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Detection Technologies for Dynamic Origin-Destination Matrices and Heavy Vehicles' Road Selection Studies

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ABSTRACT

Heavy vehicles (HV) are considered one of the most important factors in the deterioration of the road infrastructure. In fact, the pavement structure is usually designed considering the effects of these type of vehicles in the infrastructure. However, determining the use of the road network by HV is not an easy task. This paper explores the use of new technologies to determine Dynamic Origin-Destination matrices coupled with Dynamic Traffic Assignment as a way to improve the estimation of heavy vehicle usage on the road network. Recent improvements in technology allow for a better traffic monitoring; therefore, the data to build a Dynamic O-D matrix and its corresponding dynamic routing has improved too. Those technologies can also be used for determining HV road selection. The negative impacts of HV on the pavement are well known, but on roads that were not designed for truck traffic, the physical, environmental and social impacts are higher. This paper collects the most promising technologies to track HV and categorizes them into two groups: Static and Mobile technologies. The latter seems more promising to be used in the dynamic context. Specifically, GPS devices are the most capable technology to study HV dynamic O-D and route selection.

Keywords: Origin-Destination Matrix, Road deterioration, Heavy vehicles, Route selection, Vehicle tracking

1. INTRODUCTION

Deterioration of the road network is the result of two factors: natural occurrences and human activities. The use of heavy vehicles is the most deteriorating human activity for the pavement (Yoder and Witzak, 1975; Hahn, 1985; Gillespie et al., 1993). Estimating the actual volume of heavy vehicles using the road network will help determining the future deterioration, or aging, of the road infrastructure. The estimation of heavy vehicles traffic will help to establish better road maintenance plans and planning for future constructions. Monitoring changes in the pattern of road usage by heavy vehicles (HV) will show where premature deterioration of certain roads (links) might occur; otherwise, that premature deterioration would have been unexpected. If expected to happen, several measures can be used to avoid premature aging of the infrastructure; therefore extending its service life (AASHTO, 2001).This paper focuses on Heavy Vehicle Dynamic O-D matrices as part of Dynamic Traffic Assignment for the estimation of HV traffic.

Planning and monitoring a road requires the analyst to assume an estimated Origin-Destination (O-D) Matrix. This estimated O-D matrix shows the anlysts the volume of vehicles that wish to use the road (including percentage of heavy vehicles) on a given period of time. The problem is that O-D matrices are difficult to estimate, and those difficulties result in estimation errors. These estimation errors are the reason for the use of different approaches to solve this problem (Bell, 1991; Sherali et al., 1997; Yang et al., 2001; Lin and Chang, 2005; Lundgren and Peterson, 2008).

Once the roads are in use, O-D matrices are not essential for an appropriate traffic control, but with the development of Intelligent Transportation Systems (ITS) and Dynamic Traffic Assignment (DTA), it is very important to correctly estimate Dynamic Origin-Destination matrices. Dynamic O-D matrices are origin and destination matrices that are time dependent and take into consideration the status of the road network. Dynamic O-D matrices are mainly employed for dynamic traffic assignment (Cascetta et al., 1993; Antoniou et al.,1997; Tavana and Mahmassani,2000; Mahmassani, 2001; Ben-Akiva et al., 2007).

The objectives of this paper are: To establish basic concepts of Dynamic O-D, show the latest technologies to gather traffic data - in particular those related to heavy vehicles' road selection, and finally, to show the technology that seems to be suitable for determining trucks' O-D and road selection. It is important that other professionals, beside transportation engineers, get familiar with this topic, because solutions for this problem are multidisciplinary in nature.

The following sections define Dynamic O-D matrices (starting with static O-D matrix) and assess the problem related to heavy vehicles traffic estimation and its implications on the road infrastructure.

2. STATIC O-D MATRICES

O-D Matrices are a mathematical representation of the volume trips that want to reach some location from another location. For this, road networks have to be divided into zones. These zones are selected based on physical, social and/or organizational boundaries.

