdot P_{B_i}^{\Delta t} + a_{A/B_i}^{\Delta t} \cdot P_{B_i}^{\Delta t}) \quad \cdots\cdots (3) \end{aligned}$$

That is, time-series change of the overall trip characteristic *A* can be expressed as the summation of three elements: the change of factor trip characteristic with factor composition B_i does not change, the change of factor composition B_i with factor trip characteristic does not change, and the synergistic effect caused by factor trip characteristic change and factor composition change. Hence, by applying such factorization it becomes possible to understand the temporal macro change of trip characteristics quantitatively. Hereafter, by using formula (3) factorization analysis of time-series changes of three trip characteristics, i.e. trip rates, modal split, and trip spatial distribution are performed.

4.2 Factorization Analysis of Time Series Change of Trip Rates

Let *A*, B_i be trip rates and individual attribute, and let $a_A, a_{A/B_i}, P_{B_i}$ be the overall trip rates, trip rates of individual attribute B_i and composition of individual attribute B_i, respectively. Then the 1st-4th term of formula (3) serve as “trip rates of the previous term”, “effect by trip rates characteristic change”, “effect by individual attribute composition change” and “synergistic effect”, correspondingly.

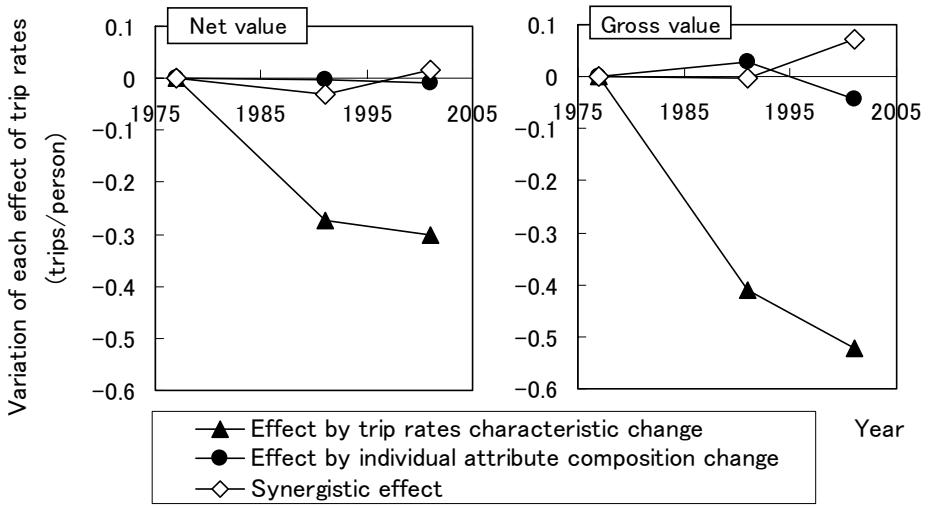
Age was divided into three categories (18-34 years old, 35-64 years old, and 65 years old or

older), occupation was also divided into three categories (student, worker, housewife and non-worker), and sex was added for individual attribute categories (except for the categories of students over 35 years old, there are 14 categories in total). The calculation results for each effect at each point in time based on the previous term and on 1977 are shown in Table 14 and Fig. 4 (weekdays only), respectively. On weekdays in those 24 years, the effect term which influenced largely on the declining of trip rates is the "effect by trip rates characteristic change". This effect which its value in net and gross trip rates is -0.30 and -0.52 (trips/person) differs extremely compared to the "effect by individual attribute composition change" and "synergistic effect". This means that, on the average, the declining of the overall trip rates depends predominantly on the decrease of number of trips that a traveler performs rather than on the change of individual attribute composition. However, the effect caused by changes of individual attribute composition such as the increase of elderly people or occupational structure change, etc. is negative and small (except in 1991 the effect by categories of middle age worker increased greatly, then the overall effect was positive). Moreover, the "synergistic effect", which is caused by the change of both the trip rates characteristic and individual attribute composition, was positive in average. This is because trip rates characteristic change is negative in almost every individual attribute categories and the individual attribute composition change is also comparatively negative in many categories, so that their product-sum is positive but the amount of effect is small.

