The impact of hourly measured speed on accident risk: results from an exploratory study on the Brabant South-East provincial and municipal road network

Tom Brijs[#] and Col Offermans[‡]

[#]Hasselt University
Transportation Research Institute (IMOB)
Agoralaan – Gebouw D
B-3590 Diepenbeek
Email: tom.brijs@uhasselt.be

[‡] Ministry of Transport, Public Works and Water Management
AVV Transport Research Centre
P.O. Box 2510
6401 DA Heerlen, The Netherlands
Email: n.offermans@avv.rws.minvenw.nl

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Samenvatting

De impact van gemeten snelheden op de verkeersveiligheid: een case study op het gemeentelijk en provinciaal wegennet in de politieregio Brabant Zuid-Oost

Verschillende wetenschappers onderstrepen de noodzaak naar meer wetenschappelijk onderzoek teneinde de relatie tussen snelheid en verkeersveiligheid beter te begrijpen. In deze paper stellen we de eerste resultaten voor van een exploratief onderzoek dat werd uitgevoerd in de Zuid-Oost Brabant politie regio in Nederland. Op basis van lusdetectoren werden gegevens over werkelijk gereden snelheden op uurniveau verzameld en gekoppeld aan ongevallen op het provinciaal en gemeentelijk wegennet over een periode van twee jaar. Daarbij werden verschillende aspecten van verkeersintensiteit en snelheid op ongevallen bestudeerd, zoals absolute snelheid, snelheidsvariantie, percentage hardrijders, en dit zowel voor voertuigen kleiner en groter dan 5,2 meter. In de paper worden ook verscheidene methodologische aspecten toegelicht die een rol spelen in dit soort analyses. Uit het onderzoek blijkt dat de absolute snelheid een belangrijkere rol speelt op wegen waar de toegelaten snelheid laag is, terwijl op wegen waar de toegelaten snelheid hoger ligt de snelheidsvariantie een belangrijkere rol speelt. Gegeven het beperkte studiegebied, dient enige voorzichtigheid aan de dag gelegd te worden wanneer men de resultaten van dit onderzoek wenst te generaliseren. De resultaten bieden echter enkele interessante inzichten die verder cross-sectioneel onderzoek wenselijk maken op een groter studiegebied.

Summary

The impact of hourly measured speed on accident risk: results from an exploratory study on the Brabant South-East provincial and municipal road network

Several scholars have defined the urgent need for more research to identify the precise relationship between speed and crash involvement more fully. In this paper, we present the first results of an exploratory study carried out in the Brabant South-East police region in the Netherlands. Hourly speed measurement data over a period of two years were collected from loop detectors on the municipal and provincial road network and were related to crashes. Different aspects of traffic intensity, speed and their impact on crashes were studied, including absolute speed, speed variation and the proportion of excessive speeders, both for vehicles below and above 5.2 meters long. The study also discusses a number of methodological aspects associated with this kind of analysis. The results show that although absolute speed plays a more important role on roads where speed limits are low, it is the variation in speed that correlates more with crashes when speed limits are higher. Given the limited study area, the results of this work cannot be generalized without risk. However, they offer interesting insights that deserve further investigation in a nation-wide cross-sectional study.

1. Introduction

In a recent traffic safety bulletin issued by the Dutch Ministry of Transport, the total cost of road crashes to the society in the Netherlands was estimated at about 6 Billion Euro (*1*). Furthermore, in the White Paper (*2*) on European Transport 2010, the European Commission claims that one person in three will be injured in an accident at some point in his or her live. These statistics clearly indicate the dominant role road safety plays in our everyday life. As a result, it is not surprising that, in recent years, road safety has become a hot issue on the political and societal agenda.

In terms of contributing factors to crashes, previous research has revealed that human failure is the most important causal factor that may lead to an accident (*3*). It is in fact much more important than failures on the part of the vehicle or the infrastructure. Furthermore, and of particular relevance for this study, speeding or inappropriate speed has proven to be a major contributor for car crashes. For instance, in 2001 the German Federal Statistic Office calculated that 25% of all crashes involved inappropriate speed as a contributing factor (*4*). It is assumed that a reduction in speed has an important potential to reduce the number of severe crashes, including fatalities and severe injuries. However, it is believed that not only the absolute speed level is of importance, but also the relative speed differences (speed variance) between motor vehicles on a road segment. The idea is that disruptive traffic conditions contribute to traffic accidents. Such disruptive traffic conditions, which are unstable and undesirable, can be represented by high temporal and spatial variations in traffic parameters. Yet, only a limited amount of research has been done relating the actual speed measured on a road segment to the number of crashes on that segment in order to verify whether indeed the actual speed driven or differences in speed between motor vehicles matters. In fact, it turns out that the relationship between speed and accident risk is complex and several studies seem to report conflicting results. Therefore, in this study we aim to contribute to this literature and shed more light on this complex relationship by using hourly speed measurement data from loop detectors and linking them to crashes on the municipal and provincial road network in the Brabant South-East police region in the Netherlands.

The paper is organized as follows. In the next section, we provide a concise overview of the existing literature on the relationship between speed and traffic safety, including the kind of data and methodologies that are being used. In section 3, we elaborate on the data that have been used in this study and we demonstrate the preprocessing steps that needed to be carried out to prepare the data for analysis. Section 4 provides the results of the analysis and discusses the main findings. Finally, section 5 is reserved for conclusions, a discussion on the limitations of this study and topics for future research.

2. Literature review

There is a general consensus in literature that speed plays an important role in crash risk. However, in literature the precise relationship between speed and crash risk has been treated in several different ways, which can make comparison across existing studies difficult. The reason is that studies differ with respect to how the variable speed is operationalized, how crash and speed data are collected and which methods are adopted to relate speed to crash risk. It is therefore not straightforward to conclude how exactly speed affects crash risk.

