IDENTIFICATION OF HAZARDOUS ROAD LOCATIONS ON THE BASIS OF FLOATING CAR DATA - METHOD AND FIRST RESULTS

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ABSTRACT
A central aspect of road safety work relies on identification of hazardous road locations (HRL). However, the method of today is based on police-reported accidents, which show massive underreporting. Thus, in Denmark, only 14% of the serious injury accidents were reported in 2007, and the proportion is decreasing. Hence, HRL identification and enhancement are carried out more or less at random. Also, they are retrospective, i.e. accidents must occur before road safety enhancements can be made. In place of that procedure, a predictive model based on serious jerks (the derivative of deceleration) found in GPS data from driving cars is under development. Other studies have found a connection between serious jerks and conflicts. This paper focuses on a small-scale study based on a distance driven of 38,000 km and 2 million observations. It is found that to be useful for HRL identification observations, they should include a clear indication of when deceleration is initiated as well as when deceleration ends. Also, to avoid erroneous results due to speed bumps etc. a measurable reduction of the driving speed has to occur within few seconds prior to the jerk. Furthermore, the speed prior to jerks has to be above a certain level to enable distinction from results involving for example the passing of kerbs and departure from driveways. However, large-scale studies are required to assess if the approach is sufficiently reliable and to establish a threshold for including jerks in the HRL identification. These studies were initiated towards the end of 2012.

BACKGROUND
Traffic accidents are one of the great causes of loss of life in the world. Worldwide more than 1.3 million people die every year and more than 50 million are injured in traffic accidents. This number is even expected to increase to more than 2.4 million fatalities in 2030, due to increased motorisation in developing countries (World Health Organization 2012). The cost to society is worrying, and the EU and the USA alone have estimated their internal annual cost of road accidents at € 130 billion and $ 164 billion, respectively (European Commission 2010, Meyer 2008). The last few years have shown a promising development in traffic safety. Thus, in the EU, the number of fatalities has decreased by 44% between 2001 and 2011, but more than 30,000 were still killed on the European roads each year (European Commission 2012). Improved vehicle technology such as Anti-lock Braking System (ABS), airbags and especially Electronic Stability Control (ESC) have increased road safety significantly (eSafety Support 2010, Elvik et al. 2009), and car fleet renewal has shown the same general effect due to a high penetration rate of the aforementioned technologies (Lyckegaard et al. 2012). The financial crisis has probably also contributed significantly to the positive development in terms of less transportation and a changed transportation pattern. Although the exact effect of this is unclear. Despite the

technological development it is therefore uncertain if the positive tendency can be sustained after the crisis.

Notwithstanding the improved road safety all available measures to improve road safety must still be used, not forgetting the road design, which is central for road safety (Elvik et al. 2009). A more safe and forgiving road design is required in many locations. The effect of improving the safety level of the road network in general is good. A central aspect of road safety work relies on identification and enhancement of Hazardous Road Locations (HRL). An HRL is a point or section of a road network where road design or traffic regulation differs sufficiently from its general standard in that particular road or in the total road network of the country in question so as to create an increased risk of unforeseeable accidents. (Thorsen 1970). HRLs are also known as Black Spots.

The elimination of HRLs appears to have worked well (Elvik et al. 2009). It seems that the enhancement of the most problematic HRLs has had a good safety effect, focus has consequently been turned towards the remaining HRLs (SWOV 2007). These HRL seem to be less dangerous, and it is hard to gain further safety benefits from road design improvement unless at very high costs (SWOV 2007). Most HRL identifications are made on the basis of police-reported accidents, which are the official accident statistics in many countries. These public accident statistics are suffering from dark figure problems to a greater or lesser extent. It is a worldwide problem and no clear solution seems available (Elvik et al. 2009). It is a problem particularly in Denmark where the proportion of injury accidents reported to the police has decreased from 21 to 14% from 1998 to 2007 (Plovsing, Lange 2009). Moreover, Hansen, Lauritsen found that the identification of HRL differs significantly depending on which of three definitions was used for HRL identification in intersections: 1: the 90% percentile of injury generating intersections; (2) intersections with at least one injured/dead person; and (3) the intersections covering the 90% percentile of injuries. Only 1% of the intersections were identified by all three methods so the traditional approach to identifying HRL is associated with some problems (2010). At least the situation in Denmark highlights challenges regarding HRL identification on the basis of police-reported accidents:

1. There is considerable underreporting. Two Danish studies found that the identified HRLs based on police-reported accidents were imprecise (Celis, Bunton 2009, Sørensen, Andersen 2004).
2. The method is retrospective, i.e. action is taken only after accidents have occurred. This is not a new challenge, but it delays road safety enhancement and is hardly suitable with any approach to Vision 0 (Elvik et al. 2009).
3. The decreased number of reported accidents has resulted in poorer knowledge about HRLs.