Table 14. Changes of Each Effect of Trip Rates (all purposes, all modes)

	Trip rates	Year	Trip rates of the previous term	Effect by trip rates characteristic change	Effect by individual attribute composition change	Synergistic effect	Total
Weekdays	Net value (trips/person)	1977	–	–	–	–	3.41
		1991	3.41	−0.27	0.00	−0.03	3.10
		2001	3.10	−0.03	−0.01	0.05	3.12
	Gross value (trips/person)	1977	–	–	–	–	3.27
		1991	3.27	−0.41	0.03	0.00	2.88
		2001	2.88	−0.11	−0.07	0.07	2.77
Weekend days	Net value (trips/person)	1991	–	–	–	–	3.05
		2001	3.05	−0.11	−0.06	0.04	2.92
	Gross value (trips/person)	1991	–	–	–	–	2.11
		2001	2.11	0.09	−0.10	0.06	2.16

＊: results based on the previous term



＊＊: results based on 1977

Figure 4. Changes of Each Effect of Trip Rates (all purposes, all modes)

On the other hand, on weekend days in those ten years, as shown in Table 14, as similar to weekdays the effect term which influenced largely on the change of trip rates is the “effect by trip rates characteristic change”. The “effect by individual attribute composition change” is positive and “synergistic effect” is negative as on weekdays.

However, in this analysis, the “effect by trip rates characteristic change” which is derived from the trip rates characteristic change in case that the individual attribute composition does not change, is considered to reflect on the tempo-spatial change of individual's residence, workplace, income etc. or the change of transport service conditions between OD pairs. Therefore, further detailed analysis is required.

4.3 Factorization Analysis of Time Series Change of Modal Split

Let A, B_i be transport mode and OD pair, and let $a_A, a_{A/B_i}, P_{B_i}$ be the overall modal split of mode A in the whole region, modal split of mode A in OD pair B_i, the share of OD trips in OD pair B_i respectively, then 1st-4th term of formula (3) orderly serves as the “modal split of the previous term”, the “effect by OD pair modal split characteristic change”, the “effect by OD pair trip composition change” and the “synergistic effect” which are caused by the change of both OD pair modal split and OD pair trip composition.

Study area was divided into four zones, and the calculation results of each effect at each point in time based on the previous term are shown in Table 15, and the results based on 1977 are shown in Fig. 5 (weekdays only). On weekdays in those 24 years, the effect term which mainly affected the modal split is the “effect by OD pair modal split characteristic change”. This effect on public transport, motorcycle and on foot are -6.7% and -14.4% respectively, while this effect on car which mode share was expanded at every OD pair is +21.1%. Time-series change of mode share caused by the tempo-spatial change of OD trips patterns accompanying by suburbanizing, etc. on public transport is not so large (+0.4%), but on motorcycle and on foot is -6.0%, and on car is +5.7%. That is, it is considered that increase of OD pair flows with high car share and low share of motorcycle and on foot have influenced slightly on time-series change of these mode shares. Furthermore, since car share change is positive in every OD pair and its corresponding OD composition change is also comparatively negative in many OD pairs, so that the overall effect of “synergistic effect” on car mode is negative. Simultaneously, its effect on public transport, motorcycle and on foot is positive because their respective mode shares and OD trip compositions had decreased in many OD pairs.

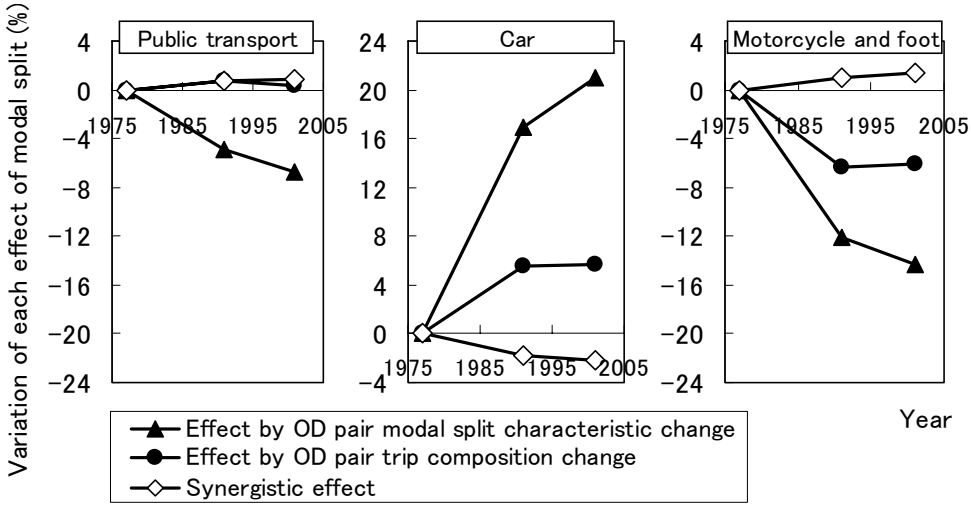
On the other hand, on weekend days in those ten years, although it is similar to weekdays that the effect term which affected each mode mostly is the “effect by modal split characteristic change”, the “effect by OD pair trip composition change” on public transport and the “synergistic effect” on car, motorcycle and on foot are also large.