Firstly, with respect to operationalization of the variable speed, some authors used the posted maximum speed and studied the effect of speed limit decreases/increases on the number and/or severity of crashes (*5*, *6*, *7*). These studies can be classified as before/after studies. Others use *measured* (real time) vehicle speeds and use aspects of the speed distribution, such as the average speed, the 85th percentile speed, the standard deviation of speed, the percentage of vehicles exceeding the speed limit, or the ratio of standard deviation to mean speed (*8*). With respect to the absolute level of speed, most of the studies point towards an exponential relationship between speed and crash risk (*5*, *9*, *10*) and some more recent studies point at the importance of speed variation in relation to crashes (*8*, *11*).

Secondly, a large difference in literature can be found on how speed and crash data are being collected. Whereas some studies use surveys (*9*, *10*), others use estimates, or real measurements. Moreoever, some studies use real accident records (road-based studies), but many studies are based on driver-stated crash involvement (driver-based studies). The idea of using loop detector data to predict crashes is relatively new; however, in the recent past there have been some efforts in this field. In general, a distinction can be made with respect to the level of aggregation in time and space of the data. In aggregate studies, the unit of analysis is the number of crashes during a certain period of time (typically per month or per year) and for a specific region (typically a particular road or a larger geographical region). Traffic flow information is then typically presented at the same level of aggregation. Research has indicated, however, that interpretations of the relationship between speed and crashes should be done with great care, due to the statistical problem of ecological fallacy (*12*, *13*).

Ecological fallacy means that a relationship that has been found between speed and crash risk on the aggregate level cannot be expected to necessarily exist at the individual level. This problem can be overcome by adopting disaggregate studies where the unit of analysis are the individual crashes and traffic flow information is related to the specific time and place where the crashes occurred.

Some interesting disaggregate studies involve the work of Lee et al. (*14*) who introduced the concept of "crash precursors" and hypothesized that the likelihood of a crash is significantly affected by short-term turbulence of traffic flow. They developed factors such as speed variation along the length of the roadway (i.e., difference between the speeds upstream and downstream of the crash location) and also across the three lanes at the crash location. Another important factor identified was traffic density at the instant of the crash. Weather, road geometry and time of day were used as external controls. With these variables, a crash prediction model was developed using log-linear analysis. In a later study (*15*), they modified the aforementioned model, noting that the average variation of speed difference across adjacent lanes doesn't have a direct impact on crashes. They also concluded that variation of speed has a relatively longer-term effect on crash potential than density and average speed difference between upstream and downstream ends of roadway sections. Abdel-Aty et al. (*16*) adopted matched case-control logistic regression, with every crash being a case with corresponding non-crashes acting as controls. The five-minute average occupancy from dual loop detectors at the upstream station during 5-10 minutes prior to the crash along with the five-minute coefficient of variation in speed at the downstream station during the same time have been found to affect the crash occurrence most significantly. Abdel-Aty and Abdalla (*17*) used the Generalized Estimating Equations (GEEs) technique with binomial probit link function to model the probability of crashes. The modeling results showed that the presence of an on-ramp increases the likelihood of a crash happening within half a mile downstream of the crash location. Bad pavement condition and the presence of horizontal curvature increase the likelihood of a crash. High variability in speed for a period of 15 minutes in a certain location was shown to increase the likelihood of a crash to occur at half a mile downstream. Unlike speed, low variability in volume over 15 minutes was shown to increase the likelihood of a crash happening at a mile downstream. Golob et al. (*18*) used data from single loop detectors to conduct multivariate analyses of 1,000 crashes on freeways in Southern California. Their analysis revealed ways in which differences in variances in speeds and volumes across lanes, as well as central tendencies of speeds and volumes, combine in complex ways to explain crash taxonomy.

The present study resembles closely, but not fully, a disaggregate approach in that real-time traffic flow data on a per-hour basis are used from loop detectors and related to crashes that occurred on the road segments where those detectors are located. Consequently, there is a close match in space (on the road segment level) and a relatively close match in time (on a per-hour basis) of the traffic flow and crash data. However, the study is not fully disaggregate since the traffic flow and crash data per segment are aggregated per hour, whereas in most other disaggregate studies real-time traffic flow data are used from seconds before a crash happened. 'Fully' disaggregate studies therefore tend to be more predictive in nature, i.e. towards prediction of individual crashes based on real-time traffic flow circumstances, whereas our approach aims at identifying correlations between traffic flow circumstances and crashes on a less disaggregate level in time.

3. Data preparation

The data for this study are collected from different data sources for the period 2002-2003 in the Brabant South-East police region in the Netherlands. Furthermore, we decided to focus the analysis on the provincial and municipal roads, since an analysis between observed vehicle speeds and crashes had not yet been carried out on this level of the road network in the Netherlands before. Roads of this type in the Netherlands can be divided into different speed limits, i.e., 50 km/h, 60 km/h, 70 km/h and 80 km/h roads. The first data source in this study contains detailed information about vehicle speeds, traffic exposure and traffic composition for 29 loop detectors (see figure 1), which was made available by the Bureau of Traffic Enforcement of the Public Prosecutor's Office (BVOM).

More precisely, for each loop detector, data were provided on an hourly basis and grouped into 10 different speed categories, depending on the road segment's legal speed limit (50-70-80 km/h, 60 km/h road segments were not present in the data source). Moreover, the data about speeds and traffic exposure were made available for vehicles with a length below and above 5.2 meters, i.e., light versus heavy vehicles.

The second data source in this study was made available by the AVV Transport Research Centre of the Dutch Ministry of Transport and contains road crashes on provincial and municipal roads in the Brabant South-East police region for the period 2002-2003.

