Understanding Travel Time Expenditures around the World Part I: How Low Can Travel Go?

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ABSTRACT

It is postulated in this paper that people have a subjective perceived minimum amount of travel time that they must undertake to fulfill the required or mandatory activities of the day. This subjective minimum required travel time represents the lower bound for the amount of travel that people feel they must undertake. This minimum threshold is not directly observed in a typical travel survey data collection effort, but can potentially be estimated using the stochastic frontier modeling methodology based on the actual observed daily travel time expenditure. This paper aims to understand travel time expenditures by modeling the minimum amount of travel (time) that individuals feel they have to undertake in a day. Travel survey data sets from around the world are analyzed and stochastic frontier models of travel time expenditures are estimated to obtain the unobserved cost frontier or minimum required travel time for the survey samples. The unobserved cost frontier is assumed to be censored at zero in the methodology presented in this paper. The findings suggest that a large proportion of the survey samples in all geographic contexts have a minimum required travel time that is greater than zero minutes and that this value differs substantially between commuters and non-commuters. Consistent with the mandatory nature of the work activity, commuters are found to have average minimum required travel times that are greater than those for non-commuters. The minimum travel time frontiers derived in this paper may be representative of subjective thresholds below which travel can not be reduced.

Keywords: travel time expenditure, travel time threshold, travel behavior, time use, stochastic frontier model, international comparison

INTRODUCTION

This paper is concerned with answering the question: How low can travel go? It is postulated that there is a minimum amount of travel that a person feels he or she must undertake to accomplish the required activities of the day. In most developed countries, the focus of transportation planning has shifted away from capacity expansion to that of operation, management, and optimization of existing capacity. This shift in planning emphasis has motivated travel behavior researchers to be concerned with relationships and trade-offs among individuals' time expenditures, travel, and activities [*1-7*]. It is envisioned that travel behavior models based on an understanding of people's time use patterns offer a robust framework for analyzing the impacts of alternative transportation policies and control measures.

If transportation control measures are aimed at reducing (vehicular) travel, then the question arises as to the extent to which travel can be eliminated. In other words, what is the minimum amount (lower bound) of travel time beyond which travel can not be reduced further? Potentially, individuals must undertake or feel that they must undertake a certain amount of minimum travel in order to accomplish activities that are mandatory or required. For example, a person may engage in 100 minutes of travel in a day even though the mandatory or required activities of the day can be accomplished in as little as 20 minutes of travel. Thus, it is clear that the subjective minimum amount of travel that a person feels he or she must undertake is closely related to the subjective judgment (perception) of the activities that are mandatory and required. Presumably, an individual undertakes additional travel because the additional (flexible or discretionary) activities offer a positive utility that outweighs any negative utility due to the travel that needs to be undertaken to participate in those activities. One can speculate, then, that this additional travel (beyond) the minimum is a candidate for potential elimination or reduction through the implementation of suitable travel demand management (TDM) strategies and transportation control measures (TCM). Modeling the minimum subjective travel time threshold would offer a basis for quantifying the potential maximum reduction in travel that can be brought about by implementing various policies.

The notion of minimum required travel time expenditure may be considered analogous to that of a minimum required monetary expenditure for subsistence. A person may spend a certain amount of money on food, clothing, and other goods. However, not all of this expenditure may be absolutely necessary for subsistence. Of all the money spent, only a small fraction may be absolutely necessary for subsistence; in the event of a crisis, the individual would not be able to spend any amount less than a subjective minimum threshold value.

In the transportation field, modeling the subjective minimum travel time threshold is also useful from the standpoint of gauging the effectiveness and performance of the transportation system. Presumably, if the actual travel time expenditure is considerably larger than the subjective minimum threshold value, then it means that the transportation system is performing at a level that motivates additional travel. The travel disutility is low enough that people are motivated to pursue additional activities and travel. In a context where the transportation system performance is very poor, one would expect the actual travel time expenditure to be close to the subjective minimum value. This is because the larger travel disutility hinders additional activity and travel engagement.

It should be possible to identify the minimum required travel time threshold by simply adding all daily travel durations to mandatory activities. However, there are three issues associated with such a simplistic approach. First, the definition of mandatory activities (and its associated travel) is unclear. What may be a mandatory activity for one individual may be non-mandatory for another. Thus, computing the minimum required travel time based on a defined set of mandatory activities would be problematic. Second, it is generally quite difficult to truly isolate the required travel associated with the mandatory activities from a travel diary survey data set. Trip patterns generally consist of a host of trip chains, journeys, and tours. Within the context of these complex patterns, one would have to make simplifying assumptions to isolate the absolutely necessary trips to accomplish the predefined set of mandatory activities. Once again, this may lead to erroneous estimates of the minimum travel time threshold. Finally, there is a third issue in that the mandatory travel (trips) observed in the data set may not constitute the minimum paths or the most efficient configuration for completing the mandatory activities of the day. Faced with a situation where an individual must undertake no more travel than absolutely necessary, it is possible that a more efficient minimum travel configuration can be found and executed while accomplishing those necessary mandatory activities. Then, even if the absolutely mandatory trips could be isolated correctly in a travel diary data set, the corresponding duration may not constitute the minimum required travel time threshold as it may be possible to accomplish the same set of activities in an even smaller duration of time. The objective of this paper is to quantify the theoretical minimum travel time that a person feels is absolutely required to accomplish the mandatory activities of the day.

Based on the above argument, one notes that the subjective minimum daily travel time threshold is an unobserved quantity. A travel survey provides actual travel time expenditure information, but no information about the person's subjective perception of the minimum travel time that must be undertaken. However, it is very likely that the subjective threshold value does influence the actual travel time expenditures observed and measured in travel diary surveys. A suitable methodology for modeling such an unobserved lower bound, in the presence of data on a value that is influenced by the unobserved lower bound, is the stochastic frontier methodology. In the stochastic frontier methodology, a cost frontier modeling approach may be adopted to represent the unobserved lower bound. In the stochastic frontier modeling approach, a cost frontier represents the theoretical minimum resources (cost) that a manufacturing plant must spend to meet a production target or goal. In this particular application, this is analogous to the cost frontier representing the theoretical minimum travel time (cost) that a person feels he or she must spend to accomplish a goal, i.e., complete the absolutely required mandatory activity schedule of the day. The only difference between the two interpretations is that the threshold is considered to be a subjective or perceived value in the case of the travel time frontier. The argument in favor of this interpretation is made later in the paper.

In this paper, stochastic frontier models are developed to estimate the unobservable subjective minimum travel time threshold through a detailed analysis of travel survey data sets derived from three countries - the United States, Switzerland, and India. All of the surveys are large sample travel diary surveys conducted in 2000-2001 and offer a unique opportunity to examine the notion of the minimum necessary travel time in a global context.

