SENSITIVITY OF ROAD SAFETY INDICATORS IN NORMAL AND CRASH CASES

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ABSTRACT. Road traffic safety is receiving increasing attention. Different real-time safety indicators relying on traffic sensor data can be found in the literature. Some are based on the posterior analysis of crash and traffic data; while others are based on real time traffic risk assessment using microscopic parameters (e.g., short time headways). Other non-traffic related parameters have an impact on safety too, such as day/night, state of the road (dry/wet), etc. Yet, in most studies, not all parameters are available or considered.

In this paper, individual traffic, road weather and crash data are considered on a Swiss canton (Vaud). All data sources are available for at least 4 years (2002-2005) on more than 200 km of motorways.

This comprehensive data enables the authors to study 1) the adaptability to Vaud canton of different safety indicators from the literature, and 2) the sensitivity of the safety indicators on Vaud canton data, both under normal situations and crash situations and specially the rear-end crashes.

INTRODUCTION

Road traffic safety is becoming a worldwide concern. According to the World Health Organization (see WHO, 2005), road traffic crash was ranked the 11th major cause of death in the world and accounts for 2.1% of all deaths globally. As motorization increases, road traffic

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injuries are predicted to rise to become the eighth leading cause of death by 2030. Many strategies have been introduced to reduce road crash risk and mitigate severe consequences of unavoidable crashes. Among different road types, motorways are the safest roads by design. Nevertheless, according to the European Transport Safety Council (ETSC), there are still 3,200 people killed annually on EU motorways (see ETSC, 2008): crashes on motorways are usually very severe.

Switzerland is the leading country in motorway traffic safety among European countries (see ETSC, 2008). This positive tendency is obtained thanks to a series of preventive measures such as speed enforcement, new speed limit regulations, improvement of pavement, etc. However, the number of motorway traffic crashes is still high, about 400 in 2005 and this number does not change much compared to previous years.

Among traffic crashes, there are crashes caused mainly by the traffic flow and there could be pre-crash traffic situations leading to these crashes. If such situations could be detected, it would be possible to avoid the crashes or at least, diminish their severity. This is also the aim of the work reported in this paper: capturing pre-crash traffic situations on Swiss motorways based on a set of safety indicators.

This paper is organized as follows: in the second section, a brief state of the art is presented as well as the set of safety indicators that are used in this paper. Data sources and test site are presented in the third section. The analysis follows in the fourth section on real-world data. It includes a sensitivity analysis of the considered safety indicators and a deeper analysis on crash cases which allow determining a risk criterion. Conclusions and perspectives of our work are given in the last section.

BACKGROUND

Many factors can influence road traffic safety such as road geometry, weather conditions, traffic flow as well as drivers' behaviors, traffic operation rules, etc. Among dynamic factors, traffic flow has been considered the main focus for improving motorway traffic safety. Many studies focused on how to predict the traffic crashes using real-time traffic data. Other studies used the fundamental time-space diagram to estimate crash risk. Along both directions, safety indicators were created and used. In this section, these studies are summarized and the safety indicators selected for this research are presented.

Crash Prediction

To prevent motorway crashes, foreseeing the crash is of paramount importance. Several models were proposed to recognize the traffic patterns leading to crashes. Most proposed models make use of traffic data and crash data and are represented by a regression function. Traffic data before and after crashes under the same conditions (date of week, time of day, weather conditions, etc) was examined.

A rear-end prediction model was proposed by Pande *et al*. (2006). Rear-end crashes were found to often occur under extended congestion or when average speeds were high. The authors suggest that there should be warnings to drivers when they are under such traffic situations and the development of variable speed limit strategies should be tested to reduce the risk of rear-end crashes.

Lee *et al.* (2006) investigated into sideswipe crashes, which occur when vehicles change lanes in comparison to rear-end crashes. They used the same traffic and crash data as described in Pande *et al*. (2006) with the help of logistic regression. The seven examined indicators were average speed, flow, and occupancy of each 30 seconds over 5-10 minutes before the crash, coefficient of variation of speed (CVS), coefficient of variation of flow (CVF), peak/off-peak period and the curvature of the road section.

In these models, the data used is aggregated data. For this reason, only aggregated traffic parameters such as average speed, flow, or their other variances are used. Weather and geometry have strong effects on traffic safety but were not taken into account by these models. On the other hand, with this kind of models, only a specific crash type is considered.

Theoretical Safety Indicators

One of the research directions is to use a set of indicators to characterize traffic situations for forecasting crash and taking necessary operational actions to reduce crash risk. Such indicators called herein “safety indicators” allow describing partially safety status of a road section with its unchanged infrastructure configuration. The indicators can characterize traffic flow properties before the occurrence of a crash. The indicators also allow estimating potential crash risk that may occur in the progress of the current traffic flow.

Originated from car manufacturers, the Time-To-Collision (TTC), which represents the time required for two vehicles to collide if they continue at their present speed and on the same path (see Hayward, 1972), plays the central role in Traffic Conflict Techniques in many countries. Van der Horst *et al*. (1993) introduced TTC as a core parameter in the Collision Avoidance system. Other similar-to-TTC indicators were then presented such as Deceleration to Safety Time (DST) by Hupfer (1997), Post-Encroachment-Time (PET) by Cooper (1984), Time-Exposed-TTC (TET) and Time-Integrated-TTC (TIT) by Minderhoud *et al*. (2001).

Uno *et al*. (2002) proposed PICUD (Potential Index for Collision with Urgent Deceleration) which is an index to evaluate the possibility that two consecutive vehicles might collide assuming that the leading vehicle applies its emergency brake. PICUD is defined as the distance between the two vehicles considered when they completely stop.

Recently, Chung (2007) presented Individual Braking Time Risk (IBTR), Platoon Braking Time Risk (PBTR), and Speed Over Speed Limit (SOSL). PBTR is an accumulative safety indicator cumulated from IBTR. The values of IBTR are obtained based on individual data, e.g. time gap between two consecutive vehicles, and individual vehicle speed which can be collected from motorway traffic loop detectors.

Selected Safety Indicators

Table 1. List of the selected Safety Indicators for rear-end crash risk.

Safety indicators	Description
IBTR (G-values)	Individual Braking Time Risk
PBTR (J-values)	Platoon Braking Time Risk
TTC	Time-To-Collision
SOSL	Vehicle Speed Over Speed Limit
Headway	Vehicle headway
PICUD	Potential Index of or Collision with Urgent Deceleration

Many safety indicators were presented so far in this paper. However, the safety indicators to be selected have to match the data currently available in Vaud canton (see next section). Finally, the safety indicators selected are shown in Table 1. In this paper, their performance towards rear-end crash risk is studied.

