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16. Abstract

The distribution of the duration of trips in a metropolitan area is an important input to estimating area-wide running loss emissions, operating mode fractions and vehicle miles of travel (VMT) accumulated on local roads in the region. In the current paper, we formulate and implement a methodology for modeling trip durations. The approach develops a log-linear regression model of the duration of trips as a function of trip purpose, time-of-day of the trip start, and other land-use and socio-demographic characteristics of the zone of trip start, using vehicle trip data from household travel surveys and supplementary zonal demographic/land-use data. A distinguishing characteristic of the methodology is the straightforward manner in which model parameters estimated from vehicle trip data can be applied to obtain zonal-level trip duration distributions. The modeling framework is applied to develop trip duration distributions for the Dallas-Fort Worth area of Texas.

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MODELING TRIP DURATION FOR MOBILE SOURCE EMISSIONS FORECASTING

by

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Transportation Control Measure Effectiveness in Ozone Nonattainment Areas

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TABLE OF CONTENTS

LIST OF TABLES

1. BACKGROUND AND SIGNIFICANCE OF WORK

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and the Clean Air Act Amendments (CAAA) of 1990 require Metropolitan Planning Organizations (MPOs) to demonstrate areawide conformity with mobile source emission budgets established in their respective State Implementation Plans (SIPs). For such conformity analyses, the Environmental Protection Agency (EPA) requires the use of the MOBILE emissions factor model for all areas except California, which uses the EMFAC7F model (MOBILE5b is the current version of the MOBILE model; MOBILE6 is currently under development and is likely to become available in Fall 2000).

The emissions factor models take several traffic-related data as inputs, one of which is the distribution of the duration of vehicle trips in the region. The vehicle trip duration distribution is important for several reasons. First, the trip duration distribution provides information for developing trip duration activity parameters used by the MOBILE emissions factor model to estimate running loss emissions. Running loss emissions are evaporative emissions that have escaped from a vehicle while the engine is operating (from spots where the vehicle's evaporative/purge system has become inoperative). Owing to greater heating of the engine fuel and evaporative system on longer trips, running loss emissions continually increase as a function of trip duration until the emissions reach a plateau at a trip duration of about 50 to 60 minutes [1]. Second, operating mode fractions, which are needed by MOBILE5 to estimate emissions rates, can be estimated from the trip duration distribution. Third, the trip duration distribution can be used to predict the vehicle miles of travel (VMT) accumulated on local roads in the region.

The modeling of trip durations in a metropolitan area is of considerable value for the reasons identified above. Trip duration is likely to depend on various factors such as the trip purpose, the time-of-day of the trip start, and other land-use and socio-demographic characteristics of the zone of trip start. In the current report, we formulate and implement a methodology for modeling trip durations using vehicle trip data from household travel surveys and supplementary zonal demographic/land-use data. The implementation is demonstrated in the context of mobile source emissions analysis for the Dallas-Fort Worth area in Texas.

The rest of the report is structured as follows. The next section reviews earlier studies relevant to the subject matter of this report and motivates the research in this report. Section 3 develops the model estimation and application framework. Section 4 focuses on data sources and data assembly procedures. Section 5 presents the empirical results. Section 6 discusses issues related to integrating the trip duration model with travel demand models. The final section concludes the report.

2. LITERATURE REVIEW AND MOTIVATION FOR STUDY

Trip duration distribution is important for estimating running loss emissions, operating mode fractions and VMT on local roads. Correspondingly, we review the state-of-the-art/practice under these three headings: running loss emissions, operating mode fractions and VMT on local roads.

2.1. Running loss emissions

The methodology for estimating running loss emissions differs between MOBILE5 and MOBILE6. In MOBILE5, running loss emissions are modeled as a direct function of the input temperature, fuel volatility, and average speed. The procedure for calculating the running loss emissions entails partitioning the vehicle trip duration into six time duration bins (*i.e.,* less than 10 minutes, 11 to 20 minutes, 21 to 30 minutes, 31 to 40 minutes, 41 to 50 minutes and 51 minutes and longer) and obtaining the proportion of VMT accumulated by trips that fall into each time duration bin (these proportions are referred to as the trip duration activity parameters). Within MOBILE5, the running loss emissions value of an average vehicle trip is calculated as the sum of the product of the emission factors associated with each time duration bin (embedded within MOBILE5) and the corresponding trip duration activity parameter. The product of these average running loss emissions with the number of trips per day represents the running loss emission level. The user has the ability to accept default daily running loss emissions values available within MOBILE5 (developed using default trip-time distributions representing national average conditions), or develop region-specific estimates by specifying a local set of trip duration activity parameters. As a general recommendation, the MOBILE5 manual suggests using area-specific trip duration activity parameters to more accurately estimate running loss emissions.