Therefore different approaches are required to ensure on-going road safety enhancements and to select the most problematic HRL to be enhanced. Offhand, two sets of data seem reasonable alternatives: emergency department data and insurance data. However, in Denmark neither of these has been sufficiently accurate regarding positioning and causes of accidents (Celis, Bunton 2009, Laursen, Møller & Frimodt-Møller 2002, Sørensen, Andersen 2004). So, one of the cornerstones of road safety work, HRL identification, is carried out more or less at random, and the existing data sources don't provide a reliable basis for identification.

METHOD

The overall objective is to develop and assess a predictive model for the identification of HRL. The model will be based on Global Positioning System (GPS) data from moving cars

(Floating Car Data (FCD)). This article includes considerations about the most suitable conflict indicator and the most reliable approach to analysing FCD. The proposed model is basically based on the same idea as is the Swedish Conflict Study Technique, from which it is known that there is a connection between the number of serious conflicts, which can be seen as near accidents, and the number of accidents in a location (Hydén 1987, Svensson & Hydén 2006). The Conflict Study Technique is suitable for fast with/without studies, because it is not necessary to wait until accidents appear before any effect can be measured. However, despite the on-going improvement of video analysis tools it is still very time consuming to analyse traffic conflicts. In this paper it is supposed that strong decelerations (m/s^2) and in particular jerks (m/s^3) in the same way as conflicts indicate near accidents, and that there is a connection between the number of really strong decelerations and jerks and the number of accidents in a location. The idea appears in Figure 1.

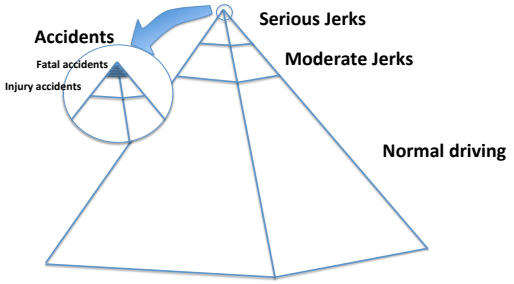

Figure 1: The theoretical connection between jerks and accidents. Inspired by Svensson & Hydén (2006).

Conflict indicator

Basically a critical conflict can result in three possible avoidance activities: deceleration, acceleration, and swerving. Intuitively, the most used approach is deceleration. Hydén (1987) supported this hypothesis. He found that braking was the evasive action in 93% of the serious conflicts and in 88% of the accidents in built-up areas. This is also supported by van der Horst (1984), who video recorded 135 serious conflicts. He found that the evasive manoeuvres included braking in 98,5% of the conflicts. Hantula (in Nygård 1999) however, found the share of fatal accidents including braking to be 72.8%. The share of evasive actions was 2.6% for acceleration and 24.6% for swerving. In total 1,360 fatal accidents were studied. This lower share of evasive braking was probably because most accidents in this study occurred outside built-up areas, where more space is often available for swerving manoeuvres. According to the literature available, it therefore seems reasonable to use decelerations and the jerks derived therefrom to indicate any near accident, and only a limited number of near accidents will be false negative.

Connection between speed variation and risk in traffic

It is well known that there is a close connection between the general driving speed and the accident risk on society level. The frequency and severity of the accidents increases exponentially with increased average speed (Elvik, Christensen & Amundsen 2004, Nilsson 2004). Also, it is found that increased speed variation results in significantly increased accident risk. Increased accident risk is also related to the fact that increased average speed increases the speed variation significantly, because any slow driving vehicles tend to deviate more from the mean speed (Finch et al. 1994, Salusjärvi 1981). A similar connection seems to exist on micro level. E.g. Bagdadi & Várhelyi found that there is a connection between the number of serious jerks and the number of self-reported accidents (Bagdadi, Várhelyi 2011) (2011). Also, in 2007 Peltola et al. found that there is a connection between how serious the drivers' jerks were, and their level of speeding, i.e. a connection between speed and accident risk, which supports Nilsson's results. Hence a fine connection between driving behaviour

and accident risk is documented in other studies. This does not necessarily mean that HRL can be found on the basis of deviating behaviour, but the latter is an indication of the former. This association is plausible and supported by a few studies. Small-scale trials have shown that strong decelerations and jerks can be used to indicate potential HRL. Nygård used data from a high-frequency data logger and from video recording of driving behaviour. He could not find a connection between serious conflicts and strong decelerations, but he found this connection regarding serious jerks and conflicts (Nygård 1999). Svendsen et al. (2008) used FCD from the Danish Intelligent Speed Adaptation project, *Pay As You Speed* to identify HRLs. It was found that each driver had various driving behaviour, and that the level of serious jerks differed significantly from one driver to the other. He found a pattern regarding serious jerks and was able to identify some HRL, but was limited by the fact that FCD were low-frequent. Both small-scale trials found that HRL can be identified by using jerks, and that jerks were more reliable indicators of HRL than decelerations.

