Environmental assessment of signalized arterials based on GPS-trajectories

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INTRODUCTION

Current guidelines on capacity analysis at traffic signals such as HCM 2012 and HBS 2001 (Germany) describe traffic performance by a number of quantitative measures such as delay, queue storage ratio and number of stops. For signalized arterials additional adjustment factors are applied to model the impact of co-ordination and through traffic arriving at green. However, this set of single performance measures do not relate directly to fuel consumption and air pollution. Since environmental performance measures become more important in decision making of traffic signal control there is a need for reliable indicators. In order to gain individual vehicle emissions the most common method are measurements of given driving cycles on a chassis dynamometer. Alternatively, the data can also be acquired using microscale models such as PHEM (Passenger car and Heavy duty vehicle Emissions Model) [1]. This paper presents a simplified method to estimate the environmental impact of co-ordinated traffic signals based on single vehicle trajectories.

METHODOLOGY

While optimizing traffic signals with respect to Green House Gas (CO_2) and toxic emission it is neither feasible to reiterate runs on the dynamometer nor to apply PHEM. A simplified method is proposed which uses GPS tracks as input. First the trajectories are used to gain kinematic data. The correlations between kinematic and environmental values are tested. In a second step the level of co-ordination is checked in a sequence of traffic lights.

Selection of appropriate kinematic parameters to assess environmental performance indicators

In order to describe single vehicle dynamics, [2] [3] [4] and [5] proposed a set of kinematic parameters ranging from kinetic energy to acceleration noise (Table 1). We have tested the correlation between these kinematic parameters and emission based values such as FC (fuel consumption) NOx (Nitrogen Oxide), CO (Carbon Monoxide) and PM (Particulate Matter) using single as well as multivariate linear regression. The method of least squares was applied to approximate a solution in such over-determined system. As test data we analyzed about 400 single GPS-trajectories of 7 different arterial roads within the city of Graz, Austria. For each trajectory the emissions were computed by PHEM. The accuracy of the emission calculation has been proven in several European research projects and the widely used HBEFA (manual on emission factors). The quality of emission calculation is not questioned in this study.

Segmentation of arterial for identification of quality of co-ordination

In order to identify the quality of co-ordination each arterial with a set of 5 to 10 intersections is divided into individual segments. Each signalized intersection defines a segment boundary. A unique method is applied to identify the boundary points in detail. While other studies usually use stop lines as boundary delimiter we applied the first position after each signalized intersection where accelerating vehicles have reached its desired speed and no significant accelerations can be observed anymore. The position is averaged between all vehicles accelerating after the stop line. A segment between two such points is called zone of influence (zoi as in figure 1). Zones of influence contain all deceleration and acceleration maneuvers of its embedded intersection, while stop line to stop line segments contain the acceleration process from the previous intersection. Stop line based segments would distort the emission calculation as acceleration related emission surplus would be assigned to the downstream intersection.

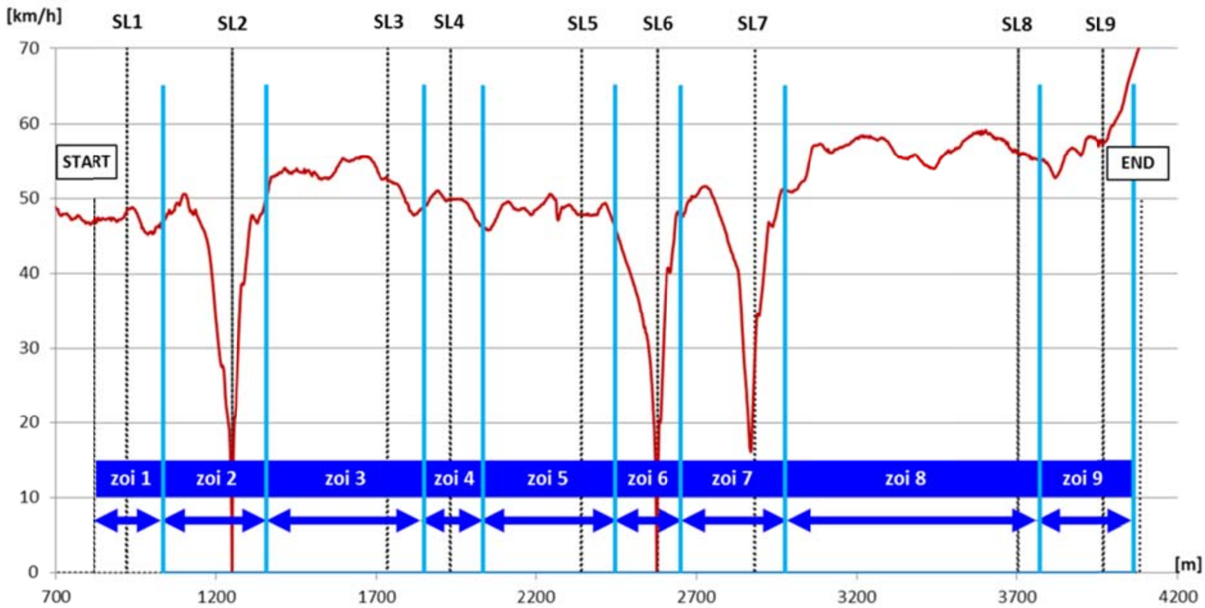

Figure 1: Representative GPS-track for an arterial road incl. stop lines (SL) and zones of influence (zoi) per traffic signal

Figure 1 illustrates a representative GPS track for an arterial road as well as the nine existing stop lines (SL1-SL9) and nine respective zones of influence (zoi1-zoi9); one for each traffic signal. The number of stops is automatically detected by analyzing speed thresholds within the GPS-trajectories. Additionally manual recordings were conducted to identify also the reason of a stop such as insufficient green time, uncoordinated offsets or spillback at end of Green. Subsequently, the number of stops can be assigned to the zone of influence (Figure 1) and therefore matched to a specific traffic signal. The emissions and kinematics are computed for each zone of influence individually. The sum of indicators per direction is used as a performance indicator of co-ordination quality.

