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Validation of Travel Times based on Cellular Floating Vehicle Data

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Abstract

Acquiring accurate traffic information on a roadway network is a constantly evolving discipline, employing all kinds of technologies world-wide. In this paper, we take a closer look at a method for deriving travel times based on the information from mobile cell phones. The technique is based on the patented Cellular Floating Vehicle Data (CFVD) technology of ITIS Holdings, whereby cell phones exchange information with stationary antenna posts.

This paper reports on results of a validation effort that assesses the usability of the CFVD technology for extracting travel times and traffic conditions, implemented in the region of Antwerp, Belgium with a study area covering all motorways and the major regional and urban roads in the neighbourhood of the city. To this end, we compared the results of the CFVD technology with different other independent traffic sources: data obtained by single inductive loop detectors embedded in the roads, and observations derived by test drives with a GPS-equipped probe vehicle. Our results indicate that the CFVD technology has a very good performance on motorways, is able to capture the large variations in travel times on roads containing intersections, and easily outperforms the standard road-based detectors.

Keywords

Travel times, floating car data, GPS probes

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1. Introduction

Considering the evolution of traffic flows nowadays, there is a trend towards the dissemination of more custom-tailored relevant traffic information to road users. One of the most fundamental problems in this view, is the ability to accurately estimate travel times, as they form the basic components for, e.g., route planners and navigation systems. Considering the modern trend of these latter tools to work with last-minute information regarding the current prevailing traffic conditions, the estimation of travel times becomes a key issue in the relaying of relevant traffic information.

Acquiring accurate traffic information on a roadway network is a constantly evolving discipline, employing all kinds of technologies world-wide. One of the more promising technologies used, is based on the anonymous transmissions from mobile cell phones that exchange position information with stationary antenna posts [Bar06]. Other possible technologies that give similar results are standard road-based detectors such as, e.g., single loop detectors. From a historical perspective, these latter have been widely deployed, and remain in use for several decades now. However, regarding the accuracy and availability of these sensors, their performance at estimating travel times in order to deduce traffic information is quite limited, thereby necessitating other and better technologies.

During 2005 – 2006, ITIS Holdings applied the patented *Cellular Floating Vehicle Data* (CFVD) technology to the Antwerp region (see also Figure 1).