DATA & STUDIED SITE

The study focuses on time periods and locations where all three types of data - traffic, weather, and crash data - are available on a standard 2*2-lane, straight and flat motorway section. One site was selected with data available from 2002 to 2005.

The Selected Site

Among 331 permanent automatic traffic counting (ATC) stations throughout Switzerland, individual vehicle data from 73 ATC is downloadable online. Of these downloadable ATC data, 13 are in the Vaud canton. And if we go back to 2002 (as crashes currently available in this study are in Vaud canton from 2002 to 2005), the number of ATC is only 9 as some were installed more recently. Narrowing the selection of traffic detectors that are less than 5 km from a road weather station leaves only 3 ATC.

The 3 ATC are part of two motorways, A1 and A9, and are installed near Lausanne city. One of the ATC is on the intersection between the two motorways where the geometry of the site is special with many curved sections for changing from one direction to another. Another ATC lies right at one end of a tunnel and on the other end of the tunnel, there is a curved section and then many other tunnels. To reduce the possible impact of geometry on traffic safety, these two ATC are not selected for further investigation at this stage of the research.

The remaining ATC which is selected for this study is on a straight section on the national road A1 and called site 149. On this straight section, the pavement is flat and there are two lanes on each of the two directions. Near site 149, there is a weather station installed to gather weather data on the motorway. The weather data provided by this station is used in association with site 149 for this research. Table 2 summarizes the characteristics of this site.

Table 2. Characteristics of site 149.

Traffic detector ID	Location	Number of lanes	Steepness (downward on lanes 1 and 2; upward on lanes 3 and 4)	Curvature (km)	Associated road weather station	Inter-station distance (m)
149	A1	4=2*2	0.70%	20	41.21.1.4	616

Figure 1 shows the positions of three ATC on motorways in Vaud canton and one weather station associated with the selected ATC.

Traffic Data

ATC provides individual information about each vehicle, which is useful for this study on safety indicators. Namely, the following information is delivered by the ATC when a vehicle passes through the ATC:

- date and time,

- lane in which the vehicle is passing,
- speed of the vehicle,
- time gap and time headway to the previous vehicle (i.e. leader),
- length of the vehicle,
- category of the vehicle.

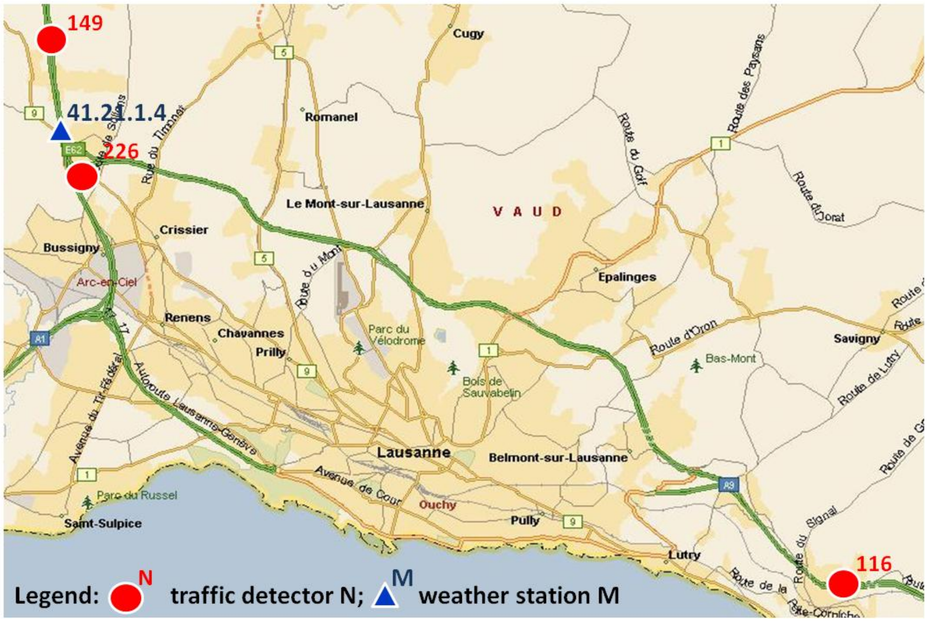

Figure 1. Three ATC and the weather station for the selected ATC

Weather Data

Boschung road weather stations are installed along the road sections, specifically for monitoring the weather conditions on the Swiss road network. The study makes use of the Boschung road weather stations, which provide:

- date and time stamp,
- air, ground, and dew point temperatures,
- air relative humidity,
- *type of precipitation* (rain, snow, or nothing),
- *state of the road* (3 wetness levels, moist, or dry).

The study focuses on the last two dependant parameters.

Crash Data

Available crashes in this study come from the Vaud canton crash database, 2002-2005, which contains for each crash:

- the date of the crash,
- the hour period of the crash (e.g., 12:00-13:00 if the crash occurred after midday and before 1:00 pm),
- the motorway kilometric position of the crash,

- the road weather conditions:
    - type of precipitation (nothing, rain, snow),
    - road surface state (dry, moist, wet, snow),
- day / night condition,
- the type of crash (50 categories in 9 main groups),
- the drivers' status: driving under the influence of alcohol (DUI) or not,
- other information of no interest here: faults…

During the 4 studied years (2002-2005), there are totally 3,693 crashes on motorway sections in Vaud canton. As our main interest is to derive crash risk as a function of traffic conditions, DUI crashes have to be eliminated and only crashes close to selected traffic detector (149) are used. The crashes considered in the report are in a buffer of 1km from the detector. Besides, only rear-end crashes are selected to study the performance of selected safety indicators on rear-end crashes.

Eventually, 4 crashes on motorway A1 were chosen for the analyses. The description of the 4 crashes is given in Table 3:

Table 3. Studied rear-end crashes near ATC 149.

ID + Site number (detector code)	Date (yyyymmdd)	Hour period (hhmm)	Light (**D**ay / **N**ight)	Weather (**D**ry / **R**ain)	Road surface (**D**ry / **W**et)	Distance from traffic detector (m)	Position (**U**p- / **D**own-stream) from detector	Direction (+ for lanes 1 and 2 / - for lanes 3 and 4)
1 149	20030308	1600-1700	D	D	D	696	D	+
2 149	20030310	0900-1000	D	D	D	244	D	-
3 149	20040116	1900-2000	N	R	W	359	U	+
4 149	20040922	1700-1800	D	D	D	224	U	+

ANALYSES & DISCUSSIONS

There are several factors that can have effect on traffic safety. This section first discusses these factors and how to incorporate them into the safety indicators. Then, the sensitivity analyses of safety indicators are presented. The sensitivity analyses together with the analyses of crash cases will provide an idea about how to decide if a traffic situation is risky or not.

