Highway travel time information system based on cumulative count curves and new tracking technologies

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ABSTRACT

Travel time is probably the most important indicator of highway level of service, and it is also the most appreciated information for highway users. Administrations and private companies make increasing efforts to improve its real time estimation. The appearance of new technologies makes the precise measurement of travel times easier than never before. However, direct measurements of travel time are, by nature, outdated for real time applications, and lack of the desired forecasting capabilities.

This paper introduces a new methodology to improve the real time estimation of travel times by using the equipment usually present in most highways, i.e., loop detectors, in combination with the newer Automatic Vehicle Identification or Tracking Technologies. One of the most important features of the method is the usage of cumulative counts at detectors as an input, avoiding the drawbacks of common spot-speed methodologies. Cumulative count curves have great potential for freeway travel time information systems, as they provide spatial measurements, allowing the calculation of instantaneous travel times. In addition, vehicle accumulation exhibits predictive capabilities. Nevertheless, they have not been extensively used mainly because of the error introduced by the accumulation of the detector drift. The proposed methodology solves this problem by correcting the deviations using direct travel time measurements. The method results highly beneficial for its accuracy as well as for its low implementation cost.

1. INTRODUCTION

Travel time is undoubtedly a valuable information both for drivers and traffic management centers. Modern technologies have brought a renewed interest in the improvement of current estimation procedures. Nowadays, several techniques allow the direct measurement of travel time, either based on Automated Vehicle Identification (AVI) or on tracking technologies. License plates (using video recognition) or the Bluetooth signature of on-board devices are used to identify vehicles, while GPS is usually used for tracking. These methods supply accurate measurements of vehicles' travel time. However, they lack predictive capabilities,

meaning that the measurement is obtained when the trip has ended, and provides very little information on its future evolution. Thus, their applicability in real time information systems is limited.

Indirect travel time estimation from fundamental traffic variables appears as an alternative. Traditionally, spot-speed methods based on loop detectors data have been used. Nevertheless, several research studies point out their inaccuracy in case of congestion or with low detector density (Soriguera and Robusté, 2010; Martínez-Díaz and Pérez, 2015) and they do not help in predicting travel times either.

Methods based on cumulative count curves have not seen great success. Mainly, this is due to the systematic detector drift phenomenon. The count drift between input and output detectors is accumulated in these methods, leading to large errors in the results (Coifman and Cassidy, 2002; Nam and Drew, 1996; Oh et al., 2003). However, input-output methods have two important advantages: first, there is no need for a big density of detectors; and second and most importantly, these methods exhibit forecasting capabilities because the accumulation of vehicles to be served in the near future is known (Soriguera and Robusté, 2010).

The main goal of this paper is the introduction of a new methodology for travel time estimation in real time that takes advantage of the predictive ability of cumulative count methods and that uses direct measurements of travel time to correct the detector drift. The method is especially suited for being applied in congested conditions, when travel time information is more relevant and when all other methods are less accurate. Its implementation turns to be easy and cheap.

The paper is organized as follows: Section 2 contains an overview of the methodology. Section 3 presents the test site and the data that are being used for the implementation of the algorithm. Finally, in Section 4, the current state of development of the research and some additional issues planned for a near future are explained.

2. METHODOLOGY

2.1 Input – output diagrams revisited

Figure 1 shows a typical cumulative count input - output diagram. (A) is the "arrivals" count curve measured at the upstream detector (x_u) and accumulated in time. (D) is the "departures" cumulative count curve measured at the downstream detector (x_d). (V) is a "virtual" curve, representing the departures curve that would have been measured in the absence of delay. (V) is obtained by simply shifting forward in time the (A) curve a magnitude equal to the free flow travel time. In case the free flow travel time is significantly smaller than the loop detector aggregation period (Δt), the construction of (V) is simpler, as the free flow travel

time and the initial accumulation m(0) can be neglected. Sections between loops of 2 Km or less, increasingly common in freeways, ensure this condition. See Daganzo (1997) for a review on these concepts and their application. Working with the (V) and (D) curves allows easily obtaining delays while eliminating the need for keeping track of the accumulation. By definition, the excess accumulation is zero until congestion appears. Or equivalently, (V) and (D) curves coincide while free-flow prevails. This by itself limits to a large extend the problems of the detector drift (Soriguera, 2016).

