Illusion of Motion

Variation in Value of Travel Time Under Different Freeway Driving Conditions

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This paper explores drivers' subjective value of time under moving and stopped freeway travel conditions with a stated preference survey. Unlike previous studies that assumed a constant value of time, this research relates perceived satisfaction of a freeway trip to its quality indicators. Sixty-nine subjects in Minneapolis–St. Paul, Minnesota, were asked to rank 16 driving scenarios in four condition sets with different durations of ramp wait and freeway travel. Several utility functions were specified in which the weight of ramp delay was a function of the length of the delay and subject-specific variables; the resulting choice models were estimated with rank-ordered logit, binary logit, and rank-ordered mixed-logit techniques. Results suggest that drivers perceive ramp wait as more onerous than freeway travel. They also weight each minute of ramp wait more heavily as the delay increases. Subjects showed some tolerance to the first several minutes of ramp delay (less than 5 min) but perceived long delays as up to 12 times more onerous than time in motion. The derived weighting function for ramp wait can improve the design of freeway traffic control strategies that trade off freeway delay with ramp wait. The findings also enable a more utility-based approach for freeway operations than the current method, which has the engineering efficiency objective of minimizing total system delay or maximizing throughput. Minimizing total perceived travel time is probably more appropriate than minimizing total absolute travel time, which does not take into account driver acceptance. The weighting function can be easily transformed into a value-of-time function for project evaluation purposes.

Time allocation theories suggest that, with reduced travel time, people could engage longer in other utility-improving or production activities. Travel, especially in congested and waiting situations, may cause individuals to accumulate anxiety and stress and is generally deemed unpleasant. A reduction in travel time by itself may contribute positively to utility. Therefore, there is a value of time for both individuals and society as a whole. It is important to understand value of time and to be able to measure its magnitude and variance for design, forecasting future behavior, and economic appraisal.

Most empirical studies measuring subjective value of travel time (SVTT), which is the amount an individual or a firm is willing to pay to save a unit of travel time, have used essentially the same data metric and model estimation procedure. The most popular approaches have used either revealed preference or stated preference data and various forms of logit choice models (e.g., multinomial, nested, and mixed random effect) to identify marginal rates of substitution between travel time and the price of a trip.

It is intuitive that the value of travel time is not constant in all situations. Previous studies suggest it varies by assorted trip characteristics including journey purpose, length, mode, sign and size of time savings, and personal attributes such as income, although the studies were done with different degrees of rigor and some findings were inconclusive. The literature on value of travel time is vast, but the part of that literature that focuses on differentiating travel time by the quality of the trip is almost nonexistent. The mode choice literature has thoroughly distinguished and assessed values of in-vehicle and out-of-vehicle (access and wait) transit times (*1*), but similar analysis on the highway side is very recent. An experiment by Hensher distinguished between free-flow time, slowed-down time, and stop-and-go time (*2*). Little research specifically concerns how ramp metering and highway congestion affect driver perceptions in terms of time, frustration, and annoyance. A better understanding of such effects promises improvements in the design and evaluation of freeway traffic control strategies.

A recent empirical study using data from both a traditional stated preference survey and driving simulation further estimated the driver acceptance of the qualitatively dissimilar in-vehicle travel experiences of waiting at a ramp meter, driving in free-flow traffic, and driving in congested traffic (*3*, *4*). In their experiment, the drivers' preferences to ramp wait (up to 6 min) and various freeway mainline travel conditions were elicited in several sets of choice conditions. The findings, though inconclusive, indicate that people may perceive ramp wait and freeway travel differently.

An important issue ignored in previous studies is whether the weight drivers put on ramp delay in relation to freeway travel increases with the length of ramp delay. In other words, drivers may perceive each additional minute of delay as more onerous than the previous minute. Zhang and Levinson demonstrated that, if this hypothesis were true, the traditional freeway control objective of minimizing total travel time would not be consistent with utility maximization (*5*). Moreover, if a weighting function for all lengths of ramp delay is quantified, it will become possible to implement a more desirable freeway control objective, that is, minimizing perceived travel time.

This study uses a larger data set involving longer ramp delays (up to 18 min) than reported by Levinson et al. (*3*), both of which are generated in the same computer-administered stated preference survey. Unlike previous studies, which assumed a constant value of time for each specific driving situation, this research relates the perception and satisfaction of trip quality to the length of ramp wait. A nonlinear weighting function for ramp wait derived from the find-

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ings has several immediate applications to freeway operations and project evaluation. The impacts of personality, attitude, and sociodemographic variables on driver acceptance of ramp delay and freeway congestion are also explored in a rank-ordered logit model and a binary logit model.

The next section briefly discusses the value and perception of time with regard to highway travel and survey methods. The stated preference survey conducted at the University of Minnesota in 2003 is then described with emphasis on the design of the choice condition sets and the new data set. This description is followed by a detailed discussion of the specification of logit models. Estimation results are presented and their implications on the design and evaluation of freeway traffic control strategies are discussed. Conclusions and directions for future stated preference analysis on driver acceptance are offered at the end of the paper.