MOBILE6 advances the state-of-the-art/practice by providing activity parameters for each of 14 time periods in a day and by distinguishing between weekdays and weekends. The default MOBILE6 hourly activity estimates are based on an EPA-survey of 168 vehicles, and are invariant across geographic regions or across trip purpose categories. Thus, as in MOBILE5, EPA recommends the use of locally estimated trip duration activity parameters whenever possible.

In summary, using trip duration activity parameters developed from local data for estimating running loss emissions constitutes an important improvement over using the default values embedded in the MOBILE emissions factor model. In the current report, we present a methodology to develop zone-specific trip duration activity parameters that vary by time-of-day and trip purpose, using a trip duration model estimated from local data.

2.2. Operating mode fractions

Operating mode fractions are an important input to MOBILE5 in estimating mobile source emissions. There are two dimensions associated with operating mode fractions; one is the *start mode* of vehicle trips (cold versus hot), and the second is the *running mode* of vehicle trips (transient versus stabilized). The start mode of trips has been the focus of another report by the authors [2]. Trip duration modeling, the focus of this report, affects the latter dimension of operating mode, *i.e.*, the running mode of trips. To the extent that running mode fractions can be more accurately estimated using a trip duration model estimated from local data, such a model can contribute toward improved mobile source emissions forecasting.

EPA defines the *transient* mode of operation as all vehicle operations before 505 seconds after the start of a trip and the *stabilized* mode as all operations after 505 seconds of a trip. EPA recommends the following default values for running mode fractions: transient (47.9%) and stabilized (52.1%). The practice in most MPOs in the country is to accept these default running mode fractions. However, these default values were developed over twenty years ago and recent research [3] suggests that it may no longer adequately represent overall vehicle emission control performance under current driving conditions. In addition, the default fractions do not vary by trip purpose, time-of-day, or regional land-use and socio-demographic characteristics.

Few studies have attempted to develop locally estimated running mode fractions of trips. Brodtmen and Fuce [4] used field data obtained by direct on-road measurement of engine conditions to develop running mode fractions in New Jersey. Ellis *et al.* [5] analyzed origin-destination data from travel surveys in Alabama to develop aggregate measures of running mode fractions. Frank *et al.* [6] developed transient and stabilized mode fractions based on vehicle trip times, using the Puget Sound Panel Survey. This was one of the earliest studies that employed household-level travel survey information and land-use data for running mode fraction estimation. A study by Chatterjee *et al.* [7] and Venigalla *et al.* [8] used a network-based approach for modeling running modes. In these studies, the elapsed time of vehicles from trip origins was traced during traffic assignment of zone-to-zone trips on highway networks. The proportion of transient and stabilized modes on links were obtained by counting the number of trips assigned on each link that are of duration less than or greater than 505 seconds since their start. Allen and Davies [9] have similarly used the ASSIGN module of MINUTP, a commercially available planning model, to determine trips operating in transient mode for the southern New Jersey area.

A limitation of the studies reviewed above is that they compute of a single set of running mode fractions for an entire state (or for aggregate regions within a state), and for various times-of-day and trip purposes. In this report, we estimate a trip duration model using local data from a metropolitan region and present a methodology to use this estimated model to develop running mode fractions that vary by zone within the region, time-of-day and trip purpose. In addition, our methodology allows for the estimation of running mode fractions for travel on local roads.

2.3. VMT on local roads

Local roads are usually not included in the travel demand model networks used by most MPOs, and hence the travel speeds and volumes required to calculate the VMT on local links are unavailable from travel demand models. Many MPOs simply calculate the VMT on local roads as a percentage (typically about 10%) of the VMT on all other roads, and use it in developing their emissions inventories. This method is rather *ad hoc* in nature, and can result in VMT estimates quite different from the actual values. A few MPOs model the VMT on local roads by attributing the local-road VMT separately to interzonal and intrazonal trips (see Chatterjee *et al.* 1997, page 101, [10] for a discussion). The VMT attributed to interzonal trips is modeled as the product of interzonal trips assigned (during traffic assignment) on centroidal link connectors and the coded length of the connectors. The VMT on local roads attributed to *intrazonal* travel is estimated as the product of the total intrazonal trips for each zone (obtained from the origin-destination trip-interchange matrices at the end of trip distribution), and an average intrazonal trip length parameter. This trip length parameter is typically calculated as a function of the total area of the zone. While this method is a substantial improvement over using a percentage of VMT on non-local roads, it is still limited by the restrictive nature of variation of the intrazonal trip length parameter. In particular, the intrazonal trip length (and, therefore, local VMT) does not vary by trip purpose, time-of-day and zonal spatial attributes (other than zonal area). Our study develops the intrazonal trip length as a function of time-of-day, purpose and zonal attributes. We accomplish this by estimating a trip duration model, and then multiplying the predicted intrazonal trip duration with an estimate of average speed on local links (it is more straightforward to develop a direct model of intrazonal trip length, but most household surveys collect data only on trip duration and not trip length).