RESULTS AND DISCUSSION

In terms of the quality assessment of arterial roads, the highest correlation with FC was achieved with the average travel speed, with an explanation of about 84%. The coefficient of determination R^2 ranges for NOx, CO and PM between 75% and 82% (Table 1). Thus, if a quick environmentally induced performance measure is needed, travel time is better suited than any of the other kinematic values which can be computed from GPS-trajectories. Within the given limits of urban speeds, higher average travel speed will lead to decreasing fuel consumption.

Table 1: Results of correlation analysis between kinematic indicators and emission based values

Kinematic indicator	adj. R^2 of FC	adj. R^2 of NOx	adj. R^2 of CO	adj. R^2 of PM	Avrg. R^2
Average travel speed	84%	76%	75%	82%	**79%**
Average travel speed without waiting time	75%	66%	67%	78%	**71%**
Positive kinetic energy (PKE)	1%	0%	0%	2%	**1%**
Summation of PKE	1%	0%	0%	2%	**1%**
Travel speed dependent on delay time	3%	3%	3%	3%	**3%**
Average positive acceleration	55%	69%	72%	49%	**61%**
Average positive acceleration of entire arterial	24%	38%	42%	22%	**32%**
Summation of positive acceleration	12%	13%	15%	11%	**13%**
Percentage of positive acceleration of entire arterial	2%	2%	4%	4%	**3%**
Number of stops	47%	43%	46%	45%	**45%**
Acceleration noise	37%	53%	53%	33%	**44%**
Relative positive acceleration (RPA)	60%	74%	75%	54%	**66%**

For multivariate linear regressions the combination of the average travel speed and the RPA reaches the highest coefficient of determination with 87% in correlation with FC with the corresponding regression equation:

$$FC = 86.04 - 3.64\, average\ travel\ speed + 8.88\, RPA \qquad (1)$$

In a next step a level of service concept was applied based on six levels A-F. The thresholds for the LOS-categories are calculated by cluster analysis using *Partitioning Around Medoids* (k-medoid). Figure 2 shows the LOS boundaries based on average travel speed. The classification boundaries of the environmentally induced method are narrower compared to HCM.

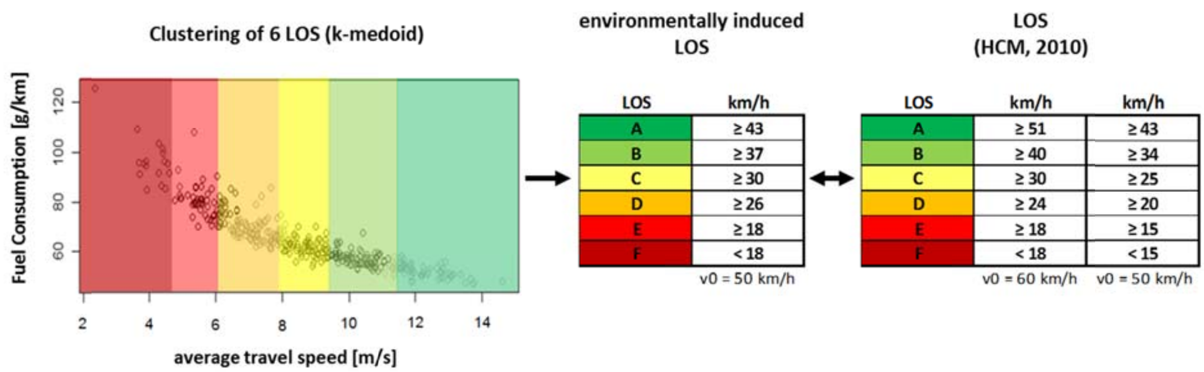

Figure 2: Clustered LOS categories and comparison of environmentally induced LOS and LOS of HCM

A quality assessment of the signal control based on the average travel speed is limited, since this parameter is influenced by many other factors like the driving behavior, platoon dispersion, geometric influences, curvature and gradient which are not directly attributable to the signal timing plan. Environmental assessment of traffic signal control in German speaking countries is often based on stop ratios [6]. The stop ratio is used as suitable indicator of co-ordination quality as it reflects the percentage of unhindered through movements at urban arterials. While the number of stops are easily extracted automatically from the GPS trajectories, the reasons of a stop can only be generated by manual assistance.

Besides the reason of a stop all other kinematic data and its environmental surrogates can be processed automatically. With the upcoming availability of massive GPS-trajectories it will be easier to evaluate the quality of traffic signal coordination. Several cities need to reduce traffic related emissions in order to meet the European Directive 2008/50 on ambient air quality. The proposed method has been verified in Graz on various arterials to estimate emissions based on automatic processing of GPS-trajectories.

The final presentation will include:

a) Details of single and multivariate linear regressions including t-tests
b) Alternative surrogates for environmental analysis
c) Method to allocate acceleration point as thresholds by averaging a set of trajectories
d) Comparison of results of “zone of influence” and “stop line to stop line” segmentation
e) Details about determination of number of stops

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