BACKGROUND

The concept of value of time stems from time allocation theories (*6–13*). It is the monetary equivalent of the reassignment of time among activities. Its theoretical value depends on how time elements are represented in consumer utility maximization. In the transportation field, empirical measurements of value of time are typically done by discrete choice analysis. The marginal rate of substitution between time and cost in choice models is referred to as SVTT, which is the amount a consumer is willing to pay to reduce commute time. SVTT has been used extensively in project design and evaluation. Bone reviewed the practice of ascribing a dollar value to travel time savings arising from transport investment projects (*14*). Hensher treated the topic of the behavioral value of travel time savings (*15*). Recently, several studies indicated that SVTT obtained from the popular multinomial logit model may understate the true mean value of travel time in a number of situations (*16–18*). Mackie et al. argued that direct use of willingness-to-pay values is inappropriate for social appraisal of projects (*19*).

One reason why travel time savings have value is because travel is generally considered as a disutility [although in some circumstances it may have positive utility (*20*)]. For instance, driving is a demanding and exhausting task, especially in congested traffic. The perceived dissatisfaction of commute time depends on many factors. There is evidence that waiting time in a queue is perceived more positively when the goal of waiting is more attractive, that time savings on long journeys are valued more than those on short ones, that the size of time savings positively affects the value of travel time savings, that time losses are more onerous than failure of time gains, and that sociodemographic variables such as gender and income are related to subjective valuation of time savings in a not-so-straightforward manner (*21–27*). Stated preference and revealed preference surveys have been the methodologies in most previous time allocation studies. Both approaches have pros and cons in terms of validity, sampling, control, and applicability. They do not appear to generate any systematic different estimation results (*28*).

One understudied area of SVTT is the perception of travel time under different driving conditions. Both driver stress and aggression are greater in high-congestion than in low-congestion conditions (*29*). Greater annoyance is also reported among high- and medium-impedance commuters (*30*). It is thus reasonable to suspect that drivers may value delay reduction more than free-flow time savings.

After collecting stated preference data about choices between various driving conditions, and developing multinomial and mixed-logit models, Hensher found that SVTT for stop-and-go traffic is five to 10 times that for freeway flow, whereas SVTT for slow-moving traffic is only two to three times that for free flow (*2*). A computer-administered stated preference experiment conducted by Levinson et al. suggested that drivers perceive ramp wait as 1.6 to 1.7 times more onerous than freeway delays (*3*). However, their virtual experience stated preference data collected from a similar population of subjects experiencing traffic within an immersive driving simulator indicate the opposite. Some explanations for the discrepancy are offered. Zhang and Levinson concluded that useful value-of-time functions for freeway operations must connect the value of time and the length of delay (*5, 31*). They also argued that, if the issue is resolved, a theoretically sound method that is capable of balancing efficiency and equity in traffic control will become practically feasible. This research aims to establish that relationship.

STATED PREFERENCE SURVEY

Data used in this study were collected during a computer-administered stated preference survey carried out in January 2003, the purpose of which was to measure subjects' perception of in-vehicle travel time under stopped and moving conditions. A detailed description of this experiment is available elsewhere (*3*). This section briefly introduces the major characteristics of the survey with emphasis on a data set that was not used in the previous study.

The stated preference test includes four nominally identical conditions. Subjects are asked to rank four optional driving scenarios from the most preferred to the least preferred in each condition set. The driving scenarios in each condition set are presented as combinations of different ramp meter waiting time and freeway travel time, with the same freeway travel distance (see Table 1). Condition Set 1 is the base case scenario with a relatively short ramp wait (0–6 min). Condition Set 2 has the same ramp delays as Condition Set 1 but different freeway travel speeds, with the total travel time controlled to be constant. The third and fourth sets have the same freeway travel times as the first one, but with doubled (0–12 min) and tripled (0–18 min) ramp waits, respectively.

By the combining of all four condition sets and 16 driving scenarios, a good data set is obtained to examine how drivers perceive ramp delays ranging from 0 to 18 min in relation to freeway mainline travel and whether they consider each unit of ramp wait more onerous as the length of the wait grows. One aspect of the data is that all scenarios have the same travel distance and hence the same free-flow travel time. All variation in freeway time is due to mainline delay, and therefore it is not possible to distinguish free-flow time and driving delay in this study.