Factors That Influence Motorway Traffic Safety

Traffic safety can be influenced by many factors such as geometry of the road section, weather conditions, traffic flow as well as drivers' behaviors. This research aims at improving traffic safety by reducing crash risk that can be caused by the weather conditions and by traffic flow. Hence, the selections of a straight and flat ATC-equipped section and of non-DUI crashes help minimize the effect of other factors.

The factors below are considered in this research:

Traffic Flow

Motorway traffic flow is self adapted with the interaction of vehicles with various operational regulations such as speed limit, minimum time gap, etc. Traffic flow can affect traffic safety in many ways. In this paper, different ranges of traffic volume will be considered to test the sensitivity of safety indicators.

Weather Conditions

There are three weather conditions according to precipitation types from weather data: no precipitation (fine weather), rain, and snow. With the selected safety indicators, the effect of each weather condition can be quantified by a parameter such as the maximum deceleration rate (see Chung, 2007) as shown in Table 4:

Table 4. Maximum deceleration rate is a function of weather conditions.

Weather conditions	Maximum deceleration rate (m/s^2)
Fine weather	6.87
Rain	4.81

Sensitivity Analyses of Safety Indicators

A safety indicator value should index the safety level of a vehicle. For example, TTC gives the time left before a supposed two-vehicle crash if both vehicles keep the same direction and speed and if the following vehicle is faster than the lead vehicle. The higher the TTC, the longer the duration before the crash is, and thus, the safer the situation is. This research also considers, as an extension of safety indicator, indicators which give risk index: an increase represents safety reduction. For example, PBTR is an indicator but its low values imply safe status. Such indicators are sometimes called risk indicators in the literature. Yet, as risk and safety indicators both concern the safety, they will be called ‘safety’ indicators in this paper.

The process includes two levels. At the first level, individual data was used to calculate values of the Individual Safety Indicators, or briefly ISIs, which are the safety indicator values specifying the safety status of each vehicle. The 5-minute aggregation of ISIs is then undertaken to obtain the ISI distribution over the 4 years of data. Such distribution should provide an overview of ISI value ranges, including the extreme values which are the values showing that vehicles are in unsafe situations and close to a pre-crash situation. The ISI distribution can also provide a range where the thresholds for the ISI could be decided.

The next level considers a traffic situation for an ATC which is defined by the set of events happened in front of the ATC during an aggregation period (which is 5 minutes in this research). During the situation, there can be many “unsafe” vehicles which are vehicles having one or more ISIs overstepping the safe value ranges. At this level, it is the percentage of “unsafe” vehicles in that traffic situation that could decide if the situation is risky or not. This percentage threshold is called aggregate threshold or briefly, “agghold”.

In the recent work by de Mouzon *et al* (2007), the results with two ISIs - PBTR and TTC - were presented. The conclusion was that thresholds of PBTR and TTC had to be decided based on the traffic flow and that PBTR thresholds also depended on the weather conditions. The results for PBTR and TTC will not be repeated in this paper.

Speed is a basic parameter in safety studies. In this paper, the criteria to make speed a safety indicator is the proportion of vehicles running faster than speed limit (Speed Over Speed Limit - SOSL), which is 120km/h at the studied site. A vehicle is seen as risky if its speed is over the speed limit and the higher the speed above the speed limit, the higher the risk is.

Figure 2 shows the speed distribution on the slow lane at the studied site. If only speed ranges for 1% of the fastest vehicles are considered, the speed ranges under different flow ranges are different: under low flow range (0-500vph), the speed for 1% of the fastest vehicles is between 150-160km/h. One percent of the highest speeds for other flow ranges are: between 140-150km/h for flow ranges of 500-800vph, 800-1100vph, and 1100-1500vph, between 130-140km/h for flows greater than 1500vph. Under high traffic flows, the chance for drivers to increase the speed is low and because there are many vehicles on the road, the speed of vehicles must be homogenous especially when the speed exceeds the speed limit. The risk in this situation is high because if there is one driver behaving strangely, a crash can happen. On the contrary, greatly exceeding the speed limit under low flow conditions can be easily undertaken due to large inter-vehicle space. The risk in this case is also high because the driver may have the feeling to be alone on the road and lose his awareness of danger.

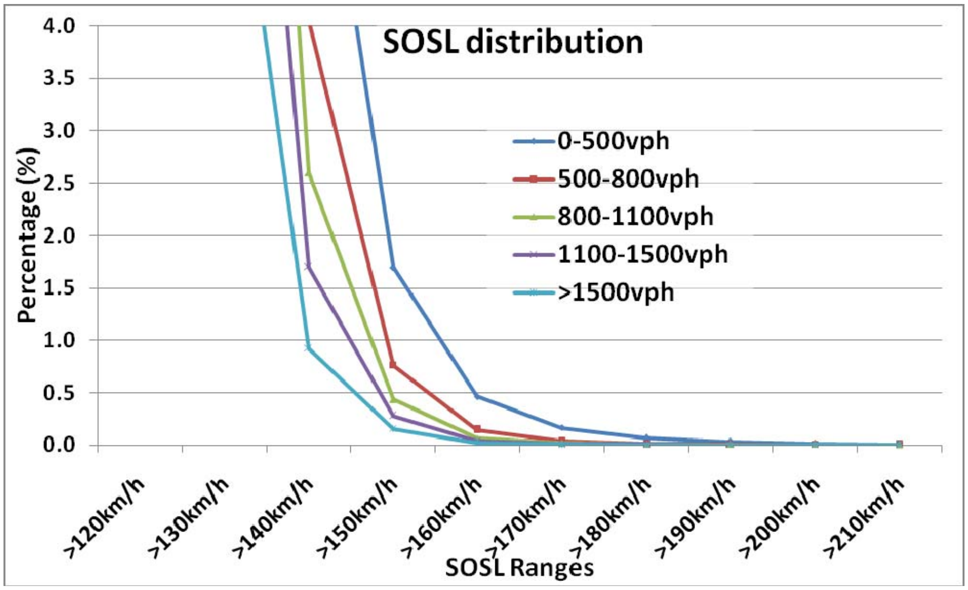

Figure 2. SOSL distribution on slow lane, zoomed in 0-4%

Figures about ISI distribution are given in ANNEX (from Figure 6 to Figure 23). The results for other ISIs were also obtained: see Table 5 and Table 6. The results show ISI value ranges where thresholds are set so that 1% of vehicles are risky according to each ISI. The exact values of the thresholds are the ‘x’ values in Table 5 and Table 6, whose upper and lower bounds are also provided. The exact ‘x’ values cannot be obtained but could be approached if the distribution of smaller ISI intervals is undertaken.

From Table 5 and Table 6, the IBTR and PBTR thresholds on the fast lane tend to be larger than on the slow lane under the same traffic flow. This is because vehicles use the fast lane for overtaking and the average speed on this lane is greater than on the slow lane (as implied by the lane names). The increase of IBTR and PBTR values on the fast lane compared to the slow lane means that it is more risky while driving on this lane. Under the rain conditions, this difference is even larger.

The thresholds for TTC and SOSL on the fast lane are generally greater than on the slow lane under the same flow ranges. This is because under the same flow range, the average speed on the fast lane is higher than on the slow lane and the time gap is also higher on the fast lane so that vehicles can change to the fast lane for overtaking.

Table 5. Results for different ISIs on the slow lane.

ISIs	Value ranges for the most unsafe 1% of vehicles				
	0-500vph	500-800vph	800-1100vph	1100-1500vph	>1500vph
IBTR (G-values)	>x:x∈[2-3]	>x:x∈[2-3]	>x:x∈[3-4]	>x:x∈[3-4]	>x:x∈[3-4]
PBTR (J-values)	>x:x∈[2-3]	>x:x∈[3-4]	>x:x∈[4-5]	>x:x∈[5-6]	>x:x∈[7-8]
IBTR (G-values), Rain	>x:x∈[2-3]	>x:x∈[3-4]	>x:x∈[3-4]	>x:x∈[3-4]	>x:x∈[4-5]
PBTR (J-values), Rain	>x:x∈[3-4]	>x:x∈[5-6]	>x:x∈[7-8]	>x:x∈[10-11]	>x:x∈[15-16]
TTC (s)	<x:x∈[7.0-7.5]	<x:x∈[5.0-5.5]	<x:x∈[4.5-5.0]	<x:x∈[4.5-5.0]	<x:x∈[4.0-4.5]
SOSL (km/h)	>x:x∈[150-160]	>x:x∈[140-150]	>x:x∈[140-150]	>x:x∈[140-150]	>x:x∈[130-140]
Headway (s)	<x:x∈[0.5-1.0]	<x:x∈[0.5-1.0]	<x:x∈[0.5-1.0]	<x:x∈[0.0-0.5]	<x:x∈[0.0-0.5]
PICUD (m)	<x:x∈[4-5]	<x:x∈[2-3]	<x:x∈[1-2]	<x:x∈[0-1]	<x:x∈[0-1]
PICUD Rain (m)	<x:x∈[5-6]	<x:x∈[2-3]	<x:x∈[1-2]	<x:x∈[1-2]	<x:x∈[1-2]

Table 6. Results for different ISIs on the fast lane.

ISIs	Value ranges for the most unsafe 1% of vehicles				
	0-500vph	500-800vph	800-1100vph	1100-1500vph	>1500vph
IBTR (G-values)	>x:x∈[3-4]	>x:x∈[4-5]	>x:x∈[4-5]	>x:x∈[4-5]	>x:x∈[4-5]
PBTR (J-values)	>x:x∈[6-7]	>x:x∈[9-10]	>x:x∈[12-13]	>x:x∈[17-18]	>x:x∈[27-28]
IBTR (G-values), Rain	>x:x∈[4-5]	>x:x∈[4-5]	>x:x∈[4-5]	>x:x∈[4-5]	>x:x∈[4-5]
PBTR (J-values), Rain	>x:x∈[8-9]	>x:x∈[13-14]	>x:x∈[19-20]	>x:x∈[29-30]	>x:x∈[49-100]
TTC (s)	<x:x∈[6.5-7.0]	<x:x∈[5.5-6.0]	<x:x∈[5.5-6.0]	<x:x∈[5.5-6.0]	<x:x∈[5.5-6.0]
SOSL (km/h)	>x:x∈[140-150]	>x:x∈[140-150]	>x:x∈[140-150]	>x:x∈[140-150]	>x:x∈[130-140]
Headway (s)	<x:x∈[0.0-0.5]	<x:x∈[0.0-0.5]	<x:x∈[0.0-0.5]	<x:x∈[0.0-0.5]	<x:x∈[0.0-0.5]
PICUD (m)	<x:x∈[2-3]	<x:x∈[1-2]	<x:x∈[1-2]	<x:x∈[0-1]	<x:x∈[0-1]
PICUD Rain (m)	<x:x∈[2-3]	<x:x∈[1-2]	<x:x∈[1-2]	<x:x∈[0-1]	<x:x∈[0-1]

When the flow increases, both headway and PICUD tend to decrease. This is because the density of vehicles increases, and vehicles have to move closely to each other. This really indicates the crash risk: 1% of vehicles move with a very small headway (less than 0.5s).

Crash Cases

This section presents the evolution of ISIs before the 4 selected crashes and analyze if the ISIs can be used for capturing traffic situations leading to the crashes.

Consider the crash happened on the 8th of March, 2003. According to Table 3, the outside conditions were good: fine weather, daylight, dry pavement, etc. Figure 3 and Figure 4 show the evolution of PBTR before, during and after the crash on the slow and fast lanes. Although the exact crash time is unknown from the police’s record, it can be approximated through the speed drop at 16:41.

Table 7 shows the traffic volume during 5-minute periods before the crash. During 5 minutes preceding the crash, traffic volume on the fast lane was high (1644vph). ISI values during 5 minutes just before the crash are calculated and compared to the ISI distributions.

Table 7. Traffic Flows (in vph) before the crash.

Lanes\Minutes	0	-5	-10	-15	-20	-25	-30	-35	-40
Low	1104	1188	1140	1044	1260	1332	1152	1356	1248
Fast	1368	1644	1152	1344	1404	1572	1308	1296	1104

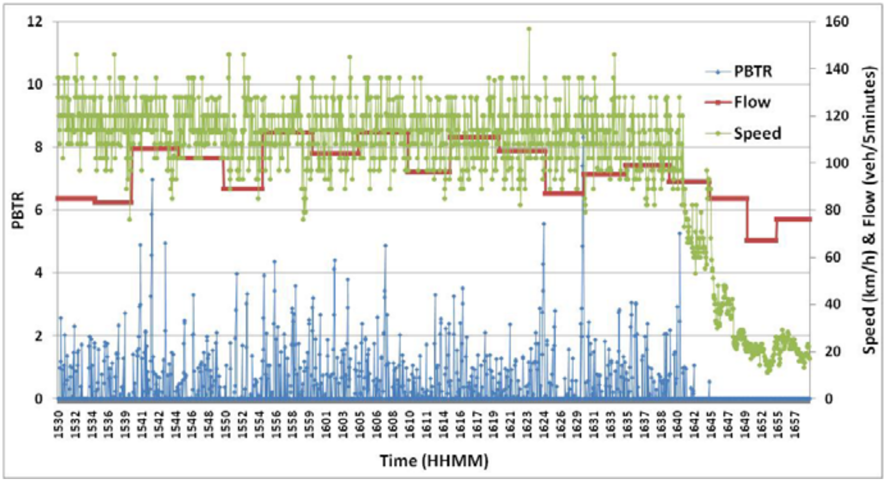

Figure 3. Traffic flow, speed and PBTR before, during, and after the crash on the slow lane

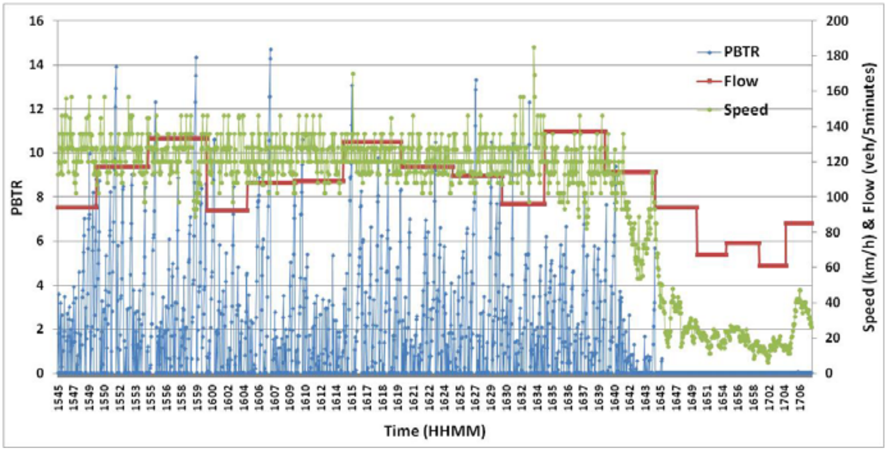

Figure 4. Traffic flow, speed and PBTR before, during, and after the crash on the fast lane

Table 8 shows the comparison results for the four crashes on the slow lane (SL) and on the fast lane (FL). In each cell, a "+" value means that the corresponding ISI is exceeding the safe limit defined in Table 5 and Table 6. A "-" value means that the corresponding ISI cannot recognize the risk of this crash during the 5 minutes preceding the crash.

Table 8. Indication by ISIs on each lane for four crashes
(crashes are represented by crash date).

Index	ISIs	20030308		20030310		20040116		20040922	
		SL	FL	SL	FL	SL	FL	SL	FL
1	IBTR (G-values)	-	+	-	-	+	+	+	+
2	PBTR (J-values)	+	+	-	-	-	+	+	+
3	TTC (s)	-	+	+	+	+	+	+	+
4	SOSL (km/h)	-	-	+	-	-	+	+	+
5	Headway (s)	-	-	-	-	+	-	+	+
6	PICUD (m)	-	-	+	+	-	+	+	-

The results in Table 8 show that IBTR, PBTR and TTC work well on the fast lane in this crash case (20030308). On the contrary, SOSL, Headway and PICUD could not capture traffic situations before the crash. Even though the first three ISIs provide the good indication, they will need to be verified with normal traffic situations under the same traffic and weather conditions. Similarly, the last three ISIs in Table 8 could provide the good indication on other crashes regardless of their bad performance on the first crash.

The numerousness of "+" values in Table 8 means that all the ISIs can capture risky situations with the risk criteria defined in Table 5 and Table 6. However, such criteria need to be verified with normal traffic situations.

Suggestion on ISI Thresholds and Aggregate Thresholds.

There are two thresholds for each ISI that need to be defined. The first threshold, called "individual threshold", is the ISI level at which a vehicle is considered as having crash risk. For example, Hayward (1972) suggested that 4 seconds was the TTC level at which a vehicle can have crash risk. Today vehicles are equipped with good security devices and hence, TTC level might have changed. If TTC threshold is still fixed at 4s, there will be 0.2% out of all vehicles being risky on the slow lane according to TTC distribution in Figure 14 and Figure 15, in the ANNEX.

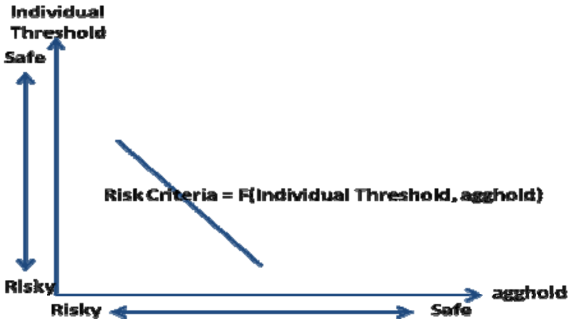

Figure 5. Risk criteria function

The second threshold (or agghold) of an ISI is the maximum percentage of vehicles during a traffic situation having value out of the safe ISI range. The agghold aims at determining if the traffic situation is risky or not.

How to choose the individual thresholds and the aggholds?

If the individual threshold for TTC is too small, i.e. it is rare to observe a vehicle having this TTC value, high TTC agghold will consider all the traffic situations as "safe". On the contrary, if the individual TTC threshold is too large, a low TTC agghold will classify all the traffic situations as "risky". Determining the thresholds could be based on the trade-off between the suitable percentage of correctly alarmed traffic situations and a percentage of false alarms. For example, if a period of 5 minutes is used as a traffic situation, there are 288 situations in a day. From the practical point of view, the percentage of alarmed periods could be decided so that drivers would remain confident with the alarm. Figure 5 shows the risk criteria line, which is a function of the individual threshold and the agghold if this method of defining the thresholds is applied.

The threshold selection in this research is undertaken for each flow range and weather conditions as the results of the ISI sensitivity analysis in the previous section. Taking into account the risk criteria function, Table 9 shows the defined thresholds for the high flow range (>1500vph) under the fine weather conditions on the slow lane. If 0.1% of vehicles are considered as “risky” according to each ISI and if 0.1% of traffic situations are classified “risky”, the thresholds should be defined as in Table 9.

Table 9. Risk criteria for high flow range (>1500vph) under fine weather conditions on the slow lane.

ISIs	Individual Thresholds	Agghold (%)
IBTR (G-values)	5.0	2.00
PBTR (J-values)	13.0	3.92
TTC (s)	1.5	2.50
SOSL (km/h)	150.0	0.78
Headway (s)	0.5	14.50
PICUD (m)	1.0	5.37

However, there are other methods to set the thresholds. The safety indicators by themselves imply somehow crash risk. Each ISI has its own detection rate, according to its performance, which must be determined first. With the crash records and normal traffic situations, the false alarm rate could be set. Thresholds will be set based on the detection rate and the false alarm rate.

Consider the reverse process: determining the false alarm rate from non-crash traffic situations. For each crash case, there are 4 non-crash situations selected for the same time of day, on the same day of the week, and under the same weather conditions. Table 10 shows the 16 selected normal situations for each crash.

Table 10. Selection of non-crash situations.

Pre-crash situations	Selected dates with normal situations
20030308 1500-1700	20030301, 20030315, 20040228, 20040313
20030310 0800-1000	20030303, 20030317, 20040301, 20040315
20040116 1800-2000	20040109, 20040123, 20050114, 20050121
20040922 1600-1800	20040915, 20040929, 20050921, 20050928

For example, for the crash happening on the 8th of March, 2003, the crash time is about 16:41. Table 8 shows that during 5 minutes before the crash (from 16:35-16:40), crash risk is captured by IBTR. If the same 5-minute period on the 1st of March, 2003 is considered and the risk criteria on Table 5 and Table 6 are applied, the IBTR still captures a crash risk. This is a false alarm caused by IBTR because there was no crash on the 1st of March, 2003.

The same procedure is undertaken for the other ISIs and on the 15 other selected dates from Table 10 leading to a false alarm rate based on 16 observations. Detection rates are computed directly from Table 8 (4 observations): for instance, IBTR captured crash risk in three cases out of four (i.e. 75%). Table 11 summarizes the detection rates and false alarm rates given by each ISI.

Table 11. Detection rates and false alarm rates for each ISI with 4 crashes and 16 selected normal situations.

	IBTR	PBTR	TTC	SOSL	Headway	PICUD
Detection rate	75%	75%	100%	75%	50%	75%
False alarm rate	56.2%	50%	75%	62.5%	43.7%	50%

As shown in Table 11, the false alarm rates by ISIs are high, which is caused by criteria defined in Table 5 and Table 6 applying for the most unsafe one percent of all vehicles. Moreover, the aggregate thresholds are not taken under consideration in this case. If the risk criteria are more carefully defined and if the aggregate thresholds are considered, the detection rate should increase and the false alarm rate should decrease. This is to say that with given detection rates and false alarm rates, it is possible to find the individual thresholds and the aggholds satisfying high detection rates and low false alarm rates.

Finally, practical aspects could also be taken under consideration, so that the alarm would not annoy the drivers. Each ISI has its own risk criteria and the combination of the ISIs could make many alarms during a day. In case there is a dense traffic detector network installed along motorways, the thresholds should also be determined based on the overview performance of safety indicators at each detector.

CONCLUSIONS

This paper presents the sensitivity analysis of six individual safety indicators (ISIs) under different traffic and weather conditions, and two methods for setting thresholds which allow defining risk criteria. The evolution of the ISIs was also tested with four crash cases as well as with normal traffic situations.

To capture the pre-crash situations, the risk criteria need to be defined. By using the ISIs, the risk criteria could be obtained in determining two thresholds: ISI threshold and aggregate threshold (or “agghold”). The trade-off between these two thresholds is important. One of the practical ways to define the criteria is to establish a desired alarm rate and then thresholds are determined accordingly. Another way is to use ISIs’ detection rates, false alarm rates, and desired alarm rates for setting the thresholds.

In this paper, the suggestion about risk criteria is also given by defining thresholds under fine weather conditions and high flow. The same procedure can be applied to define risk criteria for other weather conditions and flow ranges. The traffic flow can also be divided into smaller flow ranges.

In the continuation of the current work, the performance of safety indicators at the other traffic detectors in Vaud canton, Switzerland will be considered so that risk criteria for the whole motorway network in the canton could be obtained.

ACKNOWLEDGEMENTS

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ANNEX

The figures in this sections show the ISI distribution on two lanes and under different weather conditions.

Lane 1 (Slow Lane)

Lane 2 (Fast Lane)

1-IBTR under fine weather conditions

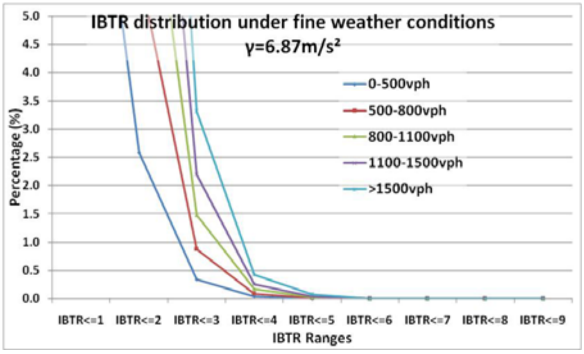

Figure 6. IBTR distribution

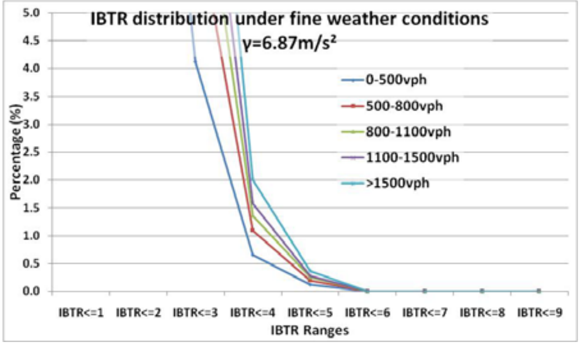

Figure 7. IBTR distribution

2-IBTR under rain conditions

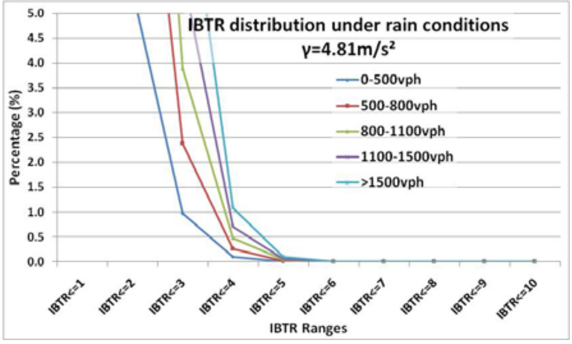

Figure 8. IBTR distribution

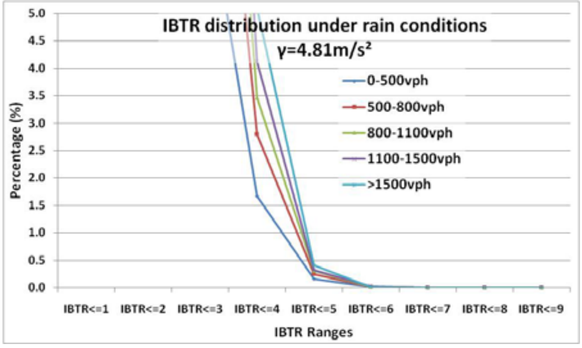

Figure 9. IBTR distribution

3-PBTR under fine weather conditions

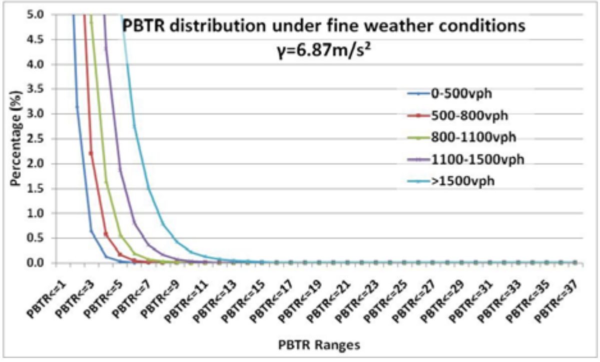

Figure 10. PBTR distribution

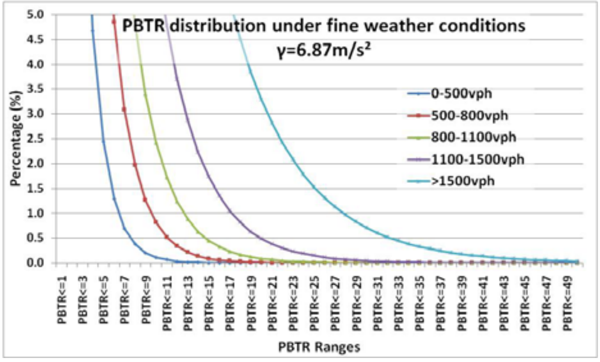

Figure 11. PBTR distribution

Lane 1 (Slow Lane) **Lane 2 (Fast Lane)**

4-PBTR under rain conditions

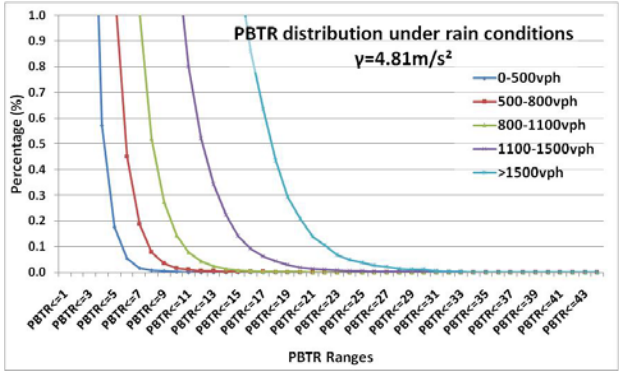

Figure 12. PBTR distribution

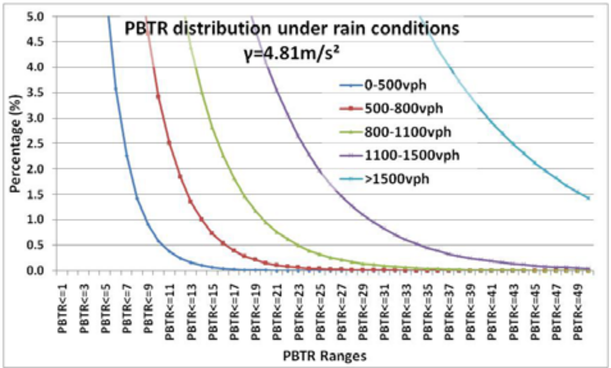

Figure 13. PBTR distribution

5-TTC for all weather conditions

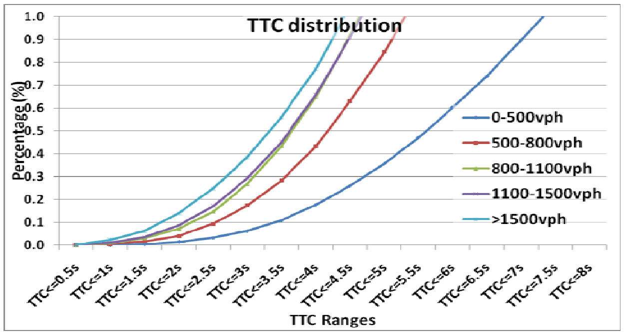

Figure 14. TTC distribution

