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CORRELATION BETWEEN RESIDUAL SPEEDOMETER NEEDLE READING AND IMPACT SPEED OF VEHICLES IN TRAFFIC ACCIDENTS

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ABSTRACT−In actual traffic accidents, a phenomenon is observed where the speedometer needle jams at a certain value after the impact. Using the residual reading of the speedometer, we may infer the approximate vehicle speed while the impact occurred. Based on the function of typical speedometer, the impact characteristic and damage mechanism of vehicles, this paper describes the research of how the speedometer needle stops during accidents and its failure modes. According to the statistics of thirty specific traffic accident cases containing residual speedometer needle readings, we obtain and summarize the characteristics and rules concerning the accidents and the related information. Furthermore, a typical accident case is analyzed by in-depth level. The results reveal that for the accident vehicles with electronic speedometers, there is a strong correlation between the residual reading of the speedometer and the real vehicle impact speed. The conclusions may provide a new effective method and reference for accident reconstruction and the estimation of vehicle speed.

KEY WORDS : Traffic accidents, Residual speedometer needle reading, Vehicle impact speed, Accident reconstruction, In-depth accident data analysis

NOMENCLATURE

v_a : velocity, km/h
n : rotation speed of engine, rpm
i_g : the transmission ratio of 5 band
i_0 : the main gear ratio
r : the radius of tire

SUBSCRIPTS
A_0, A, B, C : rank of car

1. INTRODUCTION

As a developing country, China has the largest number of road traffic accidents and casualties in the world. Consequently, it is imperative for public security traffic management and accident identification departments to make science-oriented, fair and fact-based analysis and handling of traffic accidents. At present, there is an increasing demand for vehicle speed appraisal when reconstructing traffic accidents. Driving speed of vehicle is an critical factor in road safety, which not only affects the severity of a crash, but also is related to the risk of being involved in a crash (Aarts and Ingrid, 2006). To appraise a traffic accident, it is crucial to identify the impact speed of vehicles in the accident, which is one of the primary factors in the accident reconstruction.

Based on vehicle damage, trace information, human body injury and accident scenario situations, the impact speed of vehicle involved in a traffic accident can be estimated by using related theoretical methods and mechanical model which combined the experimental data and specialist experience. Through the speed analysis, we are able to reconstruct the whole process of the accident in both time and space. Due to the complexity and uncertainty of factors in traffic accidents, the vehicle speed calculation of traffic accidents is relatively arduous. Its analysis not only depends on the accuracy and practicality of calculation models and approaches, but also is closely related to the information collection of the accident scene, vehicle trace and other relevant parameters. The progress in technologies of information collection and trace identification will promote the improvement in the analytical approaches of vehicle speed.

The key route of analyzing the vehicle speed is to investigate and rationally utilize the evidence of various trace information of vehicles in the traffic accident scene. Examples of typical trace information are of glass fragments and other thrown objects, scratches on vehicle, recorded video, and road surface damages, etc. Whether the trace information can be effectively used in speed analysis and accident reconstruction depends on the information collection in the original scene. As a result, it is no doubt

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that collecting information from the traffic accident scene is of the great significance. It is necessary to enhance the technological means and regulations on collection to ensure the follow-up work can be carried out effectively.

After the accident happened, the needle of the meter sometimes abruptly stops, due to the impact damage, at a position showing a certain speed value. This evidence can be used to help test the analytical result of vehicle speed at the time of the crash. However, because the speedometer itself has system error and vibration caused by the impact and transmission of impact force, it is necessary to make the analysis combining with the specific situation.

Due to the lack of EDR (Event Data Recorder) data among most of vehicles in the accidents, appraisers in China have to reconstruct the accident and estimate the collision speed by means of some traditional calculation methods. In domestic-related expertise, the vehicle speed appraisal approaches mainly adopt the classic theoretical methods, experience-based methods and computer-aided simulation. But on vehicle speed appraisal, the application of the trace information of the speedometer lacks related studies.

