Stated Preference Survey for Calculating Values of Time of Road Freight Transport in France

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A survey based on a stated preference experiment aimed at obtaining information about road freight transport subsequently useful in evaluating freight transporters' critical values of time is presented. The initial hypothesis in designing the survey was that values of time may vary significantly across the population; the experiment was thus designed so as to permit the evaluation of these critical values for each individual, as well as the identification of possible dependencies of the values on other trip attributes. The scope and methodology of the survey as well as an overview of the results are presented.

The first efforts in assigning values of time can be found in the economic literature in the 1960s (*1*). The formulation considered by Becker (*2*) in 1965 stated that the utility of an activity included both the elements obtained directly through the activity, the time taken, and possibly intermediate activities. The individual then tries to maximize his utility subject to budget and time constraints.

According to Gronau (*1*), applying this theory to transportation requires suppressing a common hypothesis of the more general application to economics. That is, it can no longer be assumed that the characteristics of the activity can take on a continuous range of values when the activity in question is a trip; indeed, the possible monetary costs and travel times are fixed by the infrastructure for a particular trip. Thus, to change the ratio of price to time for the trip in question, the user is required to choose another mode or itinerary. Gronau concludes that the different choices in transportation are thus perfect substitutes. This property will allow the evaluation of the user's *critical point*, where the critical point separates the efficient combinations of price and time combinations that an individual is willing to accept from those for which the trip is too costly (or too slow) to be undertaken.

The value-of-time (VOT) parameter, in general, transforms variables measured in time units to monetary units. Mathematically, it is simply a conversion factor that enables one to take a summation of both time and money constraints. Economically, however, it describes the value given by an individual for a unit time gain. This latter interpretation incorporates a number of hypotheses of human behavior. Two such hypotheses and the manner in which they are addressed are discussed next.

First, however, the use of a quantitive VOT is addressed. In general, the value obtained will represent the individual's valuation of time savings, rather than of absolute time. It is clear that the range of values considered is important in this case; a 2-min time savings is not necessarily equal to 1/5 of a 10-min savings, which may not be equal to 1/10 of a 20-min savings. Indeed, some time savings will be useful when they can be directly applied to another activity, and others will have no value. In the case of freight transport, however, where the necessity of the trip and cost-minimizing behavior are assumed, it may be assumed that most time savings lead to a savings in money (through more efficient use of trucks and drivers).

The two hypotheses concern the users. They are (a) the existence of a range of VOT across the population and (b) the existence of a correlation between the VOT and other trip attributes. Although a single VOT for the entire population is often assumed in travel demand models, some French transportation researchers have, since the 1970s, assumed that there is a continuity of VOT in passenger travel [see, notably, work by Abraham and Blauchet (*3*) and Marche (*4*)]. In this stated preference experiment, these two hypotheses for freight transport will be addressed by an appropriate survey design.

STATED PREFERENCE SURVEY

Developed in the context of market research, in which the demand for new products needed to be estimated, stated preference (SP) techniques have responded to the need of researchers to create and control a (hypothetical) situation and then to measure the responses. In the case of transportation, researchers can use these techniques most efficiently to evaluate the possible demand for potential new services (including price increases) and infrastructures.

SP techniques are known, however, to possess diverse biases, including justification or overestimation as well as a "political response" bias (*5*). The justification bias stems from a user's trying to "justify" a current choice; the user may thus be overly reluctant to indicate a change, even if he or she will later accept it. Similarly, an overestimation bias occurs when a user is initially too enthusiastic and accepts too readily a change that he or she would later refuse. Finally, a political response bias results when an individual responds to a question in such a way as to influence the outcome of the survey. (This may be the case in particular when the questions involve possible price increases, as they do in this experiment.) Nevertheless, in spite of the possible biases, SP experiments offer an important tool for the analysis of behavior.

An SP survey is the only feasible way of estimating the critical values of time. Revealed preference (RP) data describing users' present travel costs and trip times do not provide enough different ratios of (toll) price to travel time since, for a particular origin-destination pair, there is usually not more than one or two different (toll) price-time combinations; the critical ratio is impossible to estimate from only one or two points. An SP survey, however, allows the isolation the of the effects of price and travel time changes so as to obtain directly the user's critical VOT.