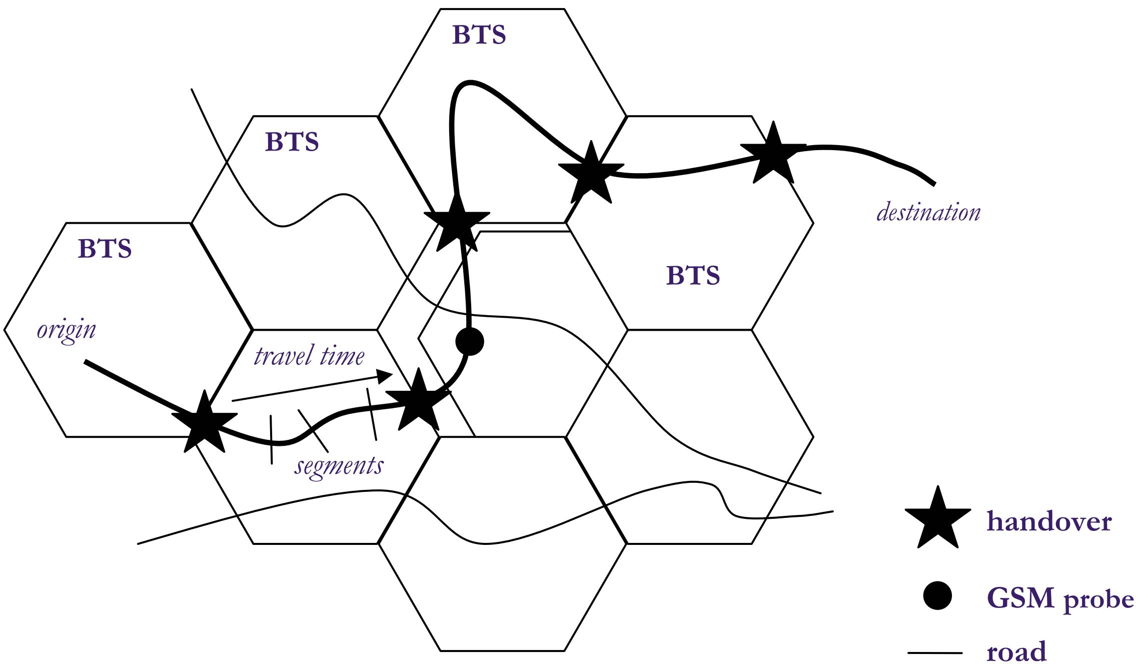

Figure 1: A GSM probe vehicle that travels from a certain origin to a certain destination, following a specific route. As the vehicle is driving, its location and passage time is recorded at each handover event between two base transceiver stations (BTS). The travel time is then calculated for each individual road segment within such a hexagonal cell.

The idea behind using mobile communication devices to obtain traffic flow information, is that each of these mobile units (i.e., GSMs) exchanges location information with so-called *base transceiver stations* (BTS); these latter are in fact modelled as a *grid of hexagonal cells,* each centred around an antenna post. As a GSM moves from one cell to another, a *handover* is executed. As only handovers between two hexagonal cells are registered, *the system needs two consecutive handovers* in order to 'accurately' determine the travel time between these two zones (see Figure 1 for an example). In a subsequent step this travel time is matched onto a map containing the underlying road network. Note that when the CFVD system derives the travel time, it always refers to the last handover zone that was crossed. As such, the travel times of vehicles are therefore related to the time instants at which they leave the considered road section (i.e., 'exit times').

Within this project, section-based travel time measurements were collected using GSM probes in collaboration with Proximus. All motorways as well as the major regional and urban roads were covered (see also Figure 2).