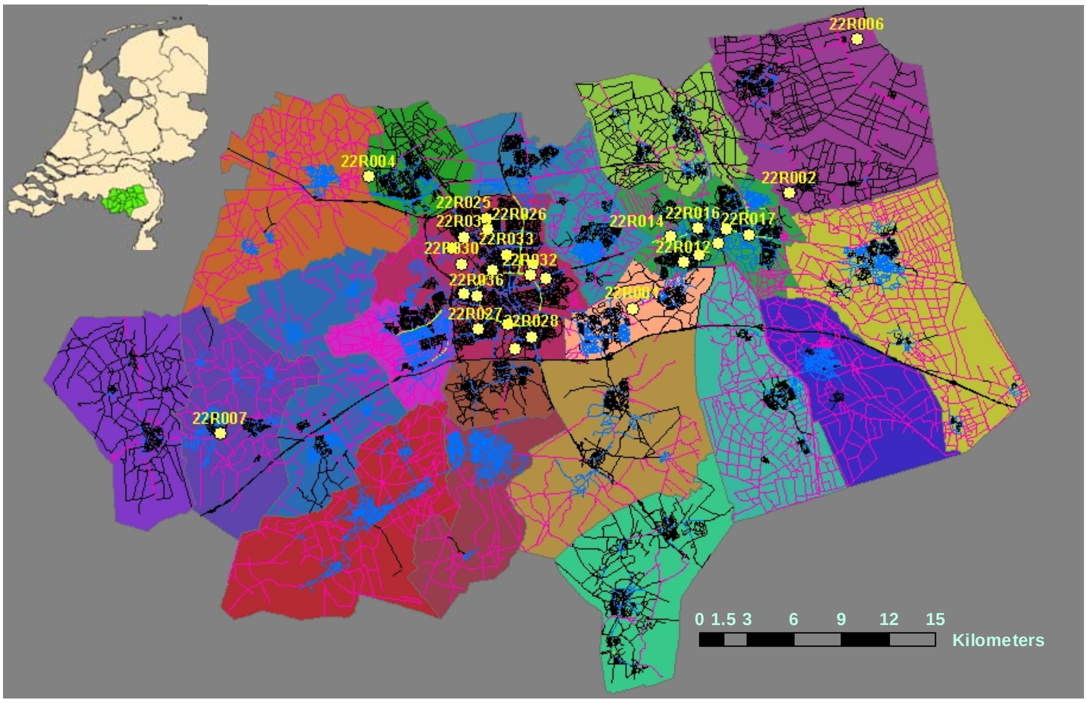

FIGURE 1: Overview of Loop Detector Positions on Provincial and Municipal Roads in the Brabant South-East Police Region in the Netherlands. The colored areas are the municipal boundaries.

Crashes resulting from parking manoeuvres were removed from the data. The reason is that we are interested in the relationship between (free flow) speed and crashes. Crashes resulting from parking manoeuvres could therefore bias our results.

Finally, the third data source, also made available by the AVV Transport Research Centre, contains detailed data from the digital road network, including the road segments of which each road is composed. Based on these three data sets, a spatial analysis was carried out in a GIS to allocate crashes to each loop detector, based on the road segment ID, which is the common identifier for both the loop detector position and the crash location (see figure 2).

In other words, all the crashes in the period 2002-2003 that have occurred on the road segment where the loop detector is located are allocated to that loop detector. Yet, two problems naturally arise in this case. Firstly, there are multiple loop detector configurations possible, depending on the number of directions, the number of lanes per direction and whether or not different directions are digitized each with a different road segment ID. This problem is illustrated in figure 3.

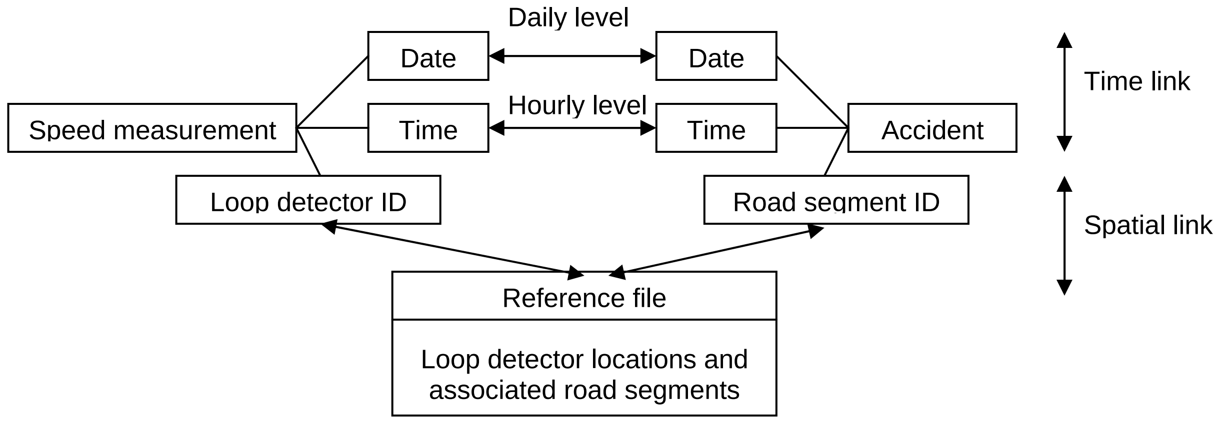

FIGURE 2 Data Architecture and Relationship Structure between Data Sources.