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Survey Design

SP surveys can be classified into three groups according to the types of questions posed: ratings, rankings, or discrete choices. The first type is given on a numerical scale on which the individual indicates the degree to which the option is preferred (e.g., 10 implies a strong preference, and 1 indicates that the option is unattractive). Rating techniques show the relative preference for the options with respect to the others presented by asking the individual to order them according to increasing attractiveness. Discrete choices present two options between which the user chooses.

The type of experiment chosen depends on the desired analysis method. Rating and ranking exercises give a larger quantity of information than discrete choices but are accompanied by less realistic results and thus higher random error. (For example, a ranking exercise naturally assumes equally spaced intervals between the options; this may hide the individual's true preference levels. Rating exercises, while overcoming this problem, may be too demanding when the behavior in question is difficult to quantify exactly.) In this study, the price or trip time at which a particular itinerary (toll highway or state road) is valued equally to the other is of interest; a single point is thus desired for each individual. Consequently, a discrete choice experiment was best adapted to the objectives of this study.

In an SP survey, correlations between the independent variables, often a problem in RP data, can be avoided by a careful selection of the questions presented, particularly by ensuring that the attributes vary independently (*6*). In this survey, it is assumed that the main attributes of the autoroutes and state roads are well understood by the subjects and that it was not necessary to enumerate them explicitly. The tolled highway ("autoroute") is considered a fast road, flat and with few perturbations, but accompanied by a high price. The state roads often have traffic lights in towns and other perturbations including steep ramps (in the mountainous regions) and sharp turns (these affecting significantly the speed and fuel efficiency of trucks), but are free and offer better opportunities for the driver to eat and rest.

Assuming that these characteristics were well understood, the survey questions were focused on the effects of modulating them. According to Pearman et al. (*5*), to be valid, the options presented in an SP survey should (a) appear plausible, (b) correspond to previous experience of the subject, (c) permit competitive trade-off decisions, and (d) cover the possible scope of responses. In this survey questions were presented concerning toll increases on the autoroutes and travel time increases on the state roads, as well as additional questions about gasoline price increases and toll decreases on the autoroutes (for those who take the free roads only). Aside from the last question, which mentions an option not genuinely plausible, the questions satisfy the first three guidelines cited above. The last guideline, that the values presented cover the scope of possible responses, may not hold; however, a more exhaustive questionnaire would not have been feasible in the context of a telephone interview. (It was decided to use telephone-based surveys because it was feared that the mail-back rate and time delay among professional transporters would be exceedingly low.)

Questionnaire

The first job of the survey taker, after introducing the project and verifying that the transporter did indeed carry out interurban road freight transport, was to ask the transporter to recall a typical recent (or regular) trip. The rest of the survey was divided into two parts: the first was a description of the interurban trip in question, including the type of merchandise, its packaging, the type of vehicle, approximate trip distance, origin and destination, itinerary, and time constraints on the trip. In addition, questions were posed as to the size of the transport company itself.

The second part of the survey contained the discrete choice questions aimed at evaluating the critical point between toll price and travel time for that transporter and that trip. This critical point could only be calculated when the transporter was forced to choose between a free state road itinerary and a faster, but high-priced, autoroute itinerary. If the choice of these two types of itineraries did not exist, the interview was not continued.

The discrete choice questions posed depended on whether the trip in question was made on the tolled autoroute or on the state roads. The survey taker provided the toll price of the trip on the autoroute and the travel time of the same trip on the state road. For those who currently chose the autoroute, the questions were devised so as to obtain the toll price at which they would no longer be willing to pay and would thus switch to the free state roads. On the basis of the price currently paid, three options could be proposed, starting with a choice between the state road and the autoroute at 125 percent of the current toll price. If that increase was accepted, the same choice was proposed with the autoroute toll at 150 percent, and last the toll price proposed was 200 percent of the currently paid toll if the subject had accepted the +50 percent increase. These levels were chosen to cover most of the expected trade-off points. An increase of less than 25 percent in the toll price would have been imperceptible for trips of medium distance, whereas an increase of over 100 percent may have been perceived as unrealistic. Though a larger number of levels would have served to more accurately identify the trade-off point, it was believed that the added fatigue and irritation on the part of the transporter would have negated these benefits by adding biases and random error.