What is a jerk?

Jerk is the derivative of deceleration. The theoretical connection between jerk, deceleration and speed appear in figure 2.

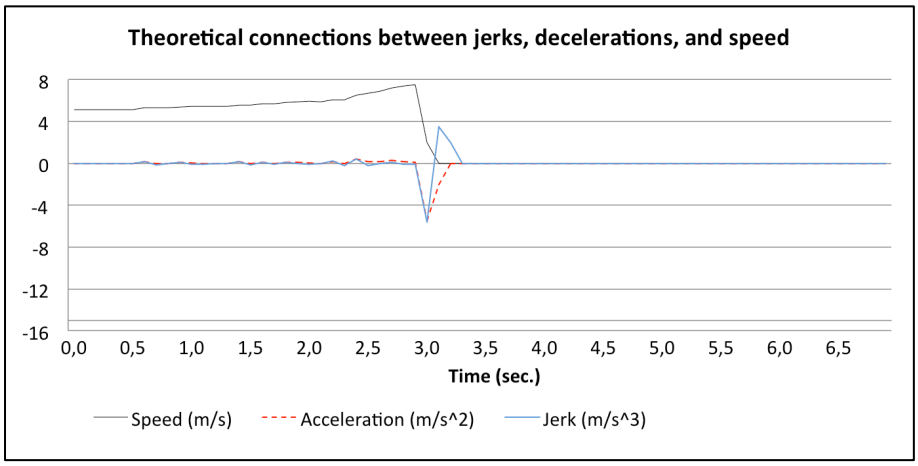

Figure 2 Theoretical connections between jerks (m/s^3), decelerations (m/s^2), and speed (m/s).

Acceleration expresses how fast speed changes. The faster a car reduces speed the bigger the deceleration and vice versa (accelerations are measured in distance/time^2, here m/s^2). The size of a jerk indicates how fast any acceleration changes (jerks are measured in m/s^3).

Acceleration is basically the difference between two speeds, and a jerk is the difference between two accelerations. The connection can be expressed as in 1 and 2.

$$Acceleration: speed_2(\frac{m}{s}) - speed_1(\frac{m}{s}) = acceleration_1(\frac{m}{s^2}), \text{ and} \quad (1)$$

$$Jerk: acceleration_2(\frac{m}{s}) - acceleration_1(\frac{m}{s}) = jerk_1(\frac{m}{s^2}), \text{ where} \quad (2)$$

$Speed_1$ is the speed (m/s) at the time t,
$Speed_2$ is the speed (m/s) at the time t+1,
$Acceleration_1$ is the acceleration (m/s^2) at the time t+1,
$Acceleration_2$ is the acceleration (m/s^2) at the time t+2, and
$Jerk_1$ is the jerk (m/s^3) at the time t+2.

In practice, many FCD loggers are calculating speed at 1 Hz frequency on the basis of the changes in GPS positions, while accelerations are often derived from a built-in accelerometer in these data loggers. These accelerometers often calculate accelerations on the basis of high-frequency registrations of accelerations. Consequently, this theoretical connection between speed and accelerations often cannot be seen for each separate acceleration observation. See figure 3 for an example.

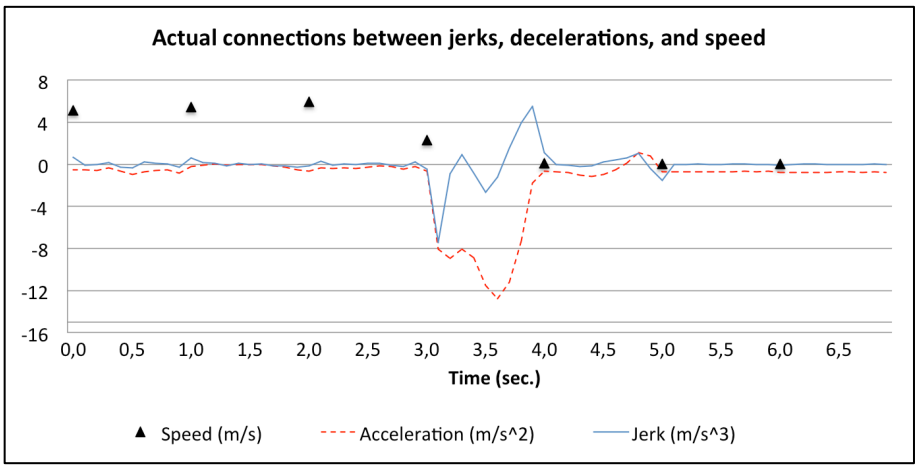

Figure 3: Speed, accelerations and jerks and their interconnections in practice.

