Automated video analysis and behavioural studies based on individual speed profiles

Aliaksei Laureshyn

Lund University, Lund Institute of Technology,
Department of Technology and Society, Traffic Engineering Division
Box 118, 221 00, Lund, Sweden, tel. +46 46 222 91 31, fax +46 46 12 32 72
aliaksei.laureshyn@tft.lth.se

Abstract

Road user's speed in traffic environment is a very informative and widely used parameter in behavioural studies. Automated video analysis system is a relatively new tool, which provides a researcher with continuous data on position and speed of the road users, passing the video-observed area. The additional information contained by continuous speed data (speed profiles) allows for more sophisticated analysis, which can affect the way the research work is planned and performed. An overview of some research studies shows that quite a wide range of speed-based indicators is currently used, while there is lack of proper discussion on their validity. A short test study illustrates the practical applicability of the speed profiles data from video analysis system.

Keywords: Automated video analysis, Behavioural studies, Speed profiles, Traffic safety

Introduction

Road user's speed in traffic environment is a very informative and thus widely used for behavioural studies parameter. Most of the conventional instruments (e.g. radar guns or loop detectors) can provide only spot measurements of speed; the continuous speed data, however, is more informative since based on it more complex speed-based indicators can be calculated (e.g. speed variation over a passage, acceleration, travel time, etc.). Such data is obtained, for example, from special speed-recording equipment installed in a vehicle. These measurements provide data for a single vehicle/driver over a relatively large distance driven; in some cases the researcher might be more interested to limit the study area to a certain element of the road infrastructure (e.g. an intersection), but have instead a larger population of road users belonging to different categories studied (not only drivers, but cyclists and pedestrians as well).

The use of video recordings can help to make such studies. The increased knowledge and experience in the video analysis make it practically possible to automate this process, thus allowing collection of continuous (as long as a road user is within the camera's view) speed data with reasonably low time consumption and costs.

Even though the first attempts to use automated video analysis for traffic applications goes back to 1980s [*Kastrinaki, 2003*], the numerous limitations of the earlier systems resulted in that their practical use for behavioural studies was not in focus and thus not discussed much in literature. However, as technology develops, a researcher gets better opportunities for more sophisticated analysis, which in its turn affects the research planning both on strategic and practical level.

The purpose of this paper is to discuss the possible applications for the speed data, obtained from an automated video analysis system, can be used. The first part contains a short description of what is meant by automated video analysis system; the second part contains a discussion on the role of speed as a behaviour descriptor and the ways to treat speed profiles data, followed by an overview of some research studies which involved speed data analysis; the last part presents a test study, where speed profiles obtained from a video recordings on an urban intersection are used to describe the behaviour of the drivers passing a pedestrian crossing.

Automated video analysis as a research tool

Video recording is a commonly used tool in the road traffic research work [*Malkhamah et al., 2005, Andersson, 2002*, *Svensson, 1998*]. It gives many advantages, such as lower interference with the traffic processes compared to a roadside observer, possibilities to look through the important situations over again, etc.

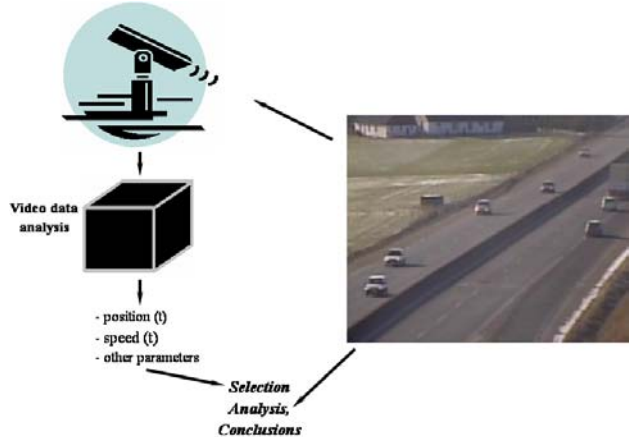
However, making exact measurements from video records manually is quite a mundane and resource-demanding work. Even semi-automation systems [e.g. *Andersson, 2002, Archer, 2005*], which require mouse-clicking the positions of moving objects frame after frame on a computer screen, implies hours of work (for example, *Archer, 2005* describes the ratio between the time spent on manual data input and the observation time as 10:1), while the accuracy is still limited by some arbitrary decisions taken by an operator (e.g. if certain parts of a vehicle are elevated over the ground-level they have to be projected "by eye"). This seriously limits the length of the observation period which practically can be proceeded and explains the fact that in most of research studies with involvement of video recordings the video films were rarely used as the main data source, but rather as an illustrative supplement to other measuring instruments.

