Emission Model Sensitivity Analysis: The Value of Smart Phone Weight-Mile Tax Truck Data

Katherine E. Bell [1*], Sirisha M. Kothuri [1], Miguel A. Figliozzi [1]

[1]*Department of Civil and Environmental Engineering, Portland State University, Portland, OR*

Abstract

This research serves to evaluate the potential use of a system developed by the Oregon Department of Transportation (ODOT) for emission estimates. The data collection system developed by ODOT – Truck Road Use Electronics (TRUE) – includes a smart phone application with a Global Positioning System (GPS) device and microprocessor. Previous research with the TRUE data served to demonstrate its use for important ancillary applications such as highly accurate trip generation rates and mobility performance measures. In addition, it was shown that the TRUE data has strong potential use for safety, accessibility and connectivity, system condition and environmental stewardship performance measures. This new research builds on that past work and evaluates the potential use of the TRUE data for emissions estimates that take into account truck type details, truck weight and detailed speed profiles. A sensitivity analysis using the U.S. Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator 2010b (MOVES2010b) is performed in order to understand the level of error that might be encountered when such detailed data are not available. The impact of grade on emissions estimates is also considered. Results indicate that TRUE data in integration with Oregon Department of Transportation (ODOT) weight-mile tax (WMT) data will greatly improve the accuracy of emissions estimations at the project and regional level.

Keywords: urban freight, emissions, road charging, modelling, GPS, transport sector externalities

1. Introduction

Reliable freight transportation is particularly important to Oregon due to its geographic location. According to *The Oregon Freight Plan* (Cambridge Systematics, Inc., 2011), Oregon is the ninth most trade-dependent state in the U.S. and is expected to see significant increases in freight flows in the future. This trade dependency comes with unwanted side effects, particularly in urban centers, such as congestion, travel unreliability, environmental and health concerns, and increased transport costs (Wheeler and Figliozzi, 2011) (Figliozzi, et al., 2011). In this regard, recent research stresses the importance of freight performance measures and associated data management processes in sustaining an effective transportation planning system (McMullen and Monsere, 2010) (NCFRP, 2011). Freight data that might be used for such performance measures

[*] Corresponding author: Katherine E. Bell (bell2@pdx.edu)

is usually incomplete, scarce and expensive to collect. However, a unique and highly promising data source is available through a system recently developed by ODOT to simplify its weight-mile tax (WMT) collection.

Oregon is one of the few states in the U.S. that currently charge a commercial truck WMT. The current WMT applies to, and is the primary form of taxation for, trucks over 26,000 lbs. In February 2010, the ODOT Motor Carrier Transportation Division (MCTD) implemented a pilot project for the use of Truck Road Use Electronics (TRUE) (ODOT, n.d.). The TRUE system provides an automated process for WMT collection that reduces the administrative burden on trucking firms and ODOT while also reducing reporting errors and tax avoidance. The system includes a smart phone application with a Global Positioning System (GPS) device and microprocessor. The application can be uploaded to the phones of truck drivers in order to track miles traveled; the data is then sent electronically to ODOT to produce the company's WMT "invoice" which can be paid online. The TRUE application has been developed with the intention that it can be used in the form of a smartphone application on a wide variety of hardware so that in the future, trucking companies could use a wireless device of their choosing (ODOT, n.d.).

Oregon is ideally suited for statewide implementation of a system such as TRUE as it already has an established WMT system. Under Oregon law, motor carriers operate as a regulated industry and are required to report miles traveled. However, Oregon Revised Statute (ORS) (Oregon State Legislature, 2011) 825.517 specifies that data collected for the WMT system is not public record. Therefore, the privacy of motor carriers using the TRUE system is protected by Oregon law. Under Oregon's existing WMT system, companies self-report the miles traveled in Oregon for each axle combination; taxes are paid on a monthly or quarterly basis. Truck drivers must maintain log books to track hours of service, truck combination, number of axles, and trip odometer readings and then calculate their WMT. The administration of WMT in Oregon has traditionally been very paperwork intensive. In 2003 ODOT implemented Oregon Trucking Online (OTO) in order to simplify WMT collection (ODOT, n.d.). In recent years, approximately 25% of WMT payments were made online through OTO. TRUE provides opportunity for further regulatory streamlining and reduction of paperwork associated with WMT, thus reducing the time and resources required (of both the state and truck companies) to calculate, pay and process WMT.

Due to its level of disaggregation and its potential to differentiate between vehicle and commodity types, the TRUE dataset has many unique characteristics and enormous advantages over truck GPS data used in past research. Data collected through TRUE not only provides commercial truck origin-destination, space/time coordinates and trajectories, but also weight class, truck type and commodity codes when combined with Weigh-in-Motion (WIM) data. Such information can be used to understand the intricacies of freight transportation and to better inform decision makers. Previous research (Bell and Figliozzi, 2013) with the TRUE data served to demonstrate its use for important ancillary applications such as highly accurate trip generation rates and mobility performance measures. In addition, it was shown that the TRUE data has strong potential use for safety, accessibility and connectivity, system condition and environmental stewardship performance measures. This new research builds on that past work and evaluates the potential use of the TRUE data for emissions estimates that take into account truck type details, truck weight and detailed speed profiles. A sensitivity analysis using the U.S. Environmental Protection Agency's (EPA) Motor Vehicle

Emission Simulator 2010b (MOVES2010b) is performed in order to understand the level of error that might be encountered when such detailed data are not available. The impact of grade on emissions estimates is also considered. Results indicate that TRUE data in combination with ODOT WMT data will greatly improve the accuracy of emissions estimations at the project and regional level.

2. Literature Review and Background

In a survey conducted in 2010, the second most frequently stated transportation policy goal (listed by 32 of the U.S. State DOT websites reviewed) was environmental stewardship (McMullen and Monsere, 2010). Performance measures used by state DOTs to measure the success of environmental stewardship include emissions of:

- volatile organic compounds (VOC)
- nitrous oxides (NOx)
- carbon monoxide (CO)
- ozone (O3)
- particulate matter (PM)
- greenhouse gasses (GHG)

Many of these emissions are known to be causes of health concerns. NOx and PM emissions are of particular concern in densely populated metropolitan cities. NOx is linked to respiratory problems; particulate matter (PM_{10}) and ultrafine particulate matter ($PM_{2.5}$) are linked to cancer and heart problems (Singh, 2008).

