COMMUTERS' PERCEPTION OF TRAVEL TIME AND UNCERTAINTY UNDER CONGESTION PRICING: EXPLORATION OF A SIX-WEEK FIELD EXPERIMENT DATA

Kengo USHIWAKA, Akira KIKUCHI and Ryuichi KITAMURA
Department of Urban Management
Kyoto University
Yoshida Honmachi, Sakyo-ku, Kyoto 606-8501
Japan
PHONE: 075-753-5916, FAX: 075-753-5916
E-mail: ushiwaka@term.kuciv.kyoto-u.ac.jp

1. Introduction

As expanding facilities for urban transportation becomes difficult physically, financially, and politically, policy measures are increasingly oriented toward demand management, e.g., flextime, staggered work hours, and road pricing. Although implementation cases are rather few, dynamic road pricing schemes have shown that they can reduce the peaking of demand.1)

When traffic condition changes due to transportation control measures, drivers' perception of trip durations and their variations will also change, which in turn will lead to modified travel choices, e.g., switching the route of travel, or changing the time of departure. It can be logically expected that travelers' decisions are based on their perceptions of how long it will take and how variable it may be along each alternative route of travel. It is then crucial that how travelers perceive travel times and their variability. This is also the case for commuters and their commute trips.

To the best knowledge of the authors, however, no analysis of commuters' travel decision has been based on both objective measurements and perceptions of travel times and their variations. This is presumably because acquiring data on both their measurements and perceptions is difficult, particularly for travel time variations. As a result, previous studies have used either objectively measured (or reported) or perceived travel times or their variations.

Commuters' perceptions of the attributes of their commute trips by alternative travel modes are examined in this study. In particular, it is hypothesized that their perception of the uncertainty in travel time can be represented by the difference between the maximum and minimum travel times, which they recall to have experienced. With this representation of perceived uncertainty, the analysis examines the relationship between perceived uncertainty and recorded variability in travel times, and also the relationship between perceived uncertainty and the safety margin established by the commuters as a buffer against the possibility of being late for work. Initial exploratory analyses are also performed on the effects of toll reduction on the perception of travel time uncertainty and safety margin.

The data used in this study are from a survey of 232 commuters who were sampled at one of the toll gates on Route 13 of the Hanshin Expressway toll-road networks in the Osaka-Kobe metropolitan area of Japan. The respondents were asked to keep records of their commute trips over a six-week survey period, regardless of the travel mode taken. Perceptions of various aspects of their typical commute trips were also obtained from the same respondents in a separate questionnaire, which was distributed at the end of the six-week diary period. Travel times obtained from the former source, in which the respondent was asked to record the departure and arrival times of each commute trip, shall be called "recorded" travel times. Those from the latter source, on the other hand, shall be called "usual" travel times. The latter are assumed to reflections of the respondents' perceptions of representative travel times of their commute trips by mode.

During the six-week diary period, a field experiment was carried out in which the survey respondents had opportunities to use Route 13 with reduced tolls; they were given back cash after passing through the tollgate in exchange for coupons, which had been sent to them along with other survey instruments. Although it is unlikely that travel times on the roadway networks are influenced by this experiment, it is likely that those respondents who took advantage of the toll reduction may have been departing at different times or traveling along different routes than their usual commutes. Then it is likely that they may have different perceptions of travel times on these occasions. At the same time, it is conceivable that monetary cost and the risk of being late may be traded off differently due to the toll reduction. An exploratory analysis is performed on this in this study.

2. Commute Trips and Safety Margins

Because travel time is uncertain, and because a commuter often must report at work by the work starting time, the commuter is expected to choose his departure time to provide a buffer between the expected arrival time and the work starting time. Hall(2) calls this buffer "safety margin," and assumes that it is established so as to minimize the sum of the expected penalty of being late and the disutility of leaving earlier. Empirical findings on safety margins have been accumulated(3, 4), including that the size of a safety margin is positively associated with the mean commute travel time, and that it is larger for trips whose arrival times are more tightly constrained.

The relationship between safety margin and perceived uncertainty of travel time, however, has not been examined in previous studies. In this study, it is assumed that a commuter establishes his safety margin to account for uncertainty in travel time based on his perception of the uncertainty. The analysis of this study attempts to identify the relationship among: recorded commute travel times, perceived uncertainty of commute travel times, and the size of safety margin.

3. The Experiment

The subjects of the experiments were recruited by distributing copies of a brief questionnaire and solicitation letter to randomly selected passenger vehicles that passed the Nagata toll gate on Route 13 of the Hanshin Expressway networks toward the City of Osaka (Figure 1) in January, 2004. The letter offered a brief description of the experiment and the anticipated levels of effort requested of participants. A total of 10,000 copies were distributed, and 672 were returned by mail. Of the 672 returned questionnaires, 542 indicated willingness to participate in the experiment. The response rate is low at least for two reasons: first, participation required a substantial amount of effort on the part of respondents, and second, distributing survey instruments at toll gates usually yield low response rates. Because of the low response rate, it is conceivable that the population representativeness of the sample has been compromised. This must be kept in mind when interpreting the results of this study.