A logical development of the method is to automate the detection and description of moving objects by using the video processing techniques [*Kastrinaki et al., 2003, Messelody et al., 2005*]. This approach was taken as a base for the system, currently developed at Faculty of Engineering of Lund University. The principle scheme of the system is presented on Figure 1. The camera(s) is(are) set at the location of interest, and the necessary video data is recorded and stored. Then it is processed by a special computer program based on spatial correlation algorithm, which extracts spatially and temporally connected segments from a background/foreground segmentation of the video. From these trajectories a speed of the objects is estimated with high precision using sub-pixel correlation. This data can be further analysed, depending on the particular purposes of the study and the results can be compared to or validated against the other types of measurements or just by visual control.

Three main goals are set for the developed system: (i) to detect and track all road user categories (including pedestrians and cyclists) in complex situations, (ii) to identify road user behaviour and (iii) interpret and analyse their behaviour in terms of safety and efficiency. After the first year of the work the system can fairly well detect and follow vehicles (further technical details are beyond the scope of this paper).

Automated video analysis allows skipping the manual work routine, which implies that the observation periods can be extended considerably and thus much more data can be collected. By introducing more sophisticated data management and filtering procedures one can select only those situations which are of the research interest, saving time for their detection (if such cases are relatively rare, e.g. serious conflicts), as well as amount of data to be stored (which might be a considerable factor if filming is done for a long period of time). This also opens up possibilities for making studies at locations and times of the day where/when it so far has not been cost-effective.

Figure 1. The interaction of a road user with the traffic environment.



Today the application of automated video analysis in the traffic area is limited by quite simple conditions and tasks performed (e.g. detection of congestions on a motorway, reading registration plates, etc. [*Coifman et al., 1998, Ji et al., 2005, Blythe, 2005*]. However, there is a great potential for more sophisticated applications if the system can perform in more complex traffic environments such as urban conditions.

Briefly, the specific of the automated video analysis as a measuring method can be summarised as follows:

- Relatively small study area (≈100-200m);
- High dependence on the weather and light conditions;
- Dependence of the good camera location;
- Continuous measurements of the position and speed;
- Intensive data flow to be stored;
- Quite good accuracy of the measurements.

This paper focuses mainly on the treatment of the speed data (particularly speed profiles, which describe the speed of a road user over the time) obtained with the help of automated video analysis.

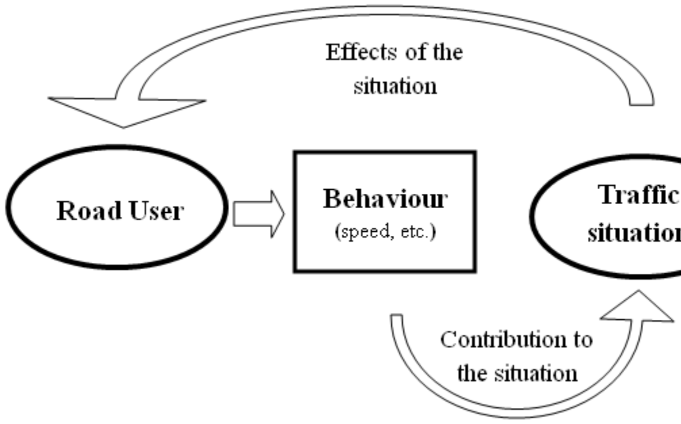
What speed data can tell us about?