Many of the emission types measured are affected by sources other than the transportation or freight sectors and the tools used for measurement are typically not transportation or freight specific. If data is available, emissions estimates can be calculated using data related to traffic, speed, and fuel type (McMullen and Monsere, 2010). Research has shown that major increases in transportation emission rates can be caused by: speeds outside the 30 to 60 mph range, changes in speed from peak hour congestion, heavy vehicle loads, increases in grade (Wheeler and Figliozzi, 2011), vehicle age and poor maintenance of vehicles (Singh, 2012). The US EPA Office of Transportation and Air Quality (OTAQ) provides a variety of models to estimate emissions (USEPA, 2012). However, MOVES2010b is EPA's current official model for estimating air pollution emissions from mobile sources (i.e., cars, trucks, motorcycles). In the future the program will also model nonroad emissions (i.e., ships, locomotives, aircraft). The simulator covers a broad range of pollutants including GHG, select mobile source air toxics (MSAT), and criteria pollutants. According to Oregon's Freight Performance Measures report (McMullen and Monsere, 2010), MOVES is the "best tool for quantifying criteria pollutant and precursor emissions". MOVES2010b, released in June 2012, and MOVES2010a, released in August 2010, are minor updates to MOVES 2010 (USEPA, 2012). The U.S. Federal Highway Administration (FHWA) performed a sensitivity analysis in 2009 using MOVES (Houk, 2009). The results indicated that emissions estimates from MOVES are very sensitive to speed, vehicle types and vehicle age. In 2010, Choi et al (Choi, et al., 2010) completed research to analyze the sensitivity of MOVES emission estimates to changes in temperature and humidity. Results emphasize the importance of obtaining accurate local meteorological data when using MOVES.

More recently, a 'regional level' sensitivity analysis was performed by the FHWA in an effort to highlight areas where air quality practitioners should focus to refine their MOVES model inputs. This study focused on running emissions process for of CO, PM2.5, NOx and VOCs. The variables considered and input ranges used included:

- Temperature (-40F to 120F)
- Humidity (0 to 100%)
- Ramp Fraction (0 to 0.20)
- Analysis Year (2010 to 2050)
- Age Distribution (three groups)
- Average Speed Distribution

The results were generally consistent with those from the aforementioned sensitivity analyses. Emissions rates were found to be very sensitive to changes in speed, vehicle type, age, humidity and temperature.

NCFRP Report 10, which focuses on performance measurements specific to the freight sector, addresses the concern of rising GHG emissions. According to the report, national targets for other types of large/heavy-duty truck emissions are on track, but the truck industry's GHG emissions continue to rise. Unlike with other types of emissions, methods to reduce vehicular GHG emissions have not yet been developed (NCFRP, 2011). ODOT recognizes the need to address this concern and has developed the Greenhouse Gas Statewide Transportation Emissions Planning (GreenSTEP) Model to assess the effects of policies and other factors (i.e., gas prices) on GHG emissions from the transportation sectors (ODOT, 2011). GreenSTEP is a sketch level planning tool used to model estimates and determine forecasts for vehicle ownership, vehicle travel, fuel consumption, and GHG emissions. GreenSTEP is currently focused on emissions from household and light duty commercial vehicles (i.e., autos, SUVs, pickup trucks, vans); modeling of GHG emissions from freight is still under development. According to ODOT reports (ODOT, 2011), estimates from GreenSTEP could further be used to assess the relative equity of different policy proposals for different road users.

3. Truck Road Use Electronics (TRUE)

3.1 Data Description and Preliminary Analysis

Data available for this research consists of 172,385 records from the TRUE pilot study for the entire year of 2011. Seventeen trucks subject to Oregon's WMT were equipped with a TRUE device for the pilot study. These trucks represent three different carriers. The TRUE devices were configured to collect the latitude and longitude locations of each vehicle every five minutes. The travel of the pilot study vehicles was tracked through seven U.S. states and three regions in Canada; however, the geographic limitations of future data collection would be dependent on the degree of partnership with the private sector. Through trips using Oregon's highway network still have to pay WMT, and hence may be included in future datasets if companies adopt the system. The intention of the pilot project was to test the TRUE system, potential applications, and associated data processes rather than to provide data that is representative of the entire population of trucks in Oregon. Likewise, regardless of the sample rate of this pilot study, the methodologies proposed could be applied to the statewide implementation of the TRUE system. According to the "GPS_ACCURACY" field of the data, the accuracy of the GPS readings range from three to 840 feet. Figure 1 provides a histogram of the cumulative distribution of the values from the "GPS Accuracy" field for readings up to 80 feet (the small number of records with accuracy worse than 80 feet are not included in the figure). An accuracy of within ten feet was recorded for over fifty percent of the GPS records; within twenty feet for over 75%; within 53 feet for over 95%; and within 79 feet for over 98%.