According to prior small-scale studies it is assumed that jerks give the clearest indication of an involuntary deceleration and maybe a HRL. However, Nygård (1999) and Bagdadi & Várhelyi (In Press) have found that it is possible to distinguish between intentional and unintentional braking manoeuvres. Nygård found a much higher correlation between serious jerks and serious conflicts than between conflicts and serious decelerations. Bagdadi & Várhelyi recognized the same, but also found that the positive jerk following deceleration should be taken into account. Focus should therefore be on peak-to-peak jerks during an incident. See figure 4.

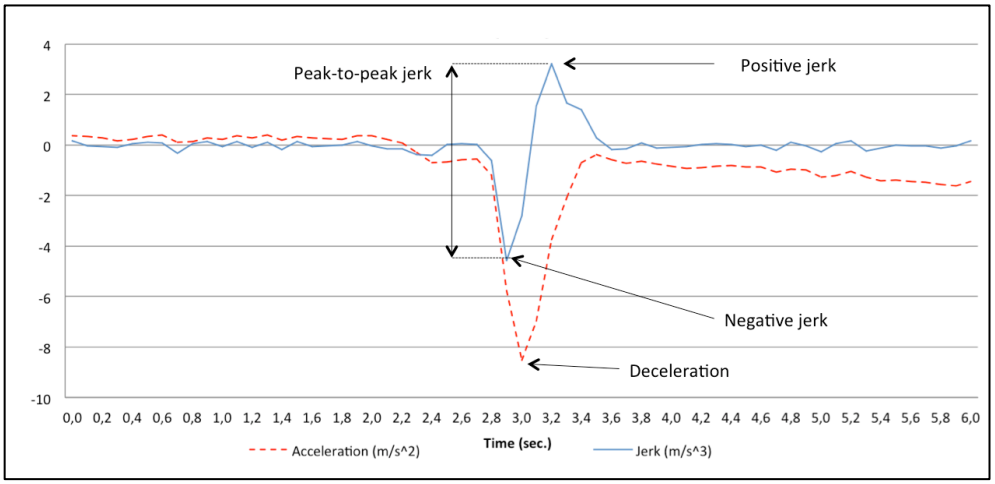

Figure 4: Peak-to-peak jerk, in case of typical braking procedure and during a conflict.

Expected density of jerks

According to other studies the interval between conflicts (and jerks) is high. Svendsen et al. found 1 jerk per 8 hour and 40 minutes of driving. Victor et al. found an average distance of 4,900 km per serious conflict (2010). Nygård, however, found more serious conflicts per distance driven with 1 per 1,170 km, but then, of course, his FCD were mainly collected in built-up areas and therefore likely to contain more potential conflicts. It is uncertain at what

intervals these marked jerks are to be expected. However, a long distance is required between each incident likely to produce a jerk.

DATA

FCD from the research-and-development project *ITS Platform* (ITS Platform 2011) including reliable acceleration data have been recorded since May 2012. An average driver has to drive significant distances before a conflict or serious conflict appears. Hence few serious jerks per driver can be expected, unless FCD have been collected over a longer period of time. To test if a unique threshold for an individual driver exists, a driving period of minimum 6 months and preferably longer is required. When the current analyses were carried out, much shorter periods of driving were available. These FCD are therefore used to illustrate typical jerks and a number of types of false-positive observations. FCD included a number of attributes collected at 1 Hz frequency and acceleration data collected at 10 Hz frequency. The most central attributes are the position, speed, direction, and quality of each observation. FCD consist of driving data from 6 privately owned vehicles over a period of 3 months collected by installed On Board Units (OBU). That comes to 2 million positions with 10 accelerations each, and a distance driven of 37,551 km. An overview of the FCD included in the analyses appears in table 1.

Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
Observations	225,351	216,008	289,663	313,059	461,978	493,506	1,999,565
Distance driven (km)	3,244	3,440	5,727	4,768	8,909	11,463	37,551
Mean speed (km/h)	51.8	57.3	71.2	54.8	69.4	83.6	68
Max. speed (km/h)	147.2	159.4	138.3	166.1	159.0	161.4	155
99% percentile (km/h)	136.9	136.0	126.6	118.0	135.3	148.9	134
95% percentile (km/h)	128.1	130.8	121.5	109.2	119.4	143.2	125
85% percentile (km/h)	105.2	117.1	116.1	96.8	100.7	137.1	112
75% percentile (km/h)	79.1	94.5	109.6	84.4	90.9	130.6	98
50% percentile (km/h)	45.8	51.9	75.9	51.4	76.3	83.3	64

Table 1. Central information on FCD included in this study.

Within three months the drivers drove 3,400 – 11,500 km. There seems to be no clear difference between the driving styles of the 6 drivers except that the drivers covering the longest distances driven have a much higher mean speed. That is probably because they drove more often on motorways (speed limit 110 and 130 km/h) than the others.