The role of speed as a behaviour descriptor

Each road user reveals his/her presence in traffic by certain actions (or even absence of expected actions), which form all together the road user's behaviour (Figure 2). The behaviour is influenced by the individual characteristics of the road user (e.g. type of personality, experience, etc.), as well as the external factors, i.e. the traffic environment (situation). On the other hand, he/she is also a part of the traffic environment, at least for the other road users, and thus also contributes to the formation of the traffic situation.

Traffic environment is considered relatively broad in this context. It includes both direct and easily perceived factors (e.g. other road users' actions, traffic light signals, etc.), as well as other, more hidden but still present aspects. The latter includes, for example, the safety level (actual and perceived), mobility and accessibility dimensions, environment effects, etc.

Figure 2. The interaction of a road user with the traffic environment.



The speed choice is one of the most important components of road user's behaviour. It feels intuitively connected to many various aspects of the traffic process, however a caution should be taken as the final speed choice is not a result of one but many rather complicated factors in the chain depicted on Figure 2. Thus the validity of the speed as an indicator for a particular phenomenon should be always studied before making any conclusions. On the other hand, once the validity of the indicators is proven, the speed data gives an invaluable possibility to study both road users' characteristics and the quality of the traffic environment and its effects on the road users.

How to deal with speed profile data?

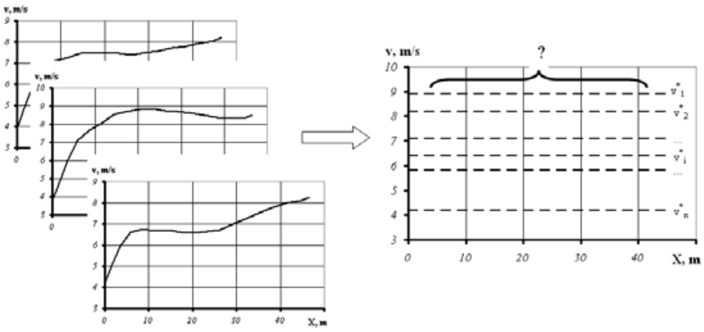
Under term "*speed profile*" further on we shall mean the dataset, describing the speed change of a road user during a certain continuous period of time. Depending on the purpose, a speed profile can be presented as a function of time – if one is interested in time relation between certain events (e.g. traffic light signal change and driver's braking) – or a function of location (distance) – in case the spatial aspects of the speed change are more important (e.g. when studying effects of the speed calming devices). Conventional measurement instruments usually relate the measured speed to just one of these parameters (e.g. in-vehicle speed loggers use time reference, while loop detectors provide speed data at fixed locations). Even though the relation between speed, time and distance is simple and well-known, it is not always possible to transfer one data type into another, thus ideally a measurement technique should allow recording both distance and time.

Analysing speed profiles actually implies managing a huge amount of data. For instance, if the measurements are produced 25 times per second (usual frame rate in video recording), one car trip through a study area having 150m in length with a speed of 40km/h (11.1m/s) will result in $150/11.1 \cdot 25 = 338$ data points. If the flow is 300 veh/h, one hour of observations will yield $\approx 1 \cdot 10^5$ data points. Other road users, like pedestrians or cyclists, as those having much lower speeds, will produce even more data. It is obvious that a certain degree of aggregation (generalisation) is necessary to avoid being buried in such data volumes.

Basically, the speed profiles data can be aggregated in two possible ways (Figure 3). The first one implies representation of an individual profile with a certain "level" indicator (average or maximal speed, etc.) This method still preserves to a certain degree individuality of the road users, allowing thus studying the variation between them; however, the temporal/spatial dimension is excluded as the parameter value is the same over the whole studied time period/road section.

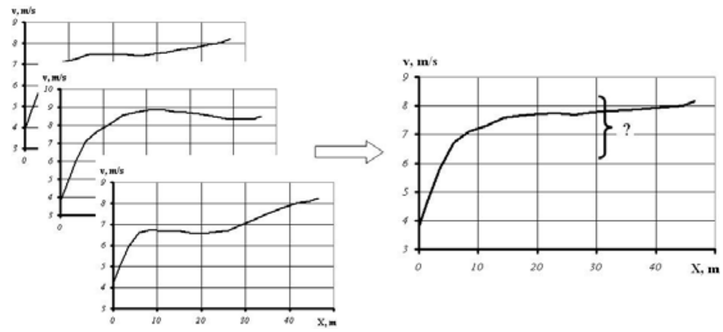
The other method, on the opposite, is based on aggregation of the individual profiles to a certain "representative" profile over the studied period (though the aggregation way can vary – average or maximal value for each point, etc.). Thus the temporal/spatial dimension is better preserved, however the variation between road users is lost.

