A PRELIMINARY STUDY: APPLICATIONS OF SMART PHONE TRUCK DATA TO DEVELOP FREIGHT PERFORMANCE MEASURES AND SUPPORT TRANSPORTATION PLANNING

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ABSTRACT

Oregon is one of the few states that currently charge a commercial Vehicle Miles Traveled (VMT) tax. This research serves to develop ancillary applications for the data of Truck Road Use Electronics (TRUE), a system developed by the Oregon Department of Transportation (ODOT) to simplify VMT tax collection. Specifically, ancillary applications that address the need for freight performance measures, planning and modeling are explored. Previous work related to the use of freight GPS data provides a valuable starting point for this research. However, the TRUE data has an advantage over data used in previous research due to its level of disaggregation and its potential to differentiate between vehicle types. This paper will provide a review of relevant past research and associated applications, as well as an outline for both similar and new applications that will be possible for Oregon given the unique characteristics of the TRUE data.

INTRODUCTION

Recent research stresses the importance of freight performance measures and associated data management processes in sustaining an affective transportation planning system (2) (3). Freight data that might be used for such measures 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 their VMT tax collection. Oregon is one of the few states that currently charge a commercial truck VMT tax. In February 2010, the ODOT Motor Carrier Transportation Division (MCTD) conducted a pilot project for the use of TRUE. The TRUE system provides an automated process for VMT tax collection that reduces the administrative burden on trucking firms and ODOT while also reducing reporting errors and tax avoidance. The TRUE system includes a smart phone application with a GPS device and microprocessor. The device tracks VMT and sends electronic data to ODOT to produce the company's VMT "invoice" which can be paid online. Data collected through TRUE provides commercial truck origin-destination, space/time coordinates and trajectories. It could be integrated into existing data sources and disaggregated by vehicle type and trip characteristics. Such information could equip decision makers and stakeholders to better understand the intricacies of truck tours, and to make more cost-effective decisions towards mitigating the consequences of freight transportation.

LITERATURE REVIEW

The work reviewed in this section is not intended to be an exhaustive list, but rather, a representation of relevant research.

Date	Authors	Freight Performance Measures						Oregon	Data Processing & Integration	Freight Planning & Modeling
		Mobility, Congestion & Reliability	System Condition - Maintenance, Preservation & Design	Environment	Safety	Accessibility & Connectivity	Adequacy of Investment in Freight System			
2008	Greaves & Figliozzi	■							■	
2010	Sharman & Roorda	■		■					■	■
2010	Holguin-Veras et al	■		■		■	■		■	■
2011	Wheeler & Figliozzi	■		■				■		
2011	Figliozzi et al	■		■				■	■	
2011	McCormack et al	■		■		■	■		■	■
2012	You & Ritchie	■		■		■	■		■	
2012	FHWA/ATRI	■								
2012	Park, Pierce & Short	■		■						

Table 1 – GPS Data Research Summary

One of the earlier examples of the use of commercial truck GPS data for transportation engineering applications was by Greaves & Figliozzi in 2008 (4). Through this research, a trip identification algorithm was developed to determine the location of trip ends. The algorithm provided a means to differentiate between "genuine" stops and "false positive" stops (those associated with congestion, signals, etc.). Perhaps one of the more progressive uses of GPS data is associated with research on traffic in the New York City Metropolitan Area (6). Holguin-Veras et al used commercial truck GPS data to support the use of financial incentives to shift truck traffic to off-peak hours. In 2011, Wheeler and Figliozzi (7) researched the potential to develop multi-criteria (mobility, cost and emissions) performance measures using truck GPS data. In particular, they confirmed that when used alone loop sensor data underestimates the impact of congestion on travel time reliability. Subsequently, the researchers developed a new methodology and algorithms for combining freight GPS data with loop sensor data to more accurately model congestion. In addition to mobility analysis, the researchers used the results from the recurrent congestion analysis to estimate emissions. The hourly travel time and speed distribution results were used as input into the U.S. Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator (MOVES) 2010 model to estimate average daily freight vehicle emissions per mile. In subsequent research, Figliozzi et al (8) developed travel time reliability algorithms and programming logic for use with truck GPS data. Their methodology served to successfully identify natural segments in corridors (i.e., interstate junctions) and to estimate travel times for each segment identified. Considerable research has also been completed in the state of Washington using commercial truck data from private GPS vendors to develop transportation metrics (9) (10) (11) (12). However, uses for the data were somewhat limited as the data did not differentiate between different truck types. Further, use of the data involved an ongoing cost as it was purchased from an outside provider. As a result, the researchers had "limited success" in developing trip generation rates with the data. It was also determined that improvements in the data would be needed before it could be used for freight transportation modeling.