For those who currently chose the free state roads, three sets of discrete choice questions were posed. The first presented increases in travel times on the free roads, and at each increase, the choice between that and the tolled autoroute was given. Four levels were proposed: a travel time of 110, 125, 150, and 200 percent of the current one on the free road. (A 10 percent trip time increase, unlike the analogous toll increase, was believed to be perceptible to the transporters.) The other two sets of questions were used as checks: three levels of toll price decreases and three levels of fuel cost increases were proposed. (It is known that trucks use significantly more fuel on state roads because of braking at traffic lights and on the ramps and sharp turns.) However, it was found that these checks were not very reliable; as suspected, the toll price decrease did not provide robust results (there was a much higher percentage of illogical responses), and many transporters did not appear to be concerned by a possible increase in fuel prices.

Sample Group

A random selection of interurban road freight carriers was obtained from a national directory. The subject of the interview was the fleet manager; in the case of very small companies, the fleet manager was often also the driver. Approximately 650 completed surveys were obtained, representing only 20 percent of the attempted telephone interviews. The low response rate can be attributed in large part to

the competitive nature of the road freight transport industry in France. (In Paris, where competition is the most intense, the response rate was significantly lower than that in the smaller towns.) Nearly 40 percent of the 650 surveys needed to be eliminated; in some cases, both autoroute and state road itineraries were not available for the trip in question; in others, a significant policy response bias was evident. The number of usable questionnaires was thus reduced to a final sample group of 408.

Nevertheless, the remaining sample covered a wide geographic range: 58 of 95 French departments were represented as trip origins and 69 as destinations. Furthermore, the sample group characteristics were shown to well represent the target population. Table 1 shows a comparison of the sample with the true population of interurban road freight haulers. It can be seen that in terms of trip distances, the range of goods transported, and the current split between free state road and autoroute itineraries, the sample group provides a reasonable representation of the target population.

CRITICAL VALUES OF TIME

In the analysis of road pricing schemes, it is necessary to have a model based on the critical points at which the individuals being studied are indifferent to the options presented, that is, between the cheaper and slower (or less comfortable, convenient, etc.) option and the better but more expensive alternative. At a price inferior to this critical point, the individual will choose the better option, but once the price of the better option exceeds that individual's critical point, the slower, cheaper alternative will be preferred. The tradeoff points obtained in the stated preference survey permit the calculation of each individual's critical VOT.

A shortest-path program over the French road network was implemented to provide the true distances, toll costs, and travel times of the itineraries obtained from the survey. In addition, vehicle operating costs were calculated on the basis of each transporter's reported vehicle type. Thus, for each individual, the generalized costs of the two alternatives at the trade-off point for the currently selected option could be set equal to one another and the critical VOT determined. Suppose that the generalized cost, G_{ij}, of transporter i on path j is given by

$$G_{ij} = c_{ij} + p_j + VOT_i\, t_j \tag{1}$$

where c_{ij} is transporter i's vehicle operating cost on path j, p_j the toll price, and t_j the travel time on path j, and setting

$$G_{iT} = G_{iF} \tag{2}$$

so that at the tradeoff toll price p_T for those who choose the toll road (or travel time t_F for those on the free roads), the two generalized costs are equal from the point of view of transporter i. Solving for each transporter's critical VOT_i,

$$VOT_i = \frac{(c_{iT} - c_{iF}) + p_T}{t_F - t_T} \tag{3}$$

The resulting values of time range from approximately 1 French franc/min to 36 francs/min. Looking ahead to the next section, it can be seen that the first hypothesis of a range of VOT across the population is strongly supported. This result is quite important since the majority of transport planning models use a single value for the entire population. Diversity of VOT will be discussed in more detail in the next section, as well as the second hypothesis, which concerned the correlation of VOT with trip characteristics.

ANALYSES OF INITIAL HYPOTHESES

If has been assumed from the outset that the value of travel time is more complex than its usual treatment indicates. An SP survey was devised to test various hypotheses, as discussed in the introduction of this paper. The first hypothesis was the existence of a range of VOT across the population of freight transporters. The second hypothesis concerned the variation of VOT with other parameters of the trip.

Diversity of VOT Across the Population

The first hypothesis was confirmed by the stated preference experiment. As stated in the previous section, a wide range of VOT was obtained for the sample population, from 1 to 36 francs/min at the high end of the spectrum. It was shown, furthermore, in the section on the stated preference survey, that the sample population represents well the desired scope of the study, that is, the interurban road freight transport industry.

The set of critical VOT can be visualized more easily by grouping them into a histogram, which gives an approximate density function (Figure 1).