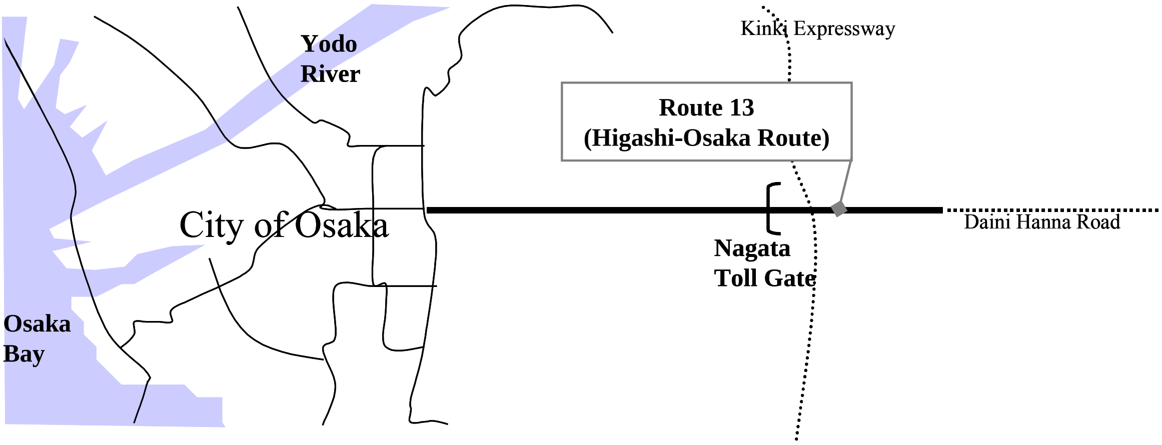

Figure 1. Hanshin Expressway Networks in the Osaka Area

The instruments for the experiment and the accompanying main survey were sent to 346 respondents randomly selected out of the 542 who indicated willingness to participate. These respondents were requested to keep diaries, recording attributes of their first trips of the day on weekdays between January 26 and March 5, 2004. Another questionnaire, sent out on March 2, contained questions about their "usual" commute trips. The response rates of the respective questionnaires are summarized in Table 1.

Table 1. Response Rates to Questionnaires

		Dairy Questionair		
		Responded	Did not respond	Total
Questionair of March2	Responded	224 65%	12 3%	236 68%
	Did not respond	8 2%	102 29%	110 32%
	Total	232 67%	114 33%	346 100%

The experiment with reduced tolls on Route 13 was carried out during the second through fifth weeks of the diary period. Those respondents who passed the Nagata toll gates during specified periods had a part of the tolled paid back in cash immediately after passing through the toll gate. The toll discount schedules and applicable periods are summarized in Table 2.

As shown in Table 2, the respondents are divided into groups and each group received a different toll discount schedule. They are first divided into two: those who used Route 13 "up to three to four days a week," and those who used Route 13 "almost everyday." Respondents in the former group shall be called *light users* and those in the latter group

Heavy Users. The light users are further divided into two groups. The first group (*Light User Group A*) received a discount of 600 yen out of the 700 yen regular toll in the second and third weeks of the diary period, and a discount of 200 yen in the fourth and fifth weeks. The second group (*Light User Group B*) received a 200-yen discount in the second and third weeks, then a 600-yen discount in the fourth and fifth weeks. Thus the respondents in Light User Group A qualified for a larger discount first then a smaller discount, while those in Group B qualified for a smaller discount first then a larger discount.

Table 2. Summary of the Field Experiment Design

Period	Passage Time through Nagata Tollgates	Toll Discount		
		Light Users		Heavy Users
		GROUPA	GROUPB	
1st week (1/26-1/30)		—	—	—
2nd week (2/2-2/6) and 3rd week (2/9-2/13)	5:00～6:00	600 yen	200yen	600yen
	6:00～7:00			300yen
	7:00～9:00			—
	9:00～10:00			300yen
	10:00～12:00			—
4th week (2/16-2/20) and 5th week (2/23-2/27)	5:00～6:00	200yen	600yen	300yen
	6:00～7:00			300yen
	7:00～9:00			—
	9:00～10:00			100yen
	10:00～12:00			—
6th week (3/1-3/5)		—	—	—

4. Data and Descriptive Statistics

As noted earlier, the respondents were asked to keep record of the first trip of the day during the diary period. Out of the data thus collected, only those records of trips that were made to commute to the respondents' regular workplaces are selected and used in the analysis of this study. Travel modes are classified into: (i) auto using Route 13, (ii) auto using surface streets, and (iii) public transit. The variables defined using the diary data and responses from the questionnaire on their usual commute trips are as follows.

Obtained from Six-Week Diary Data

- Travel mode of day n
- Departure time of day n [t_d^n]
- Predicted arrival time of day n [t_p^n]
- Actual arrival time of day n [t_a^n]
- Travel time of day n [t^n $(= t_a^n - t_d^n)$]

Obtained from Responses to Questions on "Usual" Commutes

- Departure time for usual commute [T_d]
- Arrival time of usual commute [T_p]
- Work starting time [T_w]
- Perceived mean travel time [T $(= T_p - T_d)$]
- Safety margin [SM $(= T_w - T_p)$]
- Safety nargin of day n [SM^n $(= T_w - t_p^n)$]

- Perceived longest travel time ever experienced departing at T_d [T_{max}]
- Perceived shortest travel time ever experienced departing at T_d [T_{min}]
- Difference between T_{max} and T_{min} [L (= T_{max} - T_{min})]

It is postulated in this study that the last variable, the difference between the perceived maximum and minimum travel times, represents the uncertainty in commute travel time as perceived by the respondent. The sample means and standard deviations of the average of the diary travel times by respective respondents (average of the t^n), perceived mean travel time (T) and the difference between T_{max} and T_{min} (L) are summarized in Table 3 by travel mode.

Table3. Descriptive Statistics across the Variables and Modes

		Average	S.D.	*N*
Average (t^n)	Auto on Route13	55.9	16.1	107
	Auto on Surface Streets	42.8	26.3	40
	Public Transit	67.5	24.6	37
T	Auto on Route13	63.5	21.6	154
	Auto on Surface Streets	75.3	35.9	175
	Public Transit	73.9	25.7	167
SM	Auto on Route13	25.0	28.3	116
	Auto on Surface Streets	20.5	25.0	132
	Public Transit	20.0	22.6	124
L	Auto on Route13	47.6	23.0	152
	Auto on Surface Streets	37.3	24.4	135
	Public Transit	15.4	12.6	124

Table 3 indicates that respondents on Route 13 or public transit tend to have longer commute travel times, while those on surface streets tend to have shorter trips. Judging from the mean values of the difference between perceived maximum and minimum travel times (L), commuting on Route 13 is viewed to involve the highest level of uncertainty, while commuting on public transit is associated with the lowest level of uncertainty.