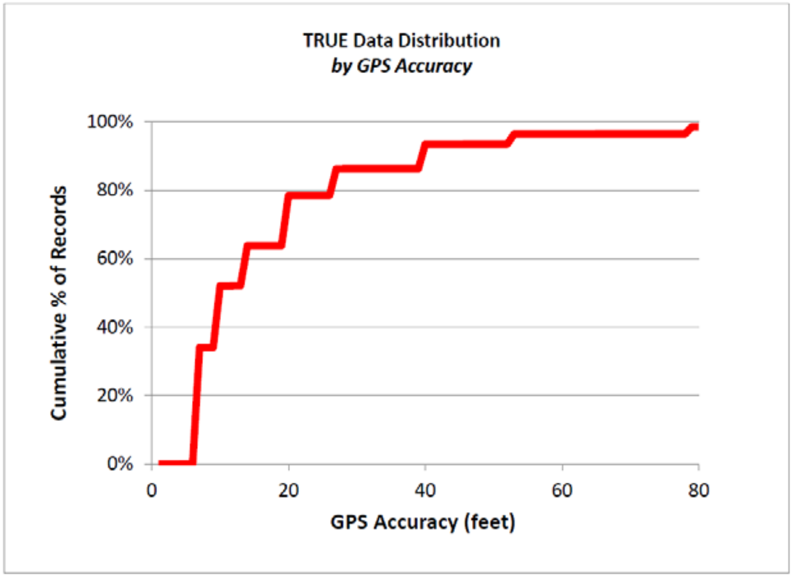

Figure 1: Distribution of GPS Accuracies

In addition to the GPS records, the data set available for this research includes corresponding weigh-in-motion (WIM) station records for the pilot project vehicles. Figure 2 provides a schematic showing data fields available through the TRUE dataset and the WIM dataset. Using the "DEVICE_ID","BASE_PLATE", "WAYPOINT_TIME" and "WEI_PSTDATETIME" fields, a TRUE record can be found for each WIM record that is: a) from the same truck as the WIM record; and b) closest in time to the WIM. This process can be completed using RStudio. Preliminary review of the TRUE records and corresponding WIM data indicates that the TRUE records from the pilot project represent vehicles of nine different weight classes (ranging from 46,000 lbs. to 105,500 lbs.), with four to eight axles, and three different commodity codes ("empty", "machinery" and "other"). Further applications available through the linkage of these two datasets are described in (Bell and Figliozzi, 2013).

	FIELD	DESCRIPTION
TRUE GPS RECORDS	ROW_ID	System generated row id
	DEVICE_ID	Unique identifier for each smartphone
	LATITUDE	Latitude of device
	LONGITUDE	Longitude of device
	WAYPOINT_TIME	Timestamp of GPS record
	WEIGHT_CLASS	Weight class of vehicle
	AXLES	Axle count of vehicle
	RECEIVED_TIME	Timestamp waypoint was received by server
	LOCATION_NAME	General location name
	PERMIT_NO	Permit number vehicle is operating under
	GPS_ACCURACY	Accuracy of the GPS fix in meters
	ODOMETER	Most recent odometer entry by driver

	FIELD	DESCRIPTION
DEVICE / TRUCK	DEVICE_ID	Unique identifier for each smartphone
	ACCT_NO	Oregon taxpayer id
	CARRIER_UNIT_ID	Unit number of vehicle assigned by carrier
	PHONE_NO	Phone number of mobile device
	BASE_PLATE	Base plate of vehicle
	BASE_ST	Base state of vehicle
	ASSIGNED_DATE	Timestamp mobile device was assigned to carrier

	FIELD	DESCRIPTION
WEIGH-IN-MOTION RECORDS	WEI_ID	System generated row id
	WEI_AUTHNO	Oregon taxpayer id
	WEI_BASEPLATE	Base plate of vehicle
	WEI_BASESTATE	Base state of vehicle
	WEI_PSTDATETIME	Timestamp of event in PST
	WEI_SCALENO	Scale number
	WEI_LOCATION	Location
	WEI_CARRIERNAME	Carrier name
	WEI_VTID	Vehicle class id (VEHTYPE)
	WEI_VCID	Vehicle type id (VEHCLASS)
	WEI_AXLES	Vehicle axle count
	WEI_COMMODITY	Commodity code of what vehicle is hauling
	WEI_GROSS	Gross weight
	WEI_WGT[1:12]	Weight at axle [1:12]
	WEI_DIRECTION	Direction of lane
	WEI_VEHICLE	Calculated value, based on class and type ids

Figure 2: TRUE Data Fields

The TRUE data in its "raw" format provides values for the fields listed in the top and middle sections of Figure 2 including latitude and longitude coordinates with corresponding timestamps, weight class and axle count of vehicles, and GPS record accuracy. The initial data processing steps consisted of formatting including conversion of timestamp values to database readable time format. Further data processing using a combination of Excel, "RStudio" and ArcView GIS allows disaggregation of the dataset to levels that have not been possible with previous datasets. Figure 3 is a GIS plot providing an example of the ability to disaggregate the dataset by weight class. As an example, this plot shows 2011 record counts from the TRUE pilot project for the 1030 (GVW up to 103,000 lbs) weight class. Similar disaggregation by commodity type, vehicle type, axle count, gross weight and axle weight is also possible. Additional data processing required for emissions applications is discussed in the proceeding sections of the paper.

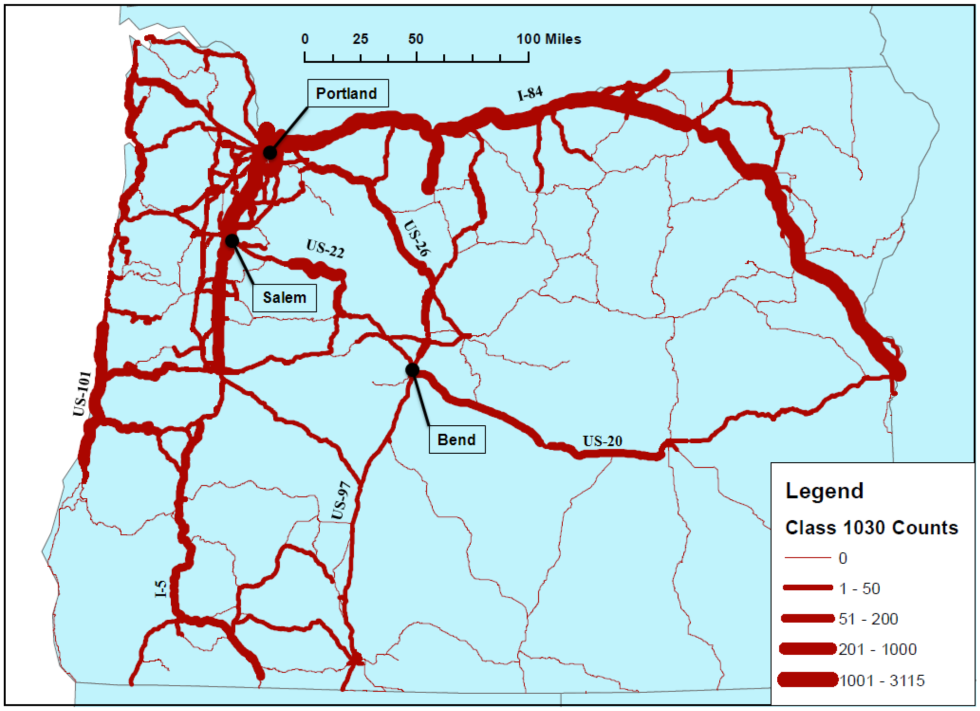

Figure 3: GPS Record Count for 1030 Weight Class

3.2 Speed Estimates

Of the freight performance measures typically used at a national and state level, those associated with mobility have received the most attention with regards to freight GPS data research (Bell and Figliozzi, 2013), specifically in relation to travel time reliability and congestion at bottlenecks (McMullen and Monsere, 2010). Emission rates are highly correlated with travel speeds and traffic conditions (Figliozzi, 2011). Hence, accurate environmental performance measures related to emissions are greatly dependent on the availability of detailed mobility performance measures.