In this histogram, each group has a width of 2 francs/min. It is easy to see that the VOTs vary more or less continuously over the population, and that, in fact, the pattern approaches a very elegant log-normal distribution. This empirically obtained result is particularly interesting, first because it contradicts the commonly held belief in a single (or a small number of) VOT in the population. Second, this result provides a distribution that is very easy to handle

TABLE 1 Analysis of Freight VOT Study Group

	Sample group	Target population (7)
% on toll road	80	76
Trip distances		
% trips 100-300 km	21	21
% trips 300-500 km	32	24
% trips 500+ km	38	25
Good types transported		
% Agricultural	36	30
% Petroleum	2	7
% Primary/semi-manufactured	13	12
% Manufactured	49	51

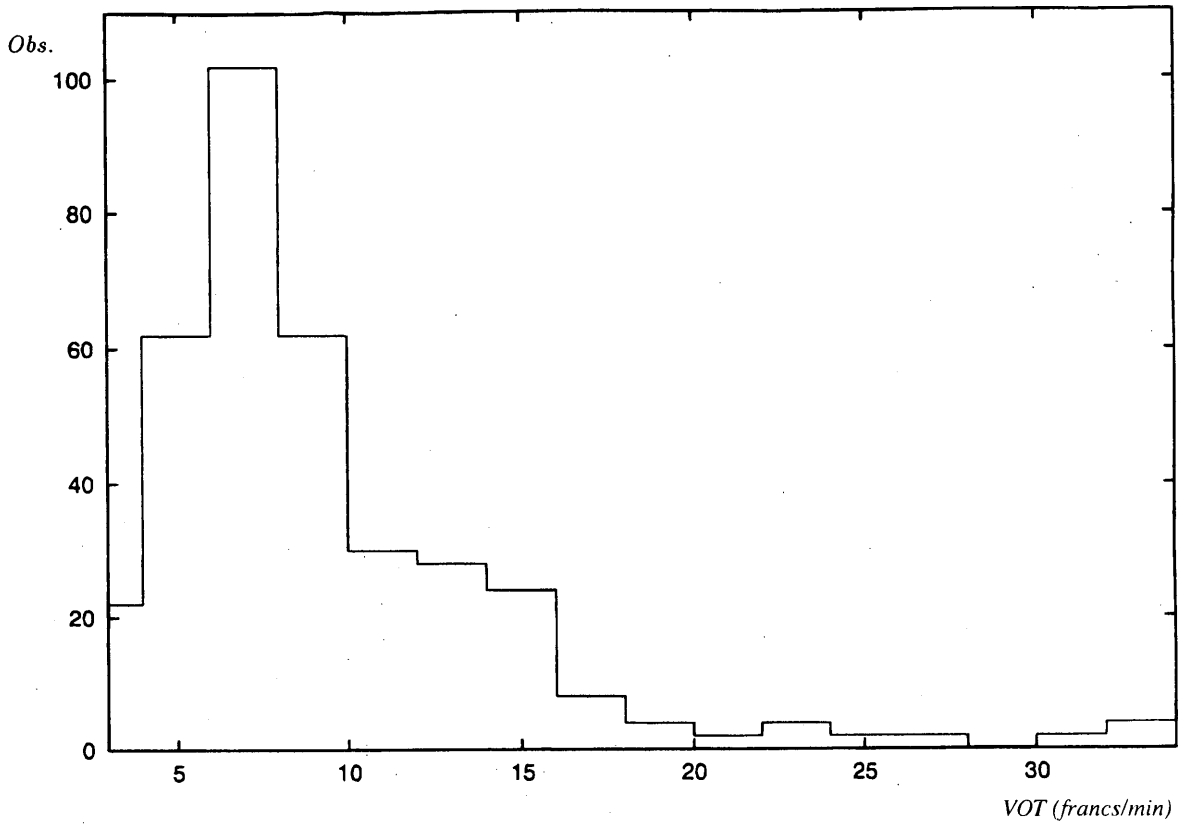

FIGURE 1 Histogram of critical VOT data points.

mathematically. In addition, it confirms a much-used hypothesis in France concerning critical VOTs. (Transport economists in France have believed for some time that passengers' VOTs follow a distribution similar to that of income in the population, which is a log-normal distribution.)