Originally, 1,308 subjects were randomly selected and e-mailed about participating in this survey. When the survey took place, they all worked for the University of Minnesota, lived in the Minneapolis–St. Paul (Twin Cities) area where the campus is located, drove to work with a valid license, and were not affiliated with the Department of Civil Engineering. The total number of subjects then dropped to 89 as most did not respond to the e-mail invitation (a response rate of 7%). Before these subjects were scheduled for the final stated preference survey using the four condition sets, they participated in a series of background surveys, including a mail-in–mail-out travel diary, a questionnaire about their sociodemographic status, a transportation attitude survey, and a NEO five-factor personality inventory survey with 60 questions (*32*). Data collected in those background surveys include daily commute time and distance, gender, age, level of

TABLE 1 Details of Four-Choice Condition Sets

	Scenario	Ramp Wait (min)	Drive Time (min)	Speed (km/h)	Distance (km)
Condition Set 1 (base case)	1A	0	20	48	16
	1B	2	15	64	16
	1C	4	12	80	16
	1D	6	10	96	16
Condition Set 2 (total travel time controlled)	2A	0	20	48	16
	2B	2	18	53	16
	2C	4	16	60	16
	2D	6	14	69	16
Condition Set 3 (doubled ramp wait)	3A	0	20	48	16
	3B	4	15	64	16
	3C	8	12	80	16
	3D	12	10	96	16
Condition Set 4 (tripled ramp wait)	4A	0	20	48	16
	4B	6	15	64	16
	4C	12	12	80	16
	4D	18	10	96	16

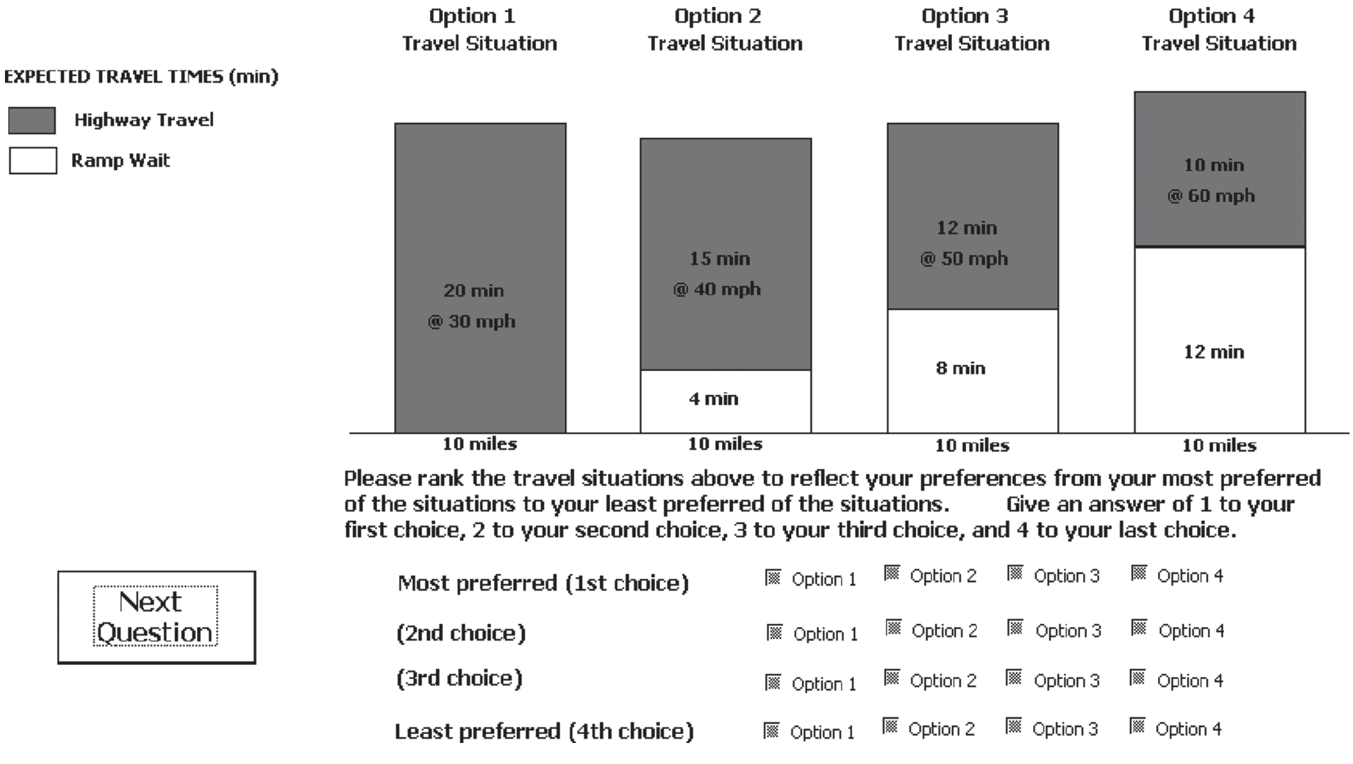
education, household income, participation in telecommunication, general attitude toward traffic congestion and ramp metering, and personality scores.