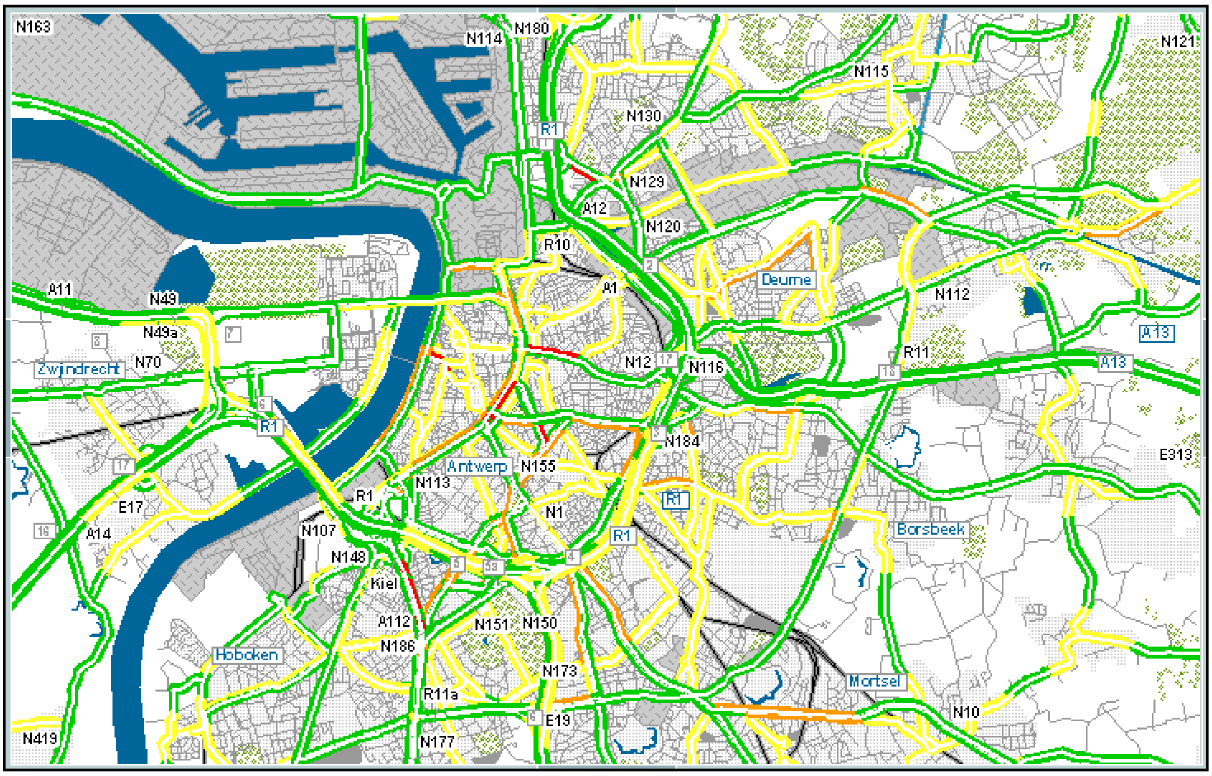

Figure 2: Overview of the CFVD deployment in the Antwerp region.

The remainder of this paper sketches the approach taken in our validation study, after which we show some observations and interpretations. The paper ends with conclusive remarks on the CFVD technology, and future perspectives.

2. Validation methodology

In order to assess the quality of the results from the CFVD system, a validation was performed that compared the CFVD measurements to independent traffic sources, i.e., a ground truth embodied by measurements performed by GPS probe vehicles driving on October 16 (Monday) and 17 (Tuesday) 2006, and measurements stemming from single loop detectors embedded in the roads.

The validation methodology entailed different types of comparisons [LM06]: travel times measured on short motorway sections (from several hundreds of metres to a few kilometres), on longer motorway stretches (some kilometres long), and on urban and regional roads containing signalized and unsignallized intersections (see also Figure 3 for an overview of the trajectories used in the study). Furthermore, the validation considered how well the mean speeds on these sections are estimated in comparison with the measurements recorded by the single loop detectors. These mean speed estimations are subsequently used to detect traffic regimes, based on a comparison with GPS measurements which act as a ground truth reference.