However, in this analysis, the “effect by modal split characteristic change” is the change of modal split in case that trip composition between each OD pair does not change. It is considered that change in level of service between each OD pair, individual vehicle ownership, etc. affect the mode choice behavior among individuals. Furthermore, the “effect by OD pair trip composition change” reflects on the change of trip generation or trip attraction in every zone, trip distribution between OD pairs. Therefore, further detailed analysis is required.

Table 15. Changes of Each Effect of Modal Split (all purposes)

	Transport mode	Year	Modal split of the previous term	Effect by OD pair modal split characteristic change	Effect by OD pair trip composition change	Synergistic effect	Total
Weekdays	Public transport	1977	–	–	–	–	12.9%
		1991	12.9%	−4.8%	0.8%	0.8%	9.5%
		2001	9.5%	−1.9%	−0.4%	0.0%	7.3%
	Car	1977	–	–	–	–	45.7%
		1991	45.7%	17.0%	5.6%	−1.7%	66.5%
		2001	66.5%	4.1%	0.1%	−0.4%	70.3%
	Motorcycle and on foot	1977	–	–	–	–	41.4%
		1991	41.4%	−12.2%	−6.3%	1.0%	23.9%
		2001	23.9%	−2.2%	0.3%	0.4%	22.4%
Weekend days	Public transport	1991	–	–	–	–	5.9%
		2001	5.9%	−1.1%	−1.0%	0.1%	3.9%
	Car	1991	–	–	–	–	79.4%
		2001	79.4%	2.3%	1.4%	−1.5%	81.7%
	Motorcycle and on foot	1991	–	–	–	–	14.7%
		2001	14.7%	−1.2%	−0.4%	1.4%	14.5%

＊: results based on the previous term



＊＊: results based on 1977

Figure 5. Changes of Each Effect of Modal Split (all purposes)

4.4 Factorization Analysis of Time Series Change of Trip Attraction Rate

Let A, B_i be trip attraction zone and trip generation zone, and let $a_A, a_{A/B_i}, P_{B_i}$ be trip attraction rate to zone A, destination choice to zone A of trips generated from zone B_i, and trip generation rate in zone B_i, respectively. Then by applying formula (3), trip attraction rate to zone A at time $t+\Delta t$ is the summation of "trip attraction rate of the previous term", the "effect by destination choice change (=effect by the change of destination choice to zone A)", the "effect by trip generation change (=effect by the change of trip generation in each zone" and the "synergistic effect".

Study area was divided into four zones, and the calculation results of each effect at each point in time based on the previous term are shown in Table 16, and the results based on 1977 are shown in Fig. 6 (weekdays only). On weekdays in those 24 years, although on the average the effect term which influenced on the change of trip attraction rate mostly is the "effect by destination choice change", the influence of "effect by trip generation change" is great in outskirt resulting from the significant decrease of destination choice of intrazonal trips.

Moreover, the influence of “synergistic effect” is small. In detail, it was found that while in the city center the “effect by destination choice change” and “effect by trip generation change” are -9.1% and -4.9% as resulted from the sharp decrease of destination choice to the city center from every zone and the decrease of trips generated in the city center itself. In suburb where destination choice from every zone increased remarkably and its own trip generation was also increased, these effects are +9.5% and +3.3%, respectively. In inner-city, due to the decrease of destination choice of intrazonal trips and trips generated in the city center, the “effect by destination choice change” and the “effect by trip generation change” are negative. In outskirt, where destination choice from intrazone and suburb increased, and trips generated in these both zones also increased, the “effect by destination choice change” and “effect by trip generation change” are positive. In addition, such a tendency is more remarkable for discretionary trips.

Table 16. Changes of Each Effect of Trip Attraction Rate (all purposes, all modes)

	Attraction zone	Year	Trip attraction rate of the previous term	Effect by destination choice change	Effect by trip generation change	Syergistic effect	Total
Weekdays	City center	1977	−	−	−	−	24.6
		1991	24.6	−6.8	−4.0	0.4	14.1
		2001	14.1	−2.3	−0.9	−0.1	10.9
	Inner−city	1977	−	−	−	−	18.6
		1991	18.6	−1.7	−1.0	0.2	16.1
		2001	16.1	0.2	−0.1	−0.1	16.1
	Suburb	1977	−	−	−	−	29.3
		1991	29.3	6.0	2.5	−0.9	36.9
		2001	36.9	3.5	0.8	0.3	41.5
	Outskirt	1977	−	−	−	−	18.2
		1991	18.2	0.9	1.7	−0.1	20.7
		2001	20.7	−0.2	0.0	−0.1	20.4
Weekend days	City center	1991	−	−	−	−	14.0
		2001	14.0	−2.5	−0.7	0.1	10.8
	Inner−city	1991	−	−	−	−	17.8
		2001	17.8	−0.4	−0.5	0.1	17.1
	Suburb	1991	−	−	−	−	36.1
		2001	36.1	4.1	0.7	0.0	40.9
	Outskirt	1991	−	−	−	−	16.6
		2001	16.6	1.0	0.3	0.3	18.2