Finally, the 16 scenarios in the stated preference survey were presented to the subjects with different lengths of ramp wait and freeway travel time in both a textual and a graphic manner using a Latin squares design to avoid order effects (see Figure 1). Scenarios in each condition set were ranked by the subject from the most preferred to the least preferred. Because some of the selected subjects did not show up or were found to be unqualified at the last minute, the total number of valid subjects is 69. The stated preference survey usually lasted <20 min. The descriptive statistics of the subjects are summarized in Table 2.

MODEL

Utility Function

Individuals are often depicted as utility maximizers in economic theory. This study presumes that drivers can always identify the most preferred driving conditions among a set of alternatives. The perceived



Please rank the travel situations above to reflect your preferences from your most preferred of the situations to your least preferred of the situations. Give an answer of 1 to your first choice, 2 to your second choice, 3 to your third choice, and 4 to your last choice.

FIGURE 1 Stated preference survey: Condition Set 3 screen shot.

TABLE 2 Descriptive Statistics of Survey Subjects

Variable	Mean	Standard Deviation
Age	43	12
Commute time (min)	32	17
Household size	2.5	1.2

NOTE: Survey respondent counts: female (49), male (20); 4-year college and above (50), other education (19); household income less than \$50K (12), equal to or over \$50K (53); attitude regarding metering: pro (38), neutral or dislike (31).

satisfaction of a freeway commute is determined by the duration of freeway travel (F) and the length of ramp delay (R), and it varies according to drivers' personal characteristics. The utility (U) can thus be expressed as a function (f) of characteristics as follows:

$$\begin{aligned} &U = f\left(F, R, \boldsymbol{S}, \boldsymbol{P}\right) \\ &\boldsymbol{S} = S\left(G, A, I, E, T\right) \\ &\boldsymbol{P} = S\left(B, P_n, P_e, P_o, P_a, P_c\right) \end{aligned} \tag{1}$$

where $\boldsymbol{S}$ is a vector of sociodemographic variables (S) composed of gender (G), age (A), household income (I), level of education (E), and one-way commute time from home to work (T) and $\boldsymbol{P}$ is a vector of personality and attitude variables including attitude or belief toward ramp metering (B) and personality scores derived from the NEO five-factor personality test for neuroticism (P_n), extraversion (P_e), openness (P_o), agreeableness (P_a), and conscientiousness (P_c). The five-factor scores provide a summary of an individual's self-reported personality traits.

Sociodemographic and personality variables should not affect utility directly. Therefore, in all five models specified, they interact with ramp delay so that some meaningful hypotheses can be tested. The utility function can then be rewritten as follows:

$$\begin{aligned} &U = \beta_0 + h\left(\cdot\right) \cdot F + g\left(\cdot\right) \cdot R \\ &h\left(\cdot\right) \equiv \text{constant} \\ &g\left(\cdot\right) = g\left(R, \boldsymbol{S}, \boldsymbol{P}\right) \end{aligned} \tag{2}$$

where $h(\cdot)$ and $g(\cdot)$ are the contribution to utility of each unit time of freeway travel and ramp wait, respectively. It is hypothesized that the weight of ramp delay is a function of ramp delay and other person-specific variables, but the weight of freeway travel is normalized to be a constant. This restriction is not a strong one as what really matters in this study is the relative value of the two weights.

The data collected in the stated preference survey still allow for testing a number of hypotheses about driver acceptance under different driving conditions, three of which are examined here.

1. Freeway travel is perceived to be less onerous than ramp time because it is intuitive and previous studies suggest that the impression of making progress is preferred to waiting.
2. It is also posited that the burden of each unit time of waiting becomes less bearable as the length of waiting increases because of the associated feeling of uncertainty, higher stress, and boredom.
3. The perception of ramp wait compared with freeway travel varies among the driving population—for example, those who believe ramp metering improves overall freeway driving conditions have better tolerance for ramp delay.

Model Specification

Model 1. $g(\cdot) \equiv$ constant

This model tests whether drivers' value of time when waiting at ramps differs from that when driving on the freeway mainline. Substituting the specified $g(\cdot)$ into Equation 2 gives the final specification for the utility function in Model 1: $U = \beta_0 + \beta_1 \cdot F + \beta_2 \cdot R$. β_2/β_1 should be interpreted as the ratio of the subjective value of ramp wait reduction to the subjective value of (delayed) freeway time savings.

Model 2. $g(\cdot) = g(R) = \beta_2 + \beta_3 \cdot R$

The weight of ramp delay is a function of ramp delay. This model introduces a second-order term of R into the utility function, which can be convex or concave. The statistical significance of β_3 would indicate whether drivers dislike each additional minute of wait more (or less) than the previous minute. By comparing Models 1 and 2, one can ascertain whether the nonlinear specification significantly improves the model's explanatory power.