The remainder of this paper is organized as follows. The second section describes the modeling methodology. The third section describes the data sets while the fourth section presents model estimation results. The fifth section presents distributions of minimum necessary travel time frontiers for the various survey samples and offers interpretations and comparisons across geographic contexts and market segments. Finally, conclusions and directions for further research are identified in the last and seventh section.

MODELING METHODOLOGY

The perceived minimum required travel time constitutes an unobserved frontier that may be estimated using the stochastic frontier modeling methodology. This section presents the formulation of the stochastic frontier modeling methodology in this particular context with a modification to censor the unobserved frontier (i.e., minimum required travel time) at zero.

Let, $T_i = MTT_i + u_i$, (1)

where i denotes the observation, T_i is observed total daily travel time expenditure and u_i is a random component that takes non-negative values. MTT_i represents the perceived minimum required travel time (or unobserved frontier) so that T_i is always greater than or equal to MTT_i. As mentioned in previous section, the stochastic frontier model *(8)* is a suitable model that may be applied in this context. However, the traditional stochastic frontier model can not guarantee that the estimated MTT_i will be positive. A negative estimate on the subjective minimum travel time threshold is unreasonable and therefore, it would be appropriate to censor the unobserved frontier at zero.

To solve this potential problem, one may introduce a latent variable MTT_i^*. If $MTT_i^* > 0$, then $MTT_i = MTT_i^*$; on the other hand, if $MTT_i^* \leq 0$, $MTT_i = 0$. In this formulation, MTT_i can never be negative.

Analogous to the traditional stochastic frontier model, let,

$$MTT_i^* = \beta' X_i + v_i , \tag{2}$$

where, $v_i \sim N(0, \sigma_v^2)$ and u_i is assumed to be distributed half-normal with a probability density function given by,

$$g(u) = \frac{2}{\sqrt{2\pi}\sigma_u} \exp\left[-\frac{u^2}{2\sigma_u^2}\right], u \geq 0. \tag{3}$$

Under the condition that $MTT_i^* > 0$, substituting equation (2) into equation (1), one obtains:

$$T_i = \beta' X_i + v_i + u_i = \beta' X_i + \varepsilon_i . \tag{4}$$

The joint distribution of ε_i has probability density function given by,

$$D_1\left(\varepsilon_i \mid MTT_i^* > 0\right) = \frac{2}{\sqrt{2\pi}\sigma}\Phi(\varepsilon_i\lambda/\sigma)\exp\left[-\frac{\varepsilon_i^2}{2\sigma^2}\right], -\infty < \varepsilon_i < \infty \tag{5}$$

where $\sigma^2 = \sigma_u^2 + \sigma_v^2, \lambda = \sigma_u / \sigma_v$.

Under the condition that $MTT_i^* \le 0$, one obtains:

$$MTT_i = 0 \text{ and } T_i = u_i,\ D_2(T_i \mid MTT_i^* \le 0) = \frac{2}{\sqrt{2\pi}\sigma_u}\exp\left[-\frac{T_i^2}{2\sigma_u^2}\right], \tag{6}$$

where, $\sigma_u = \dfrac{\lambda\sigma}{\sqrt{1+\lambda^2}}$.

The unconditional probability density (*UPD*) of the observations may be written as:

$$\Pr(MTT_i^* > 0) \times D_1(\varepsilon_i \mid MTT_i^* > 0) + \Pr(MTT_i^* \le 0) \times D_2(T_i \mid MTT_i^* \le 0) \tag{7}$$

Now,
$\Pr(MTT_i^* > 0) = \Pr(\beta' X_i + v_i > 0) = \Phi(\beta' X_i / \sigma_v)$

Also, $\Pr(MTT_i^* \le 0) = 1 - \Phi(\beta' X_i / \sigma_v)$,
where $\sigma_v = \dfrac{\sigma}{\sqrt{1+\lambda^2}}$.

$$\text{Then, } UPD_i = \Phi(\beta' X_i/\sigma_v) \times \frac{2}{\sqrt{2\pi}\sigma}\Phi(\varepsilon_i\lambda/\sigma)\exp\left[-\frac{\varepsilon_i^2}{2\sigma^2}\right]$$

$$+ \ [1-\Phi(\beta' X_i/\sigma_v)] \times \frac{2}{\sqrt{2\pi}\sigma_u}\exp\left[-\frac{T_i^2}{2\sigma_u^2}\right] \tag{8}$$

The log-likelihood function for the observations is then:

$$LL = \sum_{i=1}^{n} ln(UPD_i) \tag{9}$$

In the log-likelihood function shown in equation (9), β, σ, and λ are the only unknown parameters to be estimated.

To obtain the necessary travel time (MTT), note that $E(MTT_i^*) = \beta' X_i$. If $\hat{\beta}' X_i \le 0$, then MTT is zero. Otherwise, if $\hat{\beta}' X_i > 0$, then MTT = $\hat{\beta}' X_i$, where $\hat{\beta}$ is the maximum likelihood estimate of β.

As with the standard stochastic frontier model,

$$E(u) = \sqrt{\frac{2}{\pi}}\hat{\sigma}_u \tag{10}$$

$$\text{var}(u) = \left(1 - \frac{2}{\pi}\right)\hat{\sigma}_u^2 \tag{11}$$

The maximum likelihood estimation was done for this paper using a combination of LIMDEP *(9)* and GAUSS programming language *(10)*.

A note is due here regarding the interpretation of the stochastic frontier in the context of the perceived minimum required travel time. Under the model formulation presented here, it is theoretically not possible for the actual travel time expenditure to be lower than the estimated frontier because the term u_i is greater than or equal to zero. However, unlike in a manufacturing plant operation where the frontier may be considered to be a hard, fixed, and objective threshold value, the frontier in this particular application may be representative of a more loosely defined subjective (perceived) threshold value. This is because, the hard, fixed, and objective minimum threshold value in the context of travel time expenditure is zero. Regardless of the activity agenda, it is theoretically possible to not engage in travel at all. However, in a behavioral context such as the one considered in the paper, there is likely to be a perceived lower bound that a person feels is representative of his or her minimum travel required to accomplish the mandatory activities of the day. This is a more loose and subjective threshold value that may be violated in a day-to-day reality. Thus, even though a person feels that he or she must dedicate, say, at least 20 minutes to travel to take care of the absolutely required activities of the day, he or she may (on occasion) end up spending less than 20 minutes for travel depending on constraints, circumstances, and unexpected situations that may arise. For example, the car may break down and the person may call work to cancel the important meeting, call the spouse to reallocate child dropoff/pickup trips, and choose to skip the yoga class. When applied in a behavioral context where the frontier is representative of a subjective perceived and loosely defined threshold value, violations of the frontier are possible and consistent with expectations.