As cell phone technology has evolved, so too have efforts towards using these devices in a variety of roles in the transportation sector. A common goal of cell phone applications is the estimation of travel times. A report for the Florida Department of Transportation (13) evaluated travel time measurements that were estimated by five companies using cell phone technology. Estimates were evaluated on the basis of methodology, data filtering and aggregation, reliability of data, and other key measures. The study observed good results in free-flow or fast traffic conditions; the study was inconclusive as to the accuracy of estimations in heavy traffic. In 2000, Zhao (14) reviewed the three most common location detecting technologies – stand-alone (dead reckoning), satellite-based (GPS), and terrestrial-based (navigation systems, cell networks). Zhao concluded that the cell-ID-based method has the worst positional accuracy, while assisted GPS has the best. In 2008, Barbeau et al (15) addressed the tradeoff between data accuracy and battery life, data transmission costs, and burden on the server. The researchers introduced two algorithms, a "Critical Point" algorithm and a "Location-Aware State Machine" algorithm, intended to ensure that the GPS devices did not waste battery power obtaining fixes when these would not enhance the quality of the data. Newer uses that involve smartphones provide emissions estimates to the user and subsequent suggestions for changes to driving methods (16) (17) (18).

Among proprietary uses of commercial truck GPS data, a private company, INRIX, anonymously collects GPS data from "probe vehicles", in part through agreements with fleet operators who have GPS devices in their trucks, but also from personal vehicles (individuals who have downloaded the INRIX application to their smart phone) and taxis (19). The data is compiled into average speed profiles for freeways, highways and arterials. INRIX uses the results to provide travel information for a variety of users including individual travelers, commercial fleets and the public sector. Customers from commercial fleets are provided services such as: dispatch services, traffic map overlays, fastest routes, next-day planning and congestion pricing (20). In addition, INRIX provides the majority of the data used to produce the Texas Transportation Institute's Urban Mobility Report (UMR). INRIX also offers a mobile application developer kit (MDK) for smartphone application developers wishing to use INRIX data. On a regional level, projects within Oregon have recently acquired the availability of INRIX GPS data for use on transportation projects (21). A technology with applications similar to ODOT's TRUE system is "Xata Turnpike" (22). Xata Turnpike is a fleet management and optimization technology that provides real time information for commercial trucking companies. Xata charges users a subscription price per vehicle per month. Xata's Electronic On Board Recorder (EOBR) tracks hours of service, data for International Fuel Tax Association (IFTA) and State Mileage forms, actual route driven (with online mapping), auto arrival and departure, engine diagnostics, speed, RPM hard braking, idle time, and fuel efficiency. In 2009, EROAD used a similar device to implement the world's first autonomous Global Navigation Satellite System/Cellular Network (GNSS/CN) tolling system for commercial trucks in New Zealand (23). EROAD uses a secure On Board Unit (OBU) to collect road charges based on vehicle distance, location, mass, time and emissions. EROAD has a web application that monitors logistical information for clients including tracking driver compliance, fuel efficiency, messaging and maintenance.

DATA DESCRIPTION AND PRELIMINARY ANALYSIS

Data available for this research consists of records from the TRUE pilot study for the entire year of 2011. Data was collected for sixteen vehicles belonging to three different carriers, each equipped with a TRUE device. The TRUE devices were configured to collect the latitude and longitude locations of each vehicle every five minutes. The initial data processing steps consisted of simple formatting including conversion of time to MS Excel time format, and computation of distance and elapsed time using the data analysis program, “R”. The data was then imported into ArcView GIS and latitude and longitude readings were converted to X, Y coordinates. According to the data set, the accuracy of the GPS readings from 2011 ranged from six to 315 feet.

Further data processing using a combination of Excel, "R" and ArcView GIS allows disaggregation of the dataset to levels that have not been possible with previous datasets. Figure 1 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 commercial truck weight class. Similar disaggregation by commodity type, vehicle type, axle count, gross weight and axle weight is also possible.