Model 3. $g(\cdot) = g(R, \boldsymbol{P}) = \beta_2 + \beta_3 \cdot R + \boldsymbol{P} \cdot \beta_{\boldsymbol{P}}$, Model 4. $g(\cdot) = g(R, \boldsymbol{S}) = \beta_2 + \beta_3 \cdot R + \boldsymbol{S} \cdot \beta_{\boldsymbol{S}}$, and Model 5. $g(\cdot) = g(R, \boldsymbol{S}, \boldsymbol{P}) = \beta_2 + \beta_3 \cdot R + \boldsymbol{S} \cdot \beta_{\boldsymbol{S}} + \boldsymbol{P} \cdot \beta_{\boldsymbol{P}}$

Value of time may vary along many dimensions besides the length of delay. Models 3–5 examine the influences of personality, attitude, and sociodemographic variables on the perception of ramp delay, respectively. It is interesting to ascertain the role of personality and attitude in ramp delay tolerance, which may suggest methods to alleviate the perceived dissatisfaction. The two sets of variables are first estimated separately in two models (Models 3 and 4) because the sociodemographic characteristics may correlate with personality and attitude factors. Also, personality scores are usually not available in a typical engineering application. In this sense, Model 4 is probably more useful than the combined Model 5 involving additional personality variables. It is hoped that the average impacts of the personality and attitude factors are captured by the coefficient of R in Model 4 [β_2; note that β_3 is the coefficient of R^2 in the model once $g(\cdot)$ is substituted back into the utility function (Equation 2)] if not adequately represented by the sociodemographic variables.

Logit Models

Rank-Ordered Logit

Coefficients in Models 1–5 are estimated with a multinomial rank-ordered logit model with Stata 8.0 (*33*). The rank of driving scenarios is the dependent variable. The rank-ordered logit model is sometimes referred to as the Placket–Luce or exploded logit model. Rank-ordered choice models are of particular interest in survey research because of their cost-effectiveness. They fully utilize the ranks of all alternatives rather than just the most preferred one as in multinomial logit models, so that more information is collected per observation

(*34*). The probability (P) that a subject ranks all four alternatives in a choice set in a specific order w is as follows:

$$P\left[W = w \middle| \beta\right] = \prod_{i=1}^{4} \frac{\exp\left(U_{w_i}\right)}{\sum_{w_i}^{w_4} \exp\left(U_{w_i}\right)} \tag{3}$$

where w_i is the ith alternative in the ranking. If choice i is the most preferred and has been ranked first, the choice that is ranked second would then be the most preferred among the remaining alternatives. The probability density and log-likelihood functions of a rank-ordered logit model are similar to those of a traditional logit model.

The relative utility associated with the ith alternative evaluated by each individual j in choice situation k can be represented as follows:

$$U_{ijk} = \beta'_j X_{ijk} + \epsilon_{ijk} \tag{4}$$

where X_{ijk} is a vector of attribute variables for each alternative and ϵ_{ijk} is a random variable that represents stochastic effects in rank choice. As with traditional logit techniques, a rank-ordered logit method assumes that ϵ_{ijk} is independently and identically distributed.

Rank-Ordered Mixed Logit

Despite the cost-effectiveness of the rank-ordered logit model, the validity of imposing the condition that ranked choices from different levels as independent observations was questioned by Ben-Akiva et al. (*35*) and Hensher (*36*). The restrictive independence assumption can be relaxed by taking into account the correlation across the alternatives and choice situations:

$$U_{ij} = \beta'_j X_{ijk} + \left(\epsilon_{ijk} + \eta_{ijk}\right) \tag{5}$$

where the previous stochastic term is divided into two parts: the first part still represents the random influences that are independently and identically distributed, and the second part is correlated over alternatives and is heteroskedastic. This method is thus referred to as mixed logit. Hensher and Greene (*37*) provided a detailed description of this state-of-the-art approach and discussed new opportunities offered by this advanced discrete choice analysis technique. Mixed-logit has recently been adopted to analyze panel rank-ordered data in the field of transportation. Srinivasan et al. (*38*) conducted an empirical analysis of intercity mode choice by using a rank-ordered mixed-logit model. This study also estimated Models 1–5 by using rank-ordered mixed-logit model specifications to provide a statistical analysis of the rank choice data on a more realistic basis. The rank-ordered mixed-logit model was coded in the statistical software SAS 9.0 for Windows.

Binary Logit

For confirmation purposes, the five models specified were also estimated by using binary logit techniques. The rank data (A, B, C, and D) in each condition set were decomposed into six observations pairwise comparing A-B, A-C, A-D, B-C, B-D, and C-D for this analysis.

RESULTS

The average ranks of all choice scenarios are presented in Figure 2. Ranking outcomes from Condition Sets 1 and 2 are combined to calculate the average rank in the range of 0- to 6-min ramp delay. In general, drivers dislike ramp wait. When ramp delay is longer than 4 min, a linear increase in the average rank can be identified. Drivers also show some tolerance to very short delays, as they understand there will be relatively less congestion on the freeway mainline. The limit of such tolerance appears to be somewhere between 4 and 5 min. The survey presumes that freeway mainline congestion is mitigated for drivers waiting at ramps.