DATA SETS

Three data sets from around the world are used to explore the perceived minimum required travel time expenditure. All three data sets are derived from household travel surveys in which respondent samples provided detailed trip information for a 24-hour period. The three surveys are:

- 2001 National Household Travel Survey of the United States
- 2000 Microcensus Travel Survey of Switzerland
- 2001 Household Travel Survey of the City of Thane, India

While the first two surveys constitute national surveys, the survey from India is from a single metropolitan area in India. Unfortunately, there is no national travel survey in India that can be used for this analysis. However, as the City of Thane is a rather representative metropolitan area of India, it was considered suitable to serve as the third international context for this study. Moreover, it was a large sample survey including a respondent sample of 3,505 households and therefore is statistically valid from a model development and estimation perspective.

There are differences and similarities between the surveys that should be noted here. All three travel surveys are based on the trip-diary format in which respondents are asked to provide detailed information about trips in addition to socio-economic, demographic, and other characteristics of households and persons. However, there are differences with respect to the survey administration method. The 2001 NHTS is a combination mail-out/computer-assisted telephone interview (CATI) survey where travel data is retrieved for the household over the phone. The 2000 Swiss Microcensus is a pure mail-out/mail-back travel diary survey. Finally, the 2001 Thane, India survey is a face-to-face in-person survey where field workers actually visited households and interviewed people in their homes to retrieve travel data. Despite these differences, the survey data offer rather standard information regarding household, person, and travel characteristics and appear worthy of use in an international study of this nature. However, the authors can not rule out the possibility that differences in results, model estimates, and findings among the three data sets may, in part, be due to differences in survey administration methods.

Table 1 offers a detailed listing of household characteristics of the three data sets. While the US and Swiss data sets are large survey samples with 25,000+ households, the India survey sample includes only a respondent sample of 3,505 households. Again, this is not seen as a problem within the context of the model development effort of this paper. As expected, the US and Swiss survey samples show small household sizes, higher levels of licensed drivers and car ownership, and a highly urbanized population. India is characterized by large household sizes, more children, very few licensed drivers, and very low levels of car ownership.

Table 2 offers a detailed look at the person characteristics by commuting status. All individuals who made at least one work trip or work-related business trip on the travel survey day were treated as commuters and all others were treated as non-commuters. In the remainder of this paper, the term worker and commuter will be used synonymously; however, it should be recognized that many individuals considered non-commuters in this paper are actually workers. They did not commute on the travel survey day and are therefore classified as non-commuters. However, for purposes of convenience, commuters will also be called workers and non-commuters will also be called non-workers throughout this paper.

Also noteworthy is that the analysis in this paper is limited to “mobile adults”. These are individuals who reported at least one trip on the travel survey day and are 18 years of age or above. It was felt that the analysis should be limited to the adult samples because children often do not have the freedom to “determine” their travel patterns, have less flexibility with respect to their travel options and decisions, and have poorer response quality in travel survey data sets. Thus, the examination of the perceived minimum required travel time is done for adult samples in the international data sets. However, including only the “mobile” individuals in the analysis is a limitation that will need to be overcome in future research. Across the three data sets, it was not clear whether a clear distinction could be made between individuals who legitimately made and therefore reported zero trips versus those who simply did not respond to the survey and never provided trip information for the travel survey day. Whereas the zero-trip making individuals could be clearly identified in the 2001 US survey, the legitimate zero-trip making individuals could not be identified as clearly in the 2000 Swiss and 2001 India data sets. While this is certainly an unfortunate limitation of the study, the authors feel that the analysis will nevertheless offer useful insights into the perceived minimum required travel time. In addition, the authors feel that individuals who do not travel on a certain travel survey day may actually travel on other days of the week. So, limiting the analysis to mobile individuals may not constitute a very severe limitation in the context of this study.

Table 2 provides descriptive statistics for the mobile person samples by commuting status. In the US and Swiss samples, it is found that mobile non-commuters are more retirement age oriented while the mobile non-commuters in the India sample are more young student-age oriented. The gender split between commuters and non-commuters is also quite interesting. A majority of mobile commuters are male in all three data sets; but the percentage is much larger in the India sample at 85 percent. With respect to mobile non-commuters, the majority are female in the US and Swiss samples, but male in the India sample. Many female non-commuters in the India sample were found to have zero trips associated with their records either due to legitimate zero trip making behavior or not responding to the survey. A vast majority of individuals is licensed to drive in the US and Swiss samples, while only a very small minority is licensed to drive in India. With respect to trip frequencies, mobile commuters in US and Swiss samples make more than four trips per day. The mobile commuters in India make, on average, less than one-half as many trips at just about two trips per day indicating that they generally go to work (or work-related business) and then return home. Mobile non-commuters in the US make nearly five trips per day; the corresponding value for Swiss non-commuters is about 3.5 trips per day. Mobile non-commuters in India make just about two trips per day indicating that they undertake, on average one out-of-home activity per day (and then return home). The work trip frequency for the mobile commuter sample in the India survey is less than unity because there are about 800 mobile commuters in the India sample who reported no work trips, but reported a work-related business trip.

Finally, Table 3 provides a glimpse of average travel durations by purpose for mobile commuters and non-commuters in each of the three data sets. Average travel durations are about 1.5 hours for mobile adults in the US survey, about 1 hr 40 min for mobile adults in the Swiss survey, and closer to one hour for mobile adults in the India survey. Mobile non-commuters in the India sample are more school oriented while those in the US and Swiss samples are more oriented towards non-work and non-school travel such as shopping, social-recreation, and others. The US samples show a high value for the “other” category as it combines several purposes including serve passenger, medical/dental, eat meal, and other personal errands. Although many of the trip purposes defined in the surveys appear similar, it is not clear whether the definitions are exactly the same across the three surveys. Therefore, this paper focuses on modeling the unobserved cost frontier based on the total travel time expenditure as opposed to travel time expenditures by purpose.

MODEL ESTIMATION RESULTS

Censored cost frontier models of the perceived minimum required travel time are presented in Tables 4 through 6 for commuter and non-commuter samples in all three data sets. This section presents a brief overview of the model estimation results as seen in these tables.