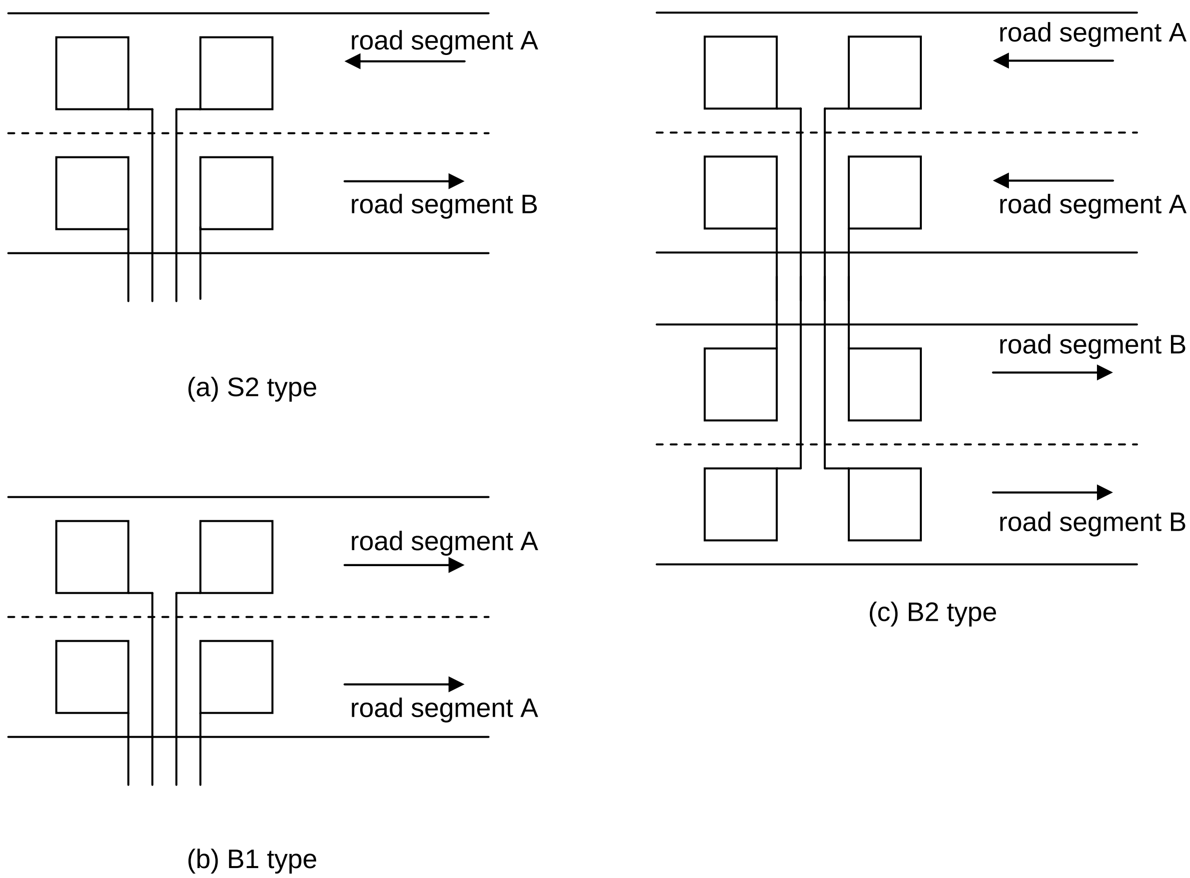

FIGURE 3 Loop Detector Configurations and Allocation to Road Segments.

In figure 3(a), the loop detector is located on a road with two lanes in opposite directions. In that case, if the two lanes each carry a different digitized road segment ID in the road network data file (as shown in the drawing), the speed measurement data from the two loop detectors is kept apart. In other words, the measurement data from the loop detector in the left direction is allocated to road segment A and the measurement data from the loop detector in the right direction is allocated to road segment B. If both opposite lanes carry the same road segment ID, the speed measurement data of both loops is aggregated and allocated to that road segment ID. In figure 3(b), the loop detectors are located on a road with two lanes in the same direction. In that case, there is only one road segment ID and thus the speed measurement data of both loop detectors are aggregated for this one road segment ID (segment A in the figure). Finally, figure 3(c) represents a loop detector configuration on a two-by-two road with two lanes in each direction, and each direction possesses a separate road segment ID. In that case, the speed measurement data of the two loop detectors in the left direction are aggregated and allocated to segment A, and the speed measurement data of the two loop detectors in the right direction are aggregated and allocated to segment B. If the digital road network defines only one segment ID for both directions, then all the speed measurement data are aggregated and allocated to that single segment ID.

For example, figure 4 illustrates a situation where a loop detector type S2 is present on a road with two lanes in opposite directions. However, since in the digital road network file, both opposite lanes carry the same road segment ID (363198026), the speed measurement data of loop detector 22R006 are aggregated and allocated to that road segment ID.

A second problem that arises when allocating crashes to loop detectors is the question how to treat crashes that have occurred on neighbouring road segments, i.e, next to or in the neighbourhood of the road segment on which the loop detector is located. We decided, in several cases, to allocate crashes from multiple neighbouring road segments to the respective loop detector. For instance, this was the case when the loop detector was located in between two intersections and where the characteristics (e.g. speed, number of lanes, etc.) of that stretch of road (consisting of different digital road segments) did not change in between those two intersections.