During the literature review, we found some related articles where some traditional methods were applied to estimate the impact speed of vehicle, such as analyzing different traces of vehicle body. Based on the configuration of the cycloidal marks left on the passenger vehicle by the truck tires, a method of determining the pre-impact speed of the truck is presented (Levy, 2000). By using the principle of momentum conservation, energy conservation, and kinetic energy and work equivalence, a method of impact reconstruction is presented, which provides us a practical calculation method to estimate vehicle speed (Wach and Jan, 2006). Similarly, Finite Difference method is also applied in accident reconstruction (Bartlett and Albert, 2003). By means of some software, e.g. Pc-Crash, MADYMO, accident reconstruction and vehicle speed estimation also can be executed to make use of vehicle traces and human injury of traffic accidents, especially for the accidents between vehicles and vulnerable road users.

Speedometer information from vehicles involved in accidents contribute extremely valuable information in accident investigation, but few relevant studies are carried out. To understand the function of mechanical speedometer, a further study concludes that needle marks could appear either in a single form or in a together form, which depends on the impact situations (Tao *et al*., 2012). In Anderson R. D's research, he concludes that without high resistance to needle motion, the residual readings on speedometers cannot represent that vehicle's speedometer reading at impact (Anderson, 2010). In Kuranowski's research, the reliability of estimation from speedometer is decided by the installation of a return spring. With this appliance, it is not impossible to take advantage of the indications of the remained meters (Kuranowski, 2009).

Combined with the investigation and analysis on real accidents in Beijing in recent years, this study caters to the actual demand of vehicle speed identification work. Based on the principles of a typical speedometer and automotive impact mechanism, theoretical analysis, classified accident statistics and in-depth data analysis are executed to find out the characteristics and variation rule of the speedometer needle damage under the impact condition. The availability and correlation of the speedometer needle's residual information after the impact are discussed and testified, which may provide a new method and reference for accident reconstruction and vehicle speed identification.

2. METHODOLOGY

2.1. Speedometer Classification

The automotive instruments are classified by the implemented forms as described in Table 1.

Table 1. Classification of speedometer.

Type	Implementation form
Electronic	Digital, analog
Electrical	Electromagnetic, dynamic magnetic, bimetal
Mechanical	Magnetic induction, Bourdon tube

The types of speedometers mainly include electrical and mechanical. Figure 1 shows the principle of a typical electronic speedometer. The mechanical speedometer uses mechanical components (shaft) to get the speed signal (non-electricity), access to executive device (permanent magnets, centrifugal device) to get power torque, and keep the balance with the reaction torque of spring. An electronic instrument possesses the electronic speed sensor (hall element, optical element) to get speed signal (power), access to actuator (step motor) through the circuit processing, and to manipulate the step motor needles directly. Electrical speedometer uses the generator connection with the output shaft of transmission to get the speed signal, and access to the actuator (motor) to get power moments, and keep balance with the reaction torque of spring. The main difference between the mechanical and

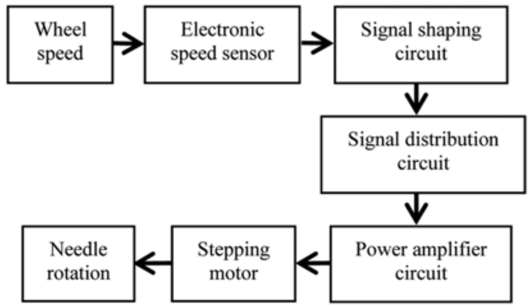

Figure 1. Principle of an electronic speedometer.

electrical type is through obtaining the speed signal, which results in different dynamic torques. The structure of speed indicating device and the way resulting reaction torque remains the same. Functioning differently from the two types mentioned above, the electronic speedometer uses power from the actuator, which is dependent on the speed signal, to push the needle back to the zero position.

According to the Automotive Industry Standard of China, the basic error of the speedometer is around ±5 km/h for mid/high speed condition or ±10 km/h for low speed.