Figure 5 assumes FIFO traffic (First in - First out, i.e. no significant passing). Freeway traffic can be considered a FIFO system in congested conditions, when multilane behavior is very limited and its effects on travel times are negligible (Muñoz and Daganzo, 2002). In addition, because the interest is not in individual vehicle travel times, but on the average, one can assume that vehicle switch labels when passing, so that FIFO holds (Daganzo, 1997).
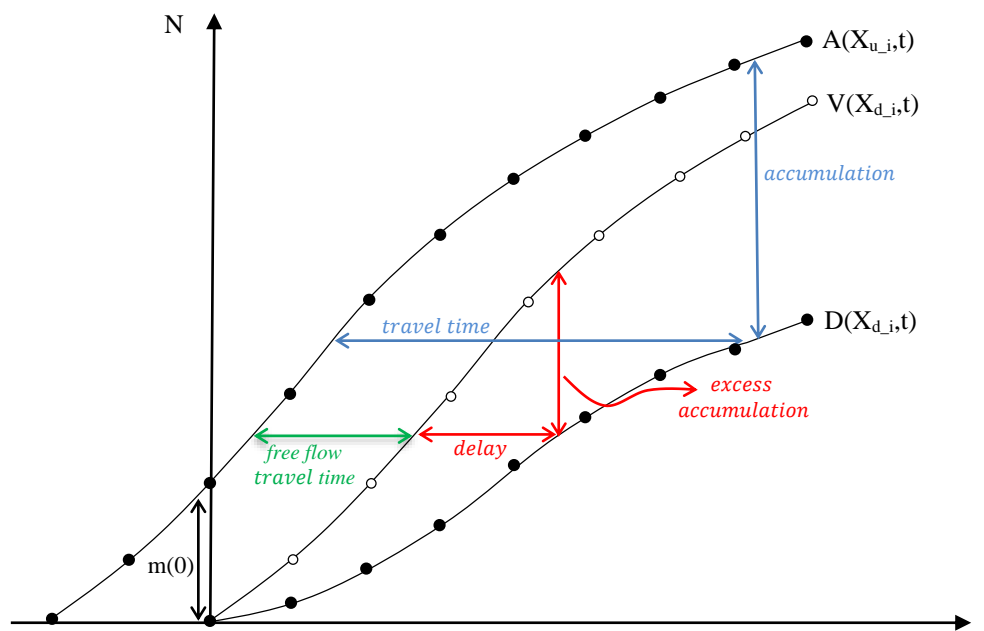

Fig. 1 – Graphical interpretation of cumulative curves

The algorithm turns on when congestion is detected. This happens on a section either if the speed at the upstream or downstream detector is lower than the free flow speed or if the slope of the virtual arrivals curve is bigger than that of the departures curve. All these comparisons take into account statistical variations. The algorithm turns off as soon as both curves, (V) and (D) coincide at some point in time.

2.2 Drift correction from direct travel time measurements

Figure 2 shows the simplest situation that the methodology will face. This is a freeway stretch defined by the upstream (X_u^s) and downstream (X_d^s) positions of the direct measurement devices. The stretch contains several sections defined by the location of loop detectors. In case that the direct measurements are obtained using tracking technologies

every stretch would correspond to a single section. Because the methodology is based on vehicle conservation, a closed measurement system is required. This means that, although the number of detectors does not need to be large, on/off ramps need to be monitored, in addition to the main trunk.
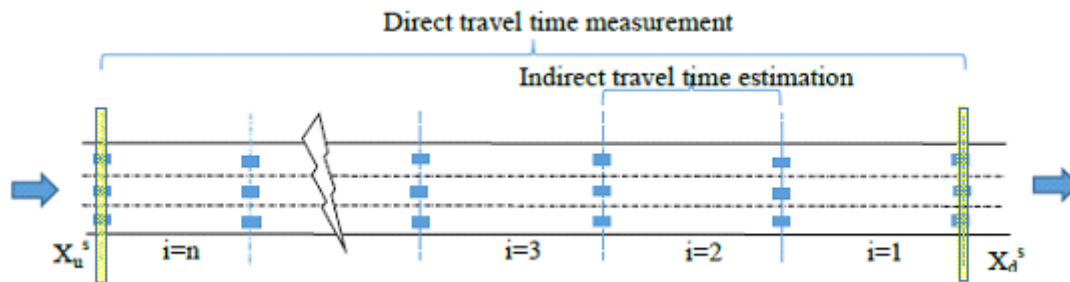

Fig. 2 – Typical detection configuration on a simple freeway stretch

The updating time interval of loop detectors (Δt) is generally shorter than that of the direct measurement devices (ΔT), as direct measurements need a significant amount of time to obtain a sample big enough to compute reliable averages. This means that, in addition to the spatial alignment of measurements, temporal alignment will also be necessary.