Previous research (Bell and Figliozzi, 2013) with the TRUE data presented a methodology to estimate space-mean speeds using the TRUE data. In order to assess the accuracy of the space-mean speed calculated from the TRUE data the calculated space-mean speeds were compared to speeds from the Portland, Oregon Regional Archive Listing (PORTAL) – the official Archived Data User Service (ADUS) for the Portland metropolitan area. Speed measurements available through PORTAL are based on inductive-loop detector data from nearly 600 sensors located throughout the Portland metropolitan area on I-5, I-205, I-405, I-84, OR-207 and US-26 (Li and Bertini, 2010).

As can be seen in Figure 4, over fifty percent of the space-mean speeds calculated from the TRUE dataset were within eight percent of the speeds calculated from PORTAL; all of the TRUE speeds were within 25% of the PORTAL speeds. The absolute values of the speed differences averaged nine percent; however, the TRUE speeds were, on average, approximately seven percent (3.65 mph) less than the PORTAL speeds. The speed differences had a standard deviation of eight percent (4.41 mph). Eighty percent of the TRUE speeds were less than the PORTAL speeds. This is likely because PORTAL speeds are an aggregation of speed measurements from a variety of vehicle types (i.e., mostly passenger vehicles that typically travel at a faster speed than trucks). The TRUE speeds ranged from 21% (12.4 mph) less than the PORTAL speeds to ten percent (5.6 mph) greater than the PORTAL speeds.

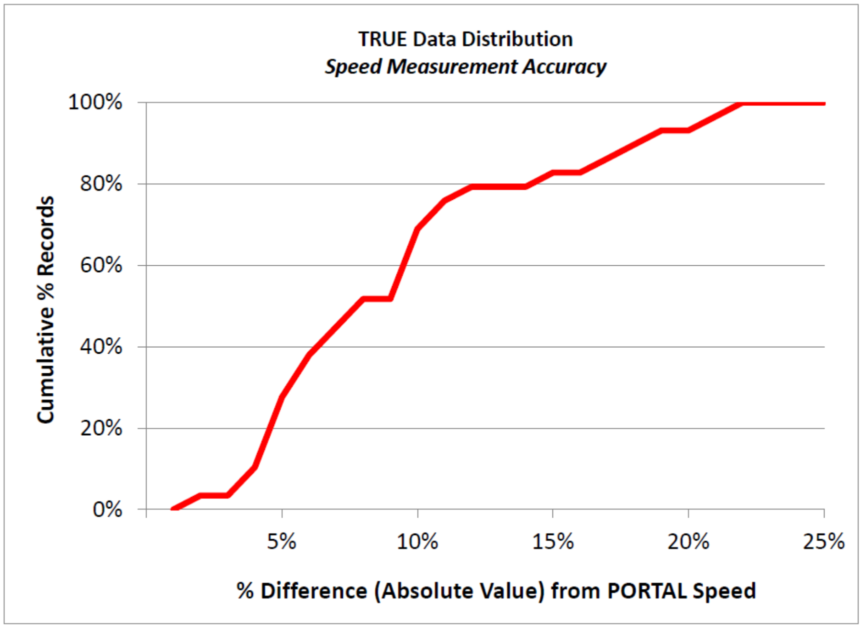

Figure 4: Distribution of GPS Accuracies

The results of a paired sample t-test indicate that at the 0.01 significance level there is sufficient evidence from the tested sample to conclude that the difference between the PORTAL speeds and those calculated from the TRUE data is significant. This conclusion is consistent with the findings of previous research on the same freeway segments in the Portland region (Wheeler and Figliozzi, 2011); previous research results indicated that speeds estimated from loop detectors were generally greater than speeds estimated by truck GPS data provided by the American Transportation Research Institute (ATRI).

4. MOVES Emission Estimates

4.1 Framework

This section describes the MOVES2010b input parameters and potential output as it relates to the analysis presented in this paper. Table 1 provides a description of the model inputs (USEPA, 2012); those selected for the model presented in this paper are highlighted and in bold.

Table 1: MOVES Inputs

Variable	*Inputs*	*Description*
Scale	National	The 'Scale' chosen for a MOVES model depends on the level of detail that will be represented by the model inputs. The 'Project' level analysis allows the user to model the emissions effects of a single roadway link.
	County	
	Project	
Calculation Type	**Emission Rates**	Emission Rates' - the rate at which emissions occur (i.e., the mass per unit of activity) is calculated. 'Inventory' - MOVES will calculate the quantity of emissions used within a user-defined region and time span.
	Inventory	
Roadtype	Off-Network	'Urban Restricted Access' roads are typically used to model freeways and interstates.
	Rural	
	Rural Restricted Access	
	Rural Unrestricted Access	
	Urban Restricted	
	Urban Unrestricted	
Sourcetype	**Single-Unit Short Haul**	Indicates what type of vehicle is modeled by MOVES. Both light-duty and heavy-duty vehicles can be modeled. Vehicle options range from motorcycle (light-duty) to intercity bus (heavy-duty). Sourcetype categories relevant to this paper are included in the 'Inputs' column of this table.
	Single-Unit Long Haul	
	Combination Short Haul	
	Combination Long Haul	

In addition to the inputs presented in Table 1 the user can also define the geographic area from which default inputs (i.e., meteorological data) are based. Time period for which the model will be run must also be defined in terms of years, months, days (i.e., weekend, weekday) and start and end hours. The level of aggregation of results with respect to time can also be set in terms of year, month, day or hour. Other relevant input parameters include vehicle age and pollutant process (i.e., running exhaust, start exhaust, brakewear).

Depending on the information available for each roadway link modeled, a MOVES user may enter data for a vehicle operating mode distribution, drive schedule, average speed and/or speed profile (USEPA, 2012). When an average link speed is used as an input, MOVES uses a default drive schedule (with an average speed as close as available to the average speed given) to model the driving behavior (changes in speed) across the link.