2.2. Failure Mechanism

The principle of speed indication by the needle for both the mechanical and electrical instruments is that there is a balance between the output torque from the actuator of the speed signal control and the reaction torque from the springs so that the speed indication can maintain a certain position. Though the needle is not directly affected by the impact, a load is still placed on the speedometer which is equivalent to the normal impact load. After the crash, though the real speed becomes zero, there exists no power torque, which under normal conditions, would pull the needle back to the zero point.

For electronic instruments, the principle of speed indication is that the speed signal is disposed by circuit and connected to the execution mechanism. The needle is manipulated by the stepper motor. When the crash happens, the speed signal will be zero, the stepper motor, regulated by the control signal, will force the needle to run back to the zero point.

For mechanical and electrical instruments, the needle does not return to zero, but is stuck in a position, which can explain the damage of a component of speed indicating device (needle shaft, bearings, etc.) by the impact equal to an additional resistance torque. If the spring is damaged, it will not return to zero, but instead will move freely. For electronic instruments, the probable reason why the needle does not return to zero is that the collision damages some parts of the control circuit or power and then the step motor cannot obtain the signal or power to return to zero.

3. ACCIDENT STATISTICS

From about 300 serious road traffic crashes between vehicles or single vehicle with road facilities in Beijing from 2010 to 2012, 30 real accidents with residual speedometer needle information have been observed and collected. Then the in-depth data analysis on these accident cases have been carried out and the types of traces, the characteristics of the collisions and the situation of vehicle damages are obtained. In order to get their correlation and speculate the reason for stuck speedometer needles, the speed value indicated by speedometer is compared with the vehicle speed by calculation and reconstrution. Additionally, there is one special accident in 30 cases, in which both the two vehicles appeared to have residual speedometer value information. Therefore, totally there are 31 vehicles with the residual speedometer needle in 30 accident cases.

Table 2. Vehicle type.

Vehicle type	Case number	Proportion
Car-A0	1	3%
Car-A	22	70%
Car-B	5	17%
Commercial vehicle	3	10%

3.1. Descriptive Statistics

3.1.1. Types of speedometer needle information

For the 30 accident cases, the stuck situation of speedometer needles all appears. Among them, there are 20 cases with a stuck tachometer needle, which account for 67%. As an absolute majority, 28 cases possess electronic speedometers, accounted for 93.3%. In only one case, there is an electrical instrument. One reason is that electronic instrumentation is widely used in passenger cars and the other reason shows that the needle of the electronic instrument is easier to retain residual needle readings.

3.1.2. Types of vehicles

Table 2 summarizes that there are 28 cases of passenger cars, including one A0-class car, 22 A-class cars, 5 B-class cars, which were made in more than 15 automotive corporations. In the A-class cars, 7 cars were designed in late years, accounted for 33%, and the older design or lower-skilled had 14 cases, accounted for 67%. Commercial vehicles are included in only three cases.

3.1.3. Types of collisions

Table 3 presents that front collisions between vehicles includes 21 cases, accounting for 70%, which takes the largest proportion. Others are the more complicated accidents, such as multi-car collision, rollover, vehicle-to-guard-bar impact in high-speed, etc. This shows that front collisions take up the majority, which testifies to the assumptions that the front collisions lead to the damage of the circuit, further causing residual reading of needle, and few side impacts can spread to the instrument panel and the circuit part of engine compartment.

Table 3. Impact type.

Impact type	Case number	Proportion
Frontal	21	70%
Multi-car collision	3	10%
Rollover	2	7%
Vehicle-to-guard bar	2	7%
Others	2	7%

Table 4. Degree of vehicle damage.

Vehicle damage degree	Case number	Proportion
Severe damage	27	90%
Moderate damage	2	6.7%
Slightly damaged	1	3%

Table 5. Position of vehicle impact.