Figure 3. Two ways of speed data aggregation.



a)

a) aggregation over the time/space;
b) aggregation over the individuals.



b)

The combination of these two methods is possible, for example the whole trip can be split into several sections for each of them a level indicator's value can be estimated.

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The following section presents an overview of several reports from the current research, in which the authors use speed data-based indicators for describing certain phenomena in road traffic. Two main questions are attempted to answer: "How the indicator is calculated?" and "What it is supposed to represent?" The main focus is set on traffic safety research, however some reports from other adjacent areas (e.g. environmental studies) were also included if the indicators used appeared interesting and contributing to the list.

Current speed-based indicators – an overview

It has a long history in traffic safety science to associate the vehicle speeds in a traffic environment to its safety level, where a strong relation has been found. *Evans, 1991* presents results of several studies where an observed change in average speeds on rural roads (e.g. due to changes in legislative norms, both increasing or decreasing speed limits) were followed by corresponding changes in fatality rates. The Power Model, developed and validated by G. Nilsson [e.g. *Nilsson, 2004*], describes the ratio of number of road accidents before and after the changes in average speed level occurred as equal to the ratio of the average speed before and after. For injury and fatal accidents only the speed ratio should be taken in second and forth power respectively.

$$\frac{Number\_injury\_accidents_{after}}{Number\_injury\_accidents_{before}} = \left(\frac{v_{after}}{v_{before}}\right)^2$$

$$\frac{Number\_fatal\_accidents_{after}}{Number\_fatal\_accidents_{before}} = \left(\frac{v_{after}}{v_{before}}\right)^4$$

Golob & Recker, 2004 report a successful attempt to associate the type of an urban freeway crash to traffic flow characteristics, measured during 0.5 hour prior-to-crash period at a closest upstream located loop detector (the median distance 0.17 miles from the crash locations). The variety of traffic conditions were further classified into several "traffic regimes" based on mean flow rate, flow variation, flow/occupation ratio (technically the speed was not directly measured in the study, however flow/occupation ratio was assumed to be a good surrogate for it) and variation of this variable. The variation of the parameters between the lanes was also included in the classification. The flow/occupation ratio variation was represented as the difference between 90th and 50th percentiles of the cumulative curve.

Abdel-Aty & Pande, 2005 developed a classification model for detection of a crash occurrence based on the traffic data from several freeway loop detectors, located both upstream and downstream the crash location. The original input data from detectors included traffic volume, lane occupancy and average speed over 30 second intervals. Three variables based on these data, namely 5-minutes average values of traffic volume and occupancy and logarithm of 5-minute coefficient of variation (i.e. standard deviation/mean value · 100%) in speed, were further tested in the model in various combinations. The best result was obtained when using speed variation at three closest upstream-located (with average 0.5 mile in-between distance) detectors 10-15 minutes prior to the crash, predicting over 72% of the all crashes from the evaluation dataset. On the opposite, inclusion of occupancy and traffic volume variables did not improve the accuracy of the model.

Observation of the road user behaviour, particularly conflicts observation, is an alternative method to estimate safety instead of using the accident statistics. *Hydén, 1987* defines a conflict as "an observable situation in which two or more road users approach each other in time and space to such extent that there is a risk of collision if their movements remain unchanged". Originally, the Swedish Traffic Conflict Technique distinguishes serious and non-serious conflicts based on speed and TA-value of the road user who takes the evasive action (TA, i.e. Time-to-Accident is the time that remained to the accident calculated on assumption that both the speeds and courses are unchanged at the moment he/she starts the evasive action). However, since braking (i.e. deceleration) is the most common evasive action in both conflict situations and accidents (in 82-95% cases according to *Hydén, 1987*), it is seems natural to search for certain deceleration patterns, typical for conflicts/accidents, which can serve as indicators for their occurrence.