Consistent with the conjecture postulated in Section 2 that the safety margin is established to account for travel time uncertainty, the safety margin (SM) is the largest with trips on Route 13 for which L is also the largest, and is the smallest for public transit trips for which L is also the smallest. The difference in SM is negligibly small between surface streets and public transit, while that in L is quite substantial between the two modes, however.

5. Differences in Uncertainty among Travel Modes

Differences between the attributes of commute trips recorded in the diary and those of "usual" commute trips are examined here. Tables 4 through 6 show the means and standard deviations of the differences between arrival time on day n and usual arrival time ($t_a^n - T_p$), departure time on day n and usual departure time ($t_d^n - T_d$), and travel time on day n and usual travel time ($t^n - T$), respectively, by travel mode. The variance is decomposed into between-individual variance and within-individual variance and shown in Figures 2 through 4.

5.1. Difference between Usual and Reported Arrival Times

As Table 4 indicates, the difference between usual and reported arrival times ($t_a^n - T_p$) is on average very small. The average differences range from –4.09 min. for surface streets to 3.81 min. for public transit; respondents arrived slightly ahead of their "usual" arrival times when they commuted on surface streets. Quite notably, Figure 2 indicates that commute trips on Route 13 have a small between-person variance and a large within-person variance. The small within-person variance may be because Route 13 represents large fractions of respondents' commute trips, implying that large fractions of their trips share the same facility traveled at similar speeds. Trips on surface streets, where different types of facilities are used, on the other hands exhibit a larger between-person variance. The large within-person variance of trips on Route 13 is consistent with the result in Table 3 that the difference between the perceived maximum and minimum travel times (L) is the largest for Route 13. As expected, within-person variance is the smallest for public transit trips whose line-haul travel times are very predictable.

Table 4. Difference between Usual and Reported Arrival Times ($t_a^n - T_p$)

	Average	S.D.	*N*
Auto On Route 13	3.26	39.51	1389
Auto On Surface Streets	-4.09	43.94	298
Public Transit	3.81	31.41	232

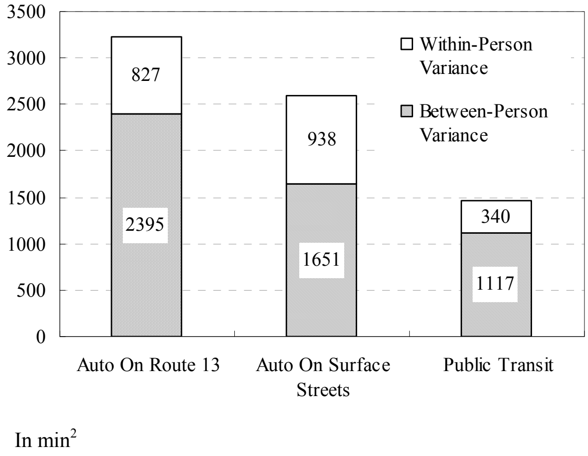

Figure 2. Within- and Between-Person Variances of ($t_a^n - T_p$)

5.2. Difference between Usual and Reported Arrival Times

Again, the average differences between usual and reported arrival times are small, irrespective of the travel mode used (Table 5). On average, respondents left home earlier than "usual" by about 5 min. when they commuted on Route 13. This may reflect their perception that travel times on Route 13 are uncertain. The absolute value of within-person variance is quite similar between Route 13 and surface streets, while it is much smaller when they commuted by public transit, again reflecting the higher reliability of public transit, and also the fact that their departure times are regulated by transit schedules.

Table 5. Difference between Usual and Reported Departure Times (t_d^n - T_d)

	Average	S.D.	*N*
Auto On Route 13	4.58	38.03	1389
Auto On Surface Streets	-1.02	40.79	281
Public Transit	-1.71	29.39	234

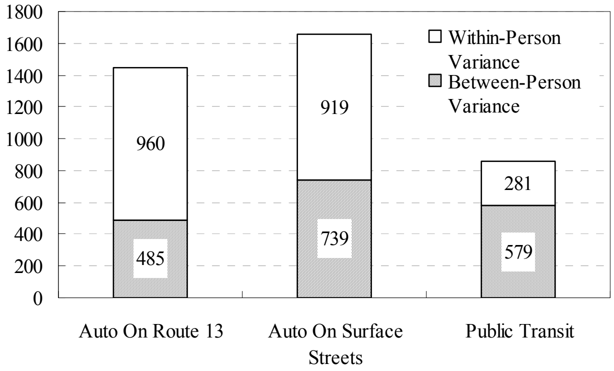

Figure 3. Within- and Between-Person Variances of (t_d^n - T_d)

5.3. Difference between Usual and Reported Travel Times

The "usual" travel times as perceived by the respondents are slightly longer than reported travel times as the means of (t^n – T) shown in Table 6 indicate. Quite notable is the result that within-person variance is quite small for commute trips on surface streets. In fact its absolute value is smaller than the one on public transit. The results suggest that auto commute trips on surface streets are quite reliable. Of course one must be aware of the selectivity involved; respondents might have chosen to commute on surface streets on days when surface streets are reliable, while have chosen to use Route 13 or public transit when traffic conditions on surface streets were less predictable, like on Fridays or under adverse weather.