FIRST RESULTS AND EXPERIENCES

Selected incidents and characteristics – Introduction

The FCD were sorted on the basis of various attributes: 1: change in speed, measured deceleration, jerks, and peak-to-peak jerks. The 100 most significant of each of these were compared with each other. However, only a few reflected significant results regarding all variables. Some showed significant reduction in speed without any effect on decelerations or jerks. Others showed significant jerks but the speed remained unchanged. An overview of the most typical observations included is elaborated on below.

Examples of incidents maybe related with conflicts

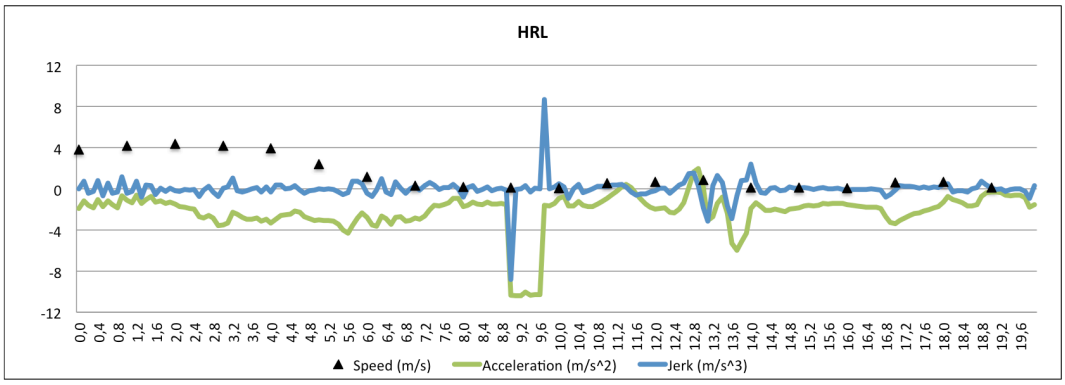

Figure 5. A reduced speed followed by a significant deceleration with abrupt ending. X-axis is sequential time (sec.). The Y-axis is m/s., m/s^2, and m/s^3.

Figure 5 shows a clearly reduced speed followed by a significant deceleration, which ended abruptly. The peak-to-peak jerk is significant (17.5 m/sec^3) and a clear deceleration a few sec. before the jerk found indicates that there is a real connection between the change in speed and the jerk. It is also notable that the peak jerk is marked. The most significant jerk resulting from changes in speed in this case was -1,26 m/sec.^{3} only. Noteworthy is also the apparently delayed reaction when speed decreased. It is found in many test measurements and is probably caused by a Kalman filter or something working on a similar principle, which the OBU has integrated. Despite this, it still fulfils the requirements for a relevant jerk.

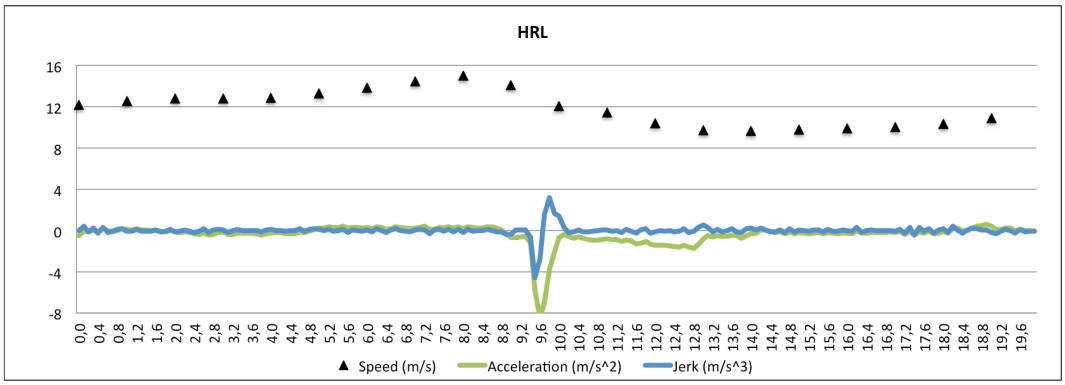

Figure 6. Significant although short deceleration.

Figure 6 shows a significant jerk at normal driving speed on a distributor road in built-up areas. Speed is somewhat reduced and deceleration is very significant but brief. This is reflected in the jerks, which at first are significantly negative, and then similarly positive. It is reasonable to assume that this situation reflects a conflict.