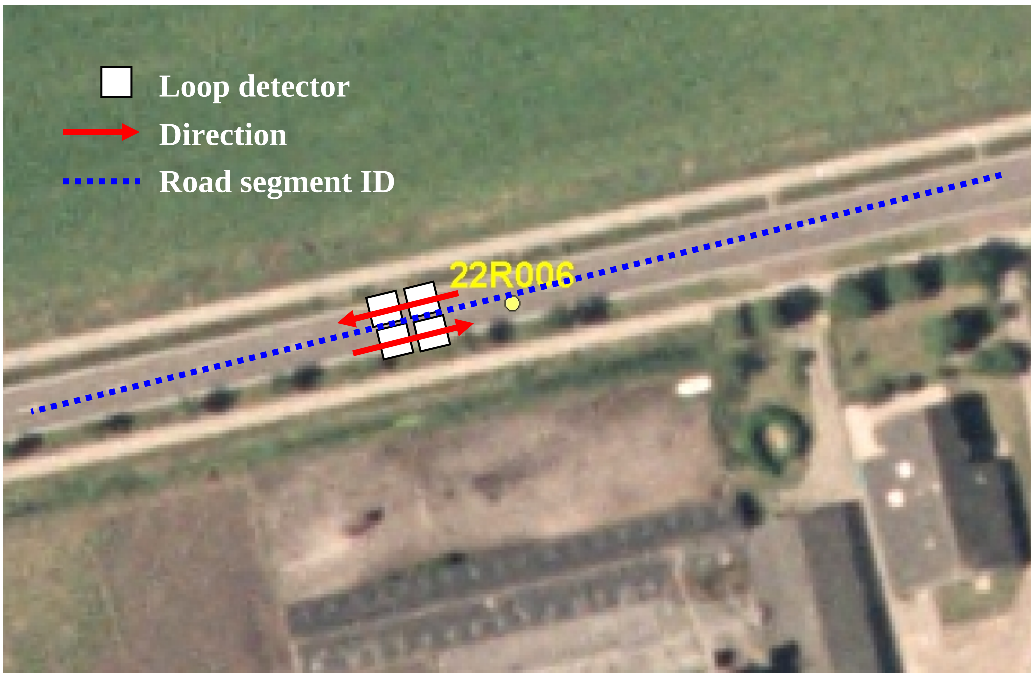

FIGURE 4 Loop Detector Configuration Linked with the Digital Road Network.

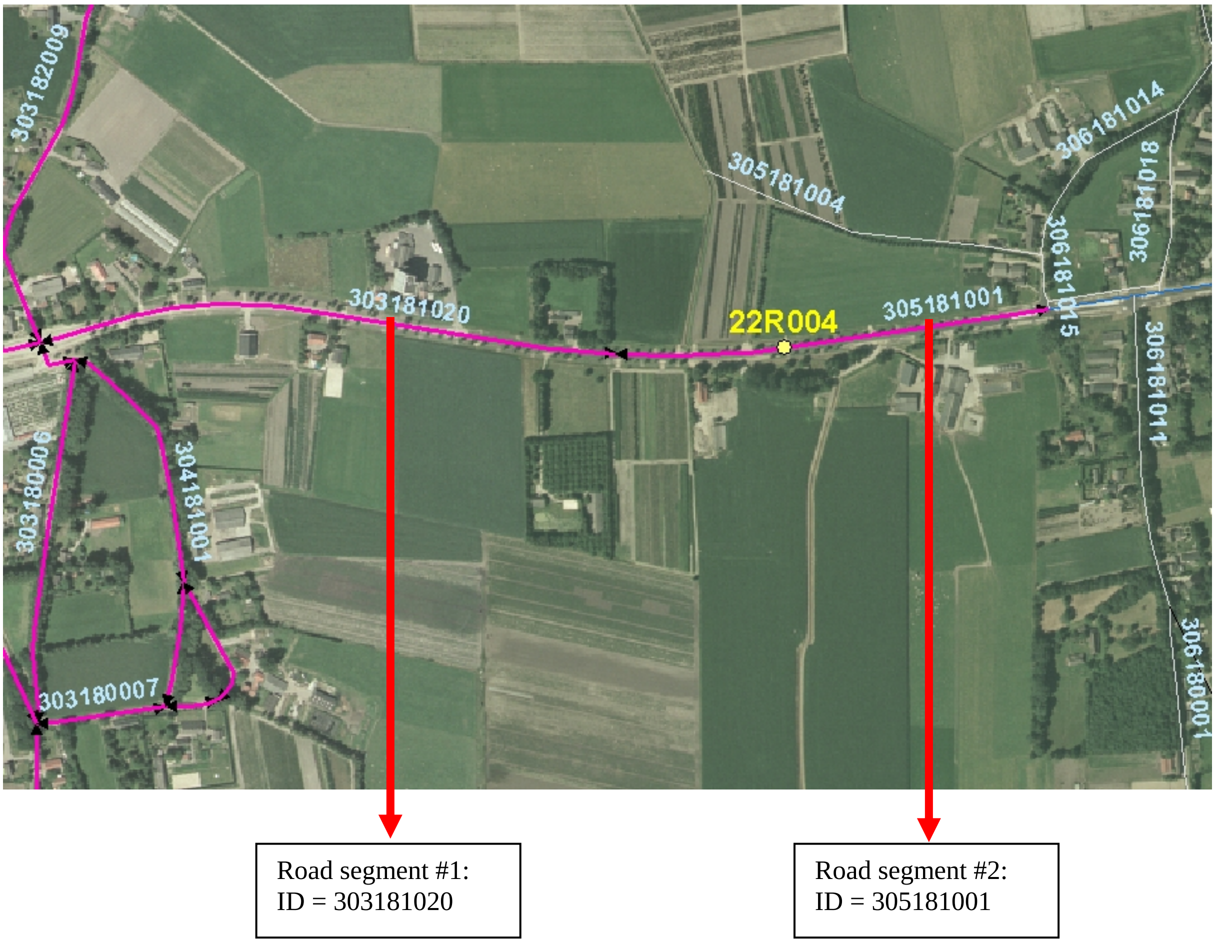

FIGURE 5: Location of a Loop Detector Allocated to Multiple Road Segments.

This is illustrated in figure 5 for one particular stretch of road, consisting of several road segments. The position of the loop detector (example 22R004) is shown on the picture and is associated with one road segment (road segment ID 305181001). However, since the total road stretch between the two intersections consists of multiple neighbouring road segments (road segment ID 305181001 and 303181020), which are very similar in terms of the above-mentioned characteristics, we decided to allocate all crashes of that complete road stretch to that loop detector.

The principle motivation behind this decision is that we believe that the measured speed, the traffic composition and exposure do not change significantly in between both intersections. As a result, the measured speed and exposure data can be considered as representative for the entire road stretch instead of just the road segment on which the loop is located. The decision which crashes to allocate to each loop detector was made separately for each loop, depending on the characteristics of the environment (homogeneous land use, no dangerous curves, etc.). Note, however, that segments covering the actual intersections were not included since crashes on these road segments could be more typical for the intersection itself, than for the speed behavior.