Table 6. Difference between Usual and Reported Travel Times (t^n - T)

	Average	S.D.	*N*
Auto On Route 13	-3.61	13.30	1359
Auto On Surface Streets	-4.75	13.37	278
Public Transit	-2.62	8.58	222

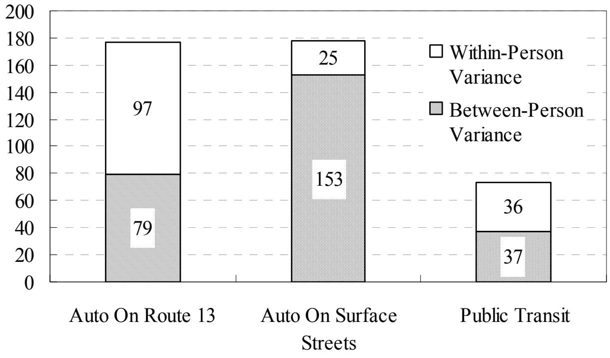

Figure 4. Within- and Between-Person Variances of (t^n - T)

The tabulations of this section have shown that within-person variance of the difference between usual and reported travel times are extremely large for commute trips on Route 13. In other words, travel times on Route 13 are much more variable on Route 13 than on surface streets or by public transit. At the same time, it has been shown in Table 5 that respondents departed on average about 5 minutes later than usual when they commuted on Route 13, while the largest average safety margin is set for commute trips on Route 13 as seen in Table 3. It appears as if respondents are not achieving the large safety margins they establish in their mind to account for higher levels of uncertainty in travel time they perceive for commute trips on Route 13.

6. The Relationship between *L* and the Variation of Commute Travel Time

The analyses so far have revealed some of the nature of uncertainty in commute travel time by travel mode. Then how do commuters perceive the uncertainty in their commute trips, and how do they establish safety margins given the uncertainty as they perceive? The analyses of this and the next sections probe into these questions with the assumption that the uncertainty in travel time perceived by commuters can be represented by the difference, L, between the maximum and minimum travel times they recall to have experienced.

The first question that needs to be addressed is how this measure of perceived uncertainty, L, is related to travel times that commuters have experienced. For example, how is L associated with the variance of travel times or with their mean? To address these questions, a linear regression model is estimated with L as the dependent variable, and the mean and standard deviation of travel times recorded in the diaries and respondents' personal attributes as the explanatory variables. The results are summarized in Table 7.

Table 7 presents somewhat different tendencies across Route 13, surface streets and public transit. In the model for Route 7, the only significant variable is the mean recorded travel time ($Avg(t^n)$), which has a positive coefficient estimate. The standard deviation of recorded travel times ($SD(t^n)$) has a negative coefficient estimate that is not significant at any appropriate level. Likewise in the model for surface streets, $Avg(t^n)$ has a significant positive coefficient estimate, but $SD(t^n)$ is not. In the model for public transit, on the other hand, $Avg(t^n)$ and $SD(t^n)$ are both insignificant.
A conclusion emerges from this regression analysis that the difference of perceived maximum and minimum travel times ever experienced, L, is not associated with the standard deviations of travel times recorded by travel mode during the six-week diary period. Recall that the questions about the experienced maximum and minimum travel times were asked at the end of the diary period. Thus the responses to them should reflect the travel times experienced during the diary period. The result thus offers an indication that L represents long-term experience, and does not reflect the variation in travel times in the immediate past. It is noted that a separate regression analysis, whose results are not presented in this paper, indicated that the difference between the maximum and minimum travel times recorded during the diary period is positively associated with the standard deviation of travel times during the same period.

The coefficient of the difference between usual travel time and the average of recorded travel times ($Avg(t^n - T)$) is negative and significant for all modes (at $\alpha = 0.10$ for Route 13 and public transit, $\alpha = 0.05$ for surface streets). This implies that those commuters who perceive usual travel time to be larger than the average of recorded (≅ actual) travel times tend to have larger *L*. In other words, those commuters who over-estimate the travel time to work tend to perceive the difference between the longest and shortest commutes they recall to be larger. The results suggest that *L* in fact is a measure of perceived uncertainty, which is not associated with the short-term variation of travel times.

7. The Relationship between *L* and Safety Margin

How safety margin is related to the attributes of the commute trip, attributes of commuters, and their perception of uncertainty as represented by *L* is examined in this section using regression analysis. Safety margin is normalized by dividing it by perceived "usual" travel time (*T*), and used as the dependent variable of the analysis. Likewise the difference of perceived maximum and travel times (*L*) is also divided by *T* for normalization. This reflects the consideration that the longer the commute duration, the larger are the actual variation of travel times and, from the analysis of the previous section, so is *L*. If safety margin is positively associated with the variation in travel time, then it will also be positively associated with the commute duration as represented by *T*. It is expected that commuters with different T can be examined by a single model with this normalization.

As indicated in Table 8, normalized safety margin (*SM*/*T*) is significantly and positively associated with normalized *L* (*L*/*T*) for Route 13 and surface streets. Safety margin is indeed proportional to perceived uncertainty in travel time as represented by *L*. This is consistent with the theoretical definitions of safety margin by Hall and others. Quite importantly, the standard deviation of travel times reported during the diary period is not associated with normalized safety margin. In fact its Pearson correlation coefficient with safety margin is less than 0.005.

Safety margin is not associated with *L* for commute trips on public transit. This is presumably due to the fact that day-to-day variations in commute travel times are much smaller on public transit. Commuters' adaptation to uncertainty in travel time appears to be different between auto trips and public transit trips.

Some variables representing attributes of commute trips and commuters are significant. For example, the dummy variable indicating a work start time between 9:00 AM and 9:59 AM has a positive and significant coefficient in the model for Route 13; those who commute on Route 13 to jobs starting between 9:00 AM and 9:59 AM tend to have larger safety margins. The model for surface streets indicates that those who commute on surface streets almost everyday tend to have larger safety margins.