Based on the observed strong correlation between the severity of vehicle-pedestrian conflicts at a Pelican crossing (expressed as Time-to-Collision value – the time that remains until a collision between two vehicles would have occurred if their courses and speeds remain unchanged – calculated at a certain point before the crossing, under condition that the approaching vehicle speeds were relatively high – above 37 km/h) and the deceleration rate, which drivers used to avoid the conflicts, *Malkhamah et.al., 2005* conclude that deceleration is a valid safety indicator, at least for given conditions. The speed data were collected by using several loop detectors before the crossing (the furthest located 79 m from the crossing), while TA (originally PET – Post-Encroachment-Time) was calculated based on video analysis tool, which detected the time of pedestrian's and vehicle's arrival to the conflict point. In further testing of a model for automatic conflict registration using loop detectors data the following threshold values were used: > 3.0 m/s^2 for a potential conflict, > 4.5 m/s^2 for a slight conflict and decelerations > 6.0 m/s^2 were classified as serious conflicts.

In an attempt to reveal typical deceleration patterns for conflict situations *Nygård, 1999* uses vehicle-installed speed loggers' data, while the conflicts (and other braking situations) were registered by a trained observer, sitting beside the driver. The total amount of conflicts observed in the study did not allow to make any firm conclusions, however the initial results showed, that the maximal deceleration rates in conflict situations did not differ much from the deceleration while braking "normally" (-1.1 to -7.2 m/s^2 deceleration interval for conflicts, both potential and serious, compared to -2.1 to 6.2 m/s^2 interval for normal braking) and it is mostly the individual driver's style which defines the braking intensity. On the other hand, the first derivative of the acceleration – *jerk*, which describes the "suddenness" of the braking, is a much better indicator for at least serious conflicts, having significant difference in values compared to braking in the other types of situation (potential conflicts and normal braking).

In a discussion on effects of different passive speed control devices (speed bumps, cushions, etc.) *Pau & Angius, 2001* point out, that it is both the magnitude of the speed reduction and the spatial range at which the speed is affected ("influence zone") that define the effectiveness of the device. Studying the results of the speed bumps installation in Italian cities, authors produce aggregated 85% speed profiles, based on individual vehicle speed measurements done by a hidden laser traffic counter at several fixed points within 200 m range, 100 m before and after the bump location. Both 85% and mean speed values at the bump location are used to estimate the speed reduction effect, however only 85% speed, considered as a more relevant indicator (since the main purpose of such devices is to eliminate higher speeds), is used in further analysis. The influence region is estimated ranging from 30-60 m, though no exact explanations are given on how these figures were retrieved from the speed profiles.

Hydén & Várhelyi, 2000 in a study of large scale introduction of roundabouts in an urban area use mean speed at the roundabout approaches as an indicator for the effects of the re-design. The speed reduction is considered as a good safety result in itself, without making connection to more obvious safety indicators (like expected conflict or accident number). The general shapes of the aggregated average speed profiles on longer sections before and after the re-design are visually compared, as well as average time consumption is calculated based on these data. The speed profiles data were collected by car-chasing method, while speed radars were used for spot speed data collection.

ISA (Intelligent Speed Adaptation system) is an example of an active speed regulation measure, which is installed in the vehicle and thus the effects of its work might be quite spread over the space and in time. *Várhelyi et.al., 2004* uses an aggregated mean speed profile over a measurement section based on individual vehicle speed loggers' data for a study of long-term effects of ISA implementation. The reduction of the peak speed values is seen as a direct positive effect of ISA, while the changes at the sections with lower initial speeds might be considered as a compensation for the reduced peak speeds. The mean arrival speed to an intersection is used as another safety indicator. The speed distribution curve at a certain point indicates how the proportion of vehicles driving at high and low speed is affected, while the variation of speed is estimated by comparing mean and 85% values. The travel time is calculated and used as a travel quality parameter.