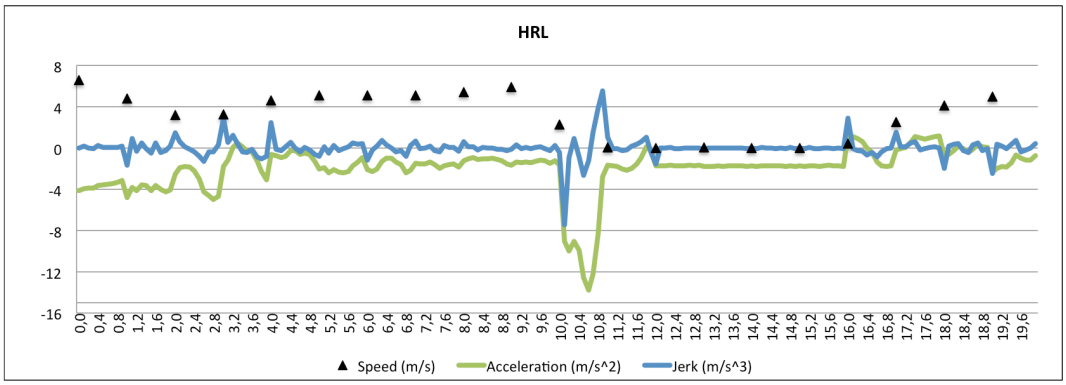

Figure 7. Significant jerk and clear speed reduction.

Figure 7 includes driving in built-up areas in a minor town. Various speeds are associated with various accelerations. A significant jerk occurs and is followed by a few seconds during which the car was at a standstill after which acceleration was resumed. This is probably a relevant jerk.

Examples of fictitious incidents caused by rough surfaces

Two examples of apparently significant jerks or decelerations, but with no effects on speed are shown in figure 8.

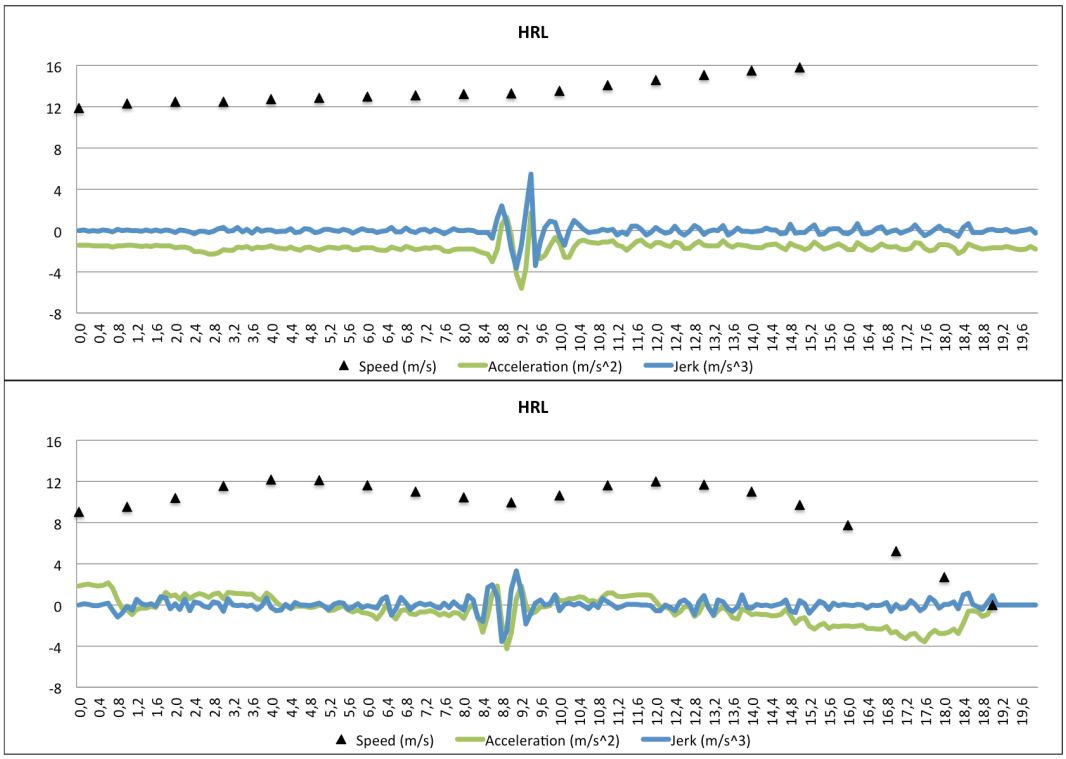

Figure 8. Two examples of significant decelerations and jerks with no connection to change in speed.

Above, the location is across a village entrance with a speed bump built for a 50 km/h speed limit (built-up areas to the left). Speed increases gradually although slowly on the way out of the village. Despite an expected upward acceleration across the bump, it results in a significant jerk in the driving direction. The figure below shows the passage of a speed bump displaying clear jerks. Despite a small change in speed around the passage of the bump, the reduction in speed to 0 in the right part of the figure is more significant, but does not result in any noteworthy jerks.