Direct measurements provide the average travel time on the stretch at time t $(\widehat{tt^s}(t))$. This can be expressed as the sum of the free flow travel time (t_f^s) plus the delay $(\widehat{w^s}(t))$, as in Equation 1:

$$\widehat{tt^s}(t) = t_f^s + \widehat{w^s}(t) \tag{1}$$

Delay on the stretch $(\widehat{w^s}(t))$, is the sum of the delays encountered by the drivers on the component sections $(\widehat{w_i}(t'))$ (see Equation 2). (t') stands for the fact that the reference time is trajectory based, and therefore temporal alignment is necessary.

$$\widehat{w^s}(t) = \sum_{i=1}^{n} \widehat{w_i}(t') \tag{2}$$

Component delays $(\widehat{w_i}(t'))$ on each section are not available from direct measurements. However, loops can provide this information. From every pair of input-output curves the current average delay on each section $(w_i(t'))$ can be obtained, although affected by the cumulative curve drift errors. Despite the long term drift of each pair of detectors (Section (i)) is addressed by multiplying the raw counts by a correction factor (β) (see Equations 3 and 4), this is not enough to provide accurate real time information, as short-term drift is also significant and not systematic.

$$\beta_i = \frac{\sum_{t=0}^{24h} n_{d\_i,t}}{\sum_{t=0}^{24h} n_{u\_i,t}} \tag{3}$$

$$n_{u\_i,t}^{new} = \beta_i \cdot n_{u\_i,t} \tag{4}$$

Where $(n_{u\_i,t})$ and $(n_{d\_i,t})$ are the traffic counts at the upstream and downstream detectors of Section (i) at time interval (t). From now on, the long-term drift will be assumed to be corrected, although not explicitly stated in the equations.

The aim of the methodology is to correct the short term drift errors in cumulative count curves by using direct measurements. To that end it is necessary to divide the total directly measured delay ($\widehat{w}^s(t)$) among the component sections ($\widehat{w}_i(t')$). It is assumed that the proportion of the delay in a particular section with respect to the total of the stretch is the same despite working with direct or indirect measurements (see Equation 5). This assumption is acceptable even though the indirect values have not been corrected yet.

$$\widehat{w}_i(t') = \frac{w_i(t')}{\sum_{i=1}^{n} w_i(t')} \cdot \widehat{w}^s(t) \tag{5}$$

If there were no drift, ($\widehat{w}_i(t')$) estimated from direct measurement, and $w_i(t')$ measured from input-output curves, would be equal. This property allows computing a short term drift correction factor (α_i) (Equation 6 and 7):

$$n_{u\_i,t}^{new} = \alpha_i \cdot \beta_i \cdot n_{u\_i,t} \tag{6}$$

$$\alpha_i \quad \text{obtained so that } \widehat{w}_i(t') = w_i(t') \tag{7}$$

Care must be taken when computing the average delay ($w_i(t')$) from input-output curves Different estimation processes must be applied depending on the nature of the direct measurements for the comparison. For example, AVI technologies deliver arrival-based travel times (i.e. they are only known once the vehicle has finished its route in the link). Accordingly, ($w_i(t')$) needs to represent an arrival based travel time. Therefore, ($w_i(t')$) should be computed as the area enclosed between (V) and (D) curves and only for the vehicles crossing the downstream detector (x_d) during the time interval (t), divided by this number of vehicles. In contrast, tracking technologies supply instantaneous travel times. Then, ($w_i(t')$) should be computed as the area enclosed between (V) and (D) curves between times ($t–\Delta t$) and (t) and divided by the number of vehicles crossing the downstream detector during the time interval. These different travel time definitions are overlooked in previous studies (Nam and Drew, 1996; Oh et al., 2003, van Arem et al., 1997).

With the corrected (V) curve (i.e. constructed from ($n_{u\_i,t}^{new}$), it is possible to calculate the current accumulation $Q_i(t)$ as the difference between the current values of (V) and (D) curves. $Q_i(t)$ is the key spatial value that allows computing predicted travel times, as Equation 8 and Figure 3 show:

$$w_i(t) = \frac{Q_i(t)}{\hat{q}_{out,i}(t)} \tag{8}$$

Where $w_i(t)$ is the predicted delay in Section (i) and ($\hat{q}_{out,i}(t)$) is the last statistical significant estimation of the average outflow at downstream detector. Finally, the predicted travel time on the stretch ($tt^s(t)$) is obtained by adding up all predicted section delays ($w^s(t)$) plus the free flow travel time.
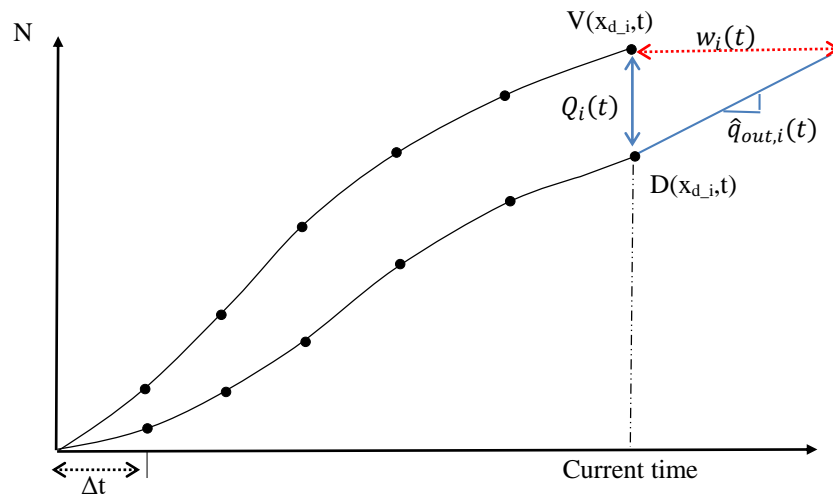