In the next section, we present the model framework for the estimation and application of the trip duration model.

3. MODEL FRAMEWORK

The modeling approach in the report uses vehicle trip data from household travel surveys and zonal demographic/land-use data from supplementary data sources. The approach involves developing the distribution of the duration of trips using a log-linear regression model. The use of a log-linear form for trip duration guarantees the non-negativity of trip time in application of the models.

The application step of the model predicts the distributions of the duration of trips for each traffic analysis zone in a metropolitan region, and for each combination of time-of-day and trip purpose. An important characteristic of the proposed method is the ease with which the estimated models from vehicle trip data can be immediately applied to obtain zonal-level trip-time distributions.

In the next section, we present the details of model estimation. In the subsequent section, we discuss the applications of the estimated model.

3.1. Model estimation

Let q be the index for vehicle trip, t be the index for time-of-day, and i be the index for activity purpose prior to the trip. Define ω_{qti} to be a dummy variable taking the value 1 if vehicle trip q occurs in time-period t with trip purpose i, and 0 otherwise; define δ_{qz} as another dummy variable taking the value 1 if vehicle trip q originates in zone z, and 0 otherwise. Define I_q to be a variable that takes the value 1 if vehicle trip q is intrazonal, and 0 otherwise. Let x_z be a vector of zonal attributes.

We assume the trip duration to be log-normally distributed in the population of trips, and develop a linear regression model for the duration as a function of trip purpose, time-of-day and land-use and socio-demographic characteristics of the zone of trip origin.

Let d_q be the duration of vehicle trip q. Then, we write the log-linear regression equation for the trip duration as:

$$\ln(d_q) = \eta + \sum_{t,i} \alpha_{ti}\omega_{qti} + \lambda\left(\sum_z \delta_{qz} x_z\right) + I_q\left(\chi + \sum_{t,i} \zeta_{ti}\omega_{qti} + \rho\left(\sum_z \xi_{qz} x_z\right)\right) + \varepsilon_q, \varepsilon_q \sim N[0,\sigma^2] \quad \text{(Eq 1)}$$

In this equation, η is the generic constant to be estimated, α_{ti} (*t=1, 2,…T; i=1,2,…I*) are scalars to be estimated and λ is a vector of parameters also to be estimated. χ, ζ_{ti}, ρ and ξ_{qz} are similar to η, α_{ti}, λ and δ_{qz} respectively, but are introduced specific to intrazonal trips (note that I_q takes the value 1 if vehicle trip q is an intrazonal trip, and 0 otherwise). ε_q is a normally distributed random error term introduced to complete the econometric specification.

In Equation 1 above, we have not allowed interactions between zonal attributes and time-of-day/trip purpose combinations; however, this is purely for notational convenience and for ease in presentation of the model application step. Such interactions can be included within the model structure without any additional conceptual or estimation complexity. Similarly, the notation structure implies full interactions of time and trip purpose, though more restrictive structures such as single dimensional effects without interaction can be imposed by appropriately constraining the α_{ti} and ζ_{ti} scalars across the different time/trip purpose combinations.

The reader will note that the inclusion of the intrazonal dummy variable, and interactions of this variable with exogenous variables, allows us to accommodate separate trip duration distributions for intrazonal vehicle trips and interzonal vehicle trips.

The model from Equation 1 can be estimated using any commercially available software with a linear regression module. Data assembly issues for estimating the model are discussed in Section 4.

3.2. Model application

This section discusses the application of the estimated model in the previous section. The subsequent three sections present the methodology to obtain 1) trip duration activity parameters for estimating running loss emissions, 2) running mode fractions of trips for use in MOBILE5, and 3) estimates of VMT for travel on local roads.

3.2.1. Trip duration activity parameters for running loss emissions

The trip duration distribution for any zone in the study area by time-period and trip purpose can be predicted in a straightforward manner after estimation of Equation 1. The (log) trip duration distribution of interzonal vehicle trips in time *t* for trip purpose *i* from zone *z* may be written as:

$$\ln\left(d_{tiz}^{a}\right) \sim N\left[\eta + \alpha_{ti} + \lambda x_{z}, \sigma^{2}\right] = N\left[\Delta_{tiz}^{a}, \sigma^{2}\right] \qquad \text{(Eq 2)}$$

The mean Δ_{tiz}^{a} and variance σ^{2} of this distribution can be estimated from the parameter estimates obtained in the estimation stage. The corresponding distribution of intrazonal vehicle trips in time *t* for trip purpose *i* in zone *z* may be written as:

$$\ln\left(d_{tiz}^{l}\right) \sim N\left[\eta + \alpha_{ti} + \lambda x_{z} + \chi + \zeta_{ti} + \rho x_{z}, \sigma^{2}\right] = N\left[\Delta_{tiz}^{l}, \sigma^{2}\right] \qquad \text{(Eq 3)}$$