Weights can be input into the "SourceMass" field in the input database. A truck type's default weight is equal to the average GVW for that truck type based on a variety of data sources analyzed by EPA. The input values, "rollingTerm" and "rotatingTerm", are a function of vehicle weight. MOVES does not automatically update these values when the weight input is changed. Equations for these coefficients are based on study by V.A. Petrushov (Petrushov, 1997).

4.2 MOVES Sensitivity Analysis

The sensitivity analysis described herein focuses primarily on the truck type, weight, speed, and grade variables. Analysis was performed to examine changes in emissions from variations of these parameters in isolation. The impact of each parameter on emissions is evaluated by determining the percent change in emissions resulting from an incremental change in each parameter. Unlike previous truck GPS data sources, truck type and weight data is available through the TRUE system (in combination with WIM data). Further, the accuracy of speed estimates from the TRUE system has been shown through comparison to estimates loop detector data and other truck GPS data. As such, this sensitivity analysis serves to evaluate the potential of the TRUE data to improve the accuracy of emission estimations at the project and regional level.

Method

A 'Project' level analysis was performed in order to analyze the sensitivity of emissions estimates at the link (highway segment) level. All parameters were kept constant except truck type, weight, speed and grade variables. Four heavy-duty diesel vehicles were included in the analysis: Single-Unit Short-Haul (SUSH), Single-Unit Long-Haul (SULH), Combination Short-Haul (CSH) and Combination Long-Haul (CLH). These vehicle types were chosen as they are consistent with the vehicle types applicable to the TRUE system. However, the bulk of this analysis focuses on the CSH vehicles as this was the most common vehicle type in the TRUE pilot study.

Emissions considered include Atmospheric CO2, CO2e, NOx, PM10 and PM2.5. Preliminary analysis indicated that Atmospheric CO2 typically follows similar trends to CO2e; PM2.5 typically follows similar trends to PM10. As such, the results for CO2 and PM2.5 emissions are not included in this report. As an initial effort to examine MOVES' sensitivity to the variables being considered, this analysis focused on emission changes related only to 'running exhaust' emissions. In addition, the 'Age' variable was held constant at zero (i.e., new trucks) for all analyses. Further input values used for the analysis are presented Table 2.

Table 2: Sensitivity Analysis Inputs

Variable	*Input*	*Description*
Geographic Bounds	Multnomah County, OR	This is the geographic area containing the majority of records from the TRUE pilot project.
Fuel Type	Default	The default fuel type for Multnomah County, OR (provided by the MOVES Default Database) was used.
Roadtype	Restricted Access	This roadtype was used in order to represent the freeway/interstate condition.
Year	2011	2011 is the year from which the TRUE data is available.
Month	May	May was chosen as it is typically a month of fairly mild (average) weather conditions in the state of Oregon.
Days	Weekdays	These are the times at which a high percentage of TRUE records on Interstate-5 (the primary north-south interstate in Oregon) have timestamps.
Time	4-5pm	

In order to determine the appropriate weight ranges to model for each truck type, weight measurements from ODOT's WIM data were analyzed. A histogram representing the total truck weight versus frequency was plotted for each truck type using records spanning several years. An example is provided in Figure 5 for Type 17 (7 axles) truck. The two peak record frequencies exhibited in these histograms indicate two different weight situations (Figliozzi, et al., 2000): 1) an empty vehicle (tractor and semitrailer weight) at the first peak frequency (i.e., approximately 36,000 lbs in Figure 5) and 2) the truck weight limit at the second peak frequency (i.e., approximately 92,000 lbs in Figure 5). Records between these two zones represent trucks that are partially loaded or that carry a full load of lighter commodities.

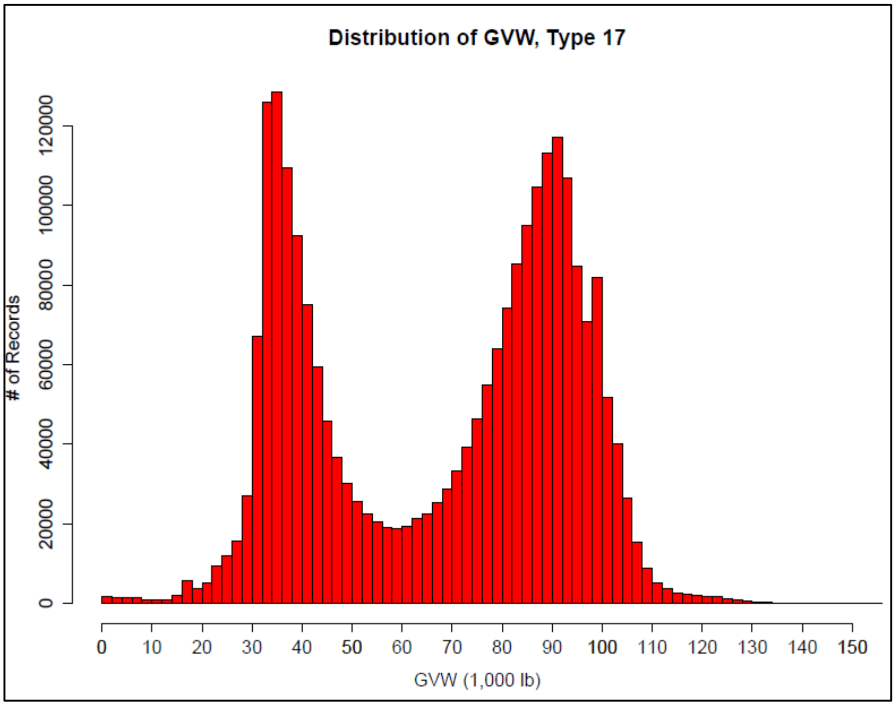

Figure 5: Distribution of GVW, Type 17

Table 3 presents the assumptions that were made regarding which ODOT vehicle classes (ODOT, n.d.) were considered 'Single Unit' and 'Combination' truck types. Weight distribution histograms (such as that in Figure 5) were created using ODOT WIM data for each of the vehicle classes listed in Table 3 in order to determine appropriate weight distribution assumptions for modeling the Combination Truck Type in MOVES. Based on an analysis of the weight distribution histograms, 'empty weights' for the Combination truck type range from 33,000 to 40,000 lbs. 'Full weights' for the Combination truck type range from 73,000 to 98,000 lbs. As such, weight variations from 20,000 to 110,000 lb at 10,000 lb increments were analyzed from CSH trucks. The weight distribution histograms for the Single Unit truck types each displayed only one peak weight distribution. Classes 8, 9 and 10 displayed peaks at 12,000 lbs, 28,000 lbs and 49,000 lbs. As such, emissions estimates were performed for SUSH trucks at 12,000, 28,000 and 49,000 lbs.