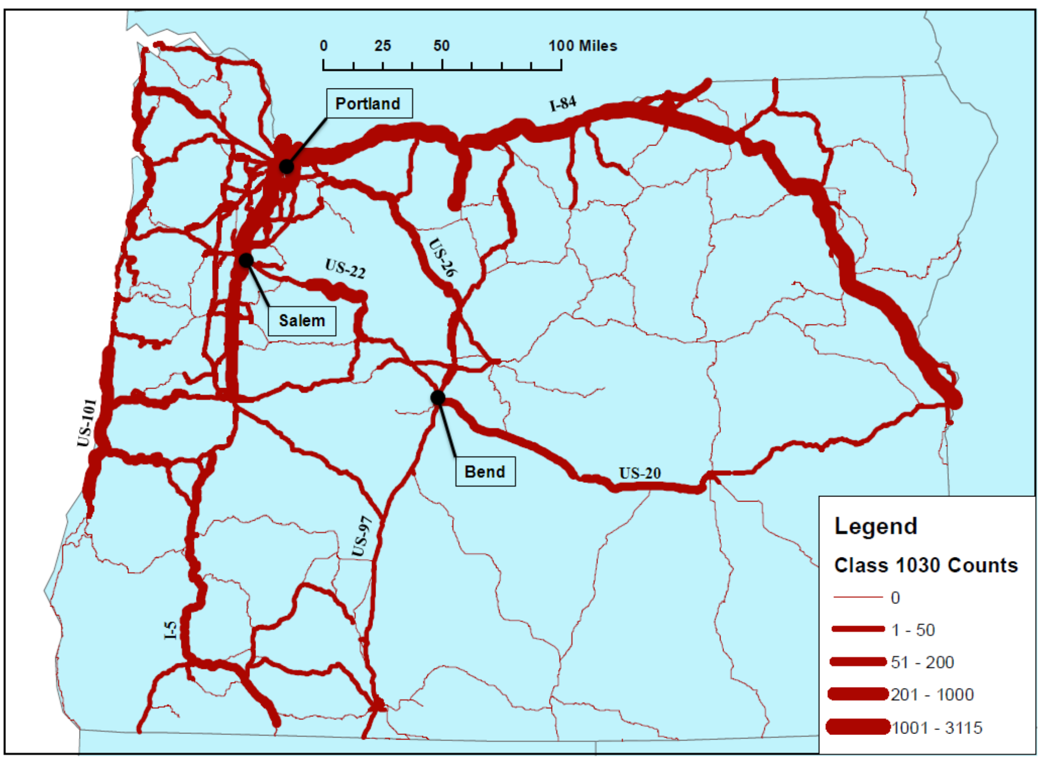

Figure 1 – Class 1030 Counts by Highway Segment

FREIGHT PERFORMANCE MEASURES

In 2011, the National Cooperative Freight Research Program (NCFRP) released *NCFRP Report 10, Performance Measures for Freight Transportation* (3). This report proposed a "Balanced Scorecard" framework for a Freight System Report Card with 29 performance measures in six categories. The report suggests that given the ability to disaggregate freight data, the "Balanced Scorecard" framework proposed could be used to analyze the performance of individual links or bridges at the state or local level. The authors also note that a major challenge towards such efforts is the availability of useful data. At the state level, a report completed for ODOT in May 2010 (2) provides recommendations for Oregon freight performance measures. Most of the measures suggested for Oregon overlap with those suggested by NCFRP (see Table 2).

FREIGHT PERFORMANCE MEASURE CATEGORIES	
NCHFRP Report 10	**ODOT Report**
Demand	Mobility, Congestion and Reliability
Efficiency	
System Condition	Maintenance & Preservation
Environmental Impact	Environmental
Safety	Safety
	Accessibility & Connectivity
Adequacy of Investment	

Table 2 – Freight Performance Measure Categories

Of the freight performance measures listed in Table 2, those associated with mobility have probably received the most attention on a national level, specifically in relation to travel time reliability and congestion at bottlenecks (2). As demonstrated in Table 1, all of the freight GPS data research reviewed for this paper explored applications in this area. Below are some commonly used mobility performance measures for which the TRUE data could provide estimations.

- Travel Time: the time taken by a driver to travel between an origin and a destination (8).
- Travel Time Reliability: NCHRP 618 (25) recommends use of 90th and 95th percentile travel times (reflecting travel delays that can occur during heavy congestion) as an indicator of travel time reliability.
- Travel Time Index (TTI): the ratio of the average speed for a given highway segment at a particular time of day to the functional free flow speed of the same segment of highway (26).
- Planning Time Index (PTI): the ratio of the "worst-case scenario" average travel speed for a given highway segment at a particular time of day to the functional free flow speed of the same segment of highway.