The following notation could be used to represent a static O-D matrix:

$$t_{ij}^{M} = \text{number of trips per mode (M) that wish to move from zone i to zone j.} \quad (1)$$

3. DYNAMIC O-D MATRICES

Dynamic O-D Matrices are time-dependent and take into consideration the status of the network (congestion). The situation is that the O-D matrix for a period of time might be considerably different from the next period of time, requiring the network to perform differently. Also, the situation of a period might affect the next.

The next example is presented to clarify the concept. Let's say that we are working on period τ (eq. 2). The number of trips of people wishing to travel from origin *i* to destination *j* during the period τ will be different than those traveling from the same O-D pair during τ-1 or during τ+1. This is the main issue in Dynamic O-D estimation. In addition to the situation previously presented, let's assume that during τ-1 a manufacture plant is about to finish its activities for the day. All vehicles from the main road are passing through the exit of the plant (i.e. an intersection) without delay. On time τ the plant end its operation for the day and most of the employees start trying to pass through the intersection; therefore, the traffic condition at the downstream intersection change almost instantly. Moreover, on τ+1, vehicles on the main road start facing congestion and may be going through alternate routes, so the network status on τ affected the status on τ+1. Of course, this condition (the exit from the plant) is expected, but similar things may occur with unexpected events that generate non-recurrent congestion. The second part of the example is related to Dynamic Traffic Assignment. To understand both issues, and estimate relevant models, is important to gather appropriate data using the new technologies available.

The following notation could be used to represent a dynamic O-D matrix:

$$t_{ij}^{M\tau} = \text{number of users per mode (M) that wish to move from zone i to zone j during period } \tau. \quad (2)$$

We may ask several questions about the dynamics of the changes in O-D during the day or even during a peak period. For example, we may ask: How much, the user desired destination, changes during the day? How a user (especially heavy vehicle drivers) decides to enter a congested network? Which routes are selected when expected events occur? Which routes are selected on unexpected events? Do heavy vehicles go through alternate routes? If so, are those roads prepared to receive heavy vehicles? How long the alternate routes are going to be used? These questions are the driving force of this paper.

Methods to obtain Dynamic O-D matrices and dynamic route patterns range from combining historical information with traffic counts (Camus et al., 1997) to using probe vehicles with automatic location devices (D'Acierno et al., 2009), some of them appear to be more appropriate to estimate heavy vehicles O-D and will be discussed further in the next section.

4. METHODOLOGY FOR SELECTING THE APPROPRIATE TECHNOLOGY

The methodology used in the selection of the most appropriate monitoring is presented in the flow chart on Figure 1. First, the available monitoring technologies are identified. Then, the requirements to determine Dynamic O-D Matrices and dynamic routing of HV are established. After that, an analysis of each technology is performed in order to determine if it complies with the requirements. In addition to requirements, other influencing factors are also taken into account to improve the analysis, considering not only the elements of the technology, but also its possible use in the vehicle or by the driver. The analysis ends by selecting the most appropriate monitoring technology that can be used for heavy vehicle monitoring and tracking.