Drivers' compliance to the traffic light signal when crossing an intersection is an important safety parameter. However, arriving at the moment when the signal is changing (from green to red), the driver must take a decision on whether to stop or continue driving, and erroneous decision can lead to incompliant behaviour. Analysing the problem, *Köll et.al., 2004* shows that even the definition of driver's compliance to the rules depends on the distance and the current speed at the moment the decision is taken. Theoretically, if a vehicle continued with its current speed, it could either pass the intersection before the red switches on or stop, using normal braking rate. There is, however, a dilemma zone, in which the driver neither has time to cross safely nor can stop normally, thus further specification on what is compliant and non-compliant is necessary. Further alterations in speed, such as acceleration from the lower speed to the current speed level, can be included into the behaviour description, too. Authors have also developed a choice model, predicting the probability for a driver to stop at signal change, in which both the speed and distance to the crossing at the decision point are significant explanatory variables.

Ericsson, 2000 in her study of variability in urban driving patterns depending on difference in street type, driver characteristics and traffic conditions defines 26 parameters to describe an individual speed profile. The intended application of the study results was traffic emissions calculations, while the data collection method was speed logging during relatively long individual trips. These two factors determined to a large extent the selection of the parameters, which were further classified into three categories: *level measures*, *oscillation measures* and *distribution measures*. The first category includes average speed, acceleration and deceleration rates and their standard deviation. Oscillation measures describe the jerkiness of the speed profile and include the frequency of extreme values on the curve (with some extended definition – see for details the original text), integral of the square of the acceleration per number of time steps ($1/n \cdot \int a^2 dt$) and relative positive acceleration ($RPA = 1/x \cdot \int (v \cdot a^+) dt$). The distribution measures describe the percentage of time within defined speed, acceleration and deceleration intervals.

Discussion

As it can be seen from the overviewed studies, speed is a very universal indicator and is used for studying various phenomena in road traffic. Most often speed is measured on certain spots only, which is explained by the limitations of the measurement equipment available. There is, however, a tradition of collecting speed profiles data by using specially equipped vehicles with speed loggers installed. Due to certain differences in the type of data obtained (long data series for an individual vehicle), the research methods based on speed loggers cannot be directly transferred to the video analysis system, however the techniques to process the speed profile data (e.g. smoothing of the scattered data [*Bratt & Ericsson, 2000*]), as well as the indicators used are quite applicable in most of the cases.

The wide use of speed in safety studies resulted in the situation when the validity of nearly any speed-based indicator is rarely discussed, not even questioned. However the proven robust relation between a certain representation of speed (e.g. average or 85-percentile, etc.) and safety level in certain conditions does not necessarily means that the other indicators in other conditions are valid, too. The validity of an indicator is a question in itself which should always be considered when implementing new indicators.

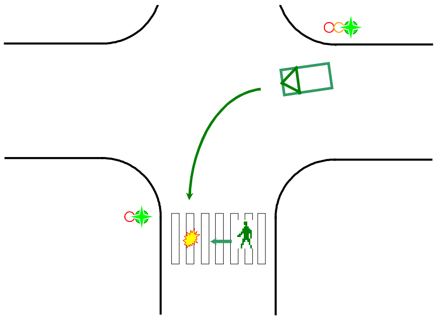
Calculation of the complex indicators puts also higher requirements to the accuracy of the speed data. For example, the mean travel speed can be easily calculated with sufficient accuracy since this indicator is averaging speed data over a relatively long sequence; on the other hand, acceleration or *jerk* values, i.e. derivatives of speed, depend very much on the accuracy of the individual data points.

The pedestrian and cyclist speed is barely used in the overviewed studies, which are focusing mainly on the vehicles' speed. However, the automated video analysis system can provides the speed profiles for other road user types as well, and proper indicators for their analysis should also be worked out. The other area to be explored is how speed profiles of several road users, moving simultaneously, can be analysed to give a description of the traffic situation development.