Since literature clearly indicates that different aspects of speed may influence crash risk differently, we defined for each loop detector, and for each hour, a number of speed characteristics both for vehicles below and above 5.2 meters that could be derived from the loop detector data, i.e., mean speed, speed variation and percentage of excessive speeders. Both the mean speed and the speed variance can be easily calculated from the distribution of vehicles frequencies over the 10 different speed categories. Note that the speed variation was calculated as a standardized variance of speed since in absolute terms a difference in speed of 10 km/h between the slowest and fastest speed measurement is a larger difference on 50 km/h roads than on 80 km/h roads. The standardized variance of speed will also enable a fair comparison of its impact on crashes across roads with different legal speed limits (see results section). The proportion of excessive speeders was defined as the proportion of vehicles that exceed the speed above which a fine is issued. This speed typically lies 10% above the legalized speed limit and thus depends on the road segment’s legal speed limit at the location of the loop detector. Furthermore, also the relationship between traffic composition and crash risk is of particular interest. We therefore also calculated, for each hour, the ratio of vehicles below and above 5.2 meters on the particular road segment.

4. Results

In order to study the effect of the above-defined speed related variables on crash risk, we compared the values of the above-mentioned speed variables at the hour of a crash (at least one crash allocated to the road segment of the loop detector) with the value observed under normal conditions (hours without crashes). In other words, we are interested in finding out, for each road segment, whether the speed behaviour at hours where a crash occurred deviates from the speed behaviour during hours without crashes. If indeed the speed behaviour is different, we postulate that speed may be a contributing factor to crashes. Note that, consistent with earlier research (19, 20), we do not speak about causality in our study, but rather a correlation between speed and crashes, since the former would require knowledge about the speed behaviour of a particular vehicle involved in a crash, that is the so-called case-control study approach. An important issue, however, is also how we calculate speed behavior under so-called ‘normal conditions’.

Indeed, it is not a good idea to calculate the mean speed, speed variation and the proportion of excessive speeders simply over all hours of the year in which no crashes happened. Obviously, traffic exposure differs significantly per hour and per day and thus the overall mean speed over the past year at a particular segment would not be a good indicator for the expected mean speed at a particular hour of a particular day at which a crash occurred. Therefore, if a crash occurred at a Tuesday morning at 8 o’clock on a particular road segment, we contrasted the speed variables at that particular day, time and location to the average speed variables calculated for that location over all Tuesdays at 8 o’clock in the morning. In other words, we compare the values of each speed variable for a particular loop detector at the time of a crash with the average speed values calculated for that loop detector over the last year for the same day of the week and at the same hour of the day when no crashes occurred. Additionally, exactly the same analysis was carried out at the hour preceding the hour of the crash. The reason is that we expected that the occurrence of a crash itself could influence the measured speed during the hour of the crash, due to congestion. The speed measured during the hour preceding the hour of the crash may therefore be more representative for the speed behavior of the vehicles at the time of the crash.

For ruling out as many intervening effects as possible, the speed behavior analysis was carried out separately for road segments with different speed limits (50-70-80 km/h), for segments within and outside the built-up area, and finally for road segments situated on municipal versus provincial roads. This enables us to compare groups of road segments that are as homogeneous as possible with respect to other observable differences. Additionally, it offers the opportunity to compare the results between the different groups, which is important from a policy perspective, e.g. does speed behaviour correlate differently with crashes on 50, 70 and 80 km/h roads?

Table 1 shows a comparison of the results about the relationship between different aspects of speed, traffic intensity and crashes for the different groups of road segments at the hours when road crashes occurred. The table shows results both for vehicles smaller and larger than 5.2 meters. Some interesting conclusions can be drawn. Firstly, but not surprisingly, traffic intensity accounts for most of the variance in relation to crashes and this is valid both for the intensity of small and large vehicles. Indeed, compared to the speed variables in the table, crashes occur more at hours when the intensity of the traffic was above average on the respective road segments where crashes occurred.

For example, 54.78% of the crashes (53 out of 115) inside the built-up area occurred during hours when the traffic intensity of vehicles smaller than 5.2 meters was above average on the respective road segments where the crashes occurred. Despite a few exceptions, this percentage is consistently higher than for the speed variables (e.g. 40.87% for absolute speed, 27.82% for excessive speeding and 46.09% for speed variance), which indicates that traffic intensity is certainly the largest contributing factor to explain crashes.

With respect to the speed variables, analysis of the results in table 1 shows that on average the variable speed variation between small vehicles is more dominant compared to the other speed-related variables (absolute speed and excessive speeding). Furthermore, speed variation becomes more important in explaining road crashes as the road’s legal speed limit increases. Indeed, when looking at the speed variation, crashes tend to occur more frequently when the variation in small vehicle speeds exceeds the normal speed variation on the respective road segments where the crashes occurred. For instance, on 50 km/h roads, 40.91% of the crashes happened at hours when the variation in speeds between small vehicles exceeded the variation that is observed on average.

This amount increases as the road’s legal speed limit increases: 49.35% on 70 km/h roads and 68.75% on 80 km/h roads. In other words, the results tend to support the conclusion that variations in speed between small vehicles are correlated more heavily with crashes on roads with higher speed limits.