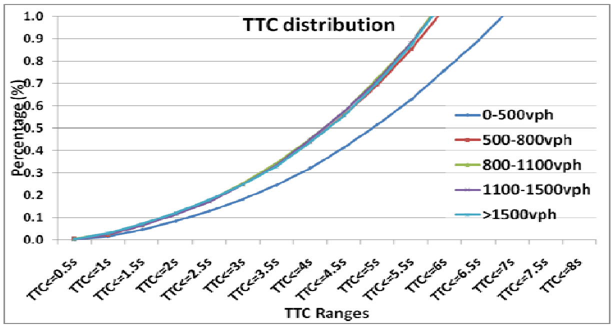

Figure 15. TTC distribution

6-SOSL for all weather conditions

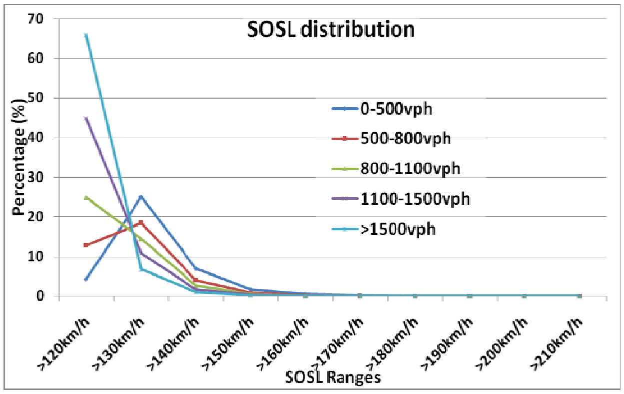

Figure 16. SOSL distribution

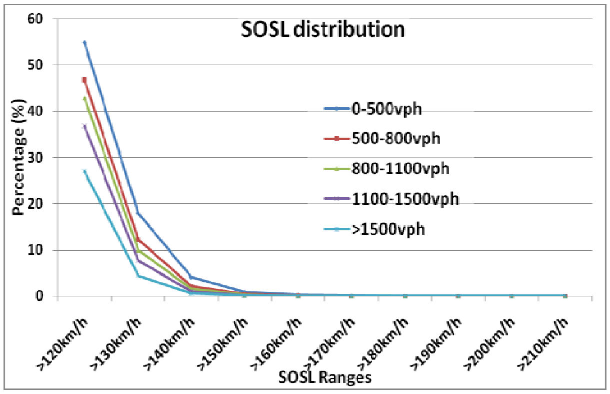

Figure 17. SOSL distribution

Lane 1 (Slow Lane) **Lane 2 (Fast Lane)**

7-Headway for all weather conditions

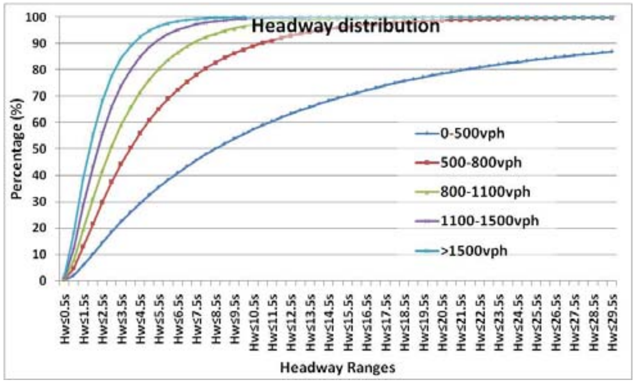

Figure 18. Headway distribution

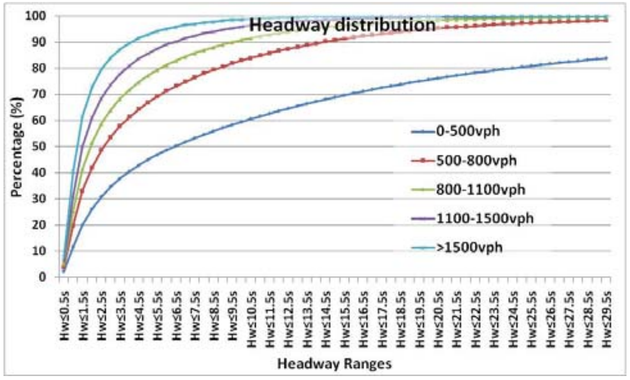

Figure 19. Headway distribution

8-PICUD under fine weather conditions

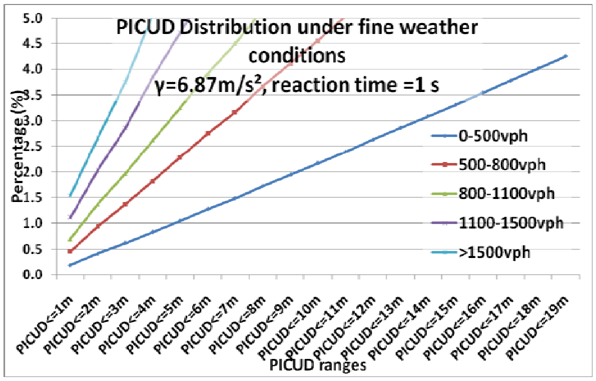

Figure 20. PICUD distribution

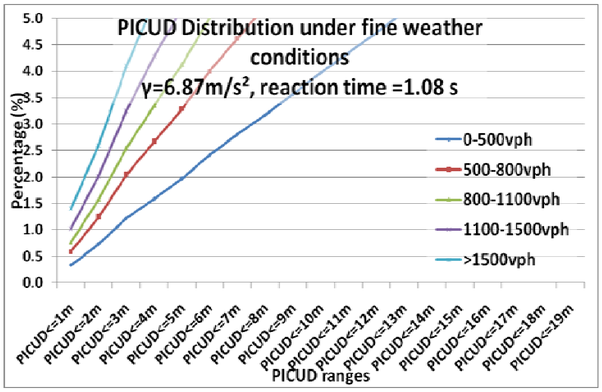

Figure 21. PICUD distribution

9-PICUD under rain conditions

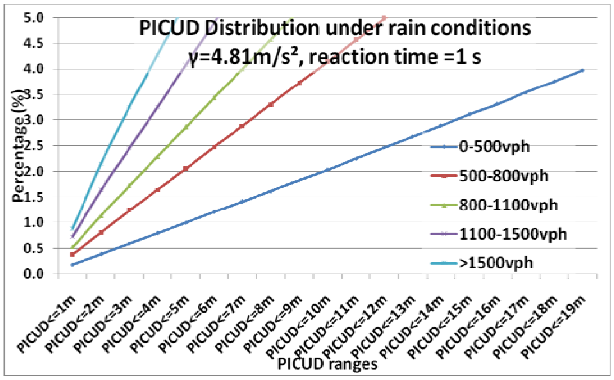

Figure 22. PICUD distribution

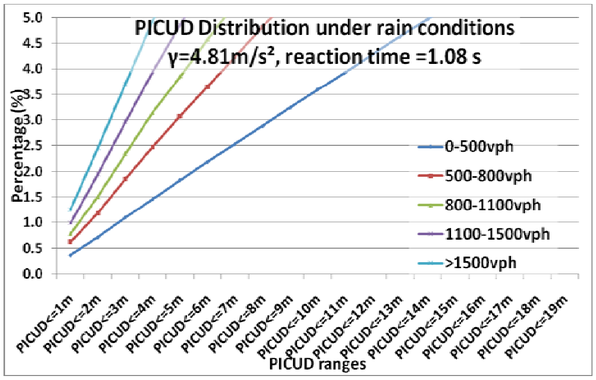

Figure 23. PICUD distribution