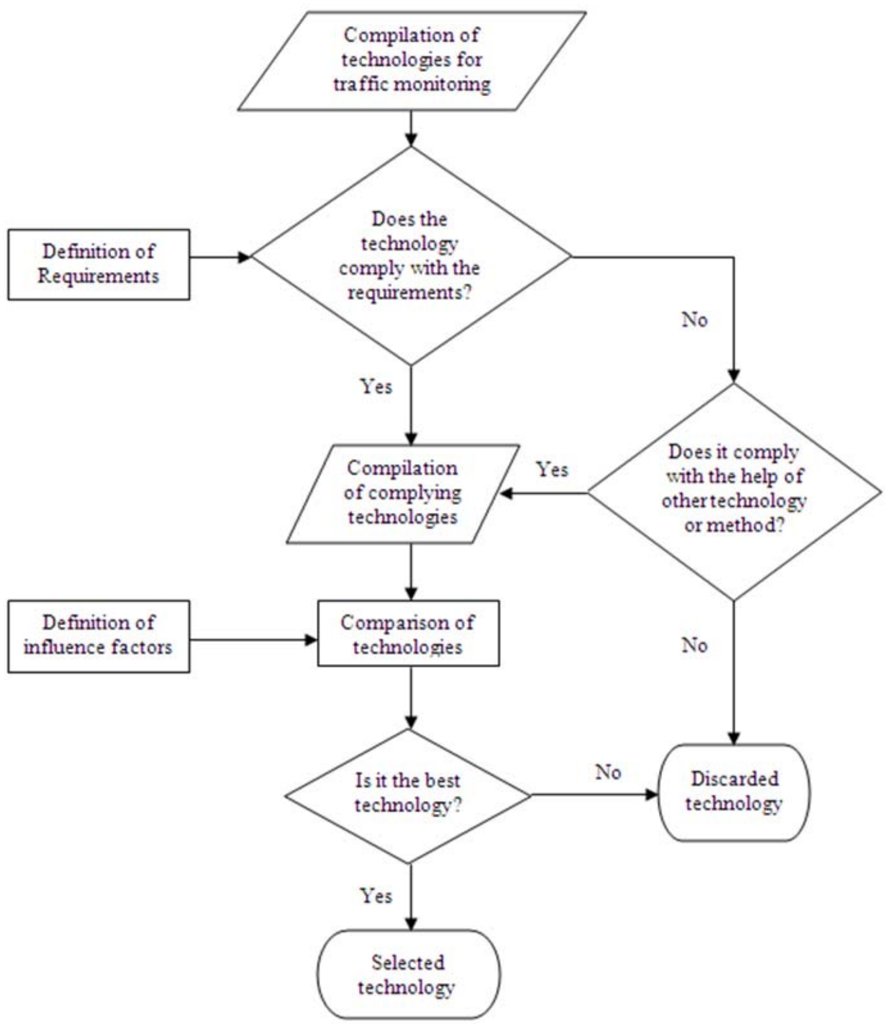

Figure 1. Selection of Monitoring Technology

It is expected that most technologies will not pass the requirements, therefore the other influential factors such as ease of application and costs will be used to compare the standing technologies.

TECHNOLOGIES AND METHODS TO ESTIMATE DYNAMIC O-D MATRICES

There are several technologies to estimate Dynamic O-D matrices. Different technologies usually require different methods to integrate information and obtain Dynamic O-D matrices. Technologies like GPS (Global Positioning System) devices, camera systems, cell-phones, transponders and dual-loop detectors will be discussed in this section. It is safe to say that these technologies can be implemented without affecting the privacy of the users.

GPS DEVICES

This technology consists on having a GPS device in the vehicle. Furthermore, this technology can be divided into two categories, auto-reported and user-reported. Auto-reported refers to those devices that send its location automatically to a data management center (DMC). User-reported are those devices in which the user have to send the travel information to a DMC.

Auto-reported devices require an authorized company to offer the service of locating the vehicles; also a fee is charged for every vehicle in the program. The refresh rate (the rate at which the location is gathered) can be selected. The cost for the use of this type of devices ranges from $500 to $1,500 (123-Vehicle-Tracking, 2009) and the fee is at least $1 per vehicle per day (CES wireless technologies, 2009).

User-reported devices save travel information in its memory. The cost for this type of devices is $500 for the GPS and $340 for the logger (McCormack and Hallenbeck, 2005), but these costs might be somewhat avoided because some users already have devices that have this function. PDAs, navigational systems and other devices can be used for this application. The user needs to send the travel information to the DMC, so this technology might be a little intrusive from the user's point of view.

Although corrections can be made, Wolf et al. indicate that raw GPS data from low-end devices can be up to 100 m off, usually ranging 15 m. After correction 3-10 m accuracy can be obtained. Also, an accurate Geographic Information System (GIS) is needed to process the GPS data (Wolf et al., 2006).

Several trucking companies in the USA use GPS to keep track of their fleet. This technology provides information for them that otherwise, will be impossible to gather.

CAMERA SYSTEM

This kind of technology records license plates to later identify them. This is similar to manually record license plates in point A and point B during a period of time to check vehicle's movements.

The identification of license plates is difficult even with current technology and software improvements. Camera angle, density of vehicles, environmental conditions, among other factors, affect (or even makes impossible) the identification of license plates. The cost of this kind of technology is $6,500 per camera including supporting equipment (Gómez-Torres, 2006).