TABLE 1 Results with Respect to Traffic Intensity and Speed Compared for Different Groups of Road Segments at the Hour of a Crash

At the hour of a crash		Vehicles < 5.2 meters				Vehicles > 5.2 meters				Crashes
		Absolute speed above average	**Excessive speeding above average**	**Speed variance above average**	**Traffic intensity above average**	**Absolute speed above average**	**Excessive speeding above average**	**Speed variance above average**	**Traffic intensity above average**	
In/out built-up area	**Inside**	47 *40.87%*	32 *27.82%*	53 *46.09%*	63 *54.78%*	43 *37.39%*	44 *38.26%*	52 *45.22%*	57 *49.56%*	115
	Outside	4 *18.18%*	4 *18.18%*	14 *63.64%*	12 *54.54%*	12 *54.54%*	6 *27.27%*	9 *40.91%*	13 *59.09%*	22
	Difference	**22.69%**	**9.64%**	**-17.55%**	**-0.24%**	**-17.15%**	**10.99%**	**4.31%**	**-9.53%**	
Road authority	**Municipality**	49 *38.28%*	34 *26.56%*	61 *47.66%*	71 *55.47%*	52 *40.62%*	48 *37.5%*	57 *44.53%*	64 *50%*	128
	Province	2 *22.22%*	2 *22.22%*	6 *66.67%*	4 *44.44%*	3 *33.33%*	2 *22.22%*	4 *44.44%*	6 *66.67%*	9
	Difference	**16.06%**	**4.34%**	**-19.01%**	**11.03%**	**7.29%**	**15.28%**	**0.09%**	**-16.67%**	
Legal speed limit	**50 km/u**	19 *43.18%*	14 *31.82%*	18 *40.91%*	25 *56.82%*	16 *36.36%*	19 *43.18%*	22 *50.00%*	22 *50.00%*	44
	70 km/u	29 *37.66%*	20 *25.97%*	38 *49.35%*	41 *53.25%*	32 *41.56%*	26 *33.77%*	32 *41.56%*	38 *49.35%*	77
	Difference	**5.52%**	**5.85%**	**-8.44%**	**3.57%**	**-5.2%**	**9.41%**	**8.44%**	**0.65%**	
	50 km/u	19 *43.18%*	14 *31.82%*	18 *40.91%*	25 *56.82%*	16 *36.36%*	19 *43.18%*	22 *50.00%*	22 *50.00%*	44
	80 km/u	3 *18.75%*	2 *12.5%*	11 *68.75%*	9 *56.25%*	7 *43.75%*	5 *31.25%*	7 *43.75%*	10 *62.5%*	16
	Difference	**24.43%**	**19.32%**	**-27.84%**	**0.57%**	**-7.39%**	**11.93%**	**6.25%**	**-12.5%**	
	70 km/u	29 *37.66%*	20 *25.97%*	38 *49.35%*	41 *53.25%*	32 *41.56%*	26 *33.77%*	32 *41.56%*	38 *49.35%*	77
	80 km/u	3 *18.75%*	2 *12.5%*	11 *68.75%*	9 *56.25%*	7 *43.75%*	5 *31.25%*	7 *43.75%*	10 *62.5%*	16
	Difference	**18.91%**	**13.47%**	**-19.40%**	**-3.00%**	**-2.19%**	**2.52%**	**-2.19%**	**-13.15%**	

In contrast, the actual speed and excessive speeding tend to be correlated less to crashes as the road's legal speed limit increases. For instance, table 1 shows that on 50 km/h roads 43.18% of the crashes tend to occur at hours when the average actual speed of small vehicles was above the overall average observed on those road segments. This number decreases as the road's legal speed limit increases. Indeed, on 70 km/h roads, this number decreases to 37.66% and on 80 km/h roads it decreases further to 18.75%.

Somewhat similar results can be drawn for the variable that measures the proportion of excessive speeders amongst small vehicles. Table 1 shows that on 50 km/h roads, 31.82% of the crashes occurred during hours when the proportion of excessive speeders was higher than average on those road segments where the crashes occurred. For 70 km/h roads and 80 km/h roads, one can observe a significant drop, i.e. 25,95% and 12.5% respectively. In other words, the proportion of excessive speeders seems less correlated with the number of crashes on 80 km/h roads than on 50 and 70 km/h roads.

Summarizing the above findings, they tend to support the conclusion that it is not the absolute speed or the proportion of excessive speeders amongst small vehicles that correlates more with the number of crashes on roads with higher speed limits. Instead, the speed variation amongst the small vehicles plays a more important role. In fact, these conclusions are further supported when comparing roads inside and outside the built-up area. For small vehicles, 63.64% of the crashes outside the built-up area (mostly 70 and 80 km/h roads) happened at hours when the speed variation was higher than average, whilst this is the case only for 46.09% of the crashes that occurred on road segments inside the built-up area (mostly 50 and 70 km/h roads). Again, also the proportion of crashes occuring during hours with higher than average speeds or a higher proportion of excessive speeders amongst small vehicles is lower outside the built-up area than inside the built-up area, which again confirms our earlier conclusions.

With respect to larger vehicles (>5.2 meters), the analysis does not arrive at entirely the same conclusions. In fact, table 1 shows that with respect to heavy vehicles, traffic intensity correlates differently with crashes depending on the road's legal speed limit. Indeed, as the road's legal speed limit increases, a higher proportion of crashes tend to occur at hours when the intensity of heavy traffic is above average on the respective road segments where those crashes occurred. For instance, on 80 km/h roads, 62.5% of the crashes occurred at hours when the intensity of heavy traffic was higher than average, whilst for 50 and 70 km/h roads this proportion is only 50.0% and 49.35% respectively. Also the absolute speed of heavy vehicles plays a rather different role in relation to crashes when looking at different road types. Indeed, where for small vehicles we found an inverse correlation between absolute speed and the road's legal speed limit, this is exactly the opposite for large vehicles. Inside the built-up area, 37.39% of the crashes occurred at hours when the absolute speed of large vehicles was higher than average, whereas this figure amounts to 54.54% on road segments outside the built-up area.

As mentioned earlier in the text, in order to rule out the possible effect of traffic congestion due to a crash on the traffic intensity and speeds measured at the hour of the crash, we also calculated the same figures for the hour preceding the crashes as we expect these measurements to be more representative to approximate the real circumstances before a crash. The results of this analysis are presented in table 2.

