Investigating Drivers’ Headway in Iran Freeways

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ABSTRACT

Headway is known as one of the most important basis for traffic studies which is widely used in road safety studies. Headway is known as suitable criteria for evaluation of drivers’ behavior. Therefore, in this paper, drivers’ behavior in Iran's freeways has been investigated based on headway data and its distribution functions. The required data are collected from Iran freeways base sections. Headway data of the congested flow and before queue has been filtered by the means of car following models and flow speed drop. Using the filtered data, headway distribution is estimated and the reliability of models has been evaluated. The lognormal model, due to having all characteristics of reliability, is the most comprehensive model. As a result, based on headway risky and the headway of more than 50% of vehicles is less than minimum safe headway in congested flows.

INTRODUCTION

Headway or time headway means a time gap between the two vehicles which follow each other and pass a constant point of facility. This headway calculated from a constant point of the two following vehicles, for example; the front or back bumper. Headway is one of the most suitable indexes for evaluation of divers’ behaviors (Dowling, 1997; Greenberg, 1966). Many of indexes in traffic flow such as capacity and safety directly connected to headway (Breiman, Lawrence, Goodwin, & Bailey, 1977; Griffiths & Hunt, 1991). Therefore, headway survey plays a vital role in accident studies. In conclusion it would play a significant role in safety of each facility. But in the current studies, researchers pay less attention to headway importance and this is because of the lack of survey on headway issues. The headway value is very important when the flow is equal to the capacity and meanwhile, the number of accidents increases. In this paper, the researchers have modeled headway distribution functions before queuing and for vehicles in the freeways of Iran. This model can be used for the prediction of drivers’ behaviors.

LITERATURE REVIEW

The headway distribution was discussed in 1960s for the first time. Greenberg (1966) found a connection between the microscopic traffic flow theory and the follower headway lognormal distribution. Branston (1976) and Buckley (1968) presented headway considering the assumption of drivers’ maneuver restriction at the time of perceiving the capacity level, and the compatibility of the hypothesis and the observed data in the conducted studies has been proven. Mei and Mei and Bullen (1993) presented different distribution functions for time headways measured on a four-lane highway. According to the results, the lognormal distribution with a shift of 0.3 or 0.4 seconds was the best fit for the time headways in high traffic volumes. Sadeghhosseini (2002) investigated the time headways at flow rates varying from 140 to 1704 vehicles per hour per lane on a highway and suggested the lognormal distribution. Tamizh Arasan and Koshy (2003) determined the negative exponential distribution for headways distribution of urban arterial in India. Bham and Ancha (2006) analyzed the time headway of
drivers in a basic freeway section and recommended the lognormal distribution for vehicles’ headway.

Some studies have been accomplished about headway distribution functions at different lanes of freeways, that the most reputable one was Zwahlen, Onen, and Suravaram (2015) