Applicability of road safety indicators to assess driving risks under Swiss road conditions

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Abstract

Road traffic crash is a problem in every country. According to World Health Organization, in Europe there are about 127,000 people killed and at least some 2.4 million injured each year. Incident detection algorithms to detect incidents on motorways are well developed. Their objective is to detect incidents as soon as possible so that emergency services can get to the scene of the incident as soon as possible to reduce congestion, to provide medical help if needed and to increase safety of the affected area.

Some crashes are traffic related and it may be possible to detect the state of the traffic where the risk of a crash is high. Based on this, premise safety indicators have been developed by [Aron et al, 2003], [Hayward, J. C., 1972], [Lee, C. et al, 2006], and [Pande, A. et al, 2006]. The derivation of these safety indicators are data driven and may be able to forecast the potential of a crash in real time.

This study aims to assess the driving risks under Swiss road conditions by using safety indicators. Real traffic data from Automatic Traffic Counts installed on motorways and crash data have been collected in Vaud canton, Switzerland. This paper also discusses the applicability of the proposed safety indicators and the issues associated with their use.

Keywords

Motorway traffic safety – safety indicators – J-values – Time-To-Collision – crash-prediction, 7th Swiss Transport Research Conference – STRC 2007

1. Introduction

Road traffic crashes are becoming a big concern of governments in many countries. According to "*World report on road traffic injury prevention*"[1] of the World Health Organization, road traffic crashes kill 1.2 million people a year or an average of 3242 people every day and injure between 20 and 50 million people a year. Road traffic crashes have been ranked the 11th leading cause of death and account for 2.1% of all deaths globally.

In many countries, motorway system has a vital role in transport system. It links cities and allows fast movements that can only be undertaken by high speed supporting vehicles such as automobiles, trucks, and motorbikes. On the one hand, the fast movement on the motorways decreases travel time. On the other hand, a series of motorway traffic safety regulations against such high speed traffic conditions have to be applied to reduce traffic crash risks where a crash would have severe consequences.

Switzerland is one of the leading countries in road traffic safety. According to SINUS report published in 2006[2], in recent years, the number of deaths and heavy injuries by road traffic crashes is decreasing. This positive tendency is obtained thank to a series of prevention methods such as the reduction of speed limits, the improvement of pavement, etc. However, the total number of road traffic crashes is still very high with about 27000 deaths and injuries in 2005, of which the number of motorway traffic crashes is about 400 and this number does not change much in comparison to previous years.

In Switzerland, many Automatic Traffic Counts (ATCs) are installed on Swiss motorway system in the purpose of better road management. Some ATCs can store individual vehicle data each time a vehicle passes the ATC. Can this data be used to forecast crash risk on the motorway? The answer could be "Yes" if traffic safety indicators are used. In this paper, we will introduce our current work relating to safety indicators and their applicability to crash prevention in Swiss conditions. In section 2, the review of previous studies is introduced, as well as the safety

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[1] *World report on road traffic injury prevention - Main messages, 2004*. http://www.who.int/violence_injury_prevention/publications/road_traffic/world_report/main_messages_en.pdf

[2] Rapport SINUS 2006. *Niveau de sécurité et accidents dans la circulation routière en 2005* by Bureau suisse de prévention des accidents - BPA. http://shop.bfu.ch/pdf/962_74.pdf

indicators that are used in this paper. Data sources and studied area are presented in section 3. The preliminary analysis follows in section 4. It includes a detailed description of the considered safety indicators and a preliminary sensitivity analysis. Then an example of the evolution of safety indicators before a crash will show in more detail the applicability of the safety indicators. Conclusions and perspectives of our work are given in section 5.

2. Background

As road safety issues arose, automatic incident detection algorithms were first proposed. Then the research went up to predicting crashes before hand. This evolution is presented in the next subsection. A second subsection then presents safety indicators, which can be parameters of crash prediction algorithms or which can be simply used alone to evaluate the level of risk of a traffic situation.

2.1 From automatic incident detection to crash prediction

Incident detection algorithms to detect incidents on motorways are well developed based on traffic flow theory, pattern recognition, statistical techniques, and recently using artificial intelligence and fuzzy logic [Martin P.T. et al., 2000]. Their objective is to detect incidents as soon as possible so that emergency services can get to the scene of the incident as soon as possible to reduce congestion, to provide medical help if needed and to increase safety of the affected area.

The idea of automatic incident detection is to use some type of traffic data, i.e. loop detector data, video data, etc. to detect a crash, for example, when it happened. However, for the purpose of crash prevention, detecting the crash occurrence is too late. Thus, the traffic pattern that can lead to the crash needs to be recognized so that some necessary interfering action can be undertaken to reduce the probability of the crash.

Recently, [Pande et al., 2006] look into the relationship between real motorway traffic data collected from traffic detectors and rear-end crashes provided by the police. The traffic and crash data for the analysis are from 36.3 miles of freeway in Orlando, USA over 5 year 1999-2005. To get more accurate time of crash, crash data were pre-processed by using a refined rule-based shockwave method. Then, for each crash, data from 7 detectors (named from B to H where B-F are upstream detectors and B is the farthest from the crash position, and G and H are downstream detectors) within 30 minutes before the crash are processed. The 30-minute period is then divided into six 5-minute time slices in each of which raw data are aggregated. For each slice, 6 parameters are considered: the average and the standard deviation of speed, volume and lane occupancy. The parameters from traffic condition before the crash are then compared to the same parameters from the other traffic conditions at the same time, on the same day of other weeks by using several data mining techniques. By this method, rear end crashes were found to often occur under extended congestion or when average speeds were high. With this conclusion, the authors suggest that there should be some 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.

In [Lee C. et al, 2006], Lee et al 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 A. et al., 2006] with the help of logistic regression. The seven examined indicators were average speed, flow, and occupancy of each 30 second over 5-10 minutes before the crash, coefficient of variation in speed (CVS), coefficient of variation in flow (CVF), peak/off-peak period and the curvature of the road section. A new indicator – Overall Average Flow Ratio (OAFR) was defined and is a revised parameter from the AFR (Average Flow Ratio) accounting for imbalance of lane flow across neighbouring lanes during short time periods (5 minutes) proposed by [Chang, G. and Kao, Y.]. The traffic conditions before the crash is characterized by the detector station immediately upstream. After the evaluation of the effect of each indicator, only three of them are concluded to be useful for the analysis. They are OAFR, CVF and peak/off-peak. With the assumption that the fractions of lane changes from lane 2 to lane 1 and to lane 3 are equal, they find that OAFR is in general higher for sideswipe crashes than for rear-end ones and this indicates that higher variation of flows across lanes contribute more to occurrence of sideswipe than rear-end crashes. They also find that sideswipe crashes occur more often under uncongested conditions (off-peak periods). This according to them may be due to the fact that in uncongested conditions, it is easier for drivers to find gaps to change lanes. The increase of lane changes may raise the risk of sideswipe crash. For this reason, reducing OAFR and CVF by balancing flow across lanes and allowing smooth lane change over longer distance may help reduce high risks of sideswipe crashes. However, this conclusion was drawn when weather effect was not taken into the account and crash time was believed to be accurately recorded.

2.2 Traffic Safety Indicators

Many studies were undertaken to better understand and improve the motorway traffic safety. One of the research directions is to use measures to characterize traffic situations in the purpose of forecasting incidents and taking necessary operational actions to reduce the risk. These measures are called “safety indicators” that allow describing partially safety status of a road section with its unchanged infrastructure configuration. The indicators can characterize traffic flow properties before the occurrences of an incident. The indicators also allow predicting potential incidents that may occur in progress of the current traffic flow.

Originated from car manufacturers, the Time-To-Collision (TTC) is an important indicator that represents the time required for two vehicles to collide if they continue at their present speed and on the same path [Hayward, J. C., 1972]. TTC plays the central role in Traffic Conflict Techniques in many countries. In 1993, Van der Horst, R., et al introduced TTC as a core parameter in the Collision Avoidance system [Van der Horst, R., et al., 1993].

Other similar-to-TTC indicators were then presented such as Deceleration to Safety Time (DST) [Hupfer C., 1997], Post-Encroachment-Time (PET) [Cooper P.J., 1984],Time-Exposed-TTC (TET) and Time-Integrated-TTC (TIT) [Minderhoud, MM. et al, 2001]. Although these safety indicators can be adapted to traffic condition on motorways, they are mostly used to evaluate safety on urban roads, especially for intersections. Most of these indicators are calculated based on manual observation due to the lack of traffic detecting facilities.

Recently, [Aron et al, 2003] presented J-value which is an accumulative safety indicator. The values of this parameter are obtained based on individual vehicle data, e.g. time gap between two consecutive vehicles, and individual vehicle speed which can be collected from motorway traffic loop detectors.

The other safety indicators mentioned in section 2.1 can also be candidates for our study.

3. Field data and Study area

Traffic data, weather data, and crash data in Switzerland are needed for this study. In this research, we focus mainly on motorways in Vaud canton where the three types of data are available altogether from 2002 to 2005. The next subsection focuses on sites having both traffic and weather data. Then, a second subsection considers accidents in the selected sites.

3.1 Weather data and traffic data

Two sources of meteorological data are available: one from the Boschung system and the other from the Federal Office of Meteorology and Climatology (MeteoSuisse). While meteorological data from MeteoSuisse have more general purposes, Boschung road weather stations are installed along the road sections, specifically for monitoring the weather conditions on the Swiss road network. Weather data from Boschung stations are thus chosen in this study. Boschung stations provide data collected every 6 minutes. The important data field, type of precipitation, has been pre-processed, and only symbolic values for this field are provided. For example, three values are assigned: “R”, “S” and “-” for rain, snow, no-precipitation (or fine weather) conditions, respectively.

In Switzerland, the network of Automatic Traffic Counts (ATCs) is operated by FEDRO (the Swiss Federal Roads Office), which is the federal authority responsible for national road infrastructure in the country. At the end of 2006, there were 259 permanent automatic traffic counting stations located in almost every motorways and main roads of the country. However, individual vehicle data from only 73 stations are downloadable online.

In Vaud canton, there are 3 ATCs that can provide downloadable traffic data and can be associated to the nearest Boschung stations: ATCs 116, 149, and 226. Site 226 is a complex site with 8 lanes and is the crossing point between A1 and A9 (as shown in Figure 2). To better concentrate on traffic properties, only sites 116 and 149 are considered: each site has 4 lanes for two directions. In each direction, the outer lane is the normal lane while the inner lane is the overtaking lane.

Table 1 below shows the combination of ATCs and Boschung stations and Figure 1 below shows the positions of ATCs and Boschung stations.

Table 1: Combination of ATC and weather stations

Site	Location	Weather station	Lanes
116	A9	41.21.1.32	4
149	A1	41.21.1.4	4

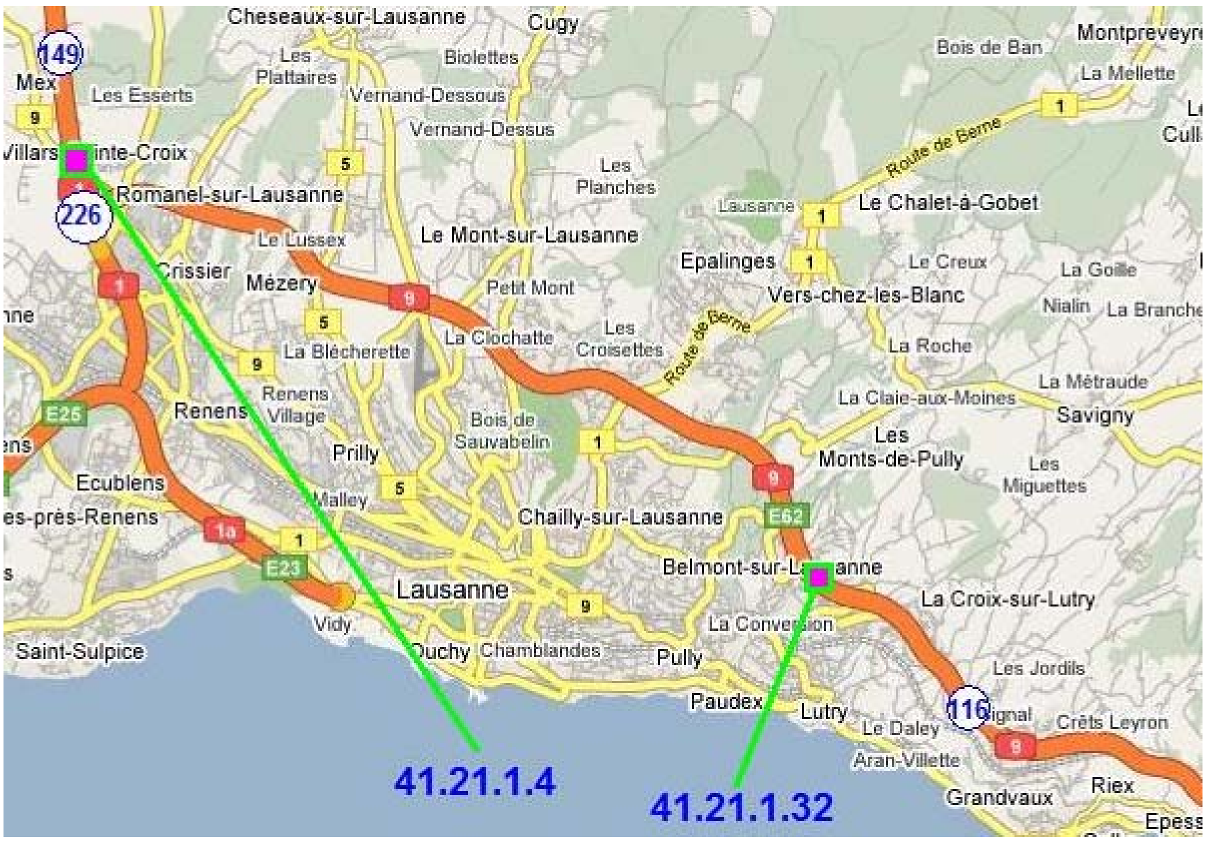


Figure 1: ATCs & Boschung stations in Vaud canton

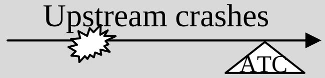
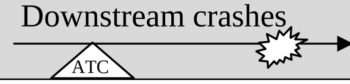
3.2 Crash database

Motorway crash data in Vaud canton, Switzerland, contain information about crash positions, date and time of crashes, weather conditions, pavement conditions, lighting conditions, types of crashes, and drivers' status during the crashes. Data in the files are coded according to OFS code (Office Fédéral de la Statistique). The time of a crash is stored under the form of a one-hour period where the crash happened: e.g. if a crash happened somewhen between 02:00PM and 03:00PM then the time of the crash recorded is 14:00-15:00. During the 4 studied years (2002-2005), there are totally 3693 crashes on motorway sections in Vaud canton, among which 470 (12.7% of all crashes) are driving under influence of alcohol crashes (DUI crashes).

All DUI-crashes are out of interest for our study and they have been excluded. The reduced crash database contains 3223 crashes. The research focuses only on two motorways N1 (the section from Lausanne to Bern – N1LB), and N9 (the section from Lausanne to Sion, N9LS) where traffic data are available from the two ATCs 116 and 149. Eliminating crashes on other road sections, the number of crashes is 1940.

To understand the evolution of traffic before, during and after a crash, the traffic patterns leading to the crash need to be analyzed. However, the constraint of distance between a crash and the location of the nearest ATC causes the strong reduction of number of crashes that can be used in this study. The locations of the ATCs are fixed points. The crashes are selected if they are inside a buffer of 500m around an ATC. Table 2 shows the number of Non-DUI crashes for each ATC.

Table 2: Crash distribution by ATCs' locations

ATC	Upstream crashes 	Downstream crashes 
116	15	14
149	24	18

4. Preliminary Analysis

The analysis is performed on the sites selected in the previous section. It is presented in three subsections. The first one defines in detail the two studied safety indicators. The second subsection gives some preliminary analysis of the sensitivity of the considered safety indicators for year 2005 and draws some preliminary guidelines on how to use those safety indicators. Finally, the last subsection applies the previous steps in a case study, using one accident of our database.

4.1 Safety Indicators

Many safety indicators mentioned in section 2 require short inter-ATC spacing to capture the backward shockwave from a particular point on the motorway. However, there are also some safety indicators that do not require the short spacing but need individual vehicle data. Under current situation in Vaud canton, Switzerland, the latter safety indicators can be tested on the two ATCs. The selected safety indicators are therefore J-values and TTC.

TTC is the time where a collision occurs when the following vehicle i moves faster than the preceding one (i-1) and if both of the vehicles maintain their speed. If speed and position of the vehicles i and (i-1) are v_i, x_i and v_{i-1}, x_{i-1}, TTC of the vehicle i is:

$$TTC(i) = \frac{x_{i-1} - x_i}{v_i - v_{i-1}} \quad (1)$$

When the vehicle i passes an ATC, the distance from the vehicle (i-1) to the ATC is $Gap_i . v_{i-1}$ with Gap_i is the time gap between the two vehicles. Then TTC can be calculated by:

$$TTC(i) = \frac{Gap_i . v_{i-1}}{v_i - v_{i-1}} \quad (2)$$

J-value was first introduced by Aron M., et al in 2003. It represents the accumulation of risk of vehicles inside a platoon. The vehicle i>0 with time gap Gap_i and deceleration rate $\gamma_{\max}$ has the "Individual Braking Time Risk – IBTR" G(i).

$$G(i) = Max\left[0, \log_2\left(\frac{1}{2}.\frac{v_i}{\gamma_{\max}}\frac{1}{Gap_i}\right)\right] \quad (3)$$

J-value of a vehicle i can be obtained by:

$$J(i)=\begin{cases} 0 \text{ if } G(i)=0 \\ J(i-1)+G(i-1) \text{ if } (G(i)>0 \end{cases} \quad (4)$$

if i=0 then G(i)=0, i.e. the vehicle i is the first vehicle in the platoon.

4.2 Sensitivity of safety indicators

Traffic data and weather data for the whole year 2005 were used to observe the distribution of J-values and TTC. The aggregation is done to J-values and TTC in each 5 minute period leading to range percentages of safety indicator outputs under different flow ranges for the whole year. One further step is taken for J-value with the integration of weather information into 5-minute periods to generate the J-value distribution under dry or wet conditions.

In (3), weather conditions can change the J-values due to the fact that deceleration rate of vehicles varies under different weather conditions. In [Aron M. et al, 2003], the suggested γ_{max} value is 6.25m/s² under fine weather conditions and 3.0m/s² under raining conditions.

According to (4), J is an accumulative safety indicator that is proportional to the risk of individual vehicles in a platoon: the higher the J-values, the more risky the traffic situation is. Because of this, high J-values are more interesting to our study on road safety.

In Figure 2, high J-values are observed more often under high flow conditions (flows above 1500veh/h), while under free flow (flows under 500veh/h) J-values greater than 10 are very rarely observed. For all the flow ranges, the percentage of high J-value ranges increases when the flow volume increases. According to (3), G-value increases when time gap between vehicles passing the detectors decreases. During high flow conditions, the presence of many vehicles reduces the inter-vehicle spacing and the time gap.

Figure 3 shows the distribution of J-values under raining conditions. Due to the application of a lower deceleration rate, J-values tend to increase, which has at least, two other effects: Firstly, the percentage of high J-value ranges increases, especially for medium to high flow ranges. For instance, when looking at the percentage of J-values greater than 19: Medium flow (800-1100veh/h) was close to 0% under fine weather conditions and is about 0.7% under raining weather conditions. Similarly, for high flows (1100-1500veh/h) the percentage raises from 0.2% to 7% from fine to raining weather conditions. The increase is even larger for very high flows (over 1500ve/h) from 1.2% under fine weather conditions to more than 30%. This means that there are more vehicles having high J-values under raining conditions than under fine weather conditions. Secondly, under raining conditions, most of the vehicles under high flow ranges are in unsafe conditions. For example, under raining weather conditions, there are only about 8% of vehicles under very high flows (over 1500veh/h) having J-value equal to zero, which means that only these vehicles should easily avoid a rear-end crash if the front vehicle suddenly brakes hard.

Contrary to J-values, TTC calculated according to (2) is not affected by weather conditions. TTC represents the time remaining before a hypothesized crash and the crash risk increases when TTC approaches zero. The percentage of low TTC is higher under high flow conditions as shown in Figure 4.

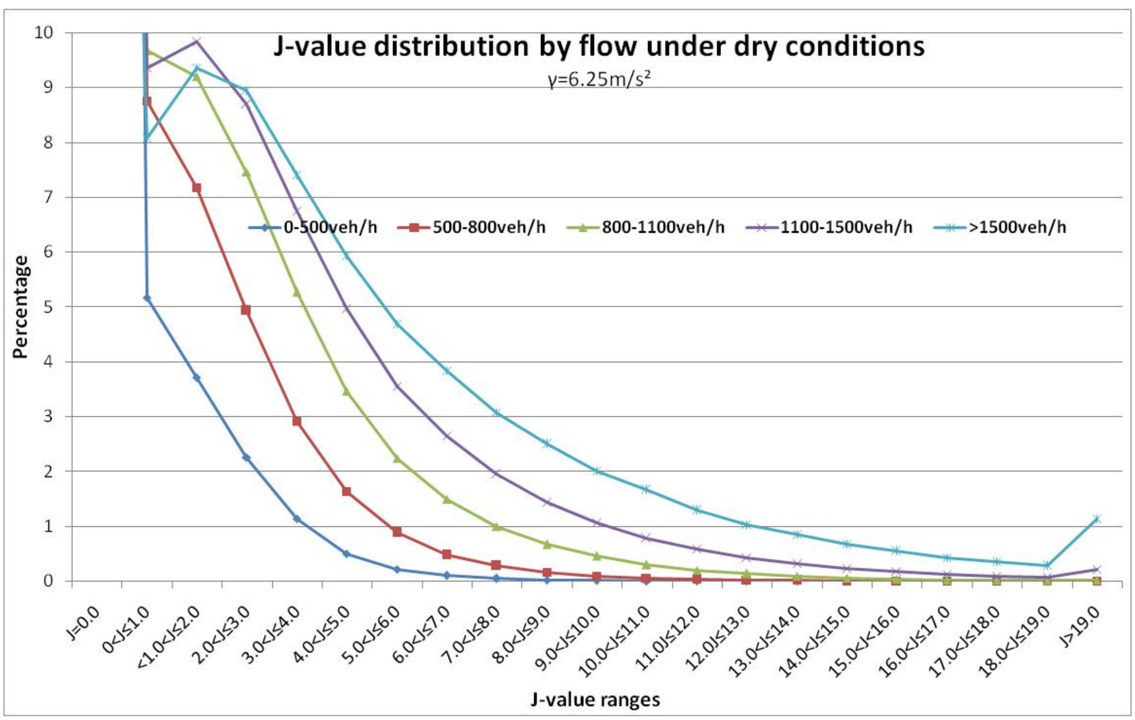


Figure 2: J-value distribution by flow ranges under fine weather conditions for the whole year of 2005, normal lane, site 116 zoomed in 0-10%.

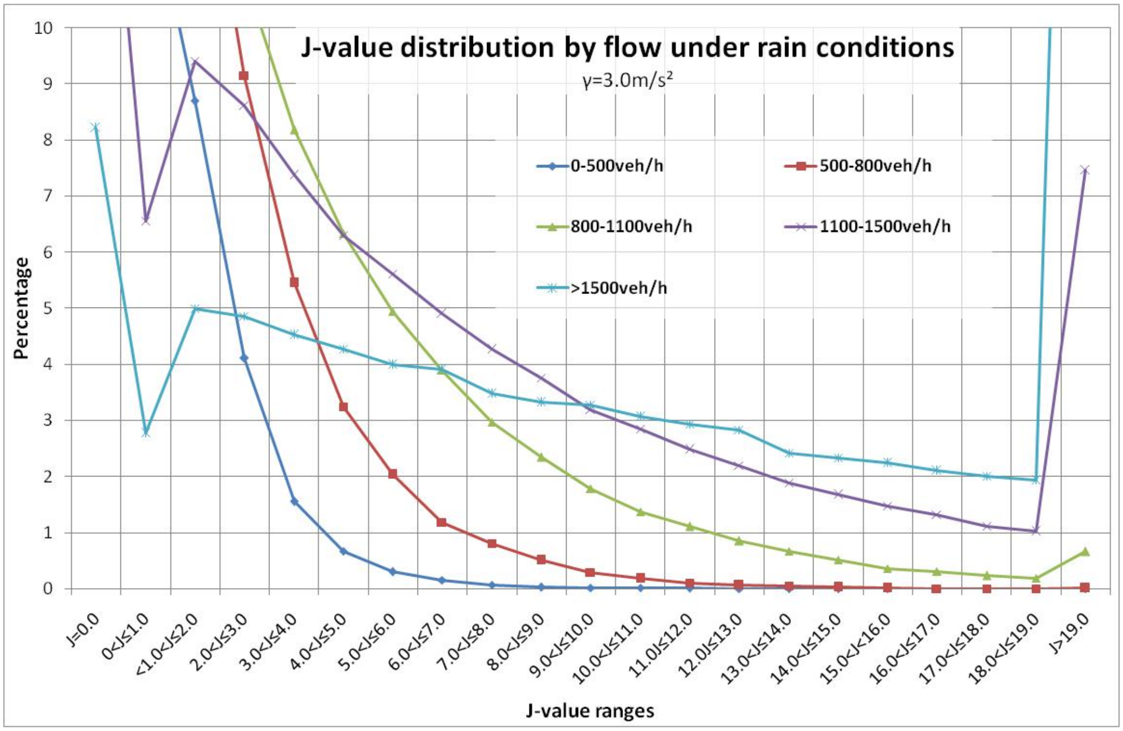


Figure 3: J-value distribution by flow ranges under raining weather conditions for the whole year of 2005 on the normal lane, site 116 zoomed in 0-10%.

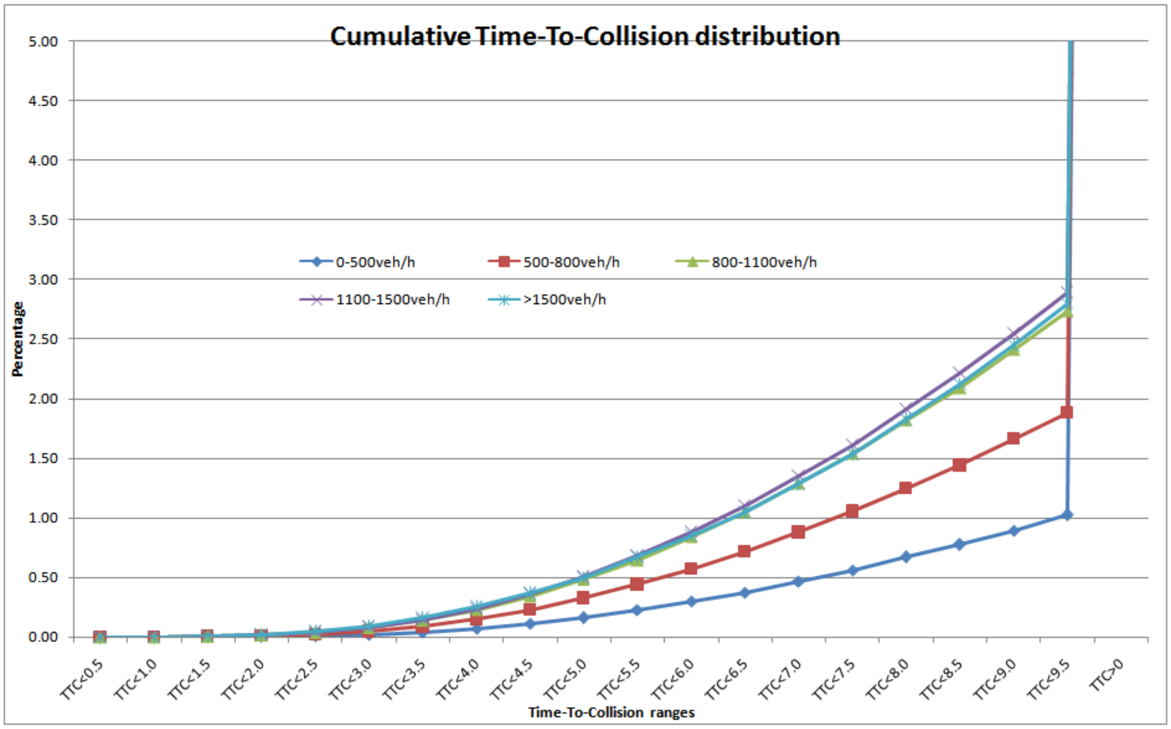


Figure 4: Cumulative TTC distribution by flow ranges for the whole year of 2005, on the normal lane, site 116 zoomed in 0-5%

In purpose of predicting accident occurrence, a critical value or threshold for J or TTC value needs to be set. When a traffic situation where J or TTC value is greater than the threshold, some action is to be undertaken in order to make the situation less risky.

The separation of different curves in Figures 2, 3, and 4 suggests that the distribution of J and TTC values depends on flow conditions. This means that the threshold of J or TTC should be set depending on traffic flows. For example, under fine weather conditions, there are about 1% of cases under high flow conditions (flows greater than 1500veh/h) where J values are in range of 13.0-14.0 while about 1% of cases under low flow conditions (smaller than 500veh/h) where J values are in range of 3.0-4.0.

Besides, the threshold for J-values also depends on weather conditions. For example, in Figure 2, the percentage of cases under high flow conditions (greater than 1500veh/h) having J-values in range of 13.0-14.0 is about 1% while in Figure 3, under the same flow condition the percentage of same J value range is about 2.5%.

4.3 Case study

In order to set the J or TTC threshold, the traffic evolution before crashes needs to be analyzed which will help determining the most suitable thresholds. For example, consider the following crash in Table 3:

Table 3: Crash information

Date & Time	Sunday, 2005-01-23, between 20:00-21:00
Position	A9, direction Sion-Lausanne: 15km500. This crash happened at upstream from the ATC 116.
DUI-crash?	No
Type of accident	Single-vehicle accident
Weather	Fine

Pavement	Dry
Lighting condition	dark

After the crash happened, the whole road section was temporally closed for 15 minutes (see Figures in Annex) and because the crash happened when vehicles passed the ATC 116, the flow value was zero at around 20:44. Although the exact time of the crash is not available in the crash report provided by the police of Vaud canton, the strong reduction of speed and flow at 20:44 can be a signal of the crash. After the crash, the road section was re-opened and the other vehicles passed in front of the ATC, though not at full speed yet.

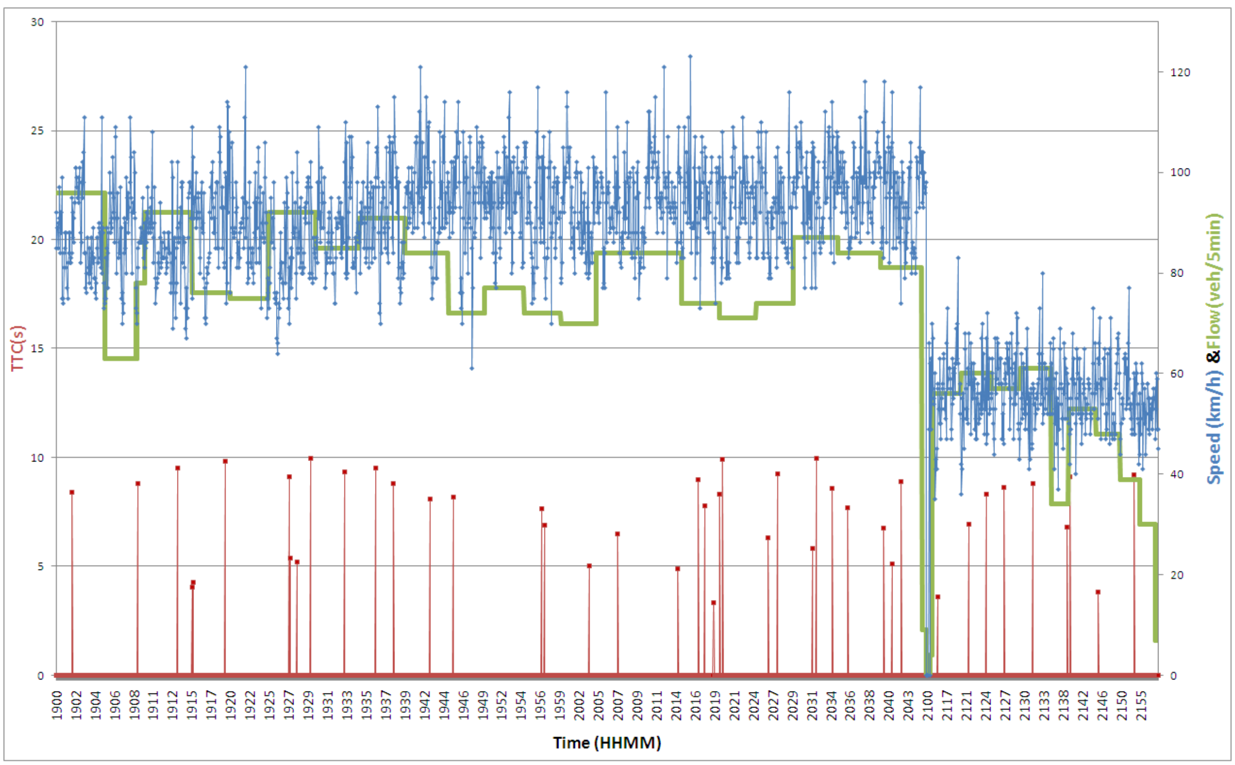


Figure 5: Flow, individual TTC, and individual speed on the normal lane when the crash happened. TTC values greater than 10s are excluded.

According to Figures 10, 11, 12, and 13 in Annex, the traffic flow on the normal lane during one hour before the crash was in range of 800-1100 veh/h and 0-500veh/h on the overtaking lane. For the normal lane, the largest percentage of vehicles having J value greater than 4 during one hour before the crash is 1.3% which is quite low for the flow range of 800-1100veh/h (see Figure 2 for fine weather condition). However, the TTC distribution during one hour before the crash shows that the traffic during that period is very risky with high percentage of low TTC in some periods. For the overtaking lane, J-value distribution (see Figure 12) shows that there are some periods before the crash where the percentage of J-values greater than 4 (which is high for the flow range of 0-500veh/h). TTC distribution of the overtaking lane (see Figure 13) also shows that during some periods before the crash, percentage of low TTC (<3.5s) is very high (2.56%).

5. Conclusion and perspectives

In this paper, our study on the applicability of two safety indicators, i.e. J-value and TTC, is presented. The preliminary results show that J-value and TTC distribution depend on traffic flow. Under different flow conditions, the distributions of J-value and TTC are different and this difference is represented by the separation of five flow-range curves in Figures 2, 3, and 4. Besides, as shown in Figures 2 and 3, J-value distribution is affected by weather conditions which are represented by various values of deceleration rates. These results are very important in purpose of preventing crash occurrences. To build a crash-predicting model, a threshold on the percentage of vehicles having high J-values and low TTC needs to be defined, based on flow conditions and weather conditions.

Although the obtained results are very encouraging, there is still more work to do to construct a crash-predicting model. Firstly, more analyses should be undertaken to provide concrete threshold values. This requires analyzing more years of traffic data, more crashes. Secondly, other safety indicators, including the safety indicators presented in section 2, also need to be analyzed to construct a more reliable multi-safety-indicator crash-predicting model.

However, under current Swiss motorway conditions, these further tasks can hardly be undertaken due to two main reasons: the lack of ATCs and the inaccuracy of crash data. The ATC spacing in Switzerland is too large for constructing an effective crash-predicting model. The large ATC spacing is also the cause for excluding many useful safety indicators which are introduced in the section 2. Besides, the crash data contains inaccurate information about the moment of the crashes and the lane where the crash happened.

In order to build a complete crash-predicting model, other sources of data should be used. The knowledge gained from analyzing this data will help constructing a crash-predicting model that can be adapted to Swiss motorway conditions. We are currently looking for new data sources in parallel to going further in understanding J-value and TTC.

6. References

Aron M., Biecheler M-B . and Peytavin J-F. (2003). Temps intervéhiculaires et vitesses : Quels enjeux de sécurité sur les routes de normandie. Deuxième étape : vitesses et interdistances pratiquées, liens avec les débits et les accidents. Convention DSCR/ INRETS 2001, fiche n°4, 172 pages, décembre 2003.

Chang, G. and Kao, Y. (1991). An Empirical Investigation of Macroscopic Lane-Changing Characteristics on Uncongested Multilane Freeways. *Transportation Research Part A 25*, No. 6, 1991, pp. 375-389.

Cooper P.J. (1984). Experience with traffic conflicts in Canada with emphasis on post encroachment time techniques. *Proceedings of the International Calibration Study of Traffic Conflicts*, *NATO ASI Series*, *vol. F5*, Springer-Verlag, Heidelberg, Germany (1984), pp. 75–96.

Hayward, J. C. (1972). Near miss determination through use of a scale of danger. The Pennsylvania State University.

Hupfer C. (1997). Deceleration to safety time (DST)—a useful figure to evaluate traffic safety. *ICTCT Conference Proceedings of Seminar 3*, Department of Traffic Planning and Engineering, Lund University, Lund (1997).

Lee, C., Abdel-Aty, M. and Hsia, L (2006). Potential Real-Time Indicators of Sideswipe Crashes on Freeways. Transportation Research Record, no 1953, Washington, D.C., 2006, pp 41-49.

Martin P.T., Perrin J., Hansen, B., (2000). Incident Detection Algorithm Evaluation. Utah Department of Transportation, UTL-0700-31, July 2000

Minderhoud, MM. and Bovy, PHL. (2001). Extended time-to-collision measures for road traffic safety assessment. ACCIDENT ANALYSIS AND PREVENTION, 33(1), 2001, pp. 89 – 97.

Pande, A. and Abdel-Aty, M (2006). Comprehensive Analysis of Relationship between Real-Time Traffic Surveillance Data and Rear-End Crashes on Freeways. Transportation Research Record, no 1953, Washington, D.C., 2006, pp 41-49.

Perkins S. R. (1969). GMR Traffic Conflicts Technique - Procedures Manual. General Motors Research Laboratories, Warren, Michigan, August 11, 1969.

van der Horst, R. and Hogema, J (1993). Time-to-Collision and Collision Avoidance Systems. In *Proceedings of the 6th ICTCT Workshop 1993: Safety Evaluation of Traffic Systems: Traffic Conflicts and Other Measures, 109–121.*

7. Annex

In this part, the detailed distributions of J-values and TTC of the normal lane and the overtaking lane at the ATC 116 are shown for the crash happening on Jan 23rd, 2005 between 20:00-21:00. Data used for the Figures 6-13 are from 19:00-22:00, on Jan 23rd, 2005.

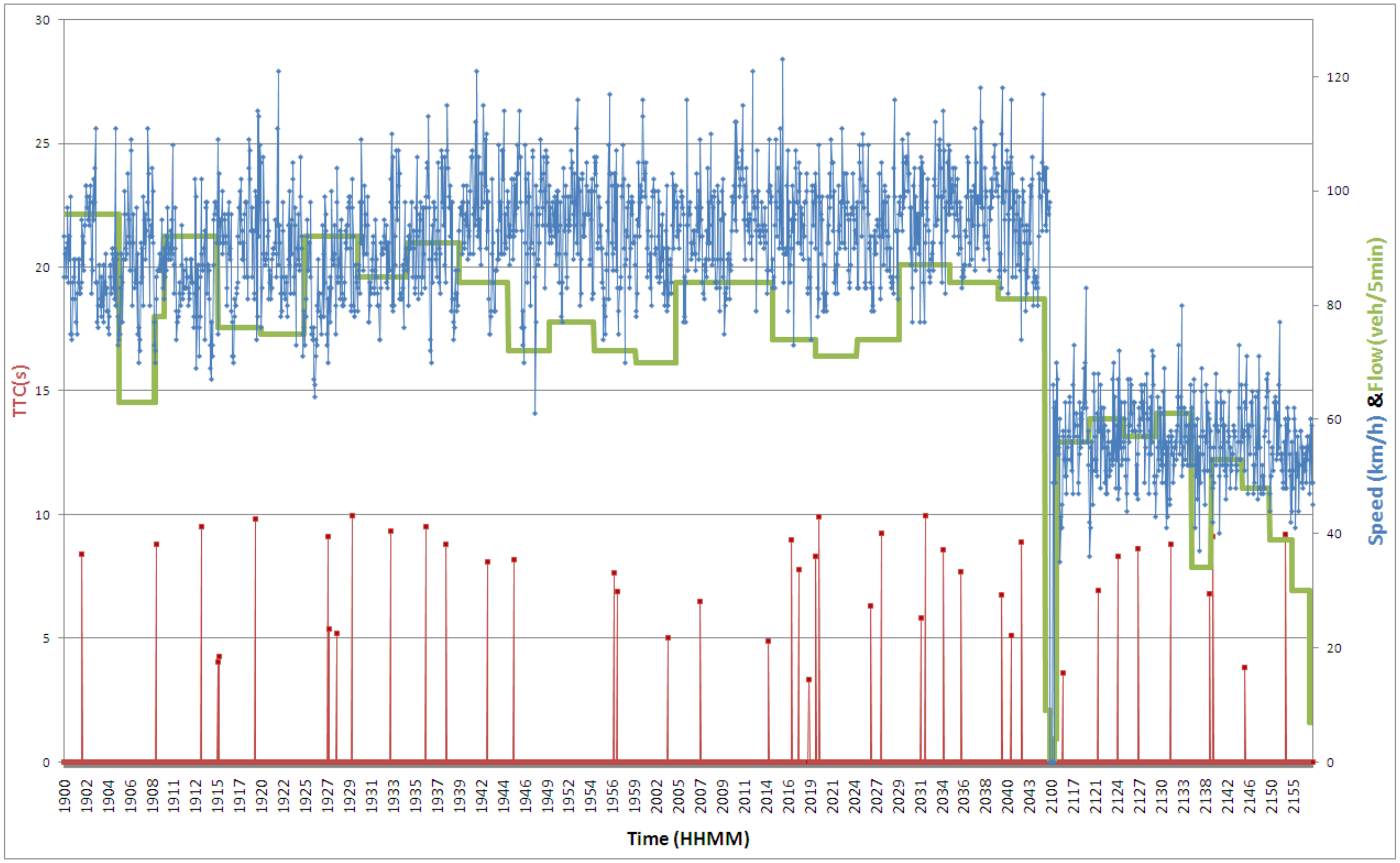


Figure 6: Flow, individual TTC, and individual speed on the normal lane when the crash happened. TTC values greater than 10s are excluded

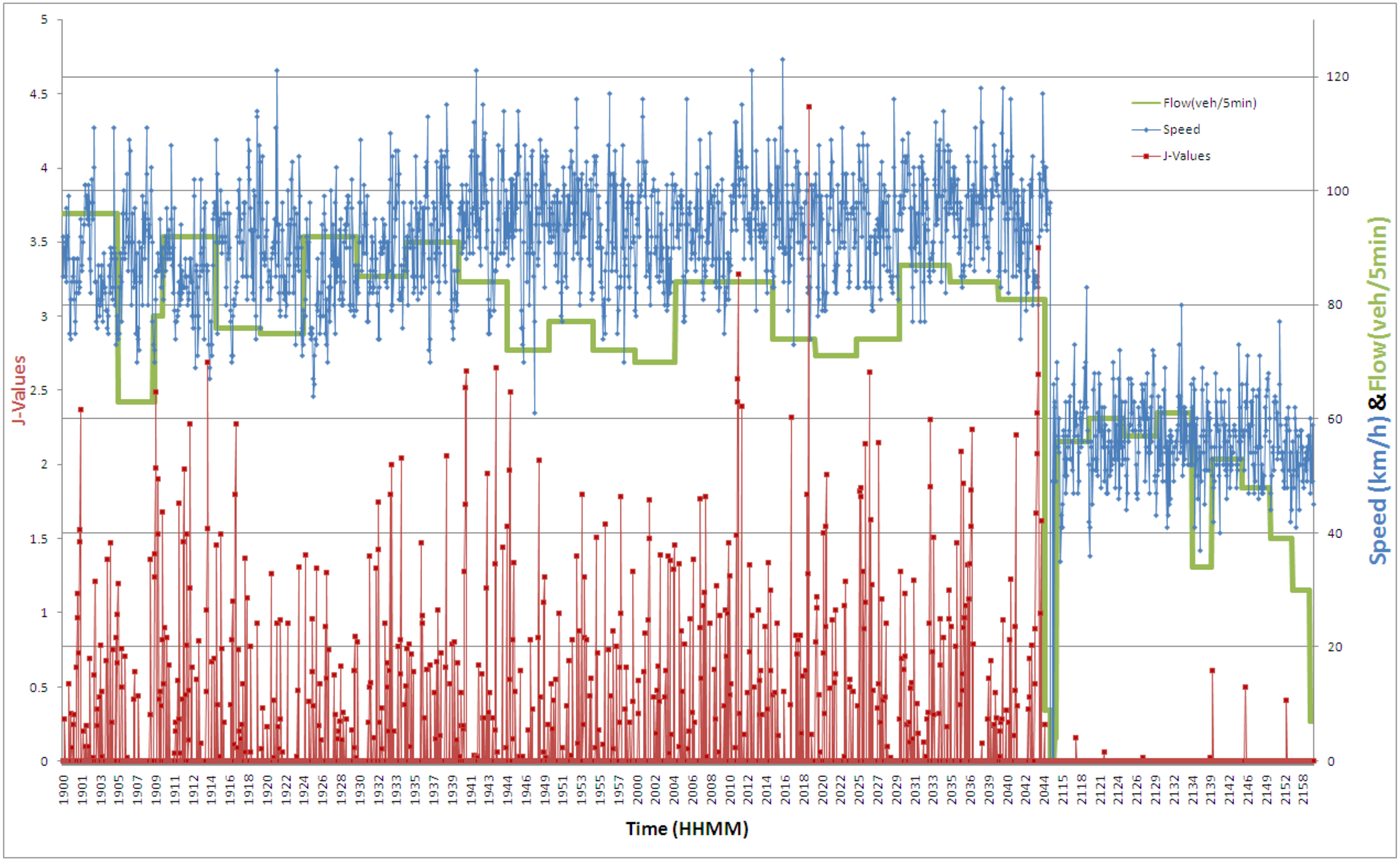


Figure 7: Flow, individual J-value, and individual speed on the normal lane when the crash happened.

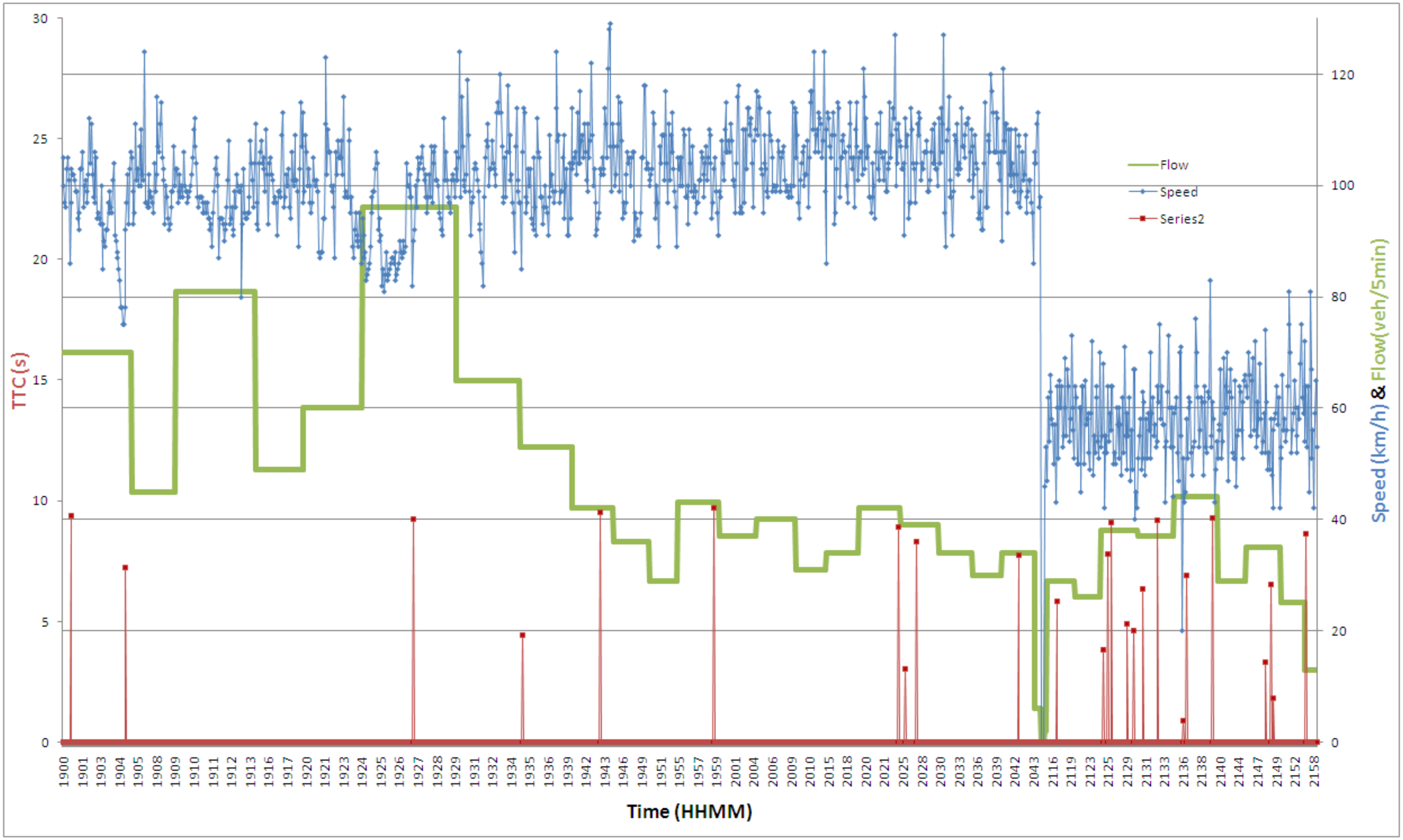


Figure 8: Flow, individual TTC, and individual speed on the overtaking lane when the crash happened. TTC values greater than 10s are excluded

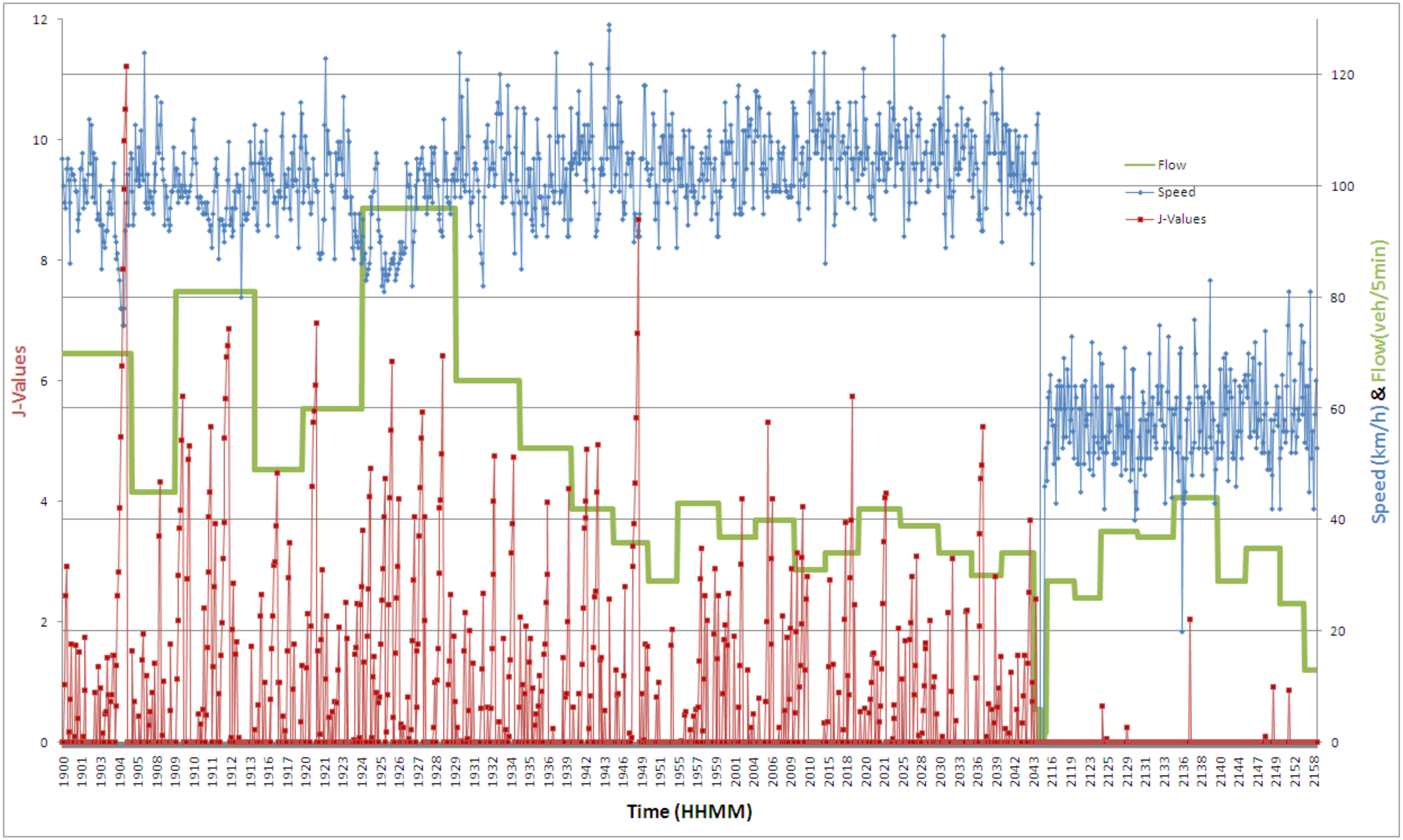


Figure 9: Flow, individual J-value, and individual speed on the overtaking lane when the crash happened.

The time field in the Figures 10-13 is 5-minute index of a day (24 hours). The light grey area is the period where the crash happened according to the police's report. The dark grey area highlights the period where average speed starts decreasing.

0<TTC<2.5	0<TTC<3.0	0<TTC<3.5	0<TTC<4.0	0<TTC<4.5	0<TTC<5.0	0<TTC<5.5	0<TTC<6.0	0<TTC<6.5	0<TTC<7.0	0<TTC<7.5	0<TTC<8.0	0<TTC<8.5	0<TTC<9.0	0<TTC<9.5	0<TTC	Flow(veh/h)	Time (5Min)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03	1.03	1.03	45.36	1164	228
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.28	1.28	48.72	936	229
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.09	47.83	1104	230
0.00	0.00	0.00	0.00	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63	46.05	912	231
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.67	900	232
0.00	0.00	0.00	0.00	0.00	0.00	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	3.26	48.91	1104	233
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.18	52.94	1020	234
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.10	2.20	47.25	1092	235
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.19	1.19	1.19	44.05	1008	236
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.39	1.39	1.39	44.44	864	237
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49.35	924	238
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.39	1.39	2.78	2.78	2.78	2.78	51.39	864	239
0.00	0.00	0.00	0.00	0.00	0.00	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	55.71	840	240
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.19	1.19	1.19	1.19	1.19	1.19	1.19	50.00	1008	241
0.00	0.00	0.00	0.00	0.00	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	39.29	1008	242
0.00	0.00	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	2.70	2.70	4.05	4.05	45.95	888	243
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.41	1.41	1.41	47.89	852	244
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.35	1.35	1.35	1.35	1.35	1.35	2.70	40.54	888	245
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15	1.15	1.15	1.15	1.15	1.15	2.30	2.30	42.53	1044	246
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.19	1.19	1.19	1.19	40.48	1008	247
0.00	0.00	0.00	0.00	0.00	0.00	1.23	1.23	1.23	2.47	2.47	2.47	2.47	3.70	3.70	50.62	972	248
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	44.44	108	249
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	251
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	252
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	24	253
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	48	254
0.00	0.00	0.00	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	53.57	672	255
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	1.67	1.67	3.33	3.33	3.33	51.67	720	256
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.75	1.75	45.61	684	257
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.64	1.64	50.82	732	258
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.94	2.94	2.94	2.94	2.94	2.94	47.06	408	259
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.89	50.94	636	260
0.00	0.00	0.00	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	39.58	576	261
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.56	48.72	468	262
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	360	263
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.17	2.17	2.17	52.17	552	264
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	46.00	600	265
1.69	1.69	1.69	1.69	1.69	3.39	3.39	3.39	3.39	3.39	3.39	3.39	5.08	5.08	6.78	44.07	708	266

Figure 10: Time-To-Collision distribution on normal lane when the crash happened.