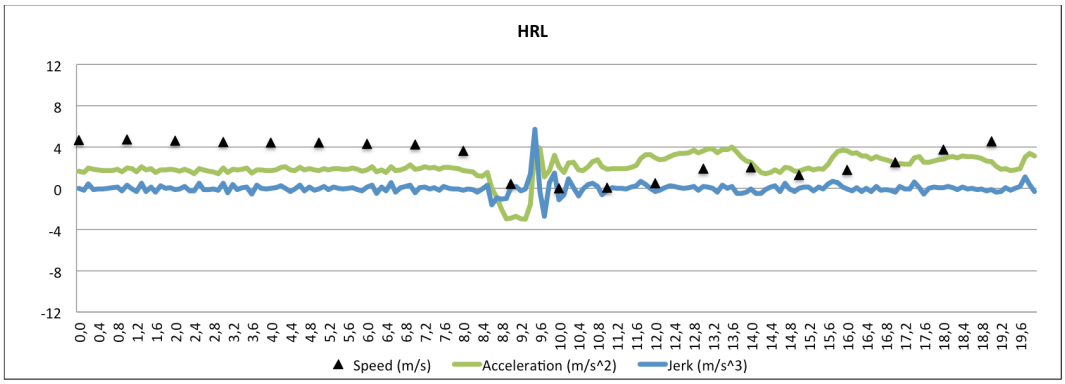

Figure 9. Significant jerk at low-speed approaching.

In figure 9, a clear speed reduction to 0 m/s appears. However, deceleration is increased gradually, and a clear jerk can be identified only after the incident. The jerk occurred when turning from a driveway onto a rural road. Due to the absence of a negative jerk, the incident is most likely caused by the car driving over an irregular road surface or a kerb. In the first part of the incident, the pattern is highly identical to the ones presented above, involving the passage of speed bumps. This indicates that a jerk or deceleration, which should be included in the identification of HRLs, should have a clear initiation, but also that they require a minimum approaching speed before an incident can be seen as a reliable indicator of an HRL.

Examples of markedly changed speeds without significant jerks

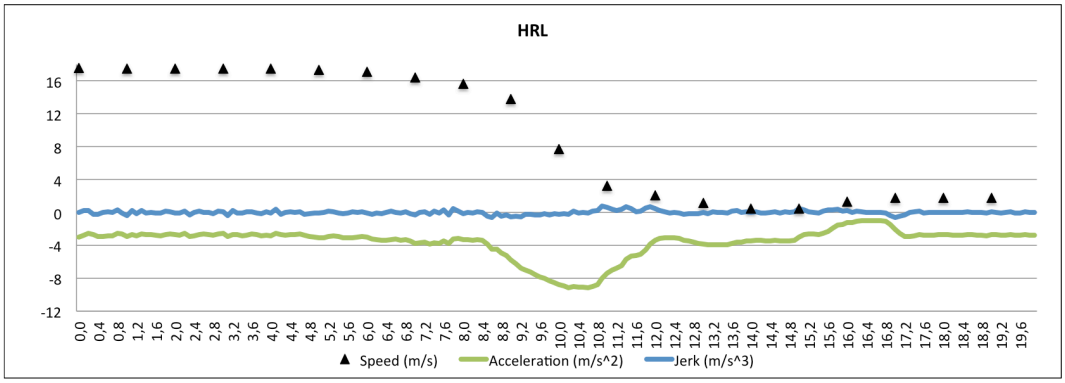

Figure 10. Significantly reduced speed without clear jerks.

Figure 10 shows a clear reduction in speed on a rural road. Despite a reduction from 55 to 0 km/h within 5 sec. the deceleration is slow and the jerks are very small, which indicates that a quite clear change in speed is included in normal driving. Note that the average curve of accelerations is offset – probable due to a problematic installation.