Table 7. Regression Models of *L* by Commute Travel Mode

Commute Mode	Independent Variables	Coef.		t-stat
		B	β	
AUTO ON ROUTE13	Constant	-11.6		-0.57
	Sex(1:Male 0:Female)	6.61	0.0888	0.79
	Age	0.0506	0.0207	0.21
	Avg (t^n)	1.07	0.600	5.64 **
	S.D. (t^n)	-0.176	-0.0926	-0.86
	Avg $(t^n - T)$	-0.468	-0.189	-1.65
	Dummy if person commutes by ROUTE13 almost everyday	-4.13	-0.0698	-0.35
	Dummy if person commutes by ROUTE13 2-3times per week	-3.40	-0.0549	-0.28
	N		78	
	F(7,70)		5.12 **	
	R^2		0.339	
	Adjusted R^2		0.272	
AUTO ON SURFACE STREETS	Constant	5.15		0.27
	Sex(1:Male 0:Female)	-34.4	-0.446	-2.05 *
	Age	0.443	0.252	1.18
	Avg (t^n)	0.453	0.454	2.29 *
	S.D. (t^n)	1.43	0.190	1.10
	Avg $(t^n - T)$	-0.703	-0.425	-2.59 *
	Dummy if person commutes by Surface Streets 2-3times per week	13.4	0.325	1.54
	N		27	
	F(6,20)		3.96 **	
	R^2		0.543	
	Adjusted R^2		0.406	
PUBLIC TRANSIT	Constant	20.6		1.57
	Sex(1:Male 0:Female)	11.9	0.310	1.57
	Age	-0.147	-0.142	-0.80
	Avg (t^n)	-0.0611	-0.129	-0.75
	S.D. (t^n)	0.225	0.101	0.60
	Avg $(t^n - T)$	-0.412	-0.377	-1.95
	Dummy if person commutes by Public Transit almost everyday	-13.4	-0.606	-2.10 *
	Dummy if person commutes by Public Transit 2-3times per week	-11.5	-0.465	-1.54
	Dummy if person commutes by Public Transit 2-3times per month	-8.17	-0.312	-1.19
	N		23	
	F(8,14)		2.79 *	
	R^2		0.615	
	Adjusted R^2		0.394	

B : Not normalized β: Normalized *p=0.05 **p=0.01

Table 8. Regression Models of Normalized Safety Margin (*SM*/*T*) by Commute Travel Mode

Commute Mode	Independent Variables	Coef.		t-stat
		B	β	
AUTO ON ROUTE13	Constant	-0.0702		-0.407
	Sex (1:Male 0.:Female)	0.0460	0.074	0.640
	Age	-0.000543	-0.025	-0.203
	Dummy if person is in 30's	-0.0411	-0.074	-0.617
	Dummy if person commutes by Route13 almost everyday	-0.0393	-0.082	-0.533
	Dummy if person commutes by Route13 2-3 times per week	-0.0215	-0.038	-0.266
	Dummy if person commutes by Route13 2-3 times per year	-0.2510	-0.219	-1.871
	Dummy if work starts before 9:00	0.0474	0.098	0.854
	Dummy if work starts before 10:00	0.1499	0.248	1.975 *
	Normalized L (=L/T)	0.2264	0.344	2.881 **
	N		88	
	F(9,78)		2.16 *	
	R^2		0.200	
	Adjusted R^2		0.107	
AUTO ON SURFACE STREETS	Constant	-0.0103		-0.037
	Sex (1:Male 0.:Female)	0.0417	0.0304	0.271
	Age	-0.000961	-0.0269	-0.217
	Dummy if person is in 30's	-0.192	-0.182	-1.471
	Dummy if person commutes by Surface Streets almost everyday	0.334	0.376	2.602 *
	Dummy if person commutes by Surface Streets 2-3 times per week	0.194	0.133	1.098
	Dummy if person commutes by Surface Streets 2-3 times per year	0.0258	0.0296	0.215
	Dummy if work starts before 9:00	-0.0202	-0.0243	-0.202
	Dummy if work starts before 10:00	0.0486	0.0406	0.333
	Normalized L (=L/T)	0.272	0.255	2.291 *
	N		79	
	F(9,69)		2.56 *	
	R^2		0.250	
	Adjusted R^2		0.152	
PUBLIC TRANSIT	Constant	0.233		1.447
	Sex (1:Male 0.:Female)	0.0646	0.106	0.890
	Age	-0.00187	-0.106	-0.759
	Dummy if person is in 30's	-0.148	-0.328	-2.428 *
	Dummy if person commutes by Public Transit almost everyday	0.0781	0.170	1.279
	Dummy if person commutes by Public Transit 2-3 times per week	-0.00698	-0.0142	-0.107
	Dummy if person commutes by Public Transit 2-3 times per year	-0.0204	-0.0510	-0.368
	Dummy if work starts before 9:00	-0.0421	-0.107	-0.919
	Dummy if work starts before 10:00	0.0573	0.103	0.798
	Normalized L (=L/T)	0.0106	0.0198	0.170
	N		82	
	F(9,72)		1.55	
	R^2		0.162	
	Adjusted R^2		0.058	

B : Not normalized β: Normalized *p=0.05 **p=0.01

8. Low Frequency Users' Experience and Perception of Uncertainty

As noted earlier, the experiment involved reduced tolls differentiated by the frequency of Route 13 usage. Infrequent users (Light Users Group A and B) were expected to increase the use of Route 13 by the toll discounts. This would in turn modify their perception of travel time uncertainty and their subsequent behaviors as well. The analysis of this section is concerned with behavioral changes exhibited by the Light User groups.