The objective in our effort is to obtain the fraction of VMT accrued by trips in each of six trip duration-bins (as needed by MOBILE) for each zone, and for each trip purpose and time-of-day combination. Let k be an index for time-bin ($k=1,2,..,6$), and let k be bounded by the continuous trip duration value of m_{k-1} to the left and by m_k to the right. Let V^k be the average speed of trips in time-bin k and let ϑ_z be the fraction of trips originating in zone z which are intrazonal[1]. Then, the fraction of VMT accrued by interzonal trips in time-bin k for in time t for trip purpose i originating in zone z ($FVMT_{tiz}^{ka}$) can be obtained as:

$$FVMT_{tiz}^{ka} = \frac{L_{tiz}^{ka} * \Omega_{tiz}^{ka} * V^k}{VMT_{tiz}^{a}} \qquad \text{(Eq 4)}$$

where,

$$L_{tiz}^{ka} = \Phi\left(\frac{\ln(m^k) - \Delta_{tiz}^a}{\sigma}\right) - \Phi\left(\frac{\ln(m^{k-1}) - \Delta_{tiz}^a}{\sigma}\right) \qquad \text{(Eq 5)}$$

$$\Omega_{tiz}^{ka} = \exp\left[\Delta_{tiz}^a + \sigma \frac{\phi\left(\frac{\ln(m_{k-1}) - \Delta_{tiz}^a}{\sigma}\right) - \phi\left(\frac{\ln(m_k) - \Delta_{tiz}^a}{\sigma}\right)}{\Phi\left(\frac{\ln(m_k) - \Delta_{tiz}^a}{\sigma}\right) - \Phi\left(\frac{\ln(m_{k-1}) - \Delta_{tiz}^a}{\sigma}\right)}\right] \qquad \text{(Eq 6)}$$

$$VMT_{tiz}^{a} = \sum_k L_{tiz}^{ka} * \Omega_{tiz}^{ka} * V^k \qquad \text{(Eq 7)}$$

In the above equation structure, L_{tiz}^{ka} represents the proportion of interzonal trips in time period t for trip purpose i originating in zone z, that fall in trip-duration bin k. Ω_{tiz}^{ka} represents the mean trip duration of interzonal trips in time period t for trip purpose i

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[1] V^k may be obtained from local metropolitan area data or using the following national default values obtained from the 1995 National Personal Transportation Study (NPTS) data: 18.96 mph (for trips of duration 0-10 mins), 20.80 mph (for trips of duration 11-20 mins), 26.40 mph (for trips of duration 21-30 mins), 29.14 mph (for trips of duration 31-40 mins), 33.60 mph (for trips of duration 41-50 mins) and 45.30 mph (for trips of duration greater than 51 mins). ϑ_z represents the fraction of intrazonal trips originating from zone z and can be obtained from the sample used for estimation. If the sample data does not support evaluation of ϑ_z for all zones, ϑ_z can be determined from the zone-to-zone origin-destination trip interchanges matrices obtained at the end of the trip distribution step in the travel demand modeling process.

originating in zone *z*, that fall in trip-duration bin *k.* The product of L_{tiz}^{ka} and Ω_{tiz}^{ka} with V^k represents the VMT accrued by interzonal trips in time period *t* for trip purpose *i* originating in zone *z*, that fall in trip-duration bin *k.* VMT_{tiz}^{a} represents the total VMT accrued by interzonal trips in time period *t* for trip purpose *i* originating in zone *z*, and is obtained by summing the VMT across all trip duration bins. Then, the proportion of VMT accrued by interzonal trips in time-bin *k* for time *t* for trip purpose *i* originating in zone *z*, $FVMT_{tiz}^{ka}$, is obtained as shown in Equation 4, by dividing the VMT accrued by trips in time-bin *k* by the total VMT.

The fraction of VMT accrued by intrazonal trips in time-bin *k* for in time *t* for trip purpose *i* originating in zone *z* ($FVMT_{tiz}^{kl}$), can be obtained by substituting Δ_{tiz}^{l} instead of Δ_{tiz}^{a} in Equations 4 through 7.

Finally, the fraction of VMT accrued by all trips in each time-bin *k* for trip purpose *i* originating in zone *z* during time *t*, ($FVMT_{tiz}^{k}$), may be written as:

$$FVMT_{tiz}^{k} = \vartheta_z * FVMT_{tiz}^{kl} + \left(1 - \vartheta_z\right) * FVMT_{tiz}^{ka} \qquad \text{(Eq 8)}$$

3.2.2. Running mode fractions for MOBILE5

This section presents the method to obtain the proportion of transient and stabilized trips required as an input to MOBILE5. We begin by discussing the approach for interzonal trips; the approach is identical for intrazonal trips, with appropriate replacements to reflect the mean and variance of intrazonal trips.

