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Motorway speed pattern identification from floating vehicle data for freight applications

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ABSTRACT

Nowadays, the diffusion of in-car navigators, location-enabled smartphones and various reasons for tracking vehicles – either for insurance and recovery, fleet management or for electronic tolling – are making floating car data (FCD) a leading solution for traffic monitoring. In the next years, this solution might be much more strengthened by the introduction and diffusion of black boxes, installed on commercial or private vehicles devoted to monitor or validate new safety technologies (e.g., the automatic in-vehicle emergency call service eCall in Europe).[1] FCD, possibly integrated with data coming from infrastructure-based monitoring systems, represents a valuable platform for intelligent transport systems (ITS). Traffic monitoring based on FCD relies on a processing algorithm for aggregating the measured data into an accurate and complete traffic map. In this paper we present an experimental study on FCD processing based on a unique large amount of data in Italy, provided by heavy-duty vehicles used as probes over the Italian A4 motorway. A processing procedure is proposed for identifying the typical speed patterns, to be used as baseline for automatic anomaly detection, transport planning or traffic analysis applications. A first assessment based on real traffic-event information shows that the comparison of the probe data to previously identified historical speed patterns allows a clear detection of anomalous events.

1. Introduction

Monitoring technologies based on probe vehicles have been emerging, in recent years, both as self-working solutions and in cooperation with infrastructure-based systems (Yoon et al., 2007; Kerner et al., 2005; De Fabritiis et al., 2008; Wei et al., 2007). Floating car data (FCD) systems are based on a set of probe vehicles equipped with satellite positioning and wireless connectivity – such as GSM/GPRS, UMTS/HSPA and LTE – to periodically send position-speed data to a central unit at a control room. Data are aggregated and processed by the central unit to draw the traffic information needed for the specific application. Applications range from traffic monitoring and forecasting, travel time estimation, construction of historical database to enable identification of anomalies or incident detection, fleet management, and dynamic navigation based on real-time traffic conditions (Yang, 2005; Sethi et al., 1995; Treiber et al., 2010).

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[1] More details can be found on the official website of the European Commission for Mobility and Transport, http://ec.europa.eu/transport/road_safety/specialist/knowledge/esave/esafety_measures_known_safety_effects/black_boxes_in_vehicle_data_recorders_en.htm, and of the European Parliament, http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+PV+20140225+ITEM-013+DOC+XML+V0//EN. For eCall see Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010, on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport, 6.8.2010, and Commission Delegated Regulation (EU) No 305/2013, of 26 November 2012, supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to the harmonised provision for an interoperable EU-wide eCall.

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For many services in transport systems, reliable speed data are useful to estimate or predict the travel time along a route, which is a sequence of road segments where traffic conditions usually change over time. In fleet management operations, for example, useful information for both operators and end users is the travel time for on-time pickup and delivery operations, if the freight distribution service is managed to comply with time constraints. A reliable baseline for speed data along the road network should be exploited to meet the time requirements. Furthermore, any event that may cause a delay in traffic is important to be detected in order to give update information on the speed observed along the route. In this context, the computation of typical speed patterns characterizing the traffic behavior over the various road sections and the detection of anomalies causing relevant delays are useful tools for the fleet management.

During the last years, the interest in FCD has been sensibly growing thanks to the diffusion of Global Positioning System (GPS) navigators – enhanced in Europe with the European Geostationary Navigation Overlay Service (EGNOS) - and location-enabled smartphones, as well as to the impressive surge of location-based services. An increasing number of dedicated companies/agencies is now dealing with data collection for fleet management, accident data recording, and vehicle insurance. The growing number of monitored vehicles, together with the extended connectivity provided by new communication systems (connecting vehicles to the central unit and also vehicles to vehicles) are making FCD a leading, sometimes even consolidated, solution for traffic monitoring.

One of the main problems, however, is the reliability of data collection which may be limited by the local penetration rate. In probe systems, sampling of traffic parameters is non-uniform and also time-varying due to the probe mobility. Resolution depends on a combination of factors including number of probes, traffic demand patterns, traffic conditions and road features (Kwon et al., 2007; Vandenberghe et al., 2012; Herrera et al., 2010; Rahmani et al., 2013; Fangfang et al., 2013). In such a complex scenario, data processing represents the key engine for integrating the sparsely sampled data into accurate and reliable traffic information, overcoming as much as possible the limits due to low penetration rate and/or non-uniform sampling.

In this paper we focus on processing of floating truck data (FTD) collected by a fleet of heavy-duty vehicles over the Italian A4 motorway, connecting Turin to Venice. We propose a procedure for the computation of mean speed patterns characterizing the typical traffic conditions along the road, to be used for construction of historical database and for detection of anomalous traffic events. GPS position-time measurements provided *locally* and *instantaneously* by single vehicles are processed to estimate the *mean* speed that results from aggregated vehicles in each road segment and each timeslot. Different methods based on the study of traffic daily patterns have been proposed in the literature (Rakha et al., 1995; Wild, 1997; Chrobok et al., 2004; Chung, 2003; Kerper et al., 2011) using data coming from either probe vehicles or loops. The analysis considered in this paper, based on probe vehicles, is particularly challenging as the available dataset relies mainly on truck measurements, it has moderate dimensions (3 months) and low penetration rate (estimated around 0.25% in capacity condition), resulting in a fragmented observation of the velocity field. To overcome this limit, we propose to estimate the typical velocity profile in each road segment using a clustering procedure that exploits data from probes in different segments, relying on the fact that speed profiles usually share common features over large sections of the road. A preliminary analysis is carried out to select reliable vehicle data, match the data samples to the road segments and compute the mean speed. A clustering procedure based on the Ward's method (Weijermsrs et al., 2005) is then applied for aggregating the road segments into homogeneous classes of speed trends and compute the typical speed profile associated to each class of segments. We also propose to exploit these typical profiles as reference for detection of anomalous traffic conditions and unusual events causing relevant delays.

Our main aim is to ascertain if typical speed patterns can be identified, even in scenarios with a fragmented observation of the velocity field due to low penetration rate, relying on the fact that speed profiles often share common features over several road segments. This basic idea allows the computation of a reliable set of speed profiles using a conventional clustering approach as the Ward's method. Other methods could be tested as well, but the evaluation of their performance is out of the scope of this paper, as the focus here is on the overall procedure not on the specific clustering component.

Even though the analysis is based on truck measurements and thus restricted to working days where heavy traffic is allowed (week-ends or holidays are excluded), the proposed method can be easily applied to extended datasets including also other vehicle-type data, if available from other sources. The analysis is validated using information broadcasted by the national provider of road traffic information, named CCISS (*Centro di Coordinamento Informazioni sulla Sicurezza Stradale*), by collecting all the anomalous events registered by CCISS over the considered motorway. The comparison to CCISS data shows that the anomalies recognized using the reference profiles correspond to real congestion events, confirming the reliability of the proposed approach.

2. Data analysis: method and procedures

The analysis herein considered is based on FTD provided by a system designed and managed by the Italian company W.A.Y. (Torino, Italy). Data are collected by an operation center which has got one of the most extended databases in Italy in this field; it receives signals from various fleets equipped with on-board devices, for a total number of more than 13,000 probe vehicles. Each road is divided in segments and data from any vehicle are mapped to a road segment only if the vehicle is localized within the Italian motorway network or an important highway, such as a ring road. The scenario considered in this paper refers to the motorways of north Italy as shown in Fig. 1. A preliminary analysis of these data has been presented in Pascale et al. (2013).