Maintenance and preservation efforts by state DOTs typically focus on highway bridge and pavement management (2). Bridge wear is primarily a function of gross vehicle weight (GVW); pavement wear is primarily a function of axle weights. As such, the capability of TRUE data to provide estimates of both GVW and axle spacing of traveling vehicles on virtually any segment of state highway could be very useful to determine user impacts. The TRUE data will have potential to be linked to other vehicle records in order to provide this information. According to *Infrastructure Costs Attributable to Commercial Vehicles* (27) DOTs typically allocate 40% or more of their annual budgets to pavement maintenance and rehabilitation projects. Further, most pavement damage is caused by heavy vehicles. In fact, the relationship between axle loads and consequent pavement damage is known to be exponential (28). For this reason, it is pertinent to consider applications of truck GPS data within the field of pavement management. The ODOT Pavement Management Unit currently evaluates the state highway system every two years via pavement condition surveys. The survey results are then used to determine appropriate maintenance, preservation and design proposals for the highway pavement system. Applications for truck GPS data could include: 1) for pavement forensics; 2) to more accurately estimate design ESALs for highway segments; and 3) to decrease the frequency of pavement condition surveys for highway segments receiving minimal truck traffic. The TRUE data could also provide route information to determine weight limit violations on bridges.

Environmental performance measures often correspond to an extent with those for mobility; however a more direct environmental application for the TRUE data could be for emissions estimations. 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), and greenhouse gas (GHG). Truck GPS data could be input into air quality modeling programs such as EPA's MOVES to improve the accuracy of model results. The methodology employed by Wheeler and Figliozzi could be used and further developed to estimate freight emissions using ODOT's GPS data. According to *NCFRP Report 10*, national targets for most types of large/heavy-duty truck emissions are on track, but the industry's GHG emissions continue to rise. 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 on GHG emissions from the transportation sectors (29). The GreenSTEP Model will be discussed in more detail in the "Freight Planning & Modeling" section of this paper.

A 2010 report for ODOT (2) suggested the ratio of "total cost of freight loss and damage from accidents" to "total freight VMT" as the ideal safety freight performance measure for both statewide analysis and specific highway segments."Total cost of freight loss" includes: 1) cost of lost and damaged equipment, 2) value of lost and damaged cargo, 3) delay imposed to other freight carriers on that highway corridor. Values of damaged equipment and cargo are valuable measures for the freight industry as they could impact insurance claims and premiums. The vehicle type, class, weight and commodity data available through TRUE data would assist in estimating such costs. The 2010 report also suggested "Motor Carrier Crash Rate and Triple Trailer Crash Rate as worthwhile performance measurements for Oregon. Oregon's existing data sources for safety performance measures, combined with the TRUE data for determining total truck VMT and VMT by truck type, could assist in determining accurate estimations for these performance measures.

Accessibility and connectivity performance measures are particularly relevant to Oregon due to the multi-modal nature of the state with respect to freight (i.e., ports, airports and highways). McMullen and Monsere (2) suggest 'percent of freight originating or terminating within a certain number of miles of Longer Combination Vehicle (LCV) corridors' as a potential measure of accessibility. The expansion of the LCV network was frozen by the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991. McMullen and Monsere note that 'shipment origin or destination data does not contain [the] level of specificity' needed to make such a measurement; however, the TRUE data could likely provide the necessary information. Truck turnaround time at terminals (ports), as measured in research by You and Ritchie, is another potential measurement for Oregon.

FREIGHT PLANNING & MODELING

The Greenhouse Gas Statewide Transportation Emissions Planning (GreenSTEP) Model was developed by ODOT to assess the effects of policies and other factors (i.e. gas prices) on greenhouse gas emissions from the transportation sectors. Specifically, the model estimates and forecasts: vehicle ownership, vehicle travel, fuel consumption, and GHG emissions. As of October 2011, GreenSTEP focused on emissions from household and light duty commercial vehicles (i.e., autos, SUVs, pickup trucks, vans); modeling of GHG emissions from freight was still in development. According to ODOT reports (29), estimates from GreenSTEP could further be used to assess the relative equity of different policy proposals for different road users. Detailed truck GPS data could be highly valuable in further developing the freight portion of GreenSTEP and in anticipating impacts of proposed policies as they relate to the freight sector.