Let the assumed speed of vehicles be v. Let the mean of the distribution of trips of duration less than 8.42 minutes (505 seconds) occurring in time-period *t* with trip purpose *i* in zone *z* be μ_{tiz}^{1a} and let the corresponding mean of the distribution of trips of duration greater than 8.42 minutes be μ_{tiz}^{2a} (μ_{tiz}^{1a} and μ_{tiz}^{2a} represent the means of the right- and left-truncated normal distributions of trip duration respectively).

We obtain the analytical expression for μ_{tiz}^{1} (see Greene [11]) as:

$$\mu_{tiz}^{1a} = \Delta_{tiz}^{a} - \sigma \frac{\phi\left(\frac{\ln(8.42) - \Delta_{tiz}^{a}}{\sigma}\right)}{\Phi\left(\frac{\ln(8.42) - \Delta_{tiz}^{a}}{\sigma}\right)} \qquad \text{(Eq 9)}$$

The VMT in transient mode accumulated by trips of duration less than (or equal to) 8.42 minutes, is given by $(\mu_{tiz}^{1a}) * (v) *$ [Number of trips of duration ≤ 8.42 min]. Trips of duration greater than 8.42 minutes are in the transient mode for the first 8.42 minutes of their operation. The VMT in transient mode accumulated by such trips is given by $\ln(8.42) * (v) *$ [Number of trips of duration > 8.42 min]. Therefore, the total VMT in *transient* mode is:

$$\left[(\mu_{tiz}^{1a}) * (v) * \Phi\left(\frac{\ln(8.42) - \Delta_{tiz}^{a}}{\sigma}\right) + \ln(8.42) * (v) * \left[1 - \Phi\left(\frac{\ln(8.42) - \Delta_{tiz}^{a}}{\sigma}\right)\right]\right] *$$

[Total number of trips] (Eq 10)

The mean duration of trips of duration greater than 8.42 minutes, μ_{tiz}^{2a}, is given by:

$$\mu_{tiz}^{2a} = \Delta_{tiz}^{a} + \sigma \frac{\phi\left(\frac{\ln(8.42) - \Delta_{tiz}^{a}}{\sigma}\right)}{1 - \Phi\left(\frac{\ln(8.42) - \Delta_{tiz}^{a}}{\sigma}\right)} \qquad \text{(Eq 11)}$$

The VMT in stabilized mode in time t for trip purpose i originating in zone z can be obtained as $[\mu_{tiz}^{2a} - \ln(8.42)] * (v) *$ [Number of trips of duration > 8.42 min]. Therefore, the expression for the VMT accumulated in the *stabilized* mode is:

$$[\mu_{tiz}^{2a} - \ln(8.42)] * (v) * \left[1 - \Phi\left(\frac{\ln(8.42) - \Delta_{tiz}^{a}}{\sigma}\right)\right] * \text{ [Total number of trips]} \qquad \text{(Eq 12)}$$

The fraction of VMT in transient and stabilized modes can be obtained from Equations 6 and 8 for any zone z, and for any combination of time period t and trip purpose i, after substituting the estimated values of Δ_{tiz}^{a} and σ from the estimation stage. Thus, a distinguishing characteristic of the proposed method is the straightforward manner in which model parameters estimated from vehicle trip data can be applied to obtain zonal-level estimates of vehicle running mode fractions.

The reader will also note that the running mode fractions for intrazonal trips may be readily obtained using Equations 9 through 12 after replacing Δ^{a}_{tiz} with Δ^{l}_{tiz}, and using an average speed for v corresponding to local roads (we assume v = 20 mph for local roads).

3.2.3. VMT on local roads

As noted in the model estimation section, the intrazonal nature of a trip is captured through the interaction effects of I_q with exogenous determinants of trip duration. The logarithm of the trip duration of intrazonal trips in time *t* with trip purpose *i* in zone *z* is normally distributed, as shown in Equation 3. It follows from this that the trip duration distribution of intrazonal vehicle trips in time *t* with trip purpose *i* in zone *z* is log-normally distributed with a mean θ^{l}_{tiz} and variance λ^{l}_{tiz} given by the following expressions (see Johnson and Kotz [12]):

$$\theta^{l}_{tiz} = \exp\left(\Delta^{l}_{tiz} + \sigma^2/2\right) \qquad \text{(Eq 13)}$$

$$\lambda^{l} = \exp\left(2 * \Delta^{l}_{tiz} + \sigma^2\right)\left[\exp\left(\sigma^2\right) - 1\right] \qquad \text{(Eq 14)}$$

The mean trip length of intrazonal trips is the product of θ^{l}_{tiz} and the average speed on local roads (which we assume to be 20 mph). The total VMT on local roads due to intrazonal travel can next be estimated as the product of the mean intrazonal trip length and the total intrazonal vehicle trips (obtained from the trip-distribution step in the travel demand modeling process). Our methodology accommodates the variation in intra-zonal VMT on local roads with time-of-day, trip purpose and zonal socio-demographic and land-use characteristics through the variation of the average intrazonal trip duration with these characteristics.