The stated preference survey with all four condition sets together produces 760 valid observations in 190 groups from 69 individuals, which were used to estimate coefficients in the rank-ordered logit models and rank-ordered mixed logit models. Observations with missing data were dropped from the analysis. Although the rank-ordered logit model provides an efficient and relatively convenient way to analyze rank choice data, the rank-ordered mixed logit method models the data more realistically by relaxing the restrictive assumption that the random component of utility is independently and identically distributed. After ranking data were broken down into a series of binomial choices, 1,140 choice pairs were obtained for esti-

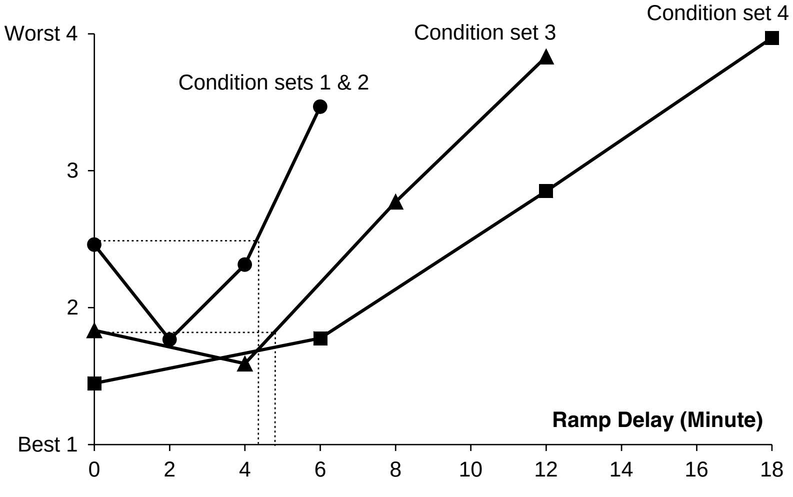


FIGURE 2 Average rank.

mating the binary logit models. Three sets of logit models generate similar coefficient estimates and their standard errors. To avoid repetition, only the results of the rank-ordered logit models and mixed-logit models are presented in Table 3. If there is a discrepancy, estimates from both logit models are compared and discussed.

The variables in Model 1, which assumes a constant weight for ramp delay (and therefore constant value of time), have signs in the expected direction. Both ramp delay and freeway travel time contribute negatively to utility. The ratio of the coefficients (β_2/β_1) suggests that on average each minute of ramp delay is about 1.7 times more onerous than freeway travel time. This finding is consistent with a previous analysis using only data from the first condition set (*3, 4*).

The inclusion of some long ramp delays in the survey questionnaire provides an opportunity to examine whether the value of ramp delay savings increases as the length of delay increases. Drivers may perceive one additional minute of stopped delay as more onerous than the previous minute. Results from the quadratic model (Model 2) clearly suggest that the inclusion of a second-order term offers additional explanatory power over the model assuming constant value of time. The χ^2 statistic derived by comparing log-likelihood of the full model (Model 2) and the restricted form model (Model 1) is statistically significant at $P = .01$. Models were estimated with other nonlinear forms, such as logarithm and cubic, but the logarithm specification does not offer as much explanatory power as the quadratic one and the cubic term is insignificant. The quadratic model predicts that the first minute of ramp delay is perceived by drivers as almost the same as a minute of freeway travel. However, as drivers are forced to wait longer, the burden of each additional minute of wait increases linearly. The 18th minute of ramp delay, the longest in this sample, is perceived as about nine times more onerous than freeway travel time.

An average value of time for freeway travel of, for example, \$10/h, implies an average driver is willing to pay up to \$1.50 (\$0.17) to get rid of the 18th (first) minute of delay. Thus, if a driver waits at a ramp for 18 min, the metering system must be able to save 88 min (not 18 min) of freeway travel time for the same driver so that the driver is no worse off or for all drivers to ensure there are still some efficiency gains (where efficiency is measured by using a nonlinear value of time). Therefore, when very long ramp delays occur, it is almost impossible to have a Pareto improving or horizontally equitable freeway ramp control system and unlikely that the control system is still improving the perceived welfare of commuters.

However, extremely long ramp delays (>20 min) had been reported in the Twin Cities metro area before a major algorithm change took place in fall 2000 (*39, 40*). In fact, as long as freeway control is under efficiency-oriented goals (e.g., minimizing total travel time), the resulting algorithms can and will inevitably create long delays at ramps just upstream of active bottlenecks (*31, 41*). Therefore, it is probably necessary to replace the efficiency-oriented goals with newer control concepts that explicitly consider drivers' perception of travel time under various driving conditions.

Zhang and Levinson demonstrated that a control strategy that minimizes total travel time may not maximize drivers' utility with a hypothetical nonlinear value-of-time function (*5*). The weighting function for ramp delays derived from Model 2 makes it possible to implement the objective of minimizing perceived travel time in reality. Future studies should design and test utility-maximizing ramp control algorithms with these results.