Time(5min)	Flow(veh/h)	J>=0	J>0	J>1	J>2	J>3	J>4
228	1164	100.00	36.08	7.22	1.03	0.00	0.00
229	936	100.00	26.92	11.54	1.28	0.00	0.00
230	1104	100.00	33.70	9.78	2.17	0.00	0.00
231	912	100.00	31.58	9.21	1.32	0.00	0.00
232	900	100.00	21.33	2.67	0.00	0.00	0.00
233	1104	100.00	29.35	3.26	0.00	0.00	0.00
234	1020	100.00	30.59	8.24	1.18	0.00	0.00
235	1092	100.00	27.47	3.30	1.10	0.00	0.00
236	1008	100.00	33.33	11.90	3.57	0.00	0.00
237	864	100.00	29.17	8.33	2.78	0.00	0.00
238	924	100.00	27.27	3.90	0.00	0.00	0.00
239	864	100.00	27.78	5.56	0.00	0.00	0.00
240	840	100.00	30.00	10.00	0.00	0.00	0.00
241	1008	100.00	29.76	8.33	0.00	0.00	0.00
242	1008	100.00	36.90	14.29	4.76	1.19	0.00
243	888	100.00	22.97	5.41	2.70	1.35	1.35
244	852	100.00	30.99	11.27	0.00	0.00	0.00
245	888	100.00	29.73	14.86	4.05	0.00	0.00
246	1044	100.00	36.78	8.05	1.15	0.00	0.00
247	1008	100.00	30.95	11.90	2.38	0.00	0.00
248	972	100.00	34.57	9.88	6.17	1.23	0.00
249	108	100.00	0.00	0.00	0.00	0.00	0.00
250	-	-	-	-	-	-	-
251	-	-	-	-	-	-	-
252	-	-	-	-	-	-	-
253	24	100.00	0.00	0.00	0.00	0.00	0.00
254	48	100.00	0.00	0.00	0.00	0.00	0.00
255	672	100.00	1.79	0.00	0.00	0.00	0.00
256	720	100.00	1.67	0.00	0.00	0.00	0.00
257	684	100.00	1.75	0.00	0.00	0.00	0.00
258	732	100.00	0.00	0.00	0.00	0.00	0.00
259	408	100.00	2.94	0.00	0.00	0.00	0.00
260	636	100.00	1.89	0.00	0.00	0.00	0.00
261	576	100.00	2.08	0.00	0.00	0.00	0.00
262	468	100.00	2.56	0.00	0.00	0.00	0.00
263	360	100.00	0.00	0.00	0.00	0.00	0.00
264	552	100.00	0.00	0.00	0.00	0.00	0.00
265	600	100.00	0.00	0.00	0.00	0.00	0.00
266	708	100.00	1.69	0.00	0.00	0.00	0.00

Figure 11: J-value distribution on normal lane when the crash happened

0<TTC<1.0	0<TTC<1.5	0<TTC<2.0	0<TTC<2.5	0<TTC<3.0	0<TTC<3.5	0<TTC<4.0	0<TTC<4.5	0<TTC<5.0	0<TTC<5.5	0<TTC<6.0	0<TTC<6.5	0<TTC<7.0	0<TTC<7.5	0<TTC<8.0	0<TTC<8.5	0<TTC<9.0	0<TTC<9.5	0<TTC	Flow(veh/h)	Time (5Min)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.41	1.41	1.41	1.41	2.82	42.25	852	228
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.00	540	229
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	48.15	972	230
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.82	588	231
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.67	720	232
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.04	50.00	1152	233
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43.08	780	234
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	43.40	636	235
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.38	52.38	504	236
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	432	237
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.93	348	238
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	41.86	516	239
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	48.65	444	240
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.50	480	241
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.61	372	242
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	47.06	408	243
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.38	2.38	42.86	504	244
0.00	0.00	0.00	0.00	0.00	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	5.13	5.13	5.13	38.46	468	245
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	408	246
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.67	360	247
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.94	2.94	2.94	2.94	47.06	408	248
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	66.67	72	249
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		250
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	251
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	252
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	253
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	24	254
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	44.83	348	255
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	42.31	312	256
0.00	0.00	0.00	0.00	0.00	0.00	2.63	2.63	7.89	7.89	7.89	7.89	7.89	7.89	10.53	10.53	10.53	13.16	42.11	456	257
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.70	2.70	2.70	2.70	2.70	2.70	5.41	54.05	444	258
2.27	2.27	2.27	2.27	2.27	2.27	2.27	2.27	2.27	2.27	2.27	2.27	4.55	4.55	4.55	4.55	4.55	6.82	50.00	528	259
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.72	348	260
0.00	0.00	2.86	2.86	2.86	5.71	5.71	5.71	5.71	5.71	5.71	5.71	8.57	8.57	8.57	8.57	8.57	8.57	48.57	420	261
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64.00	300	262
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.69	7.69	46.15	156	263
0.00	0.00	3.45	3.45	6.90	6.90	6.90	6.90	6.90	10.34	13.79	17.24	17.24	17.24	17.24	17.24	17.24	17.24	51.72	348	264
0.00	0.00	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63	5.26	5.26	5.26	5.26	5.26	42.11	456	265
0.00	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	4.26	4.26	4.26	4.26	4.26	40.43	564	266

Figure 12: TTC distribution on overtaking lane when the crash happened

Time(5min)	Flow(veh/h)	J>=0	J>0	J>1	J>2	J>3	J>4	J>5	J>6	J>7	J>8	J>9	J>10	J>11
228	852	100.00	52.11	29.58	16.90	11.27	9.86	9.86	8.45	7.04	5.63	5.63	2.82	1.41
229	540	100.00	35.56	20.00	4.44	4.44	2.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
230	972	100.00	50.62	40.74	29.63	20.99	13.58	9.88	3.70	0.00	0.00	0.00	0.00	0.00
231	588	100.00	44.90	26.53	18.37	6.12	2.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
232	720	100.00	48.33	36.67	20.00	8.33	8.33	6.67	1.67	0.00	0.00	0.00	0.00	0.00
233	1152	100.00	62.50	43.75	30.21	19.79	13.54	5.21	2.08	0.00	0.00	0.00	0.00	0.00
234	780	100.00	41.54	24.62	12.31	7.69	3.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
235	636	100.00	43.40	24.53	11.32	3.77	1.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00
236	504	100.00	45.24	33.33	23.81	14.29	7.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
237	432	100.00	52.78	36.11	22.22	16.67	11.11	8.33	5.56	2.78	2.78	0.00	0.00	0.00
238	348	100.00	13.79	6.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
239	516	100.00	41.86	23.26	13.95	2.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
240	444	100.00	35.14	24.32	8.11	2.70	2.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
241	480	100.00	35.00	22.50	12.50	7.50	5.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00
242	372	100.00	38.71	29.03	16.13	9.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
243	408	100.00	41.18	29.41	20.59	8.82	2.94	2.94	0.00	0.00	0.00	0.00	0.00	0.00
244	504	100.00	45.24	21.43	9.52	7.14	4.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00
245	468	100.00	46.15	28.21	7.69	2.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
246	408	100.00	20.59	11.76	11.76	2.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
247	360	100.00	46.67	26.67	16.67	13.33	10.00	3.33	0.00	0.00	0.00	0.00	0.00	0.00
248	408	100.00	38.24	17.65	5.88	2.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
249	72	100.00	16.67	16.67	16.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
250	-	-	-	-	-	-	-	-	-	-	-	-	-	-
251	-	-	-	-	-	-	-	-	-	-	-	-	-	-
252	-	-	-	-	-	-	-	-	-	-	-	-	-	-
253	-	-	-	-	-	-	-	-	-	-	-	-	-	-
254	24	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
255	348	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
256	312	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
257	456	100.00	7.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
258	444	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
259	528	100.00	2.27	2.27	2.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
260	348	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
261	420	100.00	5.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
262	300	100.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
263	156	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
264	348	100.00	3.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
265	456	100.00	2.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
266	564	100.00	6.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 13: J-value distribution on overtaking lane when the crash happened