To summarize, this third section of the report has presented the formulation for a model of trip duration as a function of trip purpose, time-of-day and zonal/trip attributes. It also has proposed methods that can be implemented after estimation of the trip duration model to predict the following: a) running loss emissions, b) running mode fractions and c) local road VMT. The outputs from the application of the model are the above three mobile source related parameters for each time-of-day and trip purpose combination, and for each zone in a planning area. The model framework can be integrated within a broader travel demand-air quality forecasting procedure in a straightforward fashion, as discussed in Section 6.

4. DATA PREPARATION

4.1. Data sources

The data used in the empirical analysis were drawn from two sources: the 1996 Activity Survey conducted in the Dallas-Fort Worth (D-FW) area and the zonal land use and demographics characteristics file for the D-FW area. These data sources were obtained from the North Central Texas Council of Governments (NCTCOG).

4.2. Sample formation

Several data assembly steps were involved in developing the sample. First, we converted the raw composite (travel and non-travel) activity file into a corresponding person-trip file. Second, we identified person-trips that were pursued using a motorized vehicle owned by the household. Third, we translated the person-trip file into a corresponding vehicle trip file, which provided the sequence of trips made by each vehicle in the household. In this process, we extracted and retained information on the time-of-day of each vehicle trip start, the traffic analysis process (TAP) zone of trip start location and trip-end location and the purpose of activity being pursued at the origin and destination of the trip. Fourth, we aggregated the TSZ-level (traffic survey zone, or TSZ, level; there are about 5,000 TSZs in the D-FW planning area) land-use and demographic characteristics to the TAP-level, and appended this information to each vehicle trip start based on the TAP in which the trip start occurs. Finally, we conducted several screening and consistency checks on the resulting data set from the previous steps (a flow chart of this screening process is available from the authors). As part of this screening process, we eliminated observations that had missing data on departure times, activity purposes, and/or on the TAP location of the vehicle trip start.

The final sample used for analysis includes 19,455 vehicle trip observations. Of these, 2,940 trips (15.1%) are intrazonal.

5. EMPIRICAL ANALYSIS

5.1. Sample description

The dependent variable of interest in our analysis is the time duration of trips. The trip duration for interzonal trips varies from a minimum of 1 minute to a maximum of 660 minutes (11 hours). The mean trip duration is about 21 minutes with a standard-deviation of about 24 minutes. The trip duration for intrazonal trips varies from a minimum of 1 minute to a maximum of 210 minutes (3.5 hours). The mean trip duration for such trips is about 11 minutes with a standard-deviation of about 18 minutes.

Three types of variables were considered to explain trip duration. These are: a) trip purpose variables indicating the purpose of the trip, b) time-of-day variables identifying the time of trip start, and c) zonal and trip attributes. Interactions among these three sets of variables were also considered. In the description below, we briefly highlight some of the characteristics of these sets of variables.

Trip purpose was characterized by two dimensions: whether or not the trip was produced at home (home-based versus non-home based trips) and the purpose at the attraction-end of the trip (*i.e.*, whether the attraction-end activity is work, school, social/recreational, shopping, personal business or other). Of the 19,455 trips, 14,294 (73.5%) are home-based. The distribution of intrazonal and interzonal trips by trip purpose is presented in Table 1. The trips are rather evenly spread across all attraction-end activity purposes for both intrazonal and interzonal trips. The percentage of work trips is higher for interzonal trips than for intrazonal trips, while the percentage of other trips is higher for intrazonal trips than for interzonal trips.

The time-of-day of variables were associated with one of the following six time-periods: morning (midnight-6:30 a.m.), a.m. peak (6:30 a.m.-9:00 a.m.), a.m. off-peak (9:00 a.m.-noon), p.m. off-peak (noon-4:00 p.m.), p.m. peak (4:00 p.m.-6:30 p.m.), and evening (6:30 p.m.-midnight). The time-periods for the a.m. and p.m. peaks were based on the peak periods definitions employed by the transportation department of the NCTCOG in the D-

FW area. The times for the off-peak periods were determined by splitting the remaining blocks of time at noon and midnight. The distribution of intrazonal and interzonal trips by time-of-day is presented in Table 2. In general, the distributions by time-of-day are rather similar across intrazonal and interzonal trips.

Several zonal (TAP-level) land-use and demographic characteristics were considered in our analysis. Of these, the following zonal attributes were significant determinants of trip duration: total zonal area, zonal household density, acreage in retail facilities, acreage in office space, number of people in service employment, acreage in institutional facilities (like hospitals, churches *etc*.), acreage in manufacturing and warehousing facilities, zonal median income and presence of airports or airport-related infrastructure in the zone. The trip-related attribute included in the model was an indicator variable for whether or not the trip was intrazonal.