It is interesting to discover that the conclusions found for small vehicles in table 1 also hold for table 2. Yet, the conclusions found for large vehicles in table 1 are not always supported by table 2. In fact, they are more consistent with the conclusions found for small vehicles. Conclusions with respect to large vehicles are therefore difficult to take.

At this point, we should emphasize that the above results are based on a relatively small sample of road segments, in a limited study area and with a limited number of crashes that are not equally dispersed across the different types of road segments. Especially for those types of road segments where only a small number of crashes occurred (e.g. provincial, 80 km/h roads) small changes in the number of crashes may lead to relatively large differences in the proportion of crashes reported in table 1 and 2. This may affect the significance of the quantitative differences found between the results of different road types.

The external validity of the results should therefore be considered with great care. Nevertheless, based on the results in table 1 and 2 and by working closely with the data for a period of time, we believe that qualitatively the presented correlations between traffic intensity, speed and crashes are quite consistent and hold considerable promise for further research.

TABLE 2 Results with Respect to Traffic Intensity and Speed Compared for Different Groups of Road Segments at the Hour Preceding a Crash

At the hour preceding a crash		**Vehicles < 5.2 meters**				**Vehicles > 5.2 meters**				
		Absolute speed above average	**Excessive speeding above average**	**Speed variance above average**	**Traffic intensity above average**	**Absolute speed above average**	**Excessive speeding above average**	**Speed variance above average**	**Traffic intensity above average**	**Crashes**
In/out built-up area	**Inside**	46 *40.0%*	43 *37.39%*	42 *36.52%*	73 *63.48%*	63 *54.78%*	38 *33.04%*	43 *37.39%*	64 *55.65%*	115
	Outside	8 *36.36%*	2 *9.09%*	10 *45.45%*	14 *63.64%*	8 *36.36%*	7 *31.82%*	8 *36.36%*	13 *59.09%*	22
	Difference	**3.64%**	**28.3%**	**-8.93%**	**-0.16%**	**18.42%**	**1.22%**	**1.03%**	**-3.44%**	
Road authority	**Municipality**	49 *38.28%*	44 *34.37%*	47 *36.72%*	81 *63.28%*	66 *51.56%*	42 *32.81%*	48 *37.5%*	72 *56.25%*	128
	Province	5 *55.55%*	1 *11.11%*	5 *55.55%*	6 *66.67%*	5 *55.55%*	3 *33.33%*	3 *33.33%*	5 *55.55%*	9
	Difference	**-17.27%**	**23.26%**	**-18.83%**	**-3.39%**	**-3.99%**	**-0.52%**	**4.17%**	**0.7%**	
Legal speed limit	**50 km/u**	21 *47.73%*	18 *40.91%*	14 *31.82%*	30 *68.18%*	23 *52.27%*	17 *38.64%*	19 *43.18%*	31 *70.45%*	44
	70 km/u	27 *35.06%*	26 *33.77%*	29 *37.66%*	46 *59.74%*	42 *54.54%*	25 *32.47%*	27 *35.06%*	37 *48.05%*	77
	Difference	**12.67%**	**7.14%**	**-5.84%**	**8.44%**	**-2.27%**	**6.17%**	**8.12%**	**22.4%**	
	50 km/u	21 *47.73%*	18 *40.91%*	14 *31.82%*	30 *68.18%*	23 *52.27%*	17 *38.64%*	19 *43.18%*	31 *70.45%*	44
	80 km/u	6 *37.5%*	1 *6.25%*	9 *56.25%*	11 *68.75%*	6 *37.5%*	3 *18.75%*	5 *31.25%*	9 *56.25%*	16
	Difference	**10.23%**	**34.66%**	**-24.43%**	**-0.57%**	**14.77%**	**19.89%**	**11.93%**	**14.2%**	
	70 km/u	27 *35.06%*	26 *33.77%*	29 *37.66%*	46 *59.74%*	42 *54.54%*	25 *32.47%*	27 *35.06%*	37 *48.05%*	77
	80 km/u	6 *37.5%*	1 *6.25%*	9 *56.25%*	11 *68.75%*	6 *37.5%*	3 *18.75%*	5 *31.25%*	9 *56.25%*	16
	Difference	**-2.44%**	**27.52%**	**-18.59%**	**-9.01%**	**17.04%**	**13.72%**	**3.81%**	**-8.2%**	

5. Conclusions and limitations

Although this study is not exactly a cross-sectional study, it carries several characteristics of a cross-sectional study. Indeed, both real speed measurements and crashes are related on the same road segment, whereas in many other studies this link cannot be made. Furthermore, our study is based on a cross-section of road segments on different road types, i.e. within and outside the built-up area, on municipal versus provincial roads, and for 50 km/h versus 70 km/h and 80 km/h roads. Yet, it is not exactly a cross-sectional study since only road segments were included on which at least one crash happened over the past two years. Future research efforts would therefore involve both segments with and without crashes on a larger geographical study area to contrast both groups in terms of speed behavior using a regression type of analysis. Additionally, it is the objective in our future work to distinguish between different crash types, i.e., crashes with slight, serious or fatal injuries, or material damages only.

Nevertheless, we believe that our work contributes to the existing literature in several ways. Firstly, the results in this work made clear that the relationship between measured speed and crashes is influenced by road characteristics, e.g. the same difference in measured speed or traffic intensity has a different effect on crashes depending on the road's legal speed limit. Secondly, different aspects of speed are correlated differently with the occurrence of crashes, again depending on the road type. For instance, the results in this study tend to support that the variation in speed of vehicles is correlated more heavily on roads with higher legal speed limits, whereas crashes on roads with lower speed limits occur more frequently at hours when vehicles drive faster than is usual. Although this study is based on a limited number of data points in time, space and quantity of road segments, we believe that the results hold considerable promise for supporting government decision making if the findings can be confirmed in a larger study.

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