Table 3: Vehicle Classification

Truck Type	*ODOT Vehicle Class*
Single Unit	8
	9
	10
Combination	11
	15
	17
	18

Grade variations were analyzed from -6 to 6% at 1% increments. Average Speed entries of 10 to 70 mph in 5 mph increments were used as these are the speeds at which MOVES drive schedules are available for the truck types considered.

Results

CO2e emission rates (g/mi) from Combination trucks were generally found to be higher than those for Single-Unit trucks at the same weight. However, as shown in Figure 6 the slope for the % change in CO2e emissions with speed was much steeper for Single-Unit trucks compared to Combination trucks.This indicates for CO2e emissions, Single-Unit trucks are more sensitive to changes in speed than Combination vehicles.

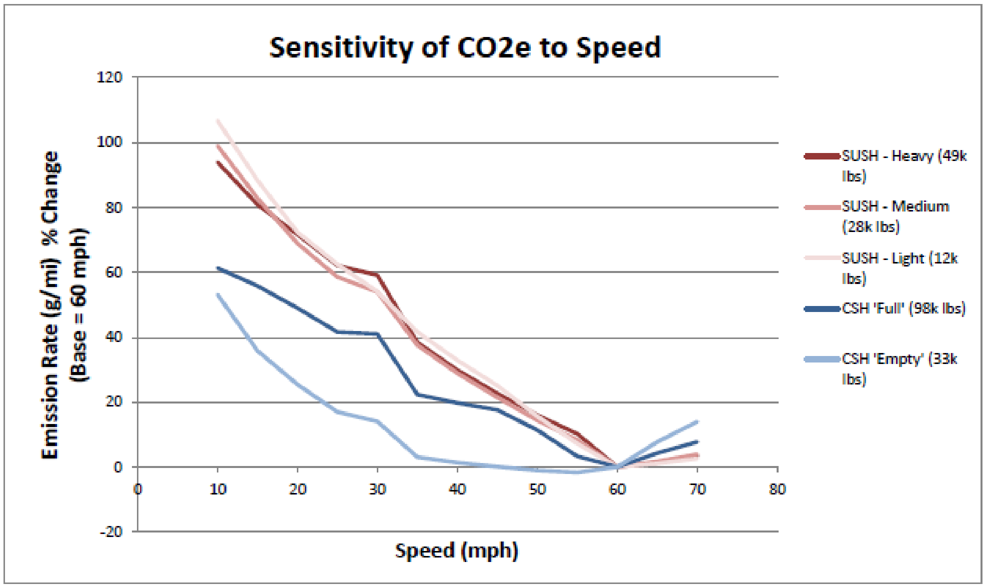

Figure 6: Sensitivity of CO2e to Speed

Percent change in CO2e, NOx and PM10 emissions in relation to incremental changes in speed are illustrated in Figure 7 for CSH vehicles. The percent change in emissions was calculated using 60 mph as the base. Trends are provided for a weight in the CSH 'empty' spectrum (33,000 lbs) as well as a weight in the 'full' spectrum (98,000 lbs). As shown in Figure 7, emissions of each type of pollutant analyzed generally increase with decreases in speed. The slope for PM10 emissions is generally steeper than those for other emissions, indicating that this pollutant is more sensitive to speed differences than the others. The graph also indicates that emissions from full vehicles are generally more sensitive to decreases in speed (congestion) than those from empty vehicles. The variation in slope with change in speed is likely related to the variation in drive schedule patterns (driving behavior) associated with different average speeds.

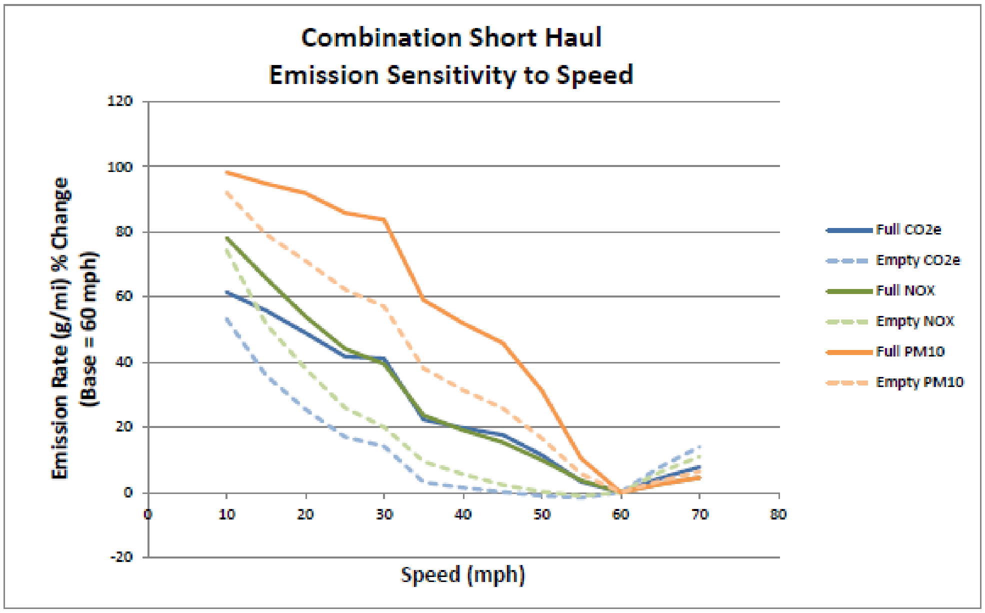

Figure 7: Combination Short Haul Emission Sensitivity to Speed and Weight – Grade 0%

Sensitivity also varies by grade. Full vehicles are generally more sensitive to changes in grade than empty vehicles across the pollutants analyzed. As indicated in Figure 8, the sensitivity of empty vehicles is generally constant with changes in grade; however, results indicate that full vehicles become less sensitive to changes in grade with increasing grades. For both full and empty vehicles, CO2e is the most sensitive to changes in grade.