＊: results based on the previous term

On the other hand, on weekend days in those ten years, similarly to weekdays the effect term which affected trip attraction rate mostly is the “effect by destination choice change”, this effect in the city center and the suburb are -2.5% and +4.1%. The “effect by trip generation change” is negative in the city center and inner-city, is positive in the suburb and outskirt the same as on weekdays.

In addition, the “effect by destination choice change” in this analysis is the change of destination choices in case that trip generation in that zone does not change, and it is considered that destination choice behavior is dependent on LOS between OD pairs or the attractiveness of destination, etc. Furthermore, the “effect by trip generation change” is the change of trip generation in case that its destination choices do not change, is considered to rely on the change of location patterns of resident, commercial facilities and so on. Hence, more detailed analysis is required while this research remains to grasp these effects quantitatively.

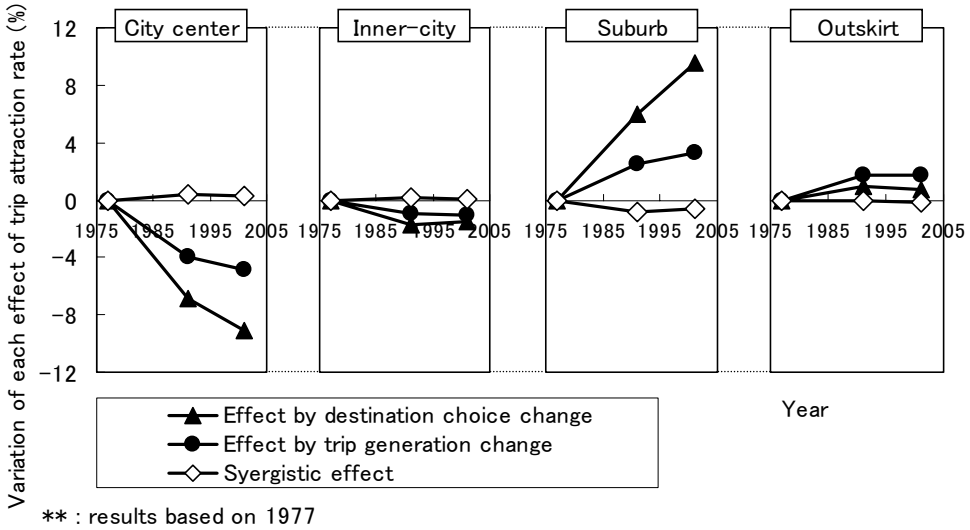


Figure 6. Changes of Each Effect of Trip Attraction Rate (all purposes, all modes)

5. CONCLUSION

This research first examines the time-series changes of trip rates, modal split and trip spatial distribution on both weekdays and weekend days in Toyohashi city, a local city in Japan. Secondly, it factorizes each amount of these serial changes into what is dependent on time-series change of factor characteristic and factor composition. Consequently, it was found that the effect caused by the change of factor characteristic is large in general. The results by each travel behavior are summarized as follows:

- Trip rates: the effect which influenced greatly on time-series change of trip rates is the "effect by trip rates characteristic change". That is, on the average the change of overall trip rates depends predominantly on the number of trips which a traveler performed rather than on the change of individual attribute composition, and the "effect by individual attribute composition change" caused by the progress of aging people, etc. influenced weakly.
- Modal split: the effect which affected time-series change of modal split mostly is the "effect by OD pair modal split characteristic change". It was influenced greatly by the temporal change of traveler mode choice between OD pairs itself rather than the tempo-spatial change of OD trips. At the same time, time series change of mode choice caused by tempo-spatial change of OD trip patterns is not so large for public transport except for other transport modes.
- Trip spatial distribution: the effect which highly influenced on the change of trip attraction rate is the "effect by destination choice change", while the influence of the "effect by trip generation change" is large in outskirt. In city center as resulted by the remarkable decrease of its destination choice from every zone, and the decrease of its own trip generation, the "effect by destination choice change" and the "effect by trip generation change" are negative and their amounts of change are great. In contrast to the city center, in the suburb, both effects are positive.

Lastly, it is necessary to conduct additional analysis which can tackle many factors considered to affect each effect term after exploring further decomposition method for multi-factor, and to examine a methodology for future urban travel demand forecasting, which can take into consideration the time series-change characteristics appropriately.

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