Table 4 presents the results for the US survey samples. It is found that the constant term is positive. While this is to be expected because the survey samples are limited to mobile adults, it nevertheless offers a first indication that the minimum required travel time frontier tends to be positive and that people perceive that they indeed have to engage in at least some amount of travel in a day. In the mobile commuter model, being male, having a college education, being employed full time, living farther away from work, and serving in a professional occupation positively impact the minimum required travel time frontier. All of these estimation results are consistent with expectations that highly educated and employed males are likely to be those who perceive that they have to engage in a certain minimum amount of travel to undertake mandatory activities. The weekend days are associated with a reduction in the perceived minimum required travel time frontier as indicated by the negative coefficient. This finding is consistent with expectations as activities on weekends tend to be less mandatory in nature when compared with weekdays. Variables representing the presence of children and higher levels of income are associated with a higher minimum required travel time frontier as indicated by the positive coefficients. Once again, these findings are consistent with expectations in that households with children and higher incomes may have greater serve-child trip obligations and thus larger minimum travel time requirements. It is interesting to note that the minimum required travel time frontier is positively impacted by the variable representing Friday. It is possible that workers feel that they must travel more on Fridays, relative to other workdays, to relax and enjoy the end of a work week. In other words, some of the flexible/discretionary and joint activities (with other household members) undertaken on a Friday may be perceived as required, thus contributing to the enhanced minimum travel time frontier.

For non-workers, it is found that being a licensed driver has a positive impact on the perceived minimum required travel time. Having a driver’s license and higher car availability provide an individual the ability to undertake some (or all) of the household mandatory activities, thus leading to a larger minimum required travel time frontier. One interesting difference between commuters and non-commuters is that the presence of children negatively impacts the minimum required travel time frontier for non-commuters. This may be indicative of the non-commuters perception that, because they have greater household obligations and in-home childcare responsibilities, their minimum travel time obligation is lower than that for those who do not have the same constraints.

In Table 5, which shows results of model estimation for the Swiss samples, the constant terms are found to be positive once again. In addition, as in the US samples, it is found that the constant term for mobile commuters is substantially larger than that for mobile non-commuters indicating that, ceteris paribus, the perceived minimum required travel time frontier is larger for commuters than non-commuters. This result is quite reasonable because commuters probably feel that they have to make the obligatory trips to and from work. All of the other findings are generally consistent with expectations. There are a few unique findings here, relative to the US model results. Zero car ownership has a positive impact on the perceived minimum required travel time for mobile commuters, but a negative impact on that for non-commuters. This is presumably because commuters without access to a car have to commute by slower modes. As the commute is generally constrained in time and space, this results in a perception that the minimum amount of travel time required is greater than in a situation where a car is available. On the other hand, non-commuters without access to a car may schedule less mandatory activities on their agenda (than non-commuters who have access to a car), and for the few activities that they do schedule on their agenda, they may end up choosing activity locations that are very close Together. People in rural areas have a lower perceived minimum required travel time frontier as do commuters who work part time. Rainy weather is associated with a negative coefficient; it is likely that travelers think of some travel as not necessarily absolutely required when the weather is not travel-friendly. Fridays once again show a positive impact on the perceived minimum required travel time for commuters. For non-commuters, income is found to make a difference with higher income associated with higher minimum required travel times.

Finally, Table 6 offers results for the Thane, India survey samples. Once again, it is found that the constant term in the model for commuters is greater than that in the model for non-commuters. Male commuters have a greater perceived minimum required travel time relative to female commuters. Homemakers (among the non-commuters) are found to have a smaller perceived minimum required travel time as evidenced by the negative coefficient; this is probably due to the higher levels of household obligations that they undertake in the Indian context. In the Indian context, larger household sizes are associated with smaller minimum travel time frontiers, possibly due to greater in-home childcare obligations and activities. Also, traveling with the entire family in India is a more burdensome experience than in the developed world. This may motivate persons in larger households to lower their perceived minimum required travel time frontier relative to persons in smaller households. In the Indian context, is found that those with a professional occupation and higher education level have a lower perceived minimum required travel time frontier. It is likely that these individuals have the resources and means to travel by faster modes and therefore perceive that their minimum required travel time frontier is lower than others. Indeed, it is found that commuters using transit have a much larger minimum travel time threshold as indicated by the large positive and significant coefficient associated with transit use. As transit is a slow mode, commuters using transit in the Indian context feel that their minimum required travel time to accomplish required mandatory activities is quite large.

As expected, having a driver’s license and a higher income level are both positively related to the subjective minimum required travel time frontier. It is conceivable that commuters who have a driver’s license and higher income have the means and resources to travel more, visit preferred destinations that are farther away, and take on a greater amount of the household mandatory activities in the Indian socio-cultural context. Commuters with longer work durations have a larger perceived minimum travel time frontier. This is consistent with expectations in that individuals with full-time jobs who work longer also commute longer distances to access the specialized occupations. As a result, these individuals perceive a higher minimum travel requirement.

Among non-commuters, younger adults have a higher minimum required travel time frontier. These individuals are generally college students in the Indian survey sample with little in-home obligations. As school is a mandatory activity, they exhibit larger minimum required travel time frontier values. It was also found that the total out-of-home activity duration and pursuing more than two activities outside home in the day positively impacted the perceived minimum travel time frontier. It is likely that these individuals are those who undertake more of the household obligations outside home and therefore have higher thresholds for the minimum required travel time.

In all of the models, the statistical goodness-of-fits are quite reasonable and the coefficients are statistically significant offering plausible interpretations. The model estimation results suggest that the stochastic frontier modeling methodology offers a suitable framework for studying unobserved frontiers related to minimum required travel time expenditures.

DISTRIBUTIONS OF TRAVEL TIME EXPENDITURES AND COST FRONTIERS

The stochastic frontier models presented in Tables 4 through 6 can be used to derive distributions of expected values of perceived minimum required travel time frontiers. These distributions are plotted together with the distributions of the actual travel time expenditures for commuter and non-commuter samples in each of the three data sets. The resulting plots offer an interesting perspective on the distributions of expected minimum required travel time frontiers and how they are related to the observed travel time expenditures. These distributions also show the proportion of individuals for whom the expected perceived minimum required travel time frontier is zero minutes, i.e., the proportion of individuals for whom travel could potentially be entirely eliminated.