Such a distribution is furthermore relatively easy to incorporate into any mode choice or traffic assignment algorithm and thus can substantially improve the predictive power of the model. In the case of the logit model, Ben-Akiva et al. (*8*) showed how one can incorporate a continuous distribution of VOTs directly into the logit function. For the price-time traffic assignment model, Leurent discusses the use of such a continuous distribution (*9*), and an implementation is discussed by Morellet (*10*). For other models, mode choice or traffic assignment, VOTs can be chosen by a discretization of the VOT curve into VOT classes for use within standard multiclass models [see, for example, the work by Sheffi (*11*)].

Thus the optimal log-normal curve representing the data from this survey was calculated. The mean and standard deviation of the data set are given by

$$\mu_{VOT} = 8.65 \qquad \sigma_{VOT} = 5.94 \tag{4}$$

where these values are in French francs per minute. Estimating the parameters m and s of the log-normal function $\ln(v) \sim N(m, s)$,

$$F(v) = \frac{1}{v\sqrt{2\pi s}} \exp \frac{[\log(v) - \log(m)]^2}{2s} \tag{5}$$

where the resulting parameter values are

$$m = 7.1257 \qquad s = 0.2726 \tag{6}$$

The resulting distribution, normalized to 1, is shown in Figure 2.

The expected value of the log-normal distribution is given by

$$E[v] = \exp\left(m + \frac{s}{2}\right) \tag{7}$$

Thus, it has been shown clearly that the hypothesis of a single (or small number of) VOT in the population does not hold. Furthermore, the use of a larger number of VOTs permits an effective testing of road pricing scenarios, in that some individuals will be incited to switch to the lower-cost routes (or times of day) as the toll prices are increased, while those users having elevated VOTs will prefer to stay on the faster autoroutes. [See work by Leurent (*9*) for more details.]

Variation of VOT with Trip Parameters

Considering the second hypothesis, that is, that the VOTs may vary with trip characteristics, examination of the VOT over characteristics such as the type of merchandise transported, the time constraints of the trip, the vehicle type, the origin-destination pair, and the trip distance reveals that the only significant dependence in the data sample is on trip distance.

This result is quite important in that it permits the quantification of a phenomenon that is often observed. That is, for longer-distance trips, a larger portion of the population (in both passenger and freight transport) choose the high-priced toll roads over the free, but slower, state roads. The use of a distance dependency permits quantification of the degree of this effect by allowing the mean VOT to vary with trip distance. This result is clearly more significant in interurban travel than in urban transport modeling, where trip distances are contained in a tighter range.

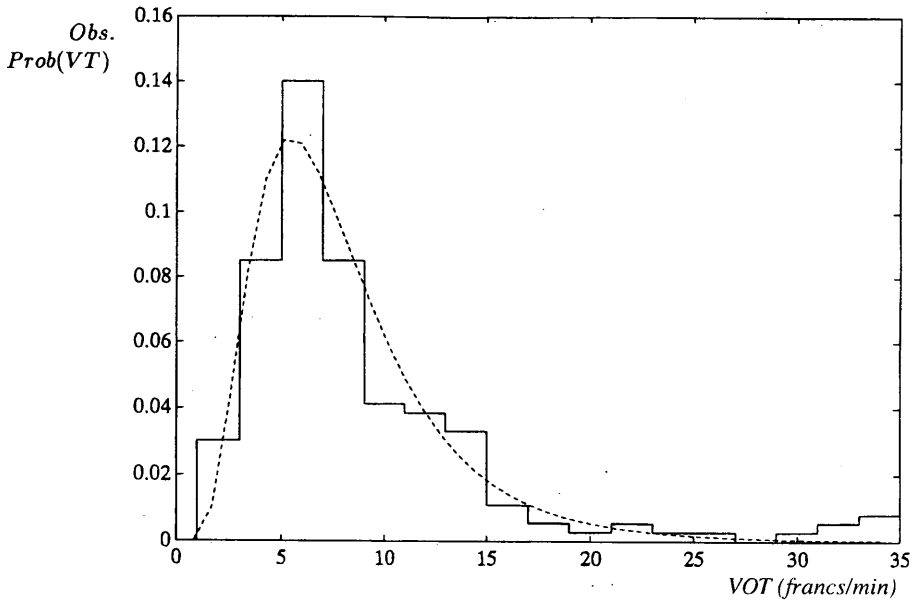

FIGURE 2 Optimal log-normal distribution of critical VOT.

The mean VOT in this case can be shown to increase linearly with distance. Estimating the line given by these points by an OLS method gives

$$\mu_v(\text{dist}) = 5.39 + 7.83 \frac{\text{dist}}{1000} \tag{8}$$

where the linear goodness-of-fit measure $r^2 = 0.75$.