The final model specification of trip duration was obtained by systematically eliminating statistically insignificant variables and combining those found to have similar and comparable effects in terms of magnitude and significance. The empirical results for the estimated model are discussed in the following section.

5.2. Results of trip duration model

The empirical results for the log-linear regression model are presented in Table 3. The table provides the estimated values of $\eta, \alpha_{ti}, \lambda, \chi$ and ζ_{ti} ($t=1, 2,\ldots T;\ i=1,2,\ldots I$) in Equation 1.

The trip purpose variables were included with non-home based trips as the base category (for home-based versus non-home based trips) and with work as the base attraction-end activity. The results indicate that home-based trips tend to be significantly longer than non-home based trips. Social/recreational trips are longer than work trips while shopping and other trips tend to be significantly shorter than work trips. These results are consistent with overall observed trends in household travel behavior (see Hu and Young [13]).

The time-of-day variables are introduced with the evening period being the base. The morning and a.m.-peak periods are combined into a single period because of very few trips in these periods (see Table 1). The time-of-day variables are statistically significant and intuitive in the direction of their effect on trip duration. In general, peak-period trips are longer in duration, followed by mid-day trips. The interaction effects of time-of-day and trip purpose suggest that non-work trips are of shorter duration during the peak periods relative to work trips, and social/recreational trips are of shorter duration than trips of other purposes during the off-peak periods.

Several zonal and other trip attributes have a statistically significant effect on trip duration. We classify these attributes into three categories: zonal size-related variables, zonal non-size related variables, and trip-related variables. The effects of these three sets of variables are discussed in the next three paragraphs.

Among the size-related variables, a larger total area of a zone, in general, increases the duration of trips originating in that zone. This is particularly the case if the zone has a high acreage in office space, perhaps reflecting the long return-home trips from work, and long non-work trips due to lower non-work activity opportunities from such zones. Similarly, trips originating in zones with a high number of people in service employment and with large acreage in manufacturing facilities also have longer durations. These may reflect congestion effects. On the other hand, acreage in retail and institutional facilities have a negative effect on trips duration, possibly due to greater accessibility to shopping and service-related activities in zones with higher retail and institutional acreage.

The zonal non-size related variables indicate smaller trip durations in zones with high household density and with high household income. However, trips originating in zones with an airport have a longer duration. This latter effect may reflect increased congestion effects on roadways in zones with airport-related infrastructure.

Finally, intrazonal trips are significantly shorter in duration than interzonal trips, especially during the p.m. peak, though the magnitude of this effect is less for shopping and social/recreational trip purposes.

6. INTEGRATION WITH TRAVEL DEMAND MODELS

This section discusses issues related to integrating the trip duration model presented in this report with existing travel demand models.

Existing travel demand models may be based on an activity approach or on a trip approach. Activity-based travel demand models focus on the activities that people pursue, as a function of the locations and attributes of potential destinations, the state of the transportation network, and the personal and household characteristics of individuals [14]. If such an approach is adopted in travel analysis, the activity stops made by individuals are explicitly modeled as a function of origin and destination activity categories, time-of-day and zone of origin. Thus, information on trip purpose, time of trip start and attributes of the zone of trip origin are readily available for all trips. Integration of the trip duration model developed in this report within this framework is rather straightforward.

If a trip-based travel demand modeling framework is used, the trip duration model in the current report can be directly applied if the MPO develops zone-to-zone origin-destination interchanges for the disaggregate trip purpose and time-of-day categories identified in this report. However, most MPOs use more aggregate classes of trip purpose and time periods (typically home-based work, home-based other and non-home based trip purposes, and peak versus off-peak time periods). In this situation, the trip duration model can be used after post-processing the aggregate origin-destination trip interchanges matrix to reflect the disaggregate classifications employed here. Factors obtained from travel surveys can be applied to achieve this post-classification. In Tables 4, 5 and 6, we present such factors developed for the D-FW region.

7. CONCLUSIONS

The modeling of trip durations in a metropolitan area is important for the following reasons: First, trip duration activity parameters used by the MOBILE emissions factor model to estimate running loss emissions can be developed from the trip duration distribution. Second, the trip duration distribution provides information for estimating operating mode fractions, which are needed by MOBILE5 to estimate emissions rates. Third, the trip duration distribution can be used to predict the vehicle miles of travel (VMT) accumulated on local roads in the region.

Trip duration is likely to depend on various factors such as trip purpose, time-of-day of the trip start, and other land-use and socio-demographic characteristics of the zone of trip origin. In the current report, we formulate and implement a methodology for modeling trip durations as a function of these characteristics, using vehicle trip data from household travel surveys and supplementary zonal demographic/land-use data. The approach involves developing the distribution of the duration of trips using a log-linear regression model. The modeling framework is implemented in the context of mobile source emissions analysis for the Dallas-Fort Worth area of Texas.