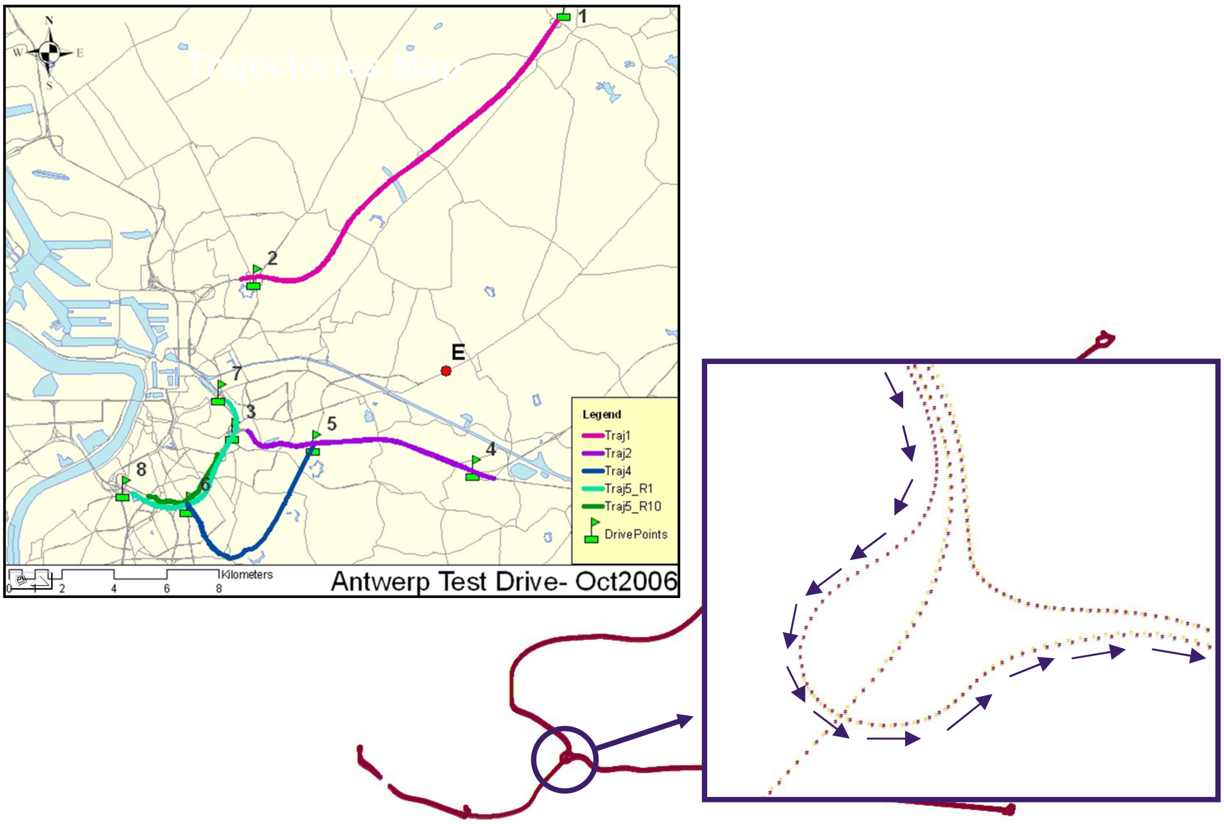

Figure 3: Layout of the trajectories used for the test drives of the GPS probe vehicles. The GPS probe continuously records its position (i.e., every second) which is then matched onto a map. As such, experienced travel times are acquired by a vehicle floating within the traffic stream.

3. Observations and comparisons

In this section, we compare the observations based on different traffic data sources with those of the CFVD system. In order to do this, we have constructed various travel time estimations based on different types of trajectories. We also compare the mean speeds calculated by the CFVD system and those recorded by the single loop detectors.

In the following, we first present the results of three travel time estimation methods, applied on short motorway sections (the results are similar for the complete trajectories in Figure 3), and we give some results on the estimations of mean speeds by both the CFVD method and the single loop detectors.

The methods that compare the travel times are [Mae06]:

(1) **GPS test drives**: test drives with GPS-equipped probe vehicles.

(2) **Inverse loop speeds**: a travel time estimator based on the speeds measured at two loop detectors. The method uses the recorded mean speeds from the loop detectors. Travel time is calculated as the inverse of these mean speeds. The results from the upstream detector are used for the first half of the section, while the downstream detector is used to estimate the travel time at the second part of the section.

(3) **CFVD**: the mobile phone generated travel times that we want to evaluate.

The different methods all produced travel times in intervals of five minutes. The results are depicted in Figure 4, and cover a section of the E19 (belonging to trajectory 1). This motorway is located in the north of Antwerp and we look at traffic that enters the city, i.e., the southbound direction.