CELL-PHONES

This technology makes the use of cell (mobile) phones to gather user information. Cell phones are widely available and most users already carry them everywhere. There are two categories within cell phones: point locations and tracking. Point location refers to the way the information is gathered, instead of tracking phone location along the network, it only records the locations when the phone changes cell (Sohn and Kim, 2008).

Cell phones use radio wave for its communications. Each phone communicates with an antenna in one of the corners of the cell (hence cell phone). Point locations may be recorded when a phone moves to another cell and the cell transference is performed. This situation may become a problem because the transferences do not necessarily occur in the same (exact) location each time (Sohn and Hwang, 2008). Phone tracking is more complicated and requires triangulation or a GPS capable phone. The costs for the use of this technology are difficult to estimate, but it will be a charge made by the phone companies to provide this information to the DMC.

TRANSPONDERS

This technology consists of devices installed in the vehicle that readers located in the road network can read. This is similar to license plates studies, but these devices have an embedded electronic signature that can be read accurately.

Transponders require sensors strategically installed throughout the network. Each site costs approximately $7,000 dollars (McCormack and Hallenbeck, 2005). Also, transponders have to be installed in the vehicle by the user, but some users have already installed Electronic Toll Collection devices that serve a similar purpose.

DUAL-LOOP DETECTORS

Dual-loop detectors can be used to obtain the signature of a vehicle (or a platoon for that matter) to later identify it again on another detector. Coifman et al. establishes that this technology is accurate up to 45 mph and that the use of platooned vehicles improves its accuracy (Coifman and Cassidy, 2002).

5. RELATION OF HEAVY VEHICLES TRAFFIC AND TECHNOLOGIES

The technologies discussed in the previous section have different implications when studying heavy vehicles (or trucks) traffic. First of all, does the technology do what is needed? And second, what is needed from the technology?

In order to obtain the routes selected by heavy vehicles we need the technology to:

1. Discern between heavy vs. light vehicles (classification) –This is of the utmost importance. The traffic is naturally mixed but the effect on the pavement is considerably different.
2. Study truck traffic on *any* road (universality) – Since one of the problems is that some heavy vehicles take routes that are unexpected for the designer (and probably the transportation agency in charge of maintenance of the facilities). The idea is to identify on which routes trucks travel.

To have all the information necessary to determine road deterioration from truck traffic, the weight of each truck is required. The technologies to weight vehicles in motion (WIM) exist (already in use), but it is not part of the scope of this paper. It is assumed that heavy vehicles weight estimation, can be done with information available from other sources, or can be modeled (Holguín-Veras and Thorson, 2003).

The following section, give a comparison in light of what is needed from the technology and some other factors that influence its selection.

6. COMPARISON OF TECHNOLOGIES AND METHODS ESTIMATING HEAVY VEHICLES TRAFFIC

After careful review of the requirements and technologies, it has been found that there is no single technology that can provide all the features by itself. In order to find which technology is more appropriate to determine truck traffic, the qualifications of each technology are compared with the requirements.

To begin with the comparison, we separate these technologies into two groups: static and mobile. The static includes technologies like camera systems, transponders and dual-loop detectors. The mobile includes technologies like GPS and cell phones. Transponders may figure in both classifications because it has characteristics of both, yet the need for readers on the road makes it static.

All the static technologies are tied to the road. These technologies may classify vehicles, but they cannot be on *any* road. Budget limitation would not allow static technologies on all roads, yet its classification capabilities may aid other technologies to estimate heavy vehicle traffic as a percentage. Percentage of trucks is not part of the scope of this project.

All mobile technologies are tied to the users. These technologies can determine traffic on almost any road, but it cannot, by itself, classify vehicles. If the technology is tied to the user (or vehicle), there should be information available on the classification of the vehicle used. For example, if we decide to install transponders on vehicles, we will be able to record its classification. The following sections will specifically consider each requirement.

CLASSIFICATION

Classification is the ability to separate heavy vehicles from light vehicles. Also, it is a necessary requisite for any technology. Most static technologies have the capacity to do classification, but as already explained; these technologies cannot (in an economical manner) study all roads. In terms of the mobile technologies, classification is not inherent to the technology but can be known. Trucking companies use GPS to improve efficiency, therefore several trucking companies already have this kind of technology in place.