The proposed model contributes significantly toward improved mobile source emissions forecasting by systematically developing area-specific estimates of running loss emissions, running mode fractions and VMT on local roads. A distinguishing characteristic of the methodology is the straightforward manner in which model parameters estimated from vehicle trip data can be applied to obtain zonal-level trip duration distributions. The model can be integrated easily within various travel demand-air quality modeling frameworks.

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Table 1. Distribution of trips by trip purpose

Trip Purpose	Percentage distribution for	
	Intrazonal	Interzonal
Home	73.4%	73.5%
Non-Home	26.6%	26.5%
Work	12.0%	22.3%
School	3.2%	2.4%
Social/Recreational	10.2%	11.3%
Shopping	6.9%	6.3%
Personal Business	40.0%	41.5%
Other	27.8%	16.2%

Table 2. Distribution of trips by time-of-day

Time-of-day of trip start	Percentage distribution for	
	Intrazonal	Interzonal
morning	1.5%	4.0%
a.m. peak	22.4%	21.0%
a.m. off-peak	13.5%	12.8%
p.m. off-peak	28.4%	23.5%
p.m. peak	19.0%	22.6%
evening	15.1%	16.1%

Table 3. Empirical results for trip duration model

Variable	*Coefficient*	*t-statistic*
Constant	1.087	76.81
Trip purpose		
"Non-Home" purpose is base		
Home	0.093	16.16
"Work" purpose is base		
School	0.018	1.56
Social/Recreational	0.054	5.11
Shopping	-0.130	-16.07
Other	-0.093	-13.07
Time-of-day variables ("evening" period is base)		
morning - a.m. peak/p.m. peak	0.193	15.57
a.m. off-peak/p.m. off-peak	0.076	6.75
Time-of-day and trip purpose interaction effects		
morning - a.m. peak/p.m. peak x Non-Work	-0.067	-11.23
a.m. off-peak/p.m. off-peak x Social/Recreational	-0.113	-8.94
Zonal and trip-related attributes		
Zonal size-related variables		
Zonal Area x 10^{-6}	5.401	2.56
Zonal Acreage in Office Space x 10^{-3}	1.030	3.85
Number of People in Service Employment x 10^{-5}	1.102	9.75
Zonal Acreage in Manufacturing Facilities x 10^{-4}	3.001	5.19
Zonal Acreage in Retail Facilities x 10^{-4}	-9.847	-4.82
Zonal Acreage in Institutional Facilities x 10^{-4}	-4.434	-2.54
Zonal non-size-related variables		
Zonal Household Density x 10^{-4}	-7.008	-4.42
Median Income of Zone x 10^{-6}	-1.124	-6.55
Presence of an airport or airport-related infrastructure	2.327	2.56
Trip-related variables		
Intrazonal trip	-0.337	-33.95
Intrazonal p.m. peak trip	-0.082	-5.08
Intrazonal Shopping, Social/Recreational trip	0.069	6.12
Number of observations	19455	
Regression sums of squares	516.24	
Residual sums of squares	2085.69	
R^2	0.198	
Adjusted R^2	0.198	

Table 4. Cross-classification of home-based work trips by time-of-day

Trip purpose	Time-of-day of trip start					
	morning	a.m. peak	a.m. off-peak	p.m. off-peak	p.m. peak	evening
Home-based work	9.02%	34.97%	6.33%	13.56%	26.57%	9.54%

Table 5. Cross-classification of home-based other trips by trip purpose and time-of-day

Trip purpose	Time-of-day of trip start					
	morning	a.m. peak	a.m. off-peak	p.m. off-peak	p.m. peak	evening
Home-based school	0.66%	1.15%	2.42%	3.69%	4.57%	9.67%
Home-based social/recreational	0.12%	0.71%	3.07%	5.15%	4.93%	4.73%
Home-based shopping	0.29%	1.89%	4.41%	4.84%	3.78%	2.53%
Home-based personal business	0.64%	10.22%	2.20%	6.73%	6.09%	5.69%
Home-based other	0.06%	3.35%	0.94%	2.90%	1.66%	0.90%

Table 6. Cross-classification of non-home based trips by trip purpose and time-of-day

Trip purpose	Time-of-day of trip start					
	morning	a.m. peak	a.m. off-peak	p.m. off-peak	p.m. peak	evening
Non-home based work	0.02%	1.10%	3.53%	4.05%	1.05%	0.27%
Non-home based school	0.00%	0.12%	0.21%	0.48%	0.41%	0.04%
Non-home based social/recreational	0.16%	0.76%	4.36%	10.13%	2.34%	2.56%
Non-home based shopping	0.06%	0.41%	2.07%	4.84%	3.60%	2.19%
Non-home based personal business	0.14%	1.72%	6.67%	10.11%	5.27%	2.13%
Non-home based other	0.41%	8.35%	3.08%	7.63%	6.68%	3.04%