Practical study

The main purpose of the study, described below, was to test the applicability of the video analysis tool for studying the behaviour of road users based on their speed profiles. The conflict between left-turning drivers and pedestrians, crossing the street in the same traffic light phase, was chosen (see Figure 4). We assumed that this conflict can be seen as an example for those types of situations in traffic environment where the individual behaviour is not strictly prescribed by the rules, thus making the processes of the road users' interaction and in some way communication more important. The other reasons were the practical limitations of the tool on its current level of development and the available position for camera installation (the view was quite obscured at the other conflict points on the intersection).

Figure 4. The studied vehicle-pedestrian conflict.



a)

b)

a) studied conflict; b) the view of the intersection from the camera installation point

Method

The observations were performed during several days during afternoon time at the intersection Tornavägen-Sölvegatan in Lund, Sweden. Since both the pedestrian flow at the chosen pedestrian crossing and the left-turning vehicles' flow are not particularly high and thus the probability of an encounter between them is quite low, it was decided to increase the number of encounters with a help of an assistant who started crossing the street when noticed a vehicle showing intention to make a left turn (by using blinkers). Even though these interactions were obviously "provoked", we considered that the behaviour of the assistant, seen to the drivers, did not differ much from the other pedestrians, and thus it was assumed that this did not alter the drivers' behaviour in any other way than a usual pedestrian would do.

At the same time the intersection was filmed by a camera, installed on a high building nearby. The filmed video data were analysed by a computer program, which retrieved the moving vehicles' positions and calculated their speeds for each moment. The short video sequences showing the manoeuvre, as well as position and speed data were saved only for the vehicles, classified as making left turn (i.e. coming to the scene from the approach on the right and leaving it through the one below).

Totally, the data used included 2.5 hours of observations with an assistant, crossing the road and some longer period of observation of the normal intersection functioning.

Results

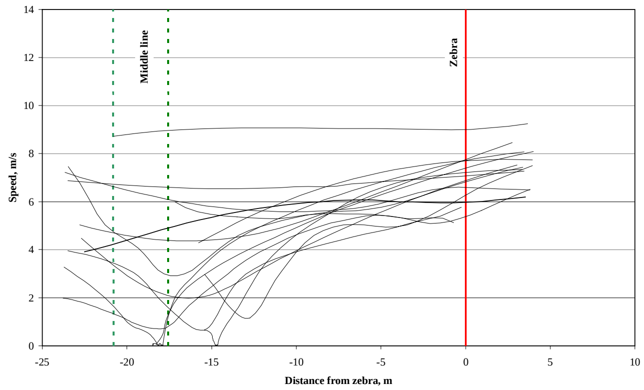
After excluding the cases when the vehicle trajectory data had obvious errors (due to poor light conditions, vehicle occlusion, noise in the image, etc.), 15 trajectories of "no-pedestrian"-turns and 19 trajectories of "pedestrian-present"-turns were used for further analysis.

The speed profiles for the selected data are presented on Figure 5*a, b.* The aggregated average speed profiles for different types of drivers' behaviour are presented at Figure 6.

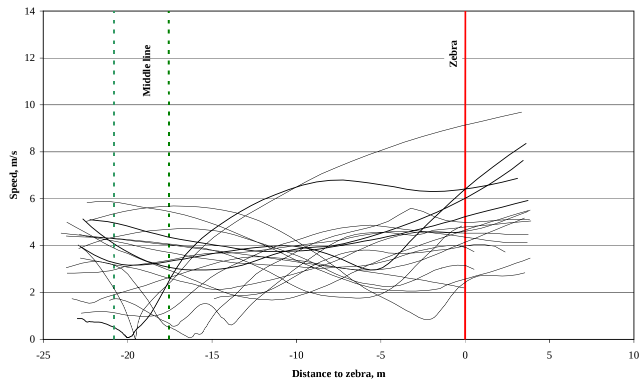
Discussion

The closer analysis of the speed profile shapes allows further classification of the drivers' behaviour. In case of no pedestrian, some drivers are forced to stop at the middle of the intersection to give the way to the on-coming traffic from the opposite direction, and then accelerate intensively and reach the pedestrian crossing at a relatively high speed (6-8 m/s). If there are no on-coming traffic, the drivers do not need to brake in the middle and drive through the intersection with approximately constant speed (5-7 m/s on the average).