Collision position	Vehicle number	proportion
Front	12	39%
Front left	15	48%
Front right	2	6.5%
Side	2	6.5%

Table 6. Spread components of vehicle damage.

Damaged components	Vehicle number	Proportion
Windscreen	25	81%
A-pillar	20	65%
Front wheel	13	42%
Cab	13	42%
Dash board	6	19%
B-pillar	3	10%

3.1.4. Degree of vehicle damage

Table 4 shows that only in one case the vehicle is slightly damaged, i.e. in 3% of the cases. Moderate damage occurs in two cases, which accounts for 6.7%. Severe damages occur in 27 cases, i.e. in 90% of the cases. The reason why serious damage occupies the majority of cases is that such impacts are more likely to damage the circuits.

Regarding the position of vehicle impact, Table 5 shows that the main impact position of vehicles is the front part of vehicle body. Table 6 describes the spread position of vehicle damage, with windshields and A-pillar accounting for the highest proportions of damages. Figure 2 illustrates the maximum deformation depths of accident vehicles, which indicate the data from 0.4 m to 2.0 m and the average is 0.9411. Concerning the effective plastic deformation of accident vehicles, Figure 3 demonstrates that the data is from 0.2 m to 1.2 m and the average value is 0.6668.

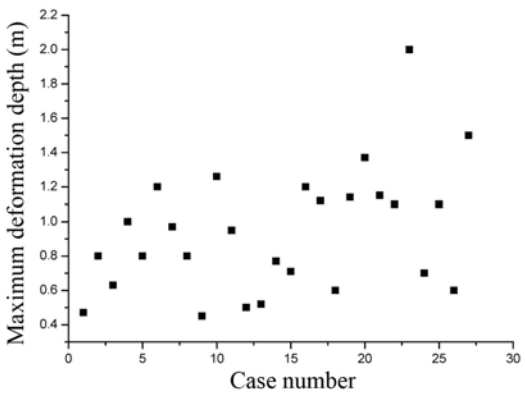

Figure 2. Maximum deformation depth of vehicles.

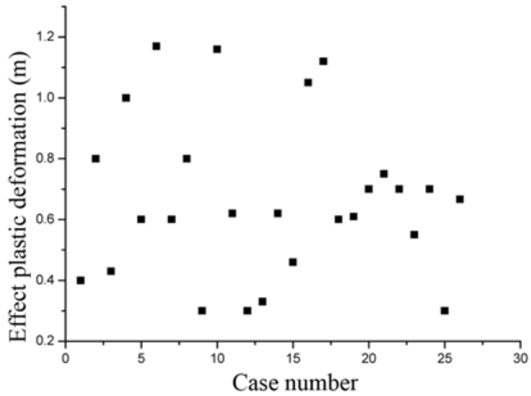

Figure 3. Effective plastic deformation of vehicles.

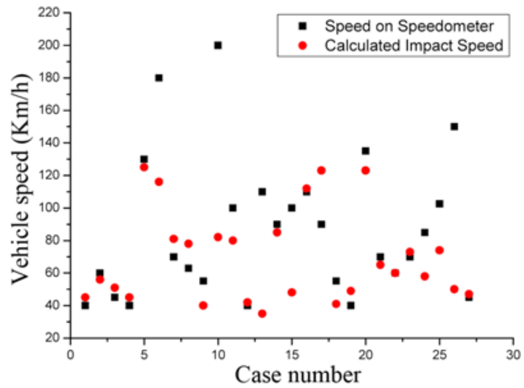

Figure 4. Comparison between calculated speeds and readings on speedometer.

3.1.5. Range and comparison of vehicle speed

In 30 accident cases, 27 vehicles have the calculated impact speed data. The speed readings on the speedometer are compared with the calculated impact speed (Figure 4), which indicates that the range of vehicle speed on speedometer is mostly over 40 km/h, and the range of calculated impact speed is from 35 km/h to 123 km/h.