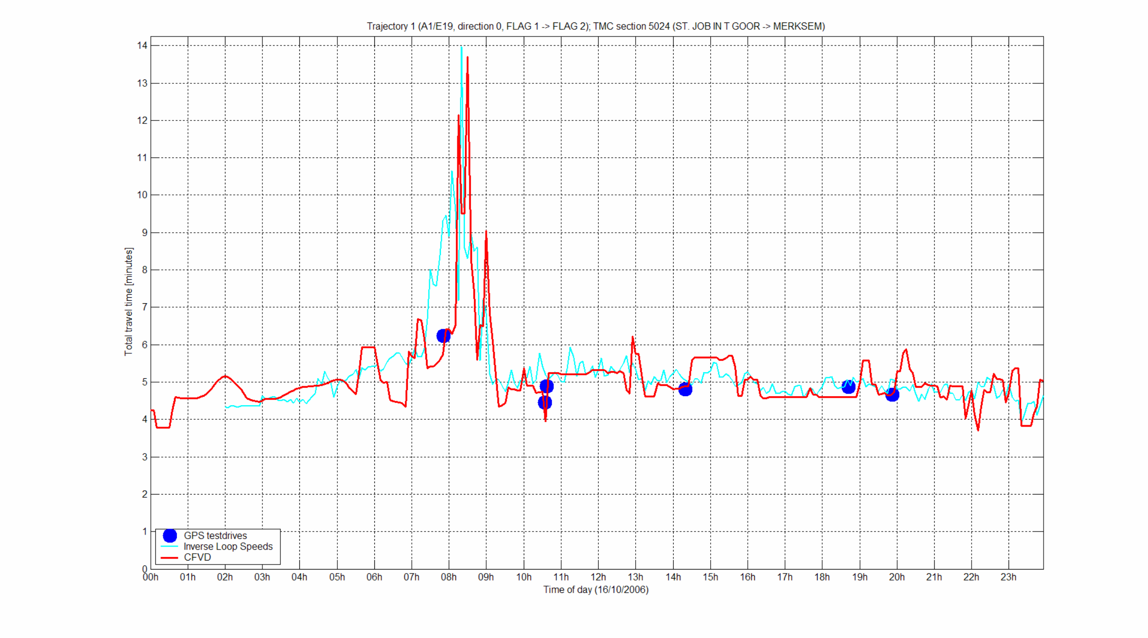

Figure 4: Travel times between St. Job in 't Goor and Merksem on the E19 at the 16th of October.

From the Figure, we can see that the CFVD data, plotted in red, shows free-flow traffic conditions with travel times below 6 minutes for most of the day. An increased travel time occurred between 07h00 and 09h15 with more than doubled travel times around 08h15.

The GPS test drives match very good with the CFVD data. All the six test drives experiences the same travel time as produced with the CFVD data. It should furthermore be noted that two test vehicles passed the section around 10h30. The similar driving style and the short time gap between them resulted in a small travel time difference.

The horizontal time axis states the time that vehicles leave the considered section for both the GPS test drives and the CFVD. The "Inverse loop speeds" differs slightly. Based on the two measured speed values at a time instant, the travel time only estimates the average travel time at that moment on the section. This must be taken into account when looking to the onset of congestion within the different methods. The loop-based travel times increase much faster. Just before 08h00, we already see a doubled travel time. The further evolution during congestion is quite similar with the CFVD. The loop detectors give fewer variations in the travel times than the CFVD method. The former calculate averages while the latter uses only a sample of the total traffic flow. Because traffic itself is very heterogeneous, the CFVD method leads to relatively more variations.

Considering the performance of the CFVD system when dealing with urban and regional roads, we note that there are two typical characteristics of these road types: (1) they have a lower speed limit (e.g., 50, 70, or 90 km/h), and (2) they contain both signallised and unsignallised intersections.

A typical evolution of the travel time in this case can be seen in the graphs in Figure 5. Whereas the previous results indicated a quite stable travel time, this is now no longer the case. Consider for example the top-left graph, based on measurements on trajectory 4, direction 0, October 17th. Between 07h00 and 19h00 the travel time has a mean located around some 15 minutes, but its minimum and maximum values lie around 10 minutes and 22 to 28 minutes, respectively. Although the mean travel time (regardless of the fluctuations) is relatively constant, its actual value jumps a bit erratically up and down. We can explain this behaviour by taking into account the local geographical layout of the road stretch. Vehicles that have a sequence of green lights, have rather low travel times, whereas vehicles that need to stop frequently encounter rather high travel times. The GPS probe vehicles show this rather well; one blue dot corresponds to a vehicle that represents the average travel time of the traffic stream, whereas the other blue dot (with the higher travel time) corresponds to a vehicle that needed to slowdown/stop more frequently.

