Speed profiles functional modeling for driving behavior and infrastructure evaluation

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The knowledge of the actual vehicle speeds on our roads is essential to several points : To locate blackspot in the network, to improve the knowledge of travel time and to evaluate the effects of the modification of the infrastructure (addition of speed bumps, roundabouts, ...). In addition, the development of speed adaptation systems (ISA) [1] requires the use of a reference speed profile that may optionally be adjusted according to weather conditions [4] or driving style (e.g. ecodriving). However, the crucial question is "What reference speed should be choosen : design speed (based on road geometry), operating speed (e.g. V85), speed limit, ... ?" [3]. Each of these three examples have limitations : speed design requires a lot of information on the road (slope, curvature, ...), operating speed like average or 85th percentile provides only a single profile whatever the driving conditions, and speed limit is just an upper bound.

Our answer is a statistical approach based on driver's behaviour. Indeed, the speed choice of drivers is one of the most important components of their behaviour and also their road usage [5] [2]. Thus, we propose to use repeated measurements of actual speeds measured by probe vehicles and to develop a statistical methodology to produce several reference space-speed profiles, each adapted to driving conditions (red or green light, free trafic or congestion, ...).

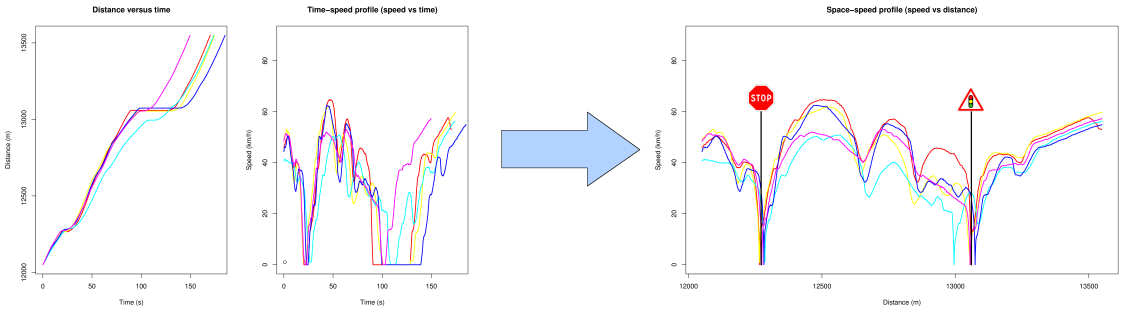

Figure 1: Consistency between the three spaces : [distance vs time, speed vs time] and [speed vs distance].

The originality of our approach is to treat speed profiles as functions and not as $\mathbb{R}^n$ vectors. So we take inspiration from "Functional Data Analysis (FDA)", a statistical domain that has developed considerably over the last twenty years [6]. However, the main difficulty is to ensure correspondance between speed and position (and implicitly time), in order to preserve the dynamic characteristics of a valid speed profile (*figure 1*). So we define mathematically the space of space-speed profiles (i.e. speed vs distance functions) as follows :

Definition 1. *Let x_f and $T \in \mathbb{R}^+$ and $F : [0;T] \longrightarrow [0;x_f]$ an increasing function of class $\mathcal{C}^2$ with $F(0) = 0$. We denote F^{-1} the generalized inverse of F defined by :*
$F^{-1}(x) = inf\{t \in [0;T], F(t) = x\},\ x \in [0;x_f]$.
Then the space of space-speed profiles is defined as follows :

$$\mathcal{E}_{SSP} = \left\{v : [0;x_f] \longrightarrow \mathbb{R}^+ \quad such\ as \quad v(x) = F'(F^{-1}(x)),\ x \in [0;x_f]\right\}$$

Then we look for the best representation of the raw speed profile belonging to this space. Dues to uncertainties in the measurements of speed and position, there is need of use a smoothing procedure in an attempt to filter out this noise as efficiently as possible.

Firstly, in order to improve the quality of the raw data and consequently the quality of smoothing, we developed an unbiased estimator of position with minimum variance from the GPS and odometer data. Secondly, we proved that performing smoothing in the distance-time space was the most appropriate and we used spline smoothing based on the minimization of the penalized least squares criterion :

$$\sum_{i=1}^{n}\{(y_i - F(t_i))^2\} + \lambda \int (F"(t))^2 dt.$$

We plan to expand this criterion by introducing speed information. For example, we could use GPS-Doppler speed measurements which don't directly result from differentiation of position data over time.

Further work is focused on the building of reference speed profiles adapted to context and driving situations by using unsupervised classification methods (*figure 2*). We also focus on the impact of some fixed elements of the infrastructure (e.g. stop, roundabouts) on the reference speed profile.

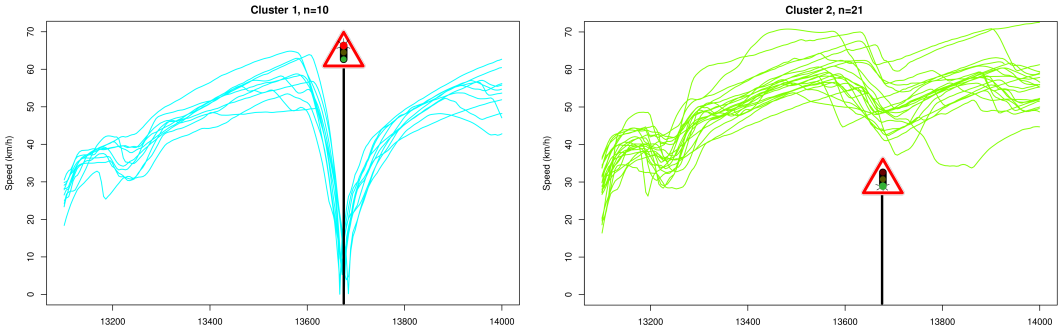

FIGURE 2: Classification of real speed profiles when crossing a traffic light : cluster 1 corresponds to red light, cluster 2 corresponds to green light.

Références

[1] J. Ehrlich. Towards isa deployment in europe : state of the art, main obstacles and initiatives to go forward. In *Proceedings from the 2009 Intelligent Speed Adaptation Conference, Sidney*, 2009.

[2] E. Ericsson. Variability in urban driving patterns. *Transportation Research Part D*, Volume 5 :337–354, September 2000.

[3] K. Fitzpatrick et al. Design speed, operating speed, and posted speed practices. *Publication NCHRP Report 504, Transportation Research Board*, 2003.

[4] R. Gallen, N. Hautière, and S. Glaser. Advisory speed for intelligent speed adaptation in adverse conditions. In *IEEE Intelligent Vehicles Symposium (IV'10), San Diego, California, USA*, pages 107–114, 2010.

[5] A. Laureshyn. Automated video analysis and behavioural studies based on individual speed profiles. In *Proceedings of 18th ICTCT, Helsinki*, October 2005.

[6] J.O. Ramsay and B.W. Silverman. *Functional Data Analysis, Second Edition.* 2005.