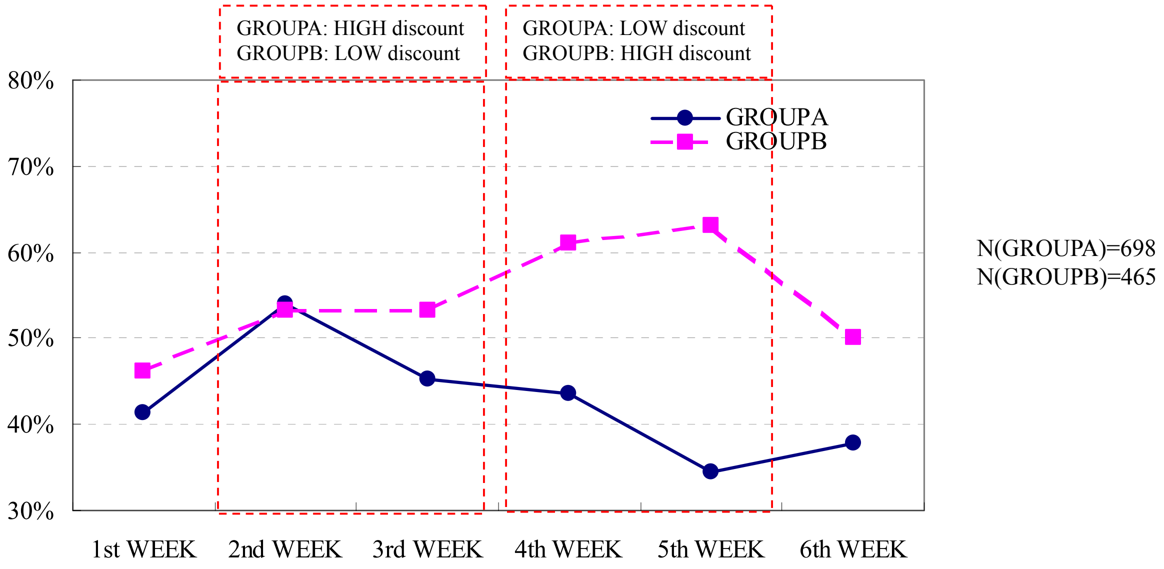

Figure 5. The Percentage of Commute Trips on Route13: Light Users Groups A and B

As Figure 5 indicates, the fraction of commute trips made on Route 13 is substantially different between Group A and Group B. The analysis below focuses on how the change in the use of Route 13 is associated with the perception of uncertainty and aspects of commute behavior. Since the analysis is concerned with the probability of being late for work, records with extraordinary commute travel times are eliminated from the analysis.[1]

8.1. Usual Commute Trips and Those under Toll Reductions

Differences between "usual" commute trips and recorded trips are first tabulated similar to the tabulations of Section 5 with respect to differences between: recorded arrival time and work starting time ($t_a - T_w$), recorded departure time and usual departure time ($t_d - T_d$), and recorded travel time and usual travel time ($t - T$). Table 9 shows the means and standard deviations of these differences for the respective weeks during the period of experiment. Figures 6 and 7 illustrate the means by group.

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[1] Specifically, travel records were eliminated when $t^n > 2T$.

Table 9. Differences between Recorded and Usual Commute Trips on Route 13: Arrival Time (t_a - T_w), Departure Time (t_d - T_d) and Travel Time (t - T)

			$t_a - T_w$			$t_d - T_d$			$t - T$		
			Average	S.D.	N	Average	S.D.	N	Average	S.D.	N
GROUP A	NO Discount	1st WEEK	-17.31	38.08	26	0.38	24.37	26	-7.50	12.10	26
	HIGH Discount	2nd WEEK	-18.70	33.87	37	-0.27	26.24	37	-6.81	14.25	37
		3rd WEEK	-15.53	35.18	19	-0.53	21.40	19	-7.63	12.19	19
	LOW Discount	4th WEEK	-26.22	27.24	23	-2.83	17.76	23	-10.35	12.02	23
		5th WEEK	-0.79	38.05	19	5.68	25.82	19	-4.37	17.59	19
	NO Discount	6th WEEK	-18.14	32.68	28	3.39	19.20	28	-3.32	11.55	28
GROUP B	NO Discount	1st WEEK	-31.33	38.12	30	0.86	18.52	29	-3.69	10.48	29
	LOW Discount	2nd WEEK	-25.08	30.16	37	1.72	21.55	36	-2.50	10.92	36
		3rd WEEK	-26.75	40.89	24	-1.58	18.92	24	-3.71	11.21	24
	HIGH Discount	4th WEEK	-23.72	31.20	36	2.81	28.72	36	-3.89	10.20	36
		5th WEEK	-23.25	35.90	44	3.23	24.98	44	-3.41	17.43	44
	NO Discount	6th WEEK	-12.36	34.41	25	12.64	25.54	25	-2.80	9.34	25

As can be seen clearly in Figures 5 and 6, not very much change can be observed for travel time difference ($t - T$) across the weeks. Average differences in departure times ($t_d - T_d$) and arrival times ($t_a - T_w$), on the other hand, show increasing tendencies toward the end of the experiment for Group B, whose members received a smaller discount first, then a larger discount. It appears that commuters in Group B delayed their departure times as they gained experience of commuting on Route 13 as the experiment progressed. Although reasons why commuters in Group A do not show such a tendency are not clear, it is conceivable that the decreased use of Route 13 in the third through fifth weeks of the experiment is a contributing factor. This is presumably because the larger discount was given first to the members of this group. As a result, they tended to stop using Route 13 before they acquired enough experience on it to modify their perceptions.

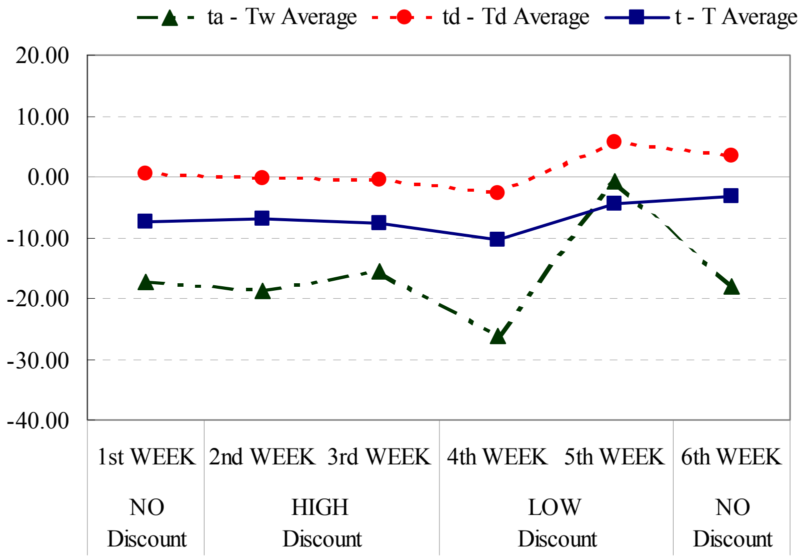

Figure 6. Average Differences between Recorded and Usual Commute Attributes on Route 13: Group A