As displayed in Figure 5, the mean value of speed readings on meters is extremely close to the one of calculated impact speeds. Then the differences between the impact speeds calculated by theoretical methods and the speed readings of the needle can be obtained. In 27 effective cases, there are 22 examples whose relative error is lower than 0.5, and the correlation coefficient is 0.88. A big discrepancy between the two values is due to the fact

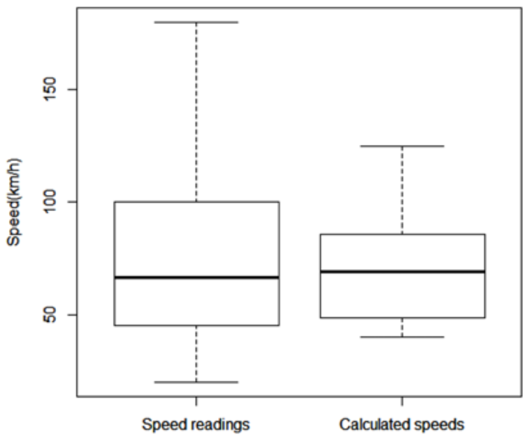

Figure 5. Data distribution of vehicle speeds.

that traditional methods can not accurately quantify the kinetic energy losses from the collision, then the calculated value of impact speed is relatively smaller than the real one.

3.2. Discussion

In 30 accident cases, there are 28 passenger-cars with electronic speedometers, which take up 93% and represent the most common types with residual needle readings. The majority of vehicles have large plastic deformation and severe damage of frontal components. For a electronic speedometer, if the needle stops at a non-zero point and there is a good correlation between the speedometer and tachometer, the specific result is due to the cut-off of circuit.

Most of the display devices are controlled by the stepping motor, therefore the probability that the needle jams will be low. The reason that the speedometer needle jams will be different from every accident. Through the preliminary work, some main reasons are summarized as following.

(1) Complete power-off factor. Because the power is off, the speedometer cannot work normally.
(2) Control signal factor for instruments. The impact leads to the damage of the signal circuit which can force the stepping motor to turn the needle back to zero.
(3) Special power-off program setting factor. There is not the program which manages the power-off and reset of the speedometer needle.

Using the information of the dashboard to determine its status, the failure modes of instruments can be preliminarily identified to be the reason of power. The readings from speedometer can be calibrated with the ones on tachometer. Depending on the relative parameters of engine, gearbox and corresponding maximum speed to determine whether the indicative speed of speedometer is in accordance to the actual speed at the impact moment.

In order to carry out accident reconstruction, we also need to investigate some specific information, such as specific vehicle type, transmission form, engine type, gear type, specifications of tire, etc.

Figure 6. Traffic accident scene.

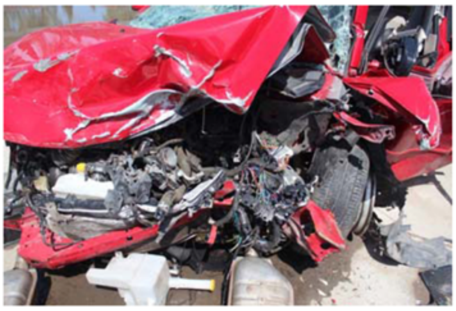

Figure 7. Wreckage of car B.

4. IN-DEPTH ACCIDENT CASE ANALYSIS

From the 30 cases, a typical accident which has two vehicles with residual speedometer information is selected to perform the in-depth data analysis.

One day in spring of 2012, at a country road of Beijing, a serious front impact accident happened between a black passenger car A (Manufacturer A, traveling from north to south) and a red passenger car B (Manufacturer B, traveling from south to north). Figure 6 presents the real accident scene.

In this case, car B was damaged by the crash (Figure 7). Figure 8 shows the residual readings in the dashboard of car B, in which the needle indicates about 135 km/h, and the tachometer shows about 3.9×10^3 rpm.

The front body of car B is severely deformed as well as the engine compartment, which is in accordance with the characteristics of the collision affecting the electric circuit.