ODOT recently developed the Oregon Freight Plan (OFP) to consider infrastructure investment and policy options related to freight (1). In order to account for current economic uncertainty, the OFP proposes to analyze various alternative futures. Four hypothetical futures, or scenarios, were developed and estimates of economic growth were made for various economic sectors, infrastructure investments, and distribution of economic benefits. ODOT's Second Generation Statewide Integrated Model (SWIM2) was used to complete this analysis. SWIM2 is a spatial economic modeling system that represents transportation, economics and land use, as well as the interactions between them (30). The model framework allows the user to track commodity flow patterns, travel and land use patterns, and interactions between economic sectors at the state and regional level. The SWIM2 output used for the OFP analysis was determined based on metrics related to the transportation system (miles traveled, hours traveled, trip costs, commodity flow) and economic welfare (industry output, commodity value, production costs). Results were evaluated on a statewide level as well as for each of the six economic regions within the state. In 2010, short, mid and long-term improvements were proposed to the Commercial Truck (CT) module of SWIM2 (31). It was noted that SWIM2 provides a comprehensive approach to household travel activity, but that the CT module was in need of enhancements to more adequately forecast freight movements and the impacts of energy price changes, and to provide sound policy analysis regarding GHG emissions taxes and tolling. According to the researchers, applications for the CT module are limited to "a subset of freight policy problems that can be appropriately modeled with simple behavior rules and limited data". The TRUE data provides an excellent opportunity to produce more accurate results in SWIM2, and for the OFP analysis in particular. Given the disaggregated nature of the TRUE data, it would be an asset in performing SWIM2 analysis at a regional level in Oregon. The TRUE data should also be considered for potential application towards the CT module improvements suggested by Figliozzi and Shabani.

CONCLUSIONS & FUTURE RESEARCH

The "Balanced Scorecard" method proposed by *NCFRP Report 10* and the suggestions from the *Freight Performance Measures: Approach Analysis* prepared for ODOT provide a useful framework from which ODOT can develop ancillary applications for commercial truck GPS data. Further, previous work related to the use of freight GPS data provides a valuable starting point for this research. Although previous research had limited success in 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 potential to differentiate between vehicle types. As such, development of trip generation rates and use in freight models are two valuable applications for the TRUE data that will be explored. Opportunity to further develop the relevant components of the SWIM2 and GreenSTEP models will also be researched further. Figure 2 provides a summary of these and other potential applications reviewed in this paper, and the data fields required in order to provide accurate results for each. All data fields listed in Figure 2 are provided by the TRUE system. *NCFRP Report 10* suggests that a freight performance measurement system should take on an evolutionary approach; continuous efforts to improve data sources should be anticipated by an agency developing such a system (3). Likewise, as potential applications for this dataset are explored, consideration will be given for potential augmentations to the TRUE system.

		Data Fields									
Category	**Performance Measure / Application**	Lat/Long Points	Time Stamp	Weight Class	Axle Count	Accuracy of GPS	Vehicle Class	Vehicle Type	Commodity Code	Gross Weight	Weight at each axle
Mobility	Travel Time										
	Travel Time Reliability										
	Trave Time Index (TTI)										
	Planning Time Index										
	Volume to Capacity (V/C)										
	% Congested Miles										
	Interstate MC VMT										
	Freight tonnage by commodity										
System Condition	Estimate Pavement Condition										
	Scope Pavement Condition Surveys										
	Pavement Forensics										
	Bridge Weight Limit Violations										
Environment	GHG Emissions Estimations										
	Other Emissions Estimations										
	GreenSTEP Integration										
Safety	*Miscellaneous*										
Assessibility & Connectivity	% Freight O/D in vicinity of LCV corridors										
	Truck turnaround time at terminals										
Planning & Modeling	Trip Generation Rates										
	SWIM2 Integration										
	GIS Analysis & Other Visualization Tools										
	Partner with Regional Projects										
	Route Choice										
	Vehicle Choice										
	Freight Activity Modeling										
	Mode Choice										

Figure 2 – Future Research & Analysis Framework

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of Greg Dal Ponte and Gina Salang (ODOT

MCTD), Becky Knudson (ODOT TPAU), Myra Sperley (ODOT Research) and Steve Ross, Chris Howell, Peter Douglas and Michael Bolliger (ODOT MCAD). Any omissions and mistakes are the sole responsibility of the authors.

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