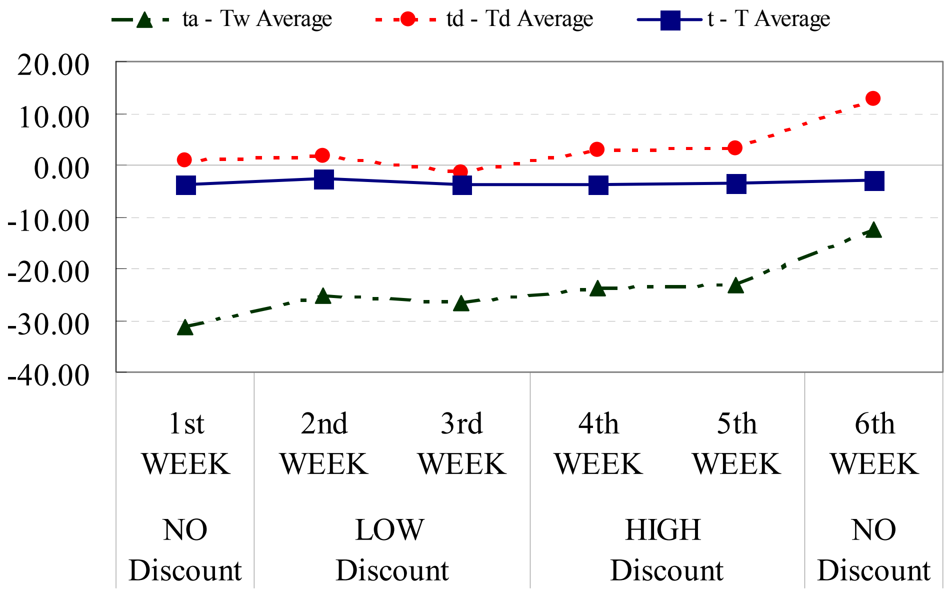

Figure 7. Average Differences between Recorded and Usual Commute Attributes on Route 13: Group B

8.2. Daily Safety Margin and the Probability of Late Arrival

Based on the data available for this study, the probability of late arrival is evaluated and compared with the safety margin set for each commute day. Safety margin was defined using "usual" arrival time, as $T_w - T_a$ in Section 7. In the analysis of this section, anticipated arrival time of the day (t_p^n) is used to define *daily safety margin* so that adjustments in departure times during the experiment can be addressed. Thus the definition adopted is

$$\text{Daily safety margin} = T_w - t_p^n.$$

The average daily safety margin is plotted in Figure 8 by group for the respective weeks. No clear patterns are present.

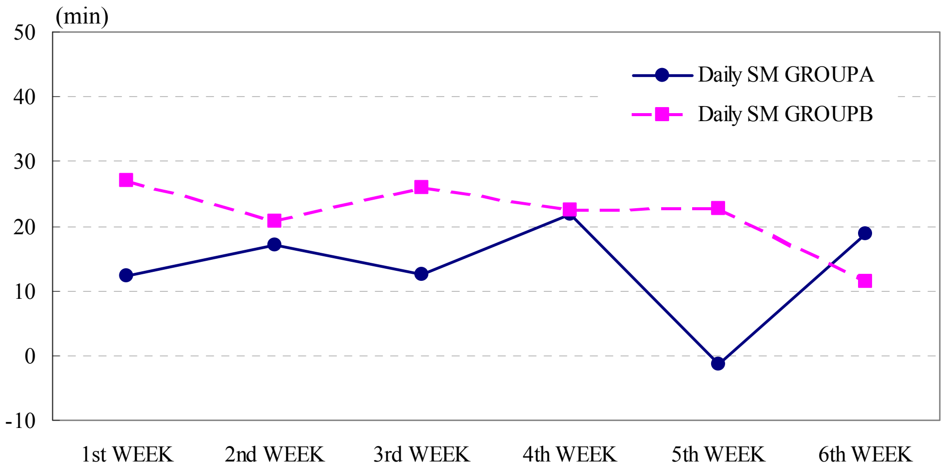

Figure 8. Average Daily Safety Margin by Group and by Week

The probability of arriving late is evaluating with the assumption that travel time has a normal distribution. The average travel time and standard deviation observed on Route 13 for each respondent are used in the analysis. The dent in the delay probability in week 2, when the discount started, is noticeable.

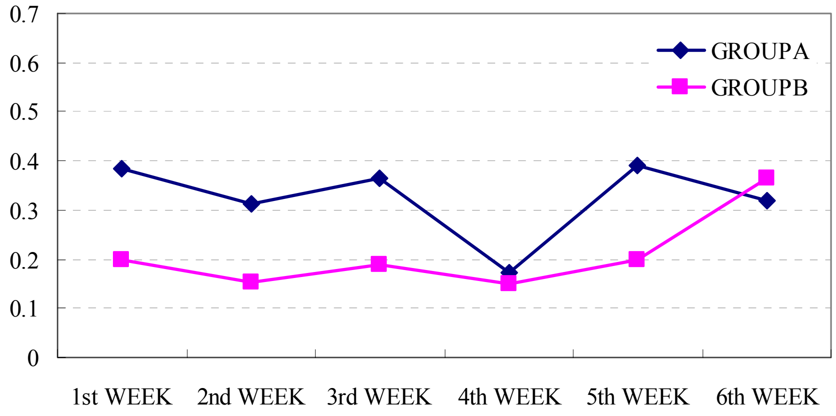

Figure 9. Average Probability of Arriving after Work Starting Time by Group and Week

Similarly the probability of arriving after the anticipated arrival time (t_p^n) is evaluated. As Figure 10 shows, the averages are below 0.5, implying that the perceived distribution of travel times is biased to the right of the actual distribution. This may be interpreted as an indication of the risk averseness of commuters.