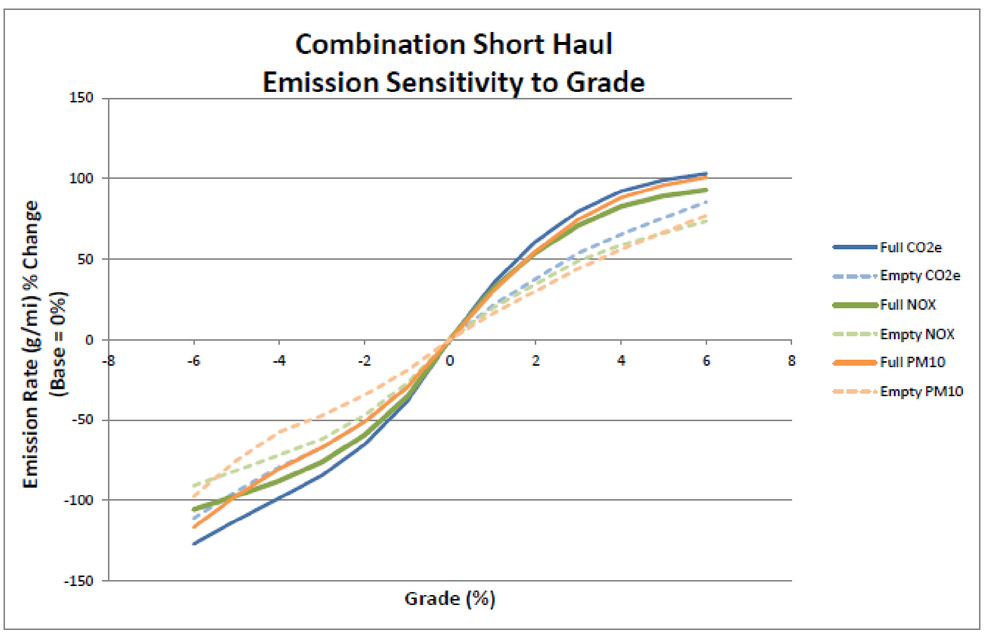

Figure 8: Combination Short Haul Emission Sensitivity to Grade and Weight – Speed 60 mph

Figure 9 represents the sensitivity of emissions from CSH vehicles with change in weight. Results indicate that vehicles are more sensitive to changes in weight at slow speeds. CO2e and PM10 have similar sensitivities to weight; CO2e and PM10 are more sensitive to changes in weight than NOx. At a constant average speed, the sensitivity of each pollutant remains fairly constant across changes in weight.

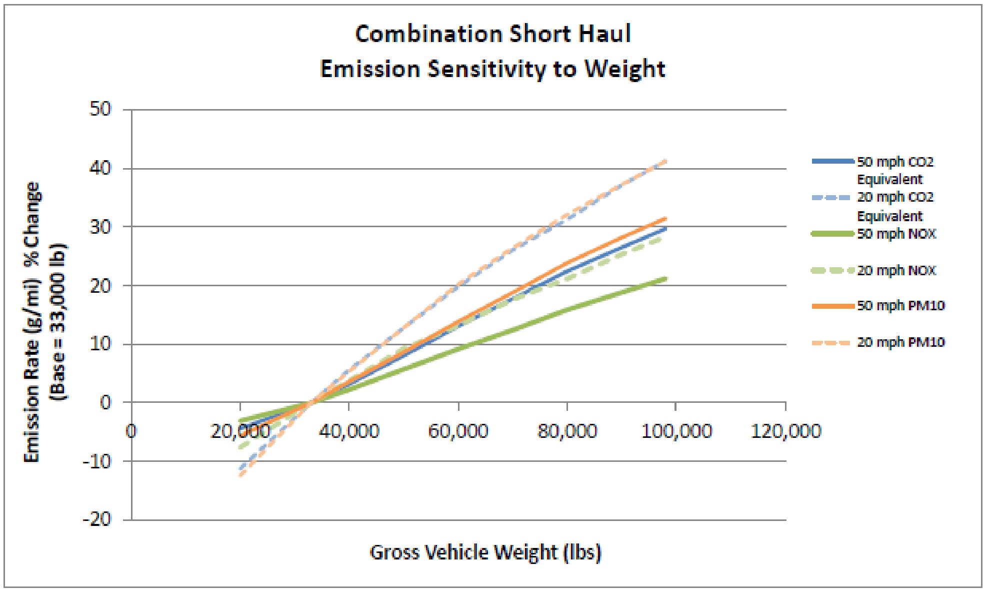

Figure 9: Combination Short Haul Emission Sensitivity to Weight and Speed – Grade 0%

Table 4 provides a summary of the sensitivity analysis. The most sensitive scenarios (based on range of emission rates) are highlighted for each Parameter-Pollutant-Range combination. CO2e emissions are the most sensitive to grade changes; PM10 emissions are the most sensitive to speed changes. CO2e is the most sensitive to weight changes in congested conditions.

Table 4: Sensitivity Analysis Summary

				% Change from Base					
Variable	Base	Range	Constant	Empty			Full		
				CO2e	NOx	PM10	CO2e	NOx	PM10
Speed (mph)	60	10 to 70	0% grade	-2 to 53	-1 to 74	0 to 92	0 to 61	0 to 78	0 to 98
Grade (%)	0%	-6 to 6	60 mph	-134 to 105	-109 to 95	-115 to 101	-124 to 87	-102 to 73	-104 to 78
Variable	**Base**	**Range**	**Constant**	**Congested (20 mph)**			**Free Flow (60 mph)**		
Weight (lb)	33,000 (Empty)	20,000 to 110,000	0% grade	-11 to 47	-8 to 32	-12 to 46	0 to 21	0 to 15	0 to 21

5. TRUE-MOVES Emission Estimates

EPA currently requires that organizations use the "best data available" when creating air quality models; however, requirements are likely to become more stringent as better data becomes available. Although previous research had limited success with the use of commercial truck GPS data for planning and modeling purposes, the TRUE data has an advantage in its level of disaggregation and its ability to differentiate between vehicle types. The methodology employed by Wheeler and Figliozzi (Wheeler and Figliozzi, 2011) provides an example of the successful use of truck GPS data in MOVES. However, the TRUE data (in combination with WIM data) provides opportunity to enhance the accuracy of MOVES estimates by incorporating vehicle weight and speed profile estimates more representative of actual conditions. A framework for future emissions estimates with the TRUE data is presented in Figure 10. Additional emissions beyond those analyzed in this paper are listed.