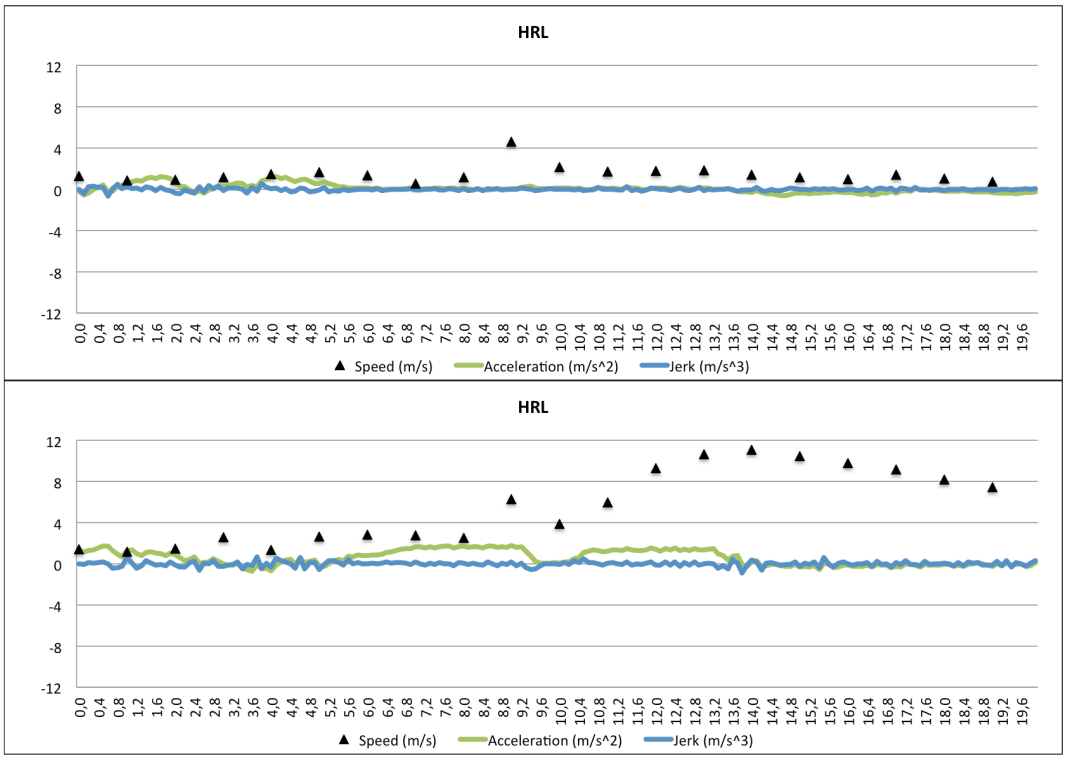

Figure 11. Two examples of significant changes in speed without significant effect on the acceleration pattern due to poor GPS connection in densely built-up areas.

Figure 11 shows two incidents where significant speed variations are associated with insignificant decelerations and jerks. Both incidents took place on roads surrounded by 4-6-storey houses – such locations often result in poor GPS connections and hence unreliable speeds. That applies to both cases.

SUMMARY AND FUTURE WORK

Main findings

Figures 5 – 11 show a number of jerks, which can reasonably be seen as reliable indicators while other incidents have characteristics, which indicate that they can't. The curve made up of jerks should have a specific shape. The jerks must have a clear initiation of the deceleration (i.e. a clear negative jerk) and likewise a clear completion of the deceleration (a clear positive jerk). However, significant jerks must also be related to a change in GPS speed because otherwise it may be caused by rough surfaces, kerbs, or speed bumps. Moreover, marked reductions in speed do not necessarily imply jerking, as even sudden, forceful braking can remain checked – thus leaving only minor variation on acceleration and especially jerking pattern. Moreover, poor GPS connections, which often occur in high-rise areas, can result in marked variations in speed without any noteworthy effect on decelerations.

The above results indicate that Nygård's approach with particular focus on jerks is reliable, while the lack of connection between jerks and the change in speed indicates that Svendsen's approach of using only the speed in low-frequent FCD as the basis of jerk calculations is subject to some uncertainties. The result may be some false negative jerks as clear jerks of duration of one or a few tenths of seconds might disappear in FCD registered at 1 Hz frequency. On the other hand this approach may likewise cause false positive results as bad GPS connection can indicate significant decelerations due to fictitious speed variation.

The above results, which are admittedly based on few FCD and possibly biased results from a few significant jerks, lead to the following three provisional requirements when using FCD to identify HRLs.

1. The incidents, which can be used for HRL identification, have to include both a clear initiation point of deceleration and a similar clear end of deceleration. I.e. the measurement of peak-to-peak jerks is probably a reasonable method to identify the right jerks.

2. Besides a significant measured reaction on accelerations/jerks a measurable reduction of the driving speed has to be present within few seconds prior to the jerk.

3. The speed before an incident occurs has to be above a certain level to avoid results caused by passage of kerbs, initiations from driveways etc. The threshold is not defined so far, but is likely 4-6 m/s.

Future work

Much more FCD must be included before a reliable approach to identifying HRLs can be established. For one thing, it has to be clarified whether the proposed method of using peak-to-peak jerks as indicators is the right solution or a single jerk or even decelerations alone are the most suitable approach. Also, it has to be clarified if the level of jerks unique to each vehicle included should be established or a common threshold will cover all/the majority of vehicles delivering FCD to this study. In the end of 2012 analyses of FCD from 200 vehicles with >6 months of driving will be carried out. It is expected that these analyses will clarify if the method proposed is the right one and give a first perspective on identification of HRLs. In the second half of 2013 a similar study will be carried out on the basis of FCD from 400 cars in > 1 year.

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