Figure 8. Dashboard of car B.

Comparison with the normal car's engine compartment shows that the battery part of car B is impacted severely in the accident, as shown in Figure 7, which caused a significant deformation and displacement, and the destruction of the circuit very likely.

The engine of car B is a 2.3 L four-cylinder gasoline engine naturally aspirated; its maximum power is 108 kw at 6500 rpm, and its maximum torque is 183 Nm at 4000 rpm. The gearbox is a 5 gear manual transmission (MT), the transmission ratio of 5 band (i_g) is 0.692, and the main gear ratio (i_o) is 3.941. The maximum speed of this car is 201 km/h. The tire size is 205/22 R16, so the radius of tire (r) is 258.2 mm.

To verify the speed reading in the speedometer for the car at a moment, the reading in tachometer is used and the parameters mentioned above are imported into the following equation to calculate the vehicle speed (v_a) (Yu, 2009).

$$v_a = 0.377\frac{nr}{i_g i_o} \tag{1}$$

Then the speed derived from the tachometer is about 139 km/h. According to Figure 8, the speedometer needle of car B points to about 135 km/h. This shows that the corresponding values of speedometer and tachometer are exceedingly close with each other.

Car A was also damaged by the collision in this accident (Figure 9). Figure 10 and Figure 11 show the residual readings in the speedometer and tachometer, in which the speedometer indicates about 70 km/h, and the tachometer displays about 1.7×10^3 rpm.

Figure 9. Wreckage of car A.

Figure 10. Speedometer of car A.

Figure 11. Dashboard of car A.

Similarly, in this case, from the residual tachometer reading of car A, we can obtain its speed by the same method as car B. By using Equation (1), the related speed result is about 78 km/h. Compared with its speedometer which shows about 70 km/h, we can also find that they are close to each other.

This case shows that the relationship between the residual information of speedometer and the one of tachometer, and that the two data can match and verify each other. Therefore, the residual information of the speedometer represents that the circuit is cut off, and it reflects the impact speed of the vehicle at a moment after the crash.

5. CONCLUSION

From the investigation of 30 traffic accident cases with stuck speedometer needles, the characteristics of such accidents are explored and analyzed. Combined with the basic function analysis on the speedometer, the usual failure modes of the speedometer needles are discussed. The following conclusions are summarized, which can be useful reference for the accident reconstruction and vehicle speed estimation.

(1) Most of the accident vehicles with residual speedometer readings present large plastics deformation and severe damage of frontal components in vehicle body, especially the circuit and its related components.

(2) For the accident vehicles with electronic speedometers, there is a strong correlation between the residual reading of the speedometer and the actual vehicle speed at the impact moment. If the impact speed is higher (e.g., more than 40 km/h), the impact spread to the circuit part, the confidence level of the residual speed reading will be higher. As an evidence, the residual reading of speedometer can be used in the vehicle speed estimation of front crash accidents or the similar impact types.

(3) In order to reconstruct the accidents based on the residual speedometer readings of vehicles, we need to investigate some specific information which mainly include vehicle type, transmission form, engine type, gear type and specifications of tire.

(4) The analysis on an typical accident case shows that the

residual information of the speedometer represents the impact speed of the vehicle at some moment after the collision.

(5) The speed readings indicated by the speedometer needles of vehicles can be verified by the residual readings on the tachometers.

In addition, by traditional accident reconstruction methods, it is difficult to quantify the loss of kinetic energy caused by the non-front vehicle impact. Therefore, the estimated vehicle speed is usually lower than the real one. The residue speedometer needle information can be used to improve the adverse situation. However, large differences in the specific circumstances of various accidents require a combination of the actual accident characteristics to execute a comprehensive multidisciplinary investigation. In the future, we will perform the analog circuit experiments, to simulate vehicle speed signal and the impact conditions. By this method, the changes of speedometer needles under the typical impact conditions and the possibility of stuck needles will be measured and analyzed.

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