Figure 5. The individual speed profiles of the vehicles, making left turn.



a)

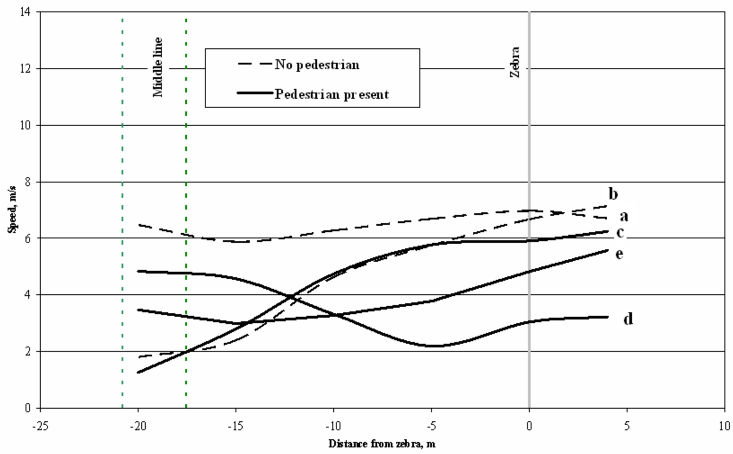


b)

a) no pedestrian;
b) pedestrian present.

In case of pedestrian presence, one can distinguish three patterns in the drivers' speed profiles. The first group of drivers were also stopped by on-coming traffic and then accelerated intensively; their speed profiles are very close to the first group of "no-pedestrian"- turns, however, the fact that the pedestrian **was** actually present, make that behaviour quite different in principle – it is more aggressive and shows less respect to the pedestrian, and in many cases the pedestrian had to stop or adjust his speed, feeling threat from the coming vehicle. The other two groups were not influenced by on-coming traffic. Among them some drivers chose to drive fast through the crossing, but then braked quite hard before the pedestrian; the other group of the drivers drove with a medium speed during the whole manoeuvre, continuously adjusting speed to let the pedestrian pass but still avoiding hard barking.

Figure 6. Aggregated speed profiles.



a) no pedestrian, pattern I: constant speed through the intersection;
b) no pedestrian, pattern II: breaking at the middle line – acceleration;
c) pedestrian present, pattern I: breaking at the middle line – acceleration;
d) pedestrian present, pattern II: high speed through the intersection - breaking before the pedestrian crossing;
e) pedestrian present, pattern III: continuous speed adjustment to avoid conflict with the pedestrian.

As mentioned before, drawing certain conclusions about the driver-pedestrian interactions was not the main purpose of this test. However, the results show that all the steps of similar behavioural studies can be successfully performed with the help of automated video analysis.

Conclusions

The speed and speed-based indicators are very commonly used in traffic research. Most often the spot speed measurements are used, however, one can get speed log by using, for example, specially equipped vehicles.

Automated video analysis is a relatively new method, which is still under development, but the tests of a system prototype, based on it, are quite promising and show its direct applicability for making behavioural studies.

One of the advantages of the automated video analysis is its ability to track the road users while they are in the camera view, providing thus continuous data on their speed and position. The speed profiles is a more information-intensive data type compared to traditional spot speed estimations and provide some descriptive parameters which might be quite hard to obtain by conventional methods (e.g. information about profile shapes). If needed, the spot speed values can be easily retrieved from the profile data. On the other hand, the continuity of the speed data makes it possible to calculate more complicated parameters, describing the passage (e.g. acceleration, travel speed, etc.). Automation of the data filtering procedure, which sorts out only manoeuvres of interest, allows making observation periods substantially longer and thus making possible studies of the events that are quite rare.

Many methodological issues have to be further studied when building up such a system. In some cases the calculation of speed-based indicators states a very high requirement to the accuracy of the input speed data, which is sensitive to the choice of camera location, procedures of the raw data processing, etc. The validity of the newly introduced indicators has also to be studied. However, the availability of a tool which can actually provide such data shifts all these questions from an almost purely theoretical plane to the practical one, giving rich material for both discussions and tests.

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