In the case of GPS, classification can be done linking the device to vehicle type. Since the device needs to be installed in the vehicle recording, vehicle type is part of the protocol. All data gathered can be separated between heavy or light vehicles at will. Cell phones are an entirely different story.

In the case of cell phones, all traffic data can be gathered with heavy and light vehicles mixed. However, in order to separate heavy vehicles from light, truck drivers (or companies) must allow cell-phone-companies to gather their information separately. Still, certainty on whether the cell phone is located at the heavy vehicle or not, is low. Therefore, the use of cell phones for determining heavy vehicles traffic would be ineffective.

Nevertheless, mixed traffic data may be collected without the individual consent of the cell phone owners. This can be done because the protocol used maintains the privacy of the cell phone owner.

UNIVERSALITY

Universality is the ability of the technology to study vehicle flow on any road. Full universality cannot be found with the technology available today, but in most cases both technologies proposed here can be practically considered universal. GPS can be considered universal because this technology has almost no limitations.

GPS location can be obtained in a way that the exact road taken can be recorded. The exactitude of GPS depends largely on the devices and the procedures used. If the assumption of 15 meters off (most common worst scenario) is taken, then for most places the exact road can be known.

Cell phones come in two varieties, GPS capable and non GPS capable. If the cell phone is GPS capable it can be considered the same as any GPS device. Non GPS capable cell phones may be considered *less than* universal on cities and suburban areas. However, the service provider may not guarantee full coverage in rural areas; therefore, universality cannot be warranted. Non GPS cell phones are considered less than universal because location data is gathered when a change of cell (or tower) is done. This might not have enough resolution in order to know the exact road used by truck drivers.

The static technologies are not considered universal, because installation on all roads is impossible. For a static technology to be effective in terms of universality, the cost of implementation of this product at each road must be extremely low.

7. GPS DEVICES VS. GPS CAPABLE CELL PHONES

From the analysis performed on classification and universality, it can be concluded that GPS devices and GPS capable cell phones are able to do what is required to study traffic patterns of heavy vehicles. These two devices are technically similar, but there is one unavoidable difference: GPS devices are tied to the vehicle, while GPS capable cell phones are tied to the person. Let’s see the implications of this difference.

GPS devices can be programmed to work anytime the *vehicle* is switched on. Therefore, the information gathered will always be from a heavy vehicle in operation. Problems may arise with idle vehicles in terms of estimating travel time (and for other purposes), but in terms of determining road selection this technology is competent.

GPS capable cell phones are programmed to work any time the *device* is turned on. Therefore, the information gathered is related to the person using the phone rather than the vehicle used. To use GPS capable cell phones for identification purposes, the user would need to notify that they are using a heavy vehicle. In other words, the users would have to continually report the transportation mode they are using. This imposes extra work from the user and is prone to error. For these reasons cell phones are not as effective as GPS devices to track heavy vehicles road selection.

8. CONCLUSIONS

Some of the technologies previously presented can be used for gathering data for Dynamic O-D matrices and to identify the roads used by truck drivers. From the technologies studied, GPS devices comply with the requirements of classification and universality. Also GPS devices provide information that is less prone to error than cell phones. Furthermore, these devices are already being used by trucking companies in the USA.

The literature search indicates that the cost for each GPS device is more than $500 dollars and the cost of daily data reporting would range from $1 to $5 dollars. These costs may be shared between the DMC (or the transportation agency) and the trucking companies, given that the trucking company will also receive the benefits of this technology (aid in fleet management).

Challenges like sample selection and sample size must be studied in detail, since these will affect other factors that influence the implementation of GPS in trucks such as:

1. Cost
2. Ease of implementation
3. Acceptance from stakeholders, such as:
    a. Policy makers
    b. Trucking companies and drivers
    c. General public

Further research is needed to identify the cost of massively employing GPS technology, and to identify potential problems during implementation. Also, there is a need to investigate the stakeholders' opinions about the application of this kind of technology.

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