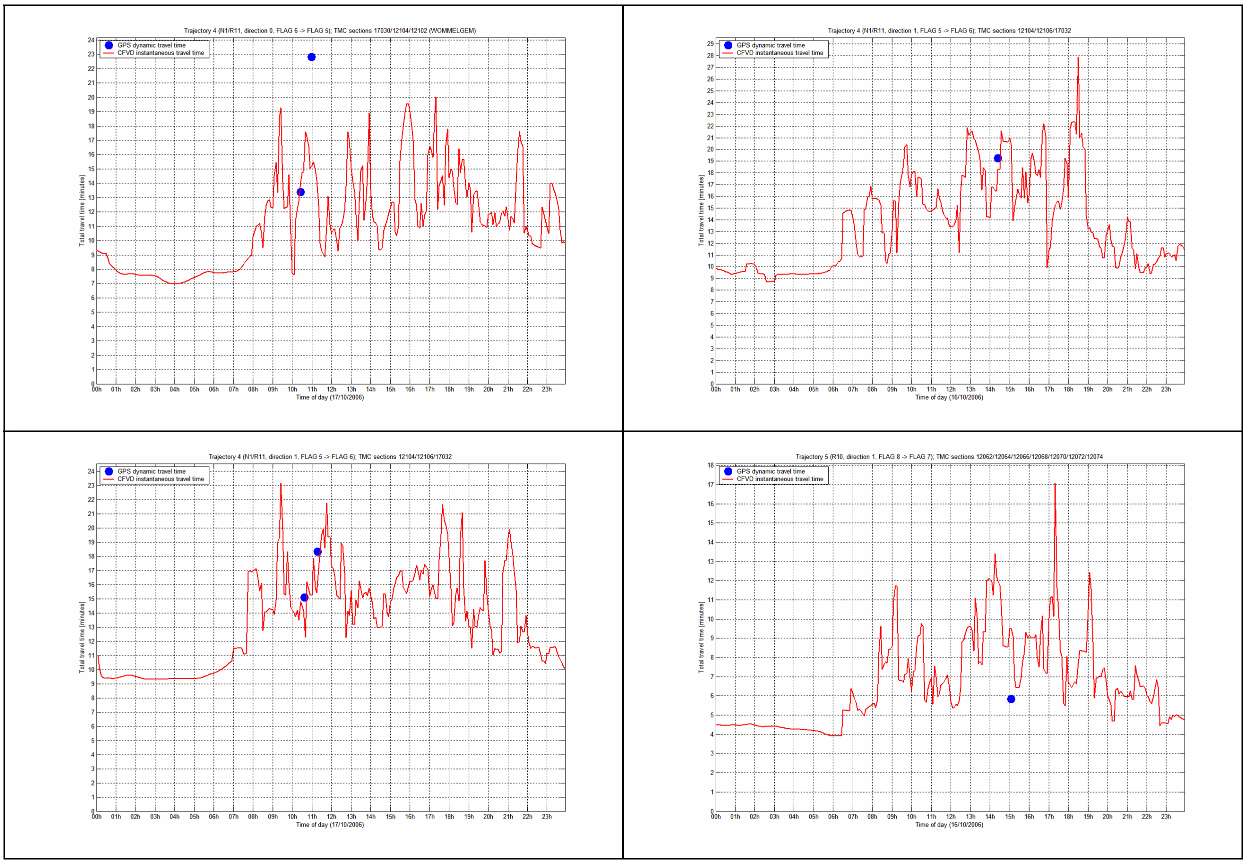

Figure 5: Evolution of the travel times on trajectory 4, direction 0, October 17th (top left), trajectory 4, direction 1, October 16th (top right) and October 17th (bottom left), based on three consecutive TMC sections, and trajectory 5, direction 0, October 17th (bottom right). Notice the large degree of variation around the mean value of the travel time. Note that the small amount of GPS measurements (blue dots) is compensated with an increase in the number of experimental comparisons.

The other graphs in Figure 5 exhibit similar results: the CFVD system is able to correctly capture the large variations in the real experienced travel times. The results from the GPS probes indicate that the CFVD system gives a good reproduction of these actual travel times. However, we should note that in our experimental setup we did not have a sufficient number of GPS probes to fully validate the range of CFVD travel time observations (although we compensated this with in an increase in the number of experimental comparisons). Furthermore, the lack of loop detectors makes it difficult to compare the CFVD observations with reference measurements.

Next, we present results with respect to the mean speeds reported by the loop detectors and those calculated from the CFVD system by means of the corresponding inverse travel times. Using an exponentially weighted smoothed averaged value of both the measured loop speed and the CFVD speeds, we get the results as presented in Figure 6.