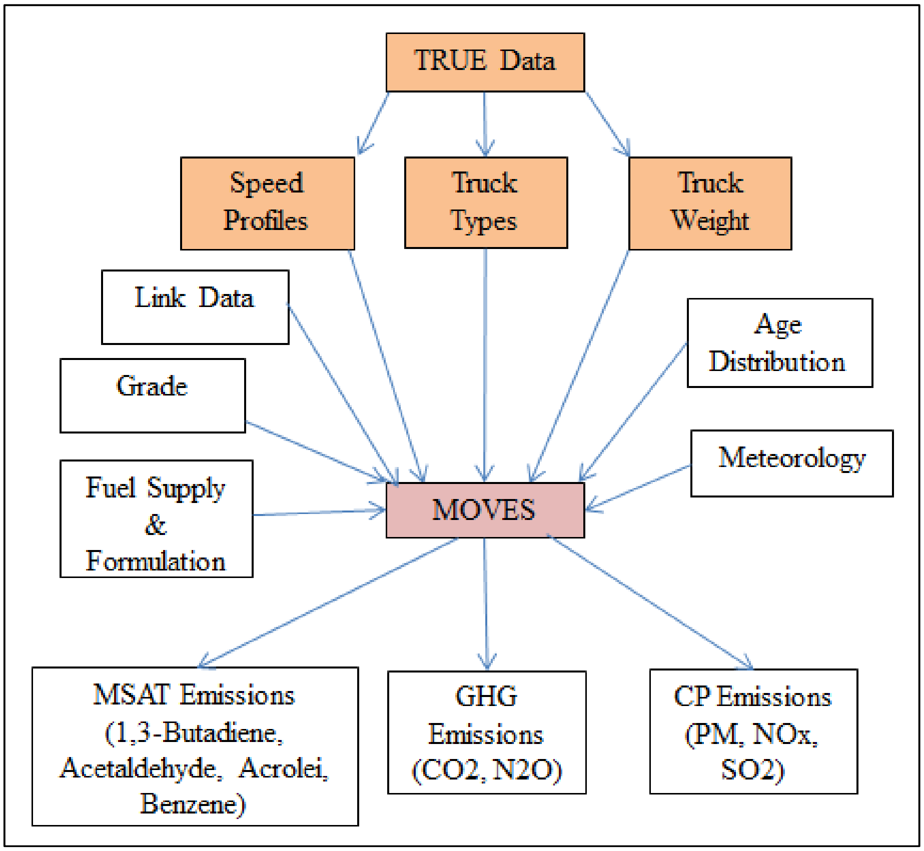

Figure 10: MOVES Emission Estimations and Sensitivity Analysis

As an initial analysis, emission estimates were performed using TRUE GPS records from one CSH truck trip on an approximately thirty mile segment of northbound interstate-5 just north of the metropolitan area of Portland, Oregon. The records used are from a weekday trip in the hour of 4 to 5pm. The truck's TRUE GPS records were integrated with the applicable WIM records in order to determine the weight value input for MOVES. Other inputs used were consistent with those described in the 'MOVES Sensitivity Analysis' section of this paper. Table 5 presents a comparison of emissions estimates obtained when using the average speed (and associated default drive schedule from MOVES) for this trip compared to those obtained when using the trip's speed profile. Results indicate that the emissions estimates obtained from MOVES using the TRUE average speed and associated default drive schedules overestimated emission quantities. PM emissions were most sensitive to the change in speed input method; NOx emissions were least sensitive.

Table 5: MOVES Emission Estimates Using TRUE Data

Pollutant	*Using TRUE Speed Profile (g/mi)*	*Using TRUE Average Speed (g/mi)*	*% Difference*
CO2	1555	1764	-13.4
CO2 Equivalent	1556	1765	-13.4
NOx	0.97	1.05	-8.5
PM10	0.016	0.018	-14.7
PM2.5	0.015	0.018	-14.7

Previous research (Wheeler and Figliozzi, 2011) used truck GPS data to obtain emissions estimates in MOVES for the same northbound segment of interstate-5 that is analyzed in Table 5. Subsequently a methodology was presented to estimate the cost effects of such emissions. The analysis presented in Table 5 could be repeated for other truck trips represented by the records from the TRUE pilot project. The results of the analysis could then be compared to those from the analysis performed by Wheeler and Figliozzi (Wheeler and Figliozzi, 2011) for the same highway segment in order to further understand the impact of the more detailed truck data available through TRUE. Similarly, such an analysis would allow a more robust understanding of the impact of detailed speed profiles on emissions estimates in comparison to average speed values and the associated default drive schedules in MOVES.

6. Conclusions and Future Research

The impact of the selected MOVES input parameters on CO, NOx and PM emissions were examined by comparing the percent change in emissions to base input values. The results demonstrate that speed, grade and weight can have substantial impact on MOVES' estimates of emissions.CO2 emissions were the most sensitive to grade changes; PM emissions were the most sensitive to speed changes. CO2 was the most sensitive to weight changes in congested conditions.The results of the analysis indicate the value of the detailed weight and speed data available through TRUE. In the future, the accuracy of emission estimates using the TRUE data could be further enhanced through the use of more accurate inputs for parameters for other variables such as age distribution and Inspection and Maintenance (I/M) program.

According to ODOT reports (ODOT, 2011), estimates from ODOT's GreenSTEP model could further be used to assess the relative equity of different policy proposals for different road users. As of October 2011, ODOT's GreenSTEP focused on emissions from household and light duty commercial vehicles (i.e., autos, SUVs, pickup trucks, vans); modeling of GHG emissions from freight is still under development. Given that commercial vehicle emissions are greatly dependent on vehicle weight and speed, emissions estimates from the TRUE data (in combination with WIM data) would be highly valuable in further developing the freight portion of GreenSTEP.

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