Again, this result is directly usable. The mean VOT can be simply calculated for each origin-destination pair in a model by first obtaining the shortest path distance and substituting it into a formula such as Equation 8. Furthermore, this result can be combined with the results of Hypothesis 1, that is, the continuous distribution of VOT. In particular, a new log-normal distribution can be written in which the function depends not only on the VOT parameter but also on the trip distance. Figure 3 illustrates this extended VOT distribution.

Further details on the calculation of these VOT distributions can be found elsewhere (*12*).

CONCLUSIONS

A stated preference survey was designed that enabled calculation of freight transporters' individual, critical VOTs. That is, the trade-off points between increased trip cost for a faster route and cost savings at the expense of a longer travel time were obtained. Because the questions were posed for a particular trip, it was possible to obtain complementary information that enabled the examination of the dependence of VOT on other trip characteristics.

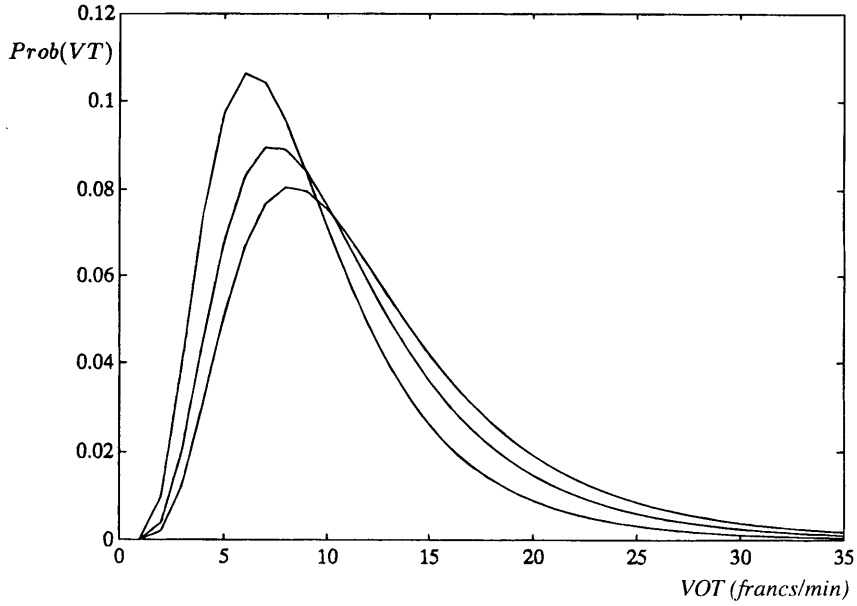

FIGURE 3 Distance-dependent log-normal distribution of critical VOT.

In doing so, it was possible to show that two commonly held beliefs about VOT are not, in fact, valid. For the case of interurban road freight transport, it was showed, first, that the VOTs of French transporters can be described by a log-normal distribution and thus that the use of a single, mean VOT is an oversimplification.

As such, transport models that use a single, mean VOT in their generalized cost functions must be called into question. This is particularly true when one of the objectives of the transport model is to analyze traveler response to changes in toll prices. Leurent (*9*) has shown that such a multi/valued VOT (continuous or discrete) is, in fact, necessary for effective testing of road pricing scenarios. Indeed, the use of a single, mean VOT in such a model means that all travelers react in an identical manner to a price increase. Clearly, it is not possible to determine the effect of toll changes on traffic flows without a VOT dispersion across the population, allowing a multiplicity of driver reactions along each path.

In addition, it was shown that these mean VOT are not independent of trip characteristics but do vary, particularly with trip distance. In this case, the VOTs of French road freight carriers were shown to vary linearly with trip distance. This confirms the general observation that a larger percentage of carriers are found on the tolled autoroutes when they are traveling long distances. Furthermore, it indicates that the use of a (marginal) VOT as a linear parameter of time should be valid.

Again, it can easily be seen how this factor would improve the predictive ability of traffic assignment models. When traffic is assigned to long-distance itineraries, a set of flows would be obtained (across tolled and untolled itineraries) that is different from the set that would be obtained for a medium-distance itinerary. More specifically, an assignment would be generated with more toll road itineraries selected as trip length increases. Concrete examples of this effect have been provided elsewhere (*13*).

Also discussed briefly is how these extensions can be incorporated into the standard mode choice and traffic assignment algorithms.

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