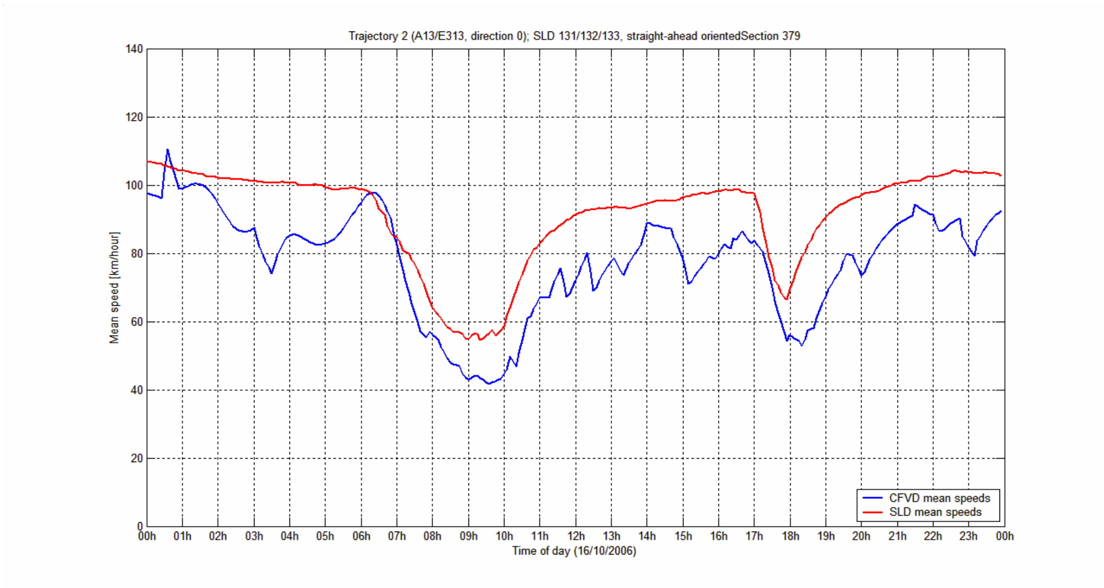

Figure 6: Illustrative time series showing the evolution of the mean speed as given by the CFVD system (blue line) and those measured by the average of the single loop detectors 131, 132, and 133 (red line) on October 16th, 2006.

From the Figure, we observe a good agreement between the evolutions of both CFVD and SLD mean speeds. Both curves show the same significant drops of the mean speed, so they accurately capture the onset of congestion. Furthermore, two other observations can be made:

- In general, the mean speeds from the CFVD system are lower than those of the SLD system. This can be explained by the fact that data stemming from single loop detectors essentially correspond to point measurements, whereas the data from the CFVD system are based on a certain spatial region. As such, single loop detectors deliver the spot-mean speed (i.e., the time-mean speed), as opposed the CFVD system which correctly reports the space-mean speed. Hence, detectors overestimate the mean speed, which does not happen in the CFVD system.

- The CFVD data shows more fluctuations than the SLD data, which remains more or less constant for longer time periods (the blue curve in Figure 6 shows more undulations than the red curve which has longer stationary periods). The reason for this difference is probably that the loop detectors calculate an average of all recorded vehicles during a minute, while the CFVD system only uses a sample of the total traffic flow. The correlation plot in Figure 7 shows each recorded SLD mean speed on the horizontal axis, and each corresponding CFVD mean speed on the vertical axis. From the Figure, we can see that the majority of the data points lies underneath the slanted black line, indicating that the CFVD mean speeds are lower than those of the SLD mean speeds, which is as expected. Also note that the cloud of data points is more or less nicely spread out along the slanted black line, indicating a large positive correlation between both SLD and CFVD mean speeds. Regarding the number of data points, we can also see that there were more observations of free-flow traffic (i.e., mean speeds around 100 km/h) as opposed to congested traffic.