Model 3 corroborates the hypothesis that drivers who believe ramp metering improves overall quality of freeway travel consider ramp delays more acceptable than those who oppose ramp metering. Specifically, a driver with a positive attitude toward ramp meters has a ramp delay weight two units smaller (β_9/β_1) than that of a driver who dislikes meters. Therefore, if a control algorithm really minimizes overall travel time based on engineering evaluation studies, it is important to get that message out to the driving population, which may change some drivers' attitude about ramp meters. People with a higher score on extraversion or lower scores on openness, agreeableness, and conscientiousness show greater acceptance of ramp delay. A thorough analysis of why that is the case is beyond the scope of this paper. However, the statistical significance of these personality factors needs explanations from psychological theories and should be addressed by future work. Such studies would also help build better driver acceptance models. The coefficient of R (β_2) is positive, which, on first glance, appears to conflict with results of other models. However, the real coefficient for ramp delay in Model 3 should be $g(R, \boldsymbol{P}) = \beta_2 + \beta_9 \cdot B + \beta_{10} \cdot P_n + \cdots + \beta_{14} \cdot P_c$. After the observed values of personality and attitude variables are substituted into Model 3, the value of $g(R, \boldsymbol{P})$ ranges from -0.94 to $+0.23$ across the 69 subjects with a mean of -0.32 and a standard deviation of 0.25, which is consistent with Models 2 and 4. This explanation also applies to the positive β_2 in Model 5, which includes personality factors.

The results from Model 4 further indicate that subjects who are young, are female, or have higher education tend to tolerate ramp waits better than those who are elderly, are male, or have no college education. Those with longer actual commutes dislike freeway congestion more and are less critical of ramp wait, which is consistent with the observation that their actual ramp delay is likely a smaller percentage (and freeway speed gains are a larger share) of their total trip time than someone with a shorter commute (which still uses freeways). On the basis of these findings, the possible range of the weighting functions of ramp delay for different population groups is plotted in Figure 3. Income does not appear to affect the perception of ramp delay in Model 4, but it is a significant factor in Model 5. It probably should still be incorporated in future studies on driver acceptance in different driving conditions to obtain more conclusive findings.

The full model (Model 5) produces results consistent with the reduced form models. Some other variables, such as telecommunication use (which might have been viewed as a measure of affinity for technology), are dropped because they are insignificant in all models.

CONCLUSIONS

This study confirms that drivers perceive stopped delay at freeway entrance ramps as more onerous than driving delay and free-flow time. The major contribution of the paper is the empirical derivation of a nonconstant weighting function for ramp delay that monotonically increases with the length of delay. The results should find applications in the design of freeway traffic control strategies that trade off freeway delay with ramp wait. The findings also enable a more utility-based approach for freeway operations than the current method with engineering efficiency being the main objective. Minimizing total perceived travel time is probably more appropriate than minimizing total absolute travel time, which does not take into account driver acceptance. The weighting function can also be easily transformed into a value-of-time function for project evaluation purposes. Reducing 1 min of stopped delay is more valuable than reducing 1 min of driving time. This difference should and now can be recognized and accounted for when assessing traffic control alternatives. Although this study