Fig. 3 – Estimation of the current accumulation $Q_i(t)$

2.3 Merging and diverging flows

(V) and (D) curves must account for mergings and divergings when they exist. The issue here is that count measurements at on/off ramps need to be "shifted" to the location of upstream or downstream detectors. Newell (1993) proposes a methodology to shift cumulative count curves consistent with LWR theory of traffic flow (Lighthill and Whitham, 1955; Richards, 1956). However, the method requires the capacity of the section as an input. For real time applications, because capacity changes and depends on the particular incidents for a given day, the method results overcomplicated.

A simpler solution is proposed here. The net flows at the junction (i.e. the difference between inflows and outflows with the appropriate sign) are transferred to the nearest trunk detector. This procedure assumes that through vehicles experience the same delay than those entering or exiting the section by the junction. Although this might not be true in some contexts, the over or underestimations of individual travel times do not imply a big error in the average final results, as long as the number of through vehicles is big in comparison to the rest.

3. IMPLEMENTATION

Preliminary results achieved to date are promising. A pilot test is being carried out on the AP-7 highway, which runs along the Spanish Mediterranean cost. Specifically, the available

data belong to its northeast part, with a length of 45.7 Km, from the *Maçanet-Blanes* junction to the turnpike at *La Roca del Vallès*, near Barcelona. Available data include traffic counts and spot speeds from double loop detectors ($\Delta t = 3$ min), Bluetooth vehicle identifications (ID and time stamp and average, $\Delta T = 6$ min), and the entrance / exit times of every vehicle from toll tickets.

Five different stretches are defined by the position of the Bluetooth detectors (see Figure 4). Each one has different characteristics: number of loop detectors (i.e. sections) within the stretch, number of lanes, and existence of junctions (or not). This diversity will add robustness to the final results.
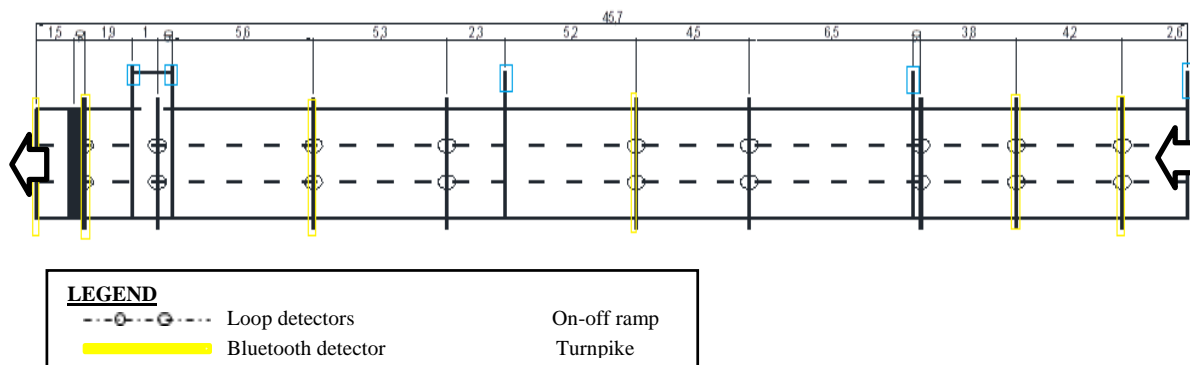

Fig. 4 - Test site layout

4. ONGOING WORK AND FUTURE RESEARCH

The methodology is currently being tested under different boundary conditions. The results achieved so far match the expectations. Nevertheless, its robustness and its exact degree of accuracy still need to be proved. Ongoing research will allow drawing quantitative conclusions.

Additionally, some future research lines have been already outlined. For example, the sensitivity of the method on factors such as the detector density, the geometry of the freeway (e.g. number of lanes or junctions) or the frequency of overtaking will be investigated. Further research will also include the integration of the method together with the most relevant tools for real time traffic management, in order to assess their potential improvement.

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