Figure 10 shows a slight tendency that the probability of arriving after t_p^n increases in Week 2 for Group A and in Week 4 for Group B, when the larger discount starts. It appears as if respondents were more risk prone when the high toll discount was available. Indications are, however, statistically very weak.

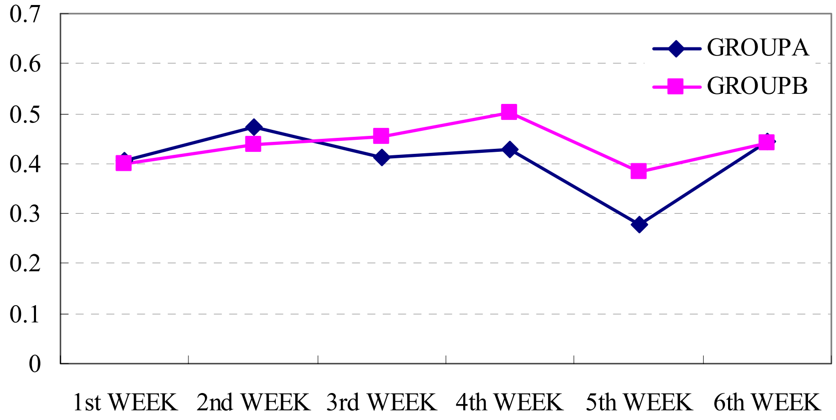

Figure10. Average Probability of Arriving after Predicted Arrival Time by Group and Week

Because of the way daily safety margin is defined, there is a strong negative correlation between the size of the daily safety margin and the probability of arriving late for work starting time. With Groups A and B combined, a correlation coefficient of –0.715 is obtained ($N = 336$, significant at $\alpha < 0.0005$). It turned out that the size of daily safety margin and the probability of being late for the anticipated arrival time are positively correlated ($\rho = 0.349$, $N = 336$, significant at $\alpha < 0.0005$). It appears that respondents just anticipated an arrival time which was earlier than it actually would be when they set a larger safety margin.

8.3. Effects of Toll Reductions on Daily Safety Margin and Probability of Late Arrival

Tabulations so far have suggested that the perception of uncertainty may have changed on the weeks when the toll discounts are applicable. To see this, daily safety margin, the probability of late arrival for work starting time, and the probability of arriving after the anticipated arrival time are plotted for weeks of: no toll discount, low toll discount—first week, low toll discount—second week, high toll discount—first week, and high toll discount—second week (Figure 11). Differences in these indices are noticeable between the first week and second week of low discount. Although overall tendencies are not clear, changes in the use of Route 13 prompted by the toll discounts have undoubtedly affected safety margin and probabilities of late arrival.

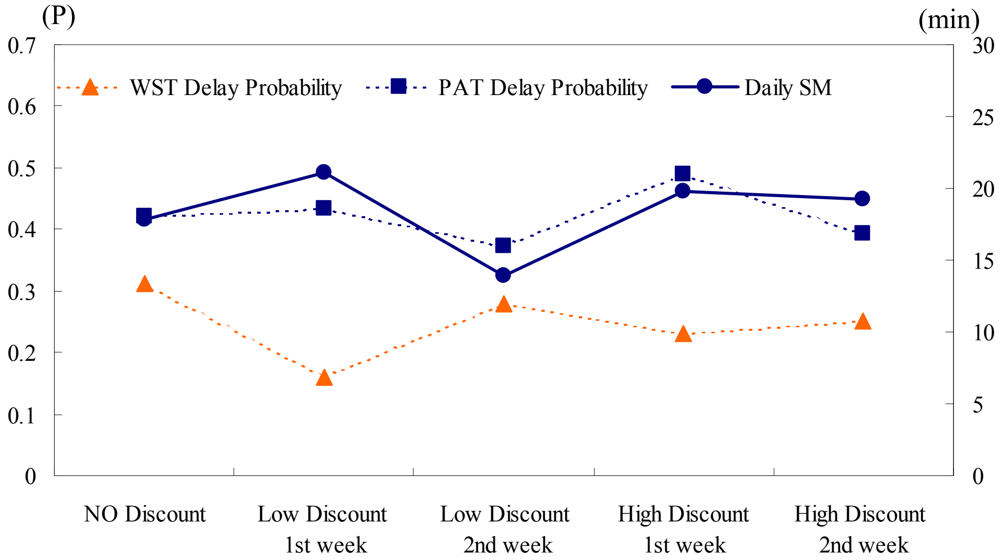

Figure11. Daily Safety Margin and Delay Probabilities by Toll Discount Pattern

9. Conclusions

In the first half of this paper, relationships have been shown among: recorded commute travel times and their variation; difference between the maximum and minimum travel times ever experienced as an indicator of perceived uncertainty in travel time; and the size of safety margin as a countermeasure against travel time uncertainty. An important finding of the study is that the difference between the maximum and minimum travel times as recalled by the respondent is influenced by the average of recorded travel times, but not by their standard deviation. It is further shown that the size of the safety margin established by commuters is a function of this difference between the maximum and minimum travel times, and that the standard deviation of travel times is again not a significant contributing factor. The study has thus offered new insights into how commuters perceive uncertainty in travel time and how the safety margins they establish are related with the perception.

The second half of this paper presented results of tabulations that indicate how respondents reacted to experimental toll reductions. It has been shown that less frequent users of Route 13 did increase its use with the toll discounts, and the rate of usage depends on the amount of discount. The tabulation, however, did not offer clear evidence that toll reductions altered respondents' perception of uncertainty or establishment of safety margins. Perception of uncertainty will change with experience and safety margins may be adjusted accordingly. Further analysis is planned with the data to probe into the relationship among travel time variability, perceived uncertainty and establishment of safety margins.

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