TABLE 3 Results

Variable	β	Model 1		Model 2			Model 3		Model 4			Model 5	
Freeway time (F, min)	β_1	−0.35^{c} (−7.30)	−0.30^{c} (−9.41)	−0.13^{b} (−2.03)	0.11^{b} (−2.41)		−0.16^{b} (−2.01)	0.12^{b} (−2.49)	−0.14^{b} (−2.05)	−0.12^{b} (−2.51)		−0.15^{a} (−1.77)	−0.12^{b} (−2.51)
Ramp delay (R, min)	β_2	−0.60^{c} (−10.8)	−0.53^{c} (−14.65)	−0.10 (−0.86)	−0.12 (−1.57)	*−0.16*^{a} *(−1.60)*	0.89^{b} (3.03)	0.18^{b} (−2.03)	−0.42^{b} (−2.63)	−0.34^{c} (−3.17)		0.79^{b} (2.27)	−0.49^{c} (−4.18)
Ramp delay squared (R^2)	β_3			−.03^{c} (−4.28)	−.02^{c} (−5.12)		−.04^{c} (−4.41)	−.03^{c} (−5.48)	−.04^{c} (−4.54)	−.03^{c} (−5.31)		−.05^{c} (−4.96)	−.03^{c} (−6.93)
Gender $*$ R (G, 1 if female)	β_4								0.29^{c} (5.61)	0.13^{c} (4.51)		0.52^{b} (5.85)	0.24^{c} 6.39
Household income $*$ R (I, 1 if $<$ 50k)	β_5								0.08 (1.58)	−0.001 (−0.17)		0.24^{c} (2.97)	−0.001 (−0.22)
Education $*$ R (E, 1 if college)	β_6								0.08 (1.04)	0.12^{a} (1.84)	*0.12*^{a} *(1.64)*	0.14^{a} (0.10)	0.14^{b} (2.4)
Age $*$ R: (A, 1 if $<$ 40)	β_7								0.14^{b} (2.74)	0.13^{c} (4.33)		0.27^{c} (3.54)	0.12^{c} (3.4)
Commute time $*$ R: (T, min)	β_8								0.002^{a} (1.74)	0.000 (0.19)		0.001 (0.55)	0.001 (1.32)
Attitude or belief $*$ R (B, 1 if in favor of metering)	β_9						0.29^{c} (4.48)	0.11^{c} (3.0)				0.04 (0.57)	0.04 (1.14)
Personality factors (P)													
Neuroticism $*$ R (P_n)	β_{10}						−0.003 (−0.66)	0.003 (1.20)				−0.01^{b} (2.27)	0.001 (0.34)
Extraversion $*$ R (P_e)	β_{11}						0.02^{c} (4.14)	0.014^{c} (5.96)				0.03^{c} (5.00)	0.01^{c} (6.06)
Openness $*$ R (P_o)	β_{12}						−0.01^{b} (−2.97)	−0.006^{c} (−2.59)				−0.02^{c} (−4.11)	−0.01^{c} (−2.87)
Agreeableness $*$ R (P_a)	β_{13}						−0.03^{c} (−4.99)	−0.009^{c} (−3.43)				−0.02^{c} (−3.29)	−0.01^{c} (−3.54)
Conscientiousness $*$ R (P_c)	β_{14}						−0.01^{b} (−2.33)	−0.001 (0.49)				−0.02^{c} (2.27)	0.01^{c} (2.67)
Observations, groups		760, 190		760, 190			616, 154		760, 190			616, 154	
Number of groups		190		190			154		190			154	
Log likelihood 0		−603.8		−603.8			−489.4		−603.8			−488.7	
Log likelihood convergence		−417.7		−405.4			−298.3		−384.3			−270.5	
Prob > chi^2		.000		.000			.000		.000			.000	

NOTE: Results in nonitalic font = rank order logit and rank order mixed-logit; Results in italic font = binary logit, not shown if consistent with rank order logit.

[a] Statistically significant at level .1.

[b] Significant at level .05.

[c] Significant at level .01.

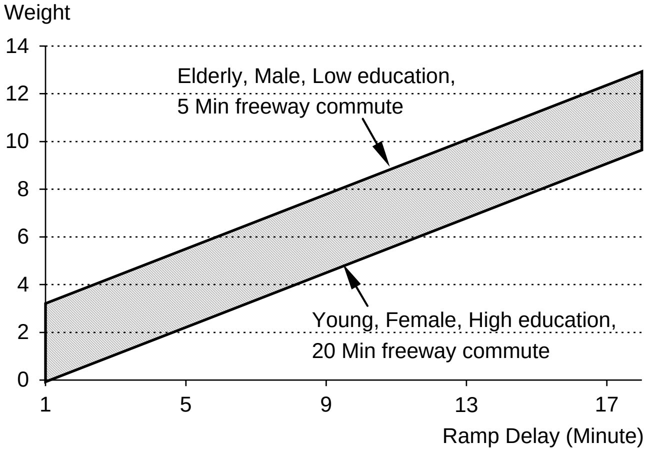


FIGURE 3 Ramp delay weighting function across population group (weight for freeway mainline travel time is 1).

focuses on drivers' perception of ramp delay in relation to freeway travel, the methodology may also be applied to evaluate driver acceptance of delays at other locations, such as traffic lights, tollbooths, and stop signs.

Driver acceptance of ramp delay also varies by personality and sociodemographic traits. A thorough understanding of how various person-specific factors affect the subjective valuation of driving experiences awaits further research on human factors and psychology. For engineering applications, it is probably necessary to use the results derived from an average driver (e.g., Model 2) or to consider only sociodemographic variables (e.g., Model 4).

The variation of the SVTT under different driving conditions has not been considered by the standard time allocation theory, which focuses more on the allocation of time among production and consumption activities. It is probably not enough just to relate utility to the duration of travel. A quality-of-service or quality-of-time factor may need to be included in the utility function. This paper demonstrates that measurability of this kind of factor should not be a hindering issue.

This study has several limitations. First, the data used in the analysis come from a stated preference survey. There is evidence that the design of a stated preference survey significantly influences the outcome. Although the questions and scenarios in the survey are designed to be as consistent as possible, it is still worthwhile to test hypotheses about driver acceptance with revealed preference or even field experiment data. Second, the data collected do not allow further breakdown of freeway travel into free-flow time and driving delay because all scenarios have the same driving distance. Future stated preference studies should consider disaggregating freeway travel.

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