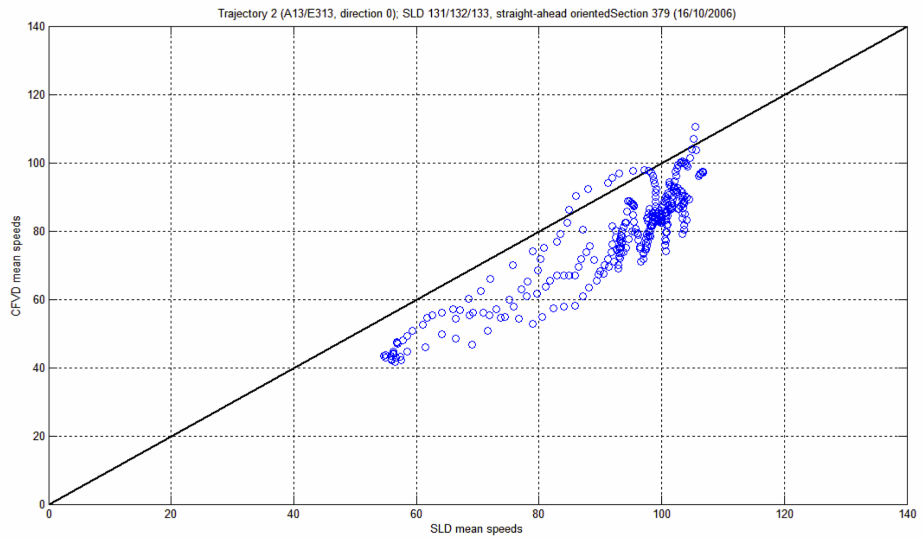

Figure 7: The correlation between the SLD (horizontal) and CFVD (vertical) mean speeds for the mean speeds shown in Figure 6. The black line corresponds to the ideal match.

In conclusion, we can make the following summary of our observations, with respect to a comparison of the mean speeds from the CFVD system and those recorded by the single loop detectors:

- In general, the CFVD measurements give quite reliable estimations of the mean speed, albeit for a spatial region (as opposed the SLD point-measurements which are actually estimations based on a presumed fixed vehicle length).

- A typical observation of CFVD measurements is that the mean speeds contain rather large fluctuations, even after smoothing. This makes the use of raw data limited, especially with respect to the short term: using and reporting mean speeds (or journey times, which are closely related to them) should be done with extreme care, as the data exhibits a large variation on the short term, even though its trend is more or less accurate.

- Depending on the type of application, it is recommended that if the CFVD mean speed data is to be used for real-time purposes, it should be merged with other data sources due to the noisy character of the measurements. If it to be used in a statistical manner, then we advise the use of an initial smoothing process.

4. Conclusions and perspectives

The main conclusions, after validation of the CFVD technology, are:

- CFVD is capable of capturing the onset and dissolution of congestion during, e.g., the morning and evening rush hours, giving a good agreement with the recorded ground truth travel times.
- CFVD has a very good performance for motorways. On urban and regional roads containing intersections, the CFVD system reproduces large variations in real experienced travel times. Depending on the application, this latter might require a post-filtering of the raw data.
- On motorways, the relative error between CFVD and GPS ground truth travel times is below 15% for over 70% to even 90% of the time. In relation to the instantaneous travel times from the single loop detectors, they agree for some 81% of the time within 15% of each other [LM06].
- CFVD outperforms the standard road-based detectors such as single loop detectors due to the fact that it can provide a more realistic magnitude of the real mean speed of the traffic flow. This

is a strength of the CFVD system, as it observes travel times directly instead of mean speeds; these latter become quite unreliable at lower speeds during congestion, and they are systematically overestimated by road-based detectors.

- In contrast to the standard road-based detectors in use at the moment, the CFVD technology gives a much better coverage of the underlying road network.
- CFVD has a large potential in that it can provide complete traffic information, spawning a whole plethora of applications based on historical and statistical CFVD results for different potential markets.

In conclusion, we state that the CFVD system has a large and promising potential that is ready to be cultivated upon, as a stand-alone technology or in aggregation with existing road-based detectors. At this moment, it easily outperforms the standard road-based detectors such as single loop detectors that are widely used.

To governments, we believe the integration of CFVD technology with existing road-based detectors can provide detailed traffic information for future oriented traffic management, giving a much broader coverage and higher accuracy as provided by the actual infrastructure. On top, we believe CFVD has the potential for the deployment of new tools like Origin-Destination analysis, congestions index calculation and detailed statistics on congestion.

To the end consumer, CFVD can provide information with respect to congestion and travel times that is more accurate than the information based on the currently implemented standard technologies.

To navigation systems, CFVD, in combination with appropriate post-processing, is suited to provide real-time traffic information with travel times, allowing to improve the comfort for the driver and the estimation of his arrival time.

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