Figure 1 shows the distributions of expected minimum required travel time and actual travel time expenditures for the US survey samples. The cost frontier distributions are the sharp and highly peaked distributions that are generally shifted to the left of the actual travel time expenditure distributions. An examination of the plots shows that the stochastic frontier models offer predictions that are plausible and behaviorally intuitive. The minimum required travel time distributions are quite well defined and show sharp peaks in the 0-30 minute range. As 100 percent of the non-commuter sample fell into this category, an inset graph showing a more detailed distribution for this group is also shown in the figure. For this market segment, the distribution is generally in the range of 0-10 minutes. Consistent with these findings, the expected value of the minimum required travel time frontier is found to be about 23 minutes for commuters and 6 minutes for non-commuters. This is consistent with the expectation that commuters have a larger subjective minimum travel time requirement due to the need to commute to and from work, which is generally considered a mandatory activity. An interesting finding is that virtually nobody has a zero-minute minimum expected travel time frontier. In other words, virtually all individuals in the US survey samples feel that they must travel for at least a certain minimum level of duration to accomplish the required activity schedule of the day. Conversely, almost nobody in the sample feels that he or she can eliminate all travel and stay at home all day.

Figure 2 shows the distributions for the Swiss survey samples. Once again, an inset graph is provided to show a more detailed distribution for the non-commuter sample. Similar to the United States, the Swiss samples show an expected minimum required travel time frontier of about 21 minutes for commuters and 3 minutes for non-commuters. It is to be noted that these values are smaller than those in the United States samples even though the actual travel time expenditures are greater in the Swiss samples than in the US samples. It is possible that the higher densities and destination choices in the Swiss context offer the ability to lower minimum required travel time thresholds. Another interesting finding is that, in the Swiss commuter sample, nearly 12 percent of the commuters have a perceive minimum travel time frontier of zero minutes. This finding merits further investigation in that commuters should generally consider the work activity and its associated travel as mandatory and one would expect virtually nobody in the commuter market segment to have a zero-minute minimum travel time threshold. On the other hand, in the Swiss context, it is possible that a small segment of the commuter sample has a work arrangements flexible enough that allow zero minute minimum travel time thresholds.

Finally, Figure 3 presents distributions for the Indian survey samples. It is found that no commuter shows an expected minimum travel time frontier value of zero minutes. An inset graph is provided to show detailed distributions; however, in this case, detailed distributions are shown in the inset graph for both commuters and non-commuters. While the non-commuters show an expected minimum required travel time frontier of about 6 minutes similar to the US and Swiss samples, the commuters show an expected value of about 60 minutes which is much higher than that seen in the US and Swiss samples. This finding is actually quite consistent with the nature of travel undertaken by commuters in the Indian survey sample. The commuters in the Indian survey sample made, on average, two trips per day – the trips to and from work. These are essentially mandatory trips. Thus, one would expect that all (or nearly all) of the observed travel time expenditure is absolutely necessary and mandatory in nature. The actual travel time expenditure averages about 75 minutes for this sample segment. Considering that most of it is mandatory, the 60 minute value for the expected minimum travel time requirement is quite consistent with expectations. It is to be noted that the high level of transit usage and dependency may be leading to the high minimum travel time frontier for a large segment of the commuter sample in the data set from India.

Table 7 summarizes the international comparison of average travel time expenditures and expected minimum travel time frontiers. In this table, the value of E[u] is added to show the average difference between the actual travel time expenditure and the expected minimum required travel time frontier. In general, it can be seen that the actual travel time expenditure far exceeds the expected minimum required travel time frontier in all cases, except in the case of Indian commuters. The E[u] value for Indian commuters is only about 10 minutes while the corresponding values for US and Swiss commuter samples are 80 minutes and 95 minutes respectively. This clearly reflects the effects of the maturity and performance of the transportation system on activity and travel engagement. In developed countries, traveling offers a disutility that is small enough to motivate substantial activity engagement (and therefore, travel) above and beyond the perceived minimum required travel. However, in developing countries, the disutility of traveling is still so large that additional activity engagement (and travel) is undertaken more sparingly. Even for non-commuters, whereas E[u] is 97 minutes and 130 minutes for the US and Swiss survey samples, it is only 49 minutes for the Indian non-commuter sample. Another finding to note is that, in all three samples, the E[u] value is greater for non-commuters than for commuters. This is consistent with the notion that a greater proportion of travel undertaken by non-commuters is for discretionary purposes and therefore non-commuter samples offer the potential for greater reductions in travel in the event of a TDM or TCM implementation.

CONCLUSIONS

This paper has presented a series of models to better understand daily travel time expenditures by attempting to determine the subjective or perceived minimum amount of travel time that people feel they must undertake to accomplish the minimum required activities of the day. An understanding of the minimum travel time threshold would offer the potential to quantitatively assess the maximum amount of travel reduction that may potentially be accomplished through TDM and TCM policy implementation. The paper postulates that the stochastic frontier modeling methodology can be employed to determine the minimum required travel time frontier that influences the actual travel time expenditure observed in travel surveys. The minimum travel time threshold is represented by an unobserved cost frontier in this modeling framework.

Cost frontier models of minimum required travel time frontier were estimated for three survey samples drawn from the 2001 US National Household Travel Survey (NHTS), 2000 Swiss Microcensus Travel Survey, and the 2001 Thane, India household travel survey. Separate models were estimated for commuters and non-commuters to recognize the inherent differences between these market segments. In addition, the analysis was limited to mobile adult samples to control for unknown factors related to the survey design and reporting.

The stochastic frontier models were found to offer statistically significant coefficients for several socio-economic and demographic characteristics indicating that the minimum required travel time frontier is likely influenced by a person's lifecycle stage, lifestyle, income, age, and household characteristics. The model estimation results were used to plot distributions of the expected necessary travel time frontier values vis-à-vis the actual travel time expenditures. The plots were found to offer plausible interpretations and suggested that the stochastic frontier modeling methodology is suitable for modeling minimum required travel time frontiers. The average expected minimum required travel time frontier values were found to be about 20 minutes for US and Swiss commuters, 60 minutes for Indian commuters, and 3-7 minutes for non-commutes. The expected minimum travel time frontier is greater than zero minutes for a vast majority of the individuals in all survey samples,. This finding suggests that individuals, in general, feel that they have to undertake at least a certain amount of minimum travel to fulfill the minimum required activity agenda.

Future research should address the question as to whether the minimum required travel time frontier is shifting over time. Stochastic frontier models estimated on longitudinal data may be able to shed light on this question. An examination of the distributions of expected minimum required travel time frontiers over time might show whether people's perceptions of their minimum travel needs are changing.

Another area for potential improvement is related to the distributional assumption made on the error component, *u*. In this paper, a half-normal distribution is assumed for *u*. Assuming the half-normal distribution for *u* implies that the actual travel time expenditure is equal to or nearly equal to the minimum required travel time frontier for a large proportion of the survey sample. However, in reality, that is not the case. For a vast majority of the survey samples, the actual travel time expenditure considerably exceeds the minimum required travel time frontier. Thus, a more appropriate distributional assumption (say, a truncated normal distribution) should be used for the error component, *u*, in future model estimation efforts of this nature. In this paper, the half-normal distribution assumption was made for ease of estimation and computational tractability. It should also be noted that the assumption of a half-normal distribution may not be wholly inappropriate if one considers that, in general, actual travel time expenditures would tend towards the minimum required threshold values if the disutility of traveling were large relative to the utility that might be derived from additional (non-mandatory) activities undertaken outside the home. This tendency is illustrated in the case of the Indian commuter sample where the average actual travel time expenditure is quite close to the expected minimum required travel time frontier. The half-normal distribution may be considered as representative of this tendency, as opposed to the actual observed pattern of behavior.

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Table 1 Household Characteristics

Characteristic	2001 US NHTS	2000 Swiss Travel Microcensus Survey	2001 Thane, India Household Survey
Sample Size	26,038	27,918	3,505
Household Size	2.56	2.43	4.12
1 person	25.82%	27.5%	2.0%
2 persons	32.63%	35.1%	12.2%
3 persons	16.53%	14.0%	19.8%
≥ 4 persons	25.02%	23.4%	66.0%
No. of Children (under 18)	0.67	0.51	0.90
0 children	64.4%	71.3%	47.4%
1 child	14.6%	11.6%	26.4%
2 children	13.8%	12.4%	16.9%
3+ children	7.3%	4.7%	9.3%
No. of Workers	1.31	N/A	1.34
0 workers	22.9%	N/A	9.3%
1 worker	34.5%	N/A	57.3%
2 workers	33.7%	N/A	25.8%
3+ workers	8.9%	N/A	7.6%
No. of Licensed Drivers	1.75	1.51	0.10
0 licensed drivers	5.38%	12.8%	91.3%
1 licensed driver	31.85%	34.1%	7.4%
2 licensed drivers	49.25%	44.6%	1.0%
3 or more drivers	13.52%	8.5%	0.3%
Annual Income			
Low income	$25K or less (29.1%)	> Fr 48K (20.8%)	≤ Rs 60K (42.2%)
Medium income	$25K - $50K (33.3%)	Fr 48K - Fr 96K (35.9%)	Rs 60K - Rs 180K (45%)
High income	> $50K (37.6%)	> Fr 96K (18.4%)	> Rs 180K (12.8%)
Vehicle Ownership	1.90	1.17	0.06
0 auto	7.9%	19.8%	94.7%
1 auto	31.4%	50.5%	4.9%
2 autos	37.1%	24.5%	0.4%
≥ 3 autos	23.6%	5.2%	0
Residential area type			
Urban	79.5%	78.6%	N/A
Non-Urban	20.5%	21.4%	N/A

Table 2 Person Characteristics (Mobile Adults)

Characteristic	2001 US NHTS		2000 Swiss Travel Microcensus Survey		2001 Thane, India Household Survey	
	Commuters	Non-Commuters	Commuters	Non-Commuters	Commuters	Non-Commuters
Sample Size	17626	22507	8247	14110	4623	1699
Age (in years)	42.4	51.9	41.5	51.7	36.4	31.0
18-24 years	9.4%	7.5%	8.6%	8.3%	15.1%	53.4%
26-64 years	86.9%	63.5%	89.6%	61.4%	84.1%	41.0%
65 years or above	3.9%	25.0%	1.8%	30.3%	0.7%	5.6%
Sex						
Male	54.6%	41.9%	58.4%	40.5%	85.4%	53.6%
Female	45.4%	58.1%	41.6%	59.5%	14.6%	46.4%
Employment Status						
Unemployed	1.8%	58.0%	N/A	N/A	N/A	N/A
Full time	84.1%	31.0%	75.6%	28.1%	N/A	N/A
Part time	13.5%	10.8%	19.2%	14.4%	N/A	N/A
Multiple Jobs	0.5%	0.2%	1.3%	0.8%	N/A	N/A
Licensed Driver	97.3%	92.8%	89.2%	75.7%	17.9%	6.6%
Highest Education Completed						
Some college or less (No Degree)	57.7%	65.4%	81.6%	87.4%	70.7%	73.0%
College graduate or more (Degree earned)	41.9%	35.1%	18.4%	12.6%	29.3%	27.0%
Occupation						
Sales/Service	25.3%	11.7%	N/A	N/A	71.0%	2.8%
Clerical/Administrative/ Support	12.0%	5.5%	N/A	N/A	N/A	N/A
Manufacturing/construction /farming/maintenance /laborer	20.2%	7.3%	N/A	N/A	7.0%	1.4%
Professional/managerial/technical	40.6%	17.4%	N/A	N/A	21.5%	6.2%
Student	N/A	N/A	N/A	N/A	0.3%	47.0%
Retired/unemployed/other	N/A	N/A	N/A	N/A	0.2%	17.4%
Homemaker	N/A	N/A	N/A	N/A	0%	25.4%
#Trips/day	4.89	4.92	4.66	3.54	2.06	2.01
Work trips	2.43	0	1.60	0.00	0.84	0
Non-work trips	2.46	4.92	3.06	3.54	1.21	2.01
Daily Miles Traveled	52.8	49.3	31.0	37.8	N/A	N/A
Daily Travel Time (min)	95.8	94.5	101.1	115.1	73.0	51.3

Adult: Persons 18 years of age or above

Mobile: Made at least one trip on travel survey day

Commuter: Made at least one work or business trip on travel survey day

Table 3 Average Travel Durations for Mobile Adults

Trip Purpose	U.S.A.		Switzerland		Thane, India	
	Commuters (N = 17684)	Non-Commuters (N = 22658)	Commuters (N = 8247)	Non-Commuters (N =14110)	Commuters (N = 4623)	Non-Commuters (N =1699)
Work	26.33	0.03	35.74	0	31.91	0
Work Related/ Business	9.75	0	8.37	4.09	4.57	0.33
School	0.59	0.99	0.38	1.46	0.02	13.68
Shopping	5.41	13.61	5.46	12.77	0.04	3.65
Social/Recreational	6.31	18.97	16.84	50.20	0.13	4.46
Return Home	31.16	31.25	32.15	43.05	36.14	25.74
Others	14.96	28.27	2.18	3.36	0.12	3.46
Total	94.51	93.12	101.12	114.93	72.93	51.32

Table 4 Stochastic Frontier Models of Minimum Required Travel Time: 2001 USA NHTS

	Mobile Commuters		Mobile Non-Commuters	
Variable	Coefficient	t-stat	Coefficient	t-stat
Constant	18.269	12.179	4.711	5.797
Licensed driver			1.782	2.482
Gender: male	2.585	3.777		
Education level: Bachelor or equivalent	3.430	4.428		
Employment status: full time	3.310	3.263		
Daily work duration (min)	-0.026	-12.460		
Distance to work from home (miles)	0.749	37.533		
Occupation: professional	2.313	3.032		
Travel day: Sat/Sunday	-7.456	-6.427	-0.836	-2.338
Travel day: Friday	4.013	4.238		
Race: White			-1.725	-3.496
Household with children	1.779	2.670	-1.071	-2.862
Household car ownership >1	-1.905	-2.056	0.914	2.049
High HH income (>= $70K/Annum)	4.343	5.633		
Low HH income (< $25K/Annum)	-4.303	-4.054		
Residential neighborhood: urban			1.157	2.857
λ	6.155	23.480	31.392	8.487
σ	100.370	151.860	121.867	191.13
L(C)	-86328.8		-115045.0	
L(β)	-85655.1		-115067.6	
χ^2 [df]	1347.330[12]		45.200[6]	
Var(v) = $\hat{\sigma}_v^2$	259.047		985.457	
$\hat{\sigma}_u^2$	9815.029		14851.57	
E(u)	79.03		97.22	
Var(u)	3569.102		5400.569	
Sample Size	15791		20740	

Table 5 Stochastic Frontier Models of Minimum Required Travel Time: 2000 Swiss Microcensus

	Mobile Commuters		Mobile Non-Commuters	
Variable	Coefficient	t-stat	Coefficient	t-stat
Constant	33.996	5.927	3.4564	2.330
Gender: male	4.784	4.278	-0.1836	-0.531
Age	-0.8304	-3.235	0.0057	0.089
Age squared	0.0084	2.796	-0.0002	-0.327
Household size	2.7095	2.391	0.8970	2.013
Household car ownership = 0	5.3813	3.440	-0.5270	-1.015
Residential neighborhood: rural	-2.7889	-2.632	-1.1273	-3.220
Nationality: Swiss	3.0127	2.294		
Employment Status: part time	-7.2539	-5.058		
Daily work duration (min)	-0.0526	-13.973		
Logarithm of distance to work from home	13.1321	24.215		
Travel day: Friday	4.8602	3.867		
Travel day: Sat/Sunday			-0.2510	-0.725
Travel day weather: rainy	-4.4204	-3.593		
High HH income (>Fr 10000 monthly)			0.0904	0.170
Low HH income (<Fr 4000 monthly)			-0.6015	-1.377
Occupation: retired			0.1416	0.223
λ	9.4745	15.880	124.8111	4.626
σ	119.485	114.605	164.2969	166.006
L(C)	-44894.562		-82298.550	
L(β)	-44408.439		-82287.827	
χ^2 [df]	972.240[12]		21.446 [10]	
Var(v) = $\hat{\sigma}_v^2$	157.291		1.733	
$\hat{\sigma}_u^2$	14119.375		26991.739	
E(u)	94.79		131.06	
Var(u)	5134.318		9815.178	
Sample Size	7981		14110	

Table 6 Stochastic Frontier Models of Minimum Required Travel Time: 2001 Thane, India

	Mobile Commuters		Mobile Non-Commuters	
Variable	Coefficient	t-stat	Coefficient	t-stat
Constant	20.8232	12.260	6.7072	5.204
Male	3.7297	3.592		
Occupation: service			-4.5045	-2.031
Occupation: professional	-5.8862	-5.327		
Occupation: homemaker			-3.1035	-3.086
Education: graduate	-4.2387	-2.938		
Daily work activity duration	0.0061	3.669		
Licensed driver	2.6697	2.387		
Household size	-0.3855	-1.632	-0.4696	-1.718
Low income (≤ Rs. 5K monthly)	-1.0333	-1.218		
Young (age: 18-29)			2.5705	2.818
Daily activity duration			0.0030	2.446
No. of daily activity participated > 2			8.3298	2.957
Transit user	63.7104	40.680		
λ	0.2108	27.510	19.2962	4.302
σ	58.7089	61.457	61.7544	54.086
L(C)	-24169.044		-8315.246	
L(β)	-22752.046		-8289.761	
χ^2 [df]	2833.996 [8]		50.970 [6]	
Var(v) = $\hat{\sigma}_v^2$	57.387		10.2147	
$\hat{\sigma}_u^2$	146.346		3803.391	
E(u)	9.65		49.21	
Var(u)	53.179		1382.077	
Sample Size	4623		1699	

Table 7 International Comparison of Average Travel Time Expenditures and Average Expected Minimum Required Travel Time Frontiers

Survey Area	Commuters			Non-commuters		
	Travel time expenditure (min)	Min Required Travel Time (min)	E(u)	Travel time expenditure (min)	Min Required Travel time (min)	E(u)
United States	93.5	23.1	79.0	94.5	6.1	97.2
Switzerland	100.9	20.9	94.8	115.1	2.7	131.1
Thane, India	72.9	59.53	9.65	51.3	6.4	49.2

Figure 1 Distributions of Travel Time Expenditures and Expected Minimum Required Travel Time Frontiers: 2001 US NHTS Mobile Commuters and Non-Commuters

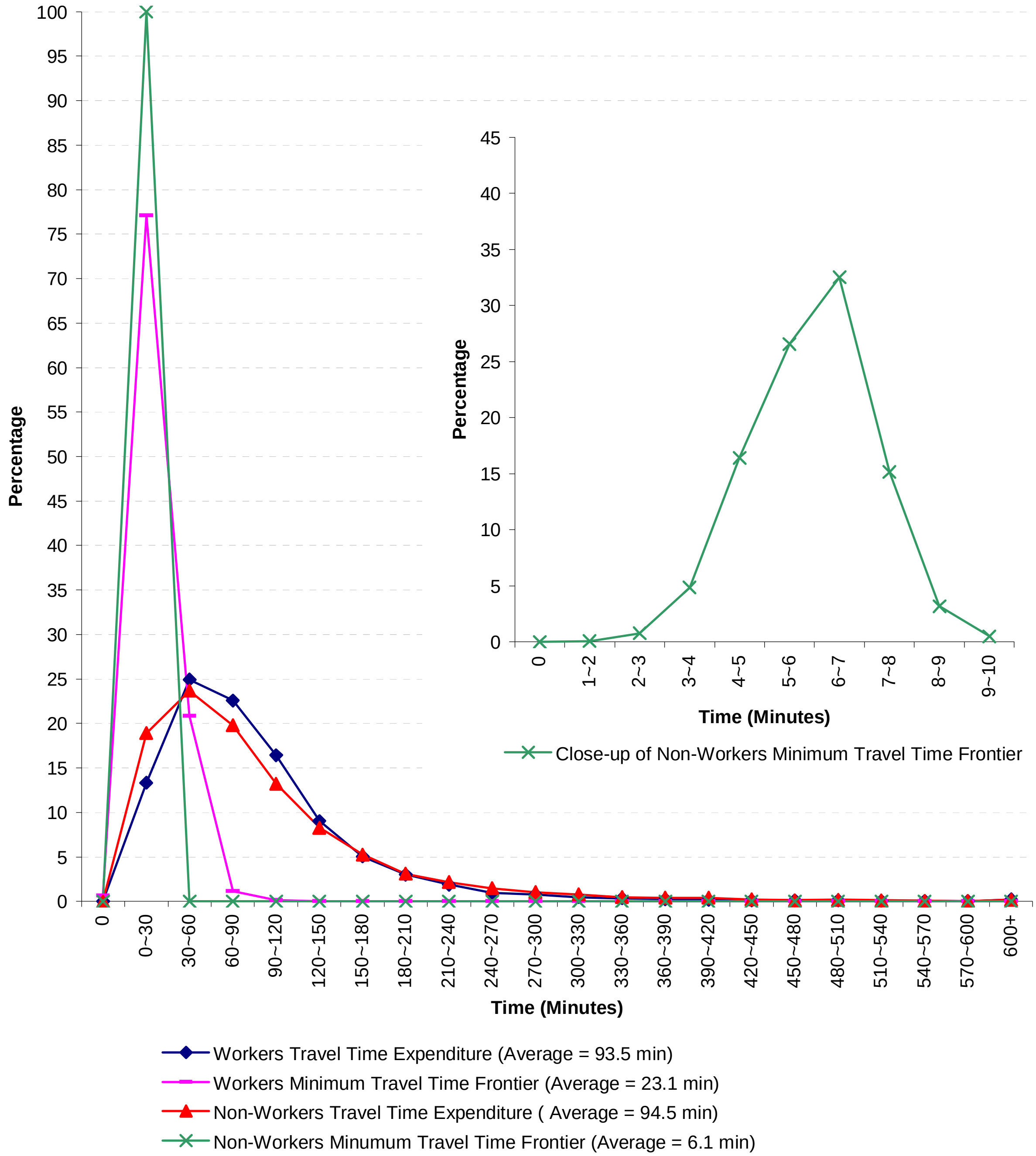

Figure 2 Distributions of Travel Time Expenditures and Expected Minimum Required Travel Time Frontiers: 2000 Swiss Microcensus Mobile Commuters and Non-Commuters

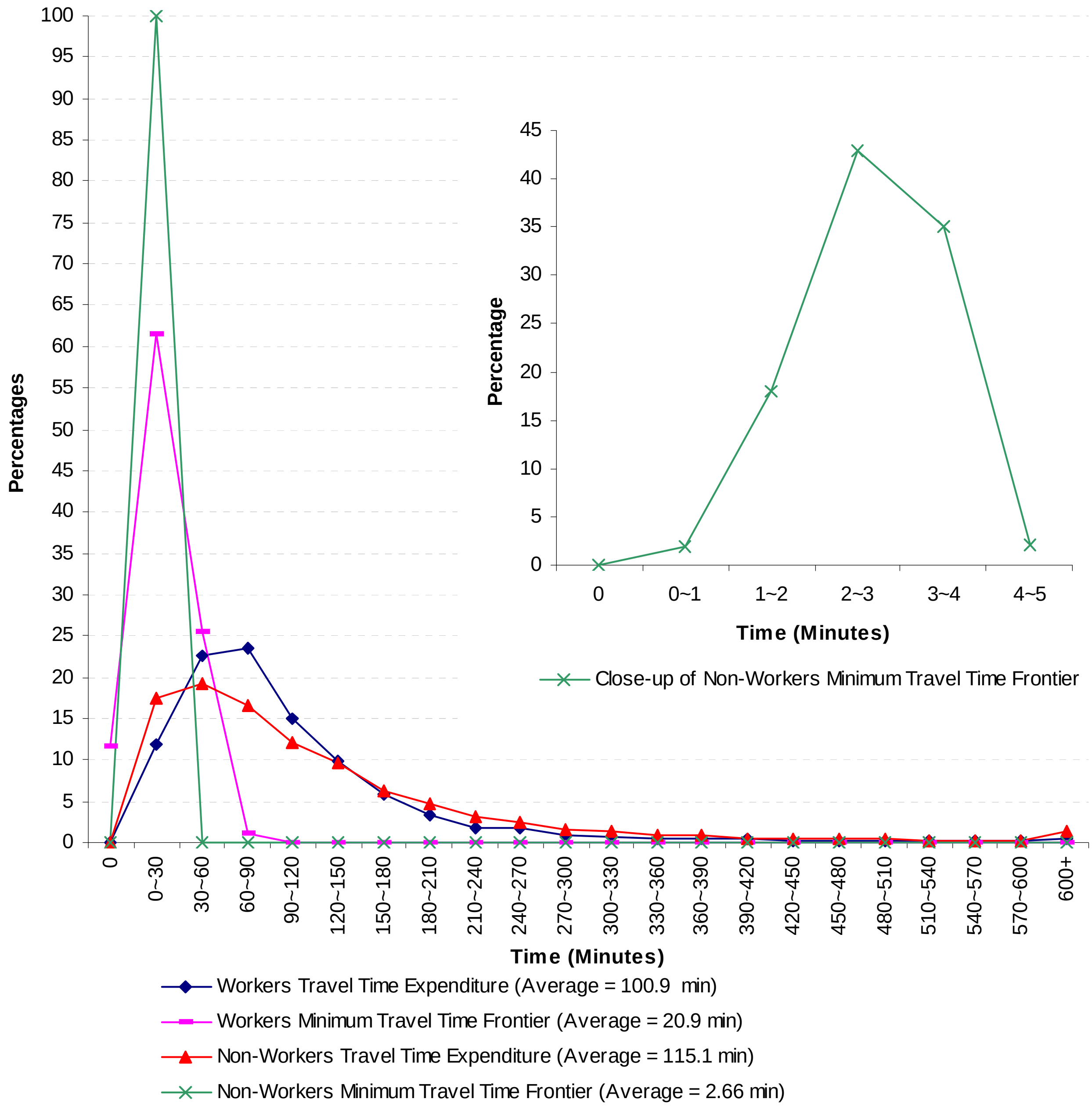

Figure 3 Distributions of Travel Time Expenditures and Expected Minimum Required Travel Time Frontiers: 2001 Thane, India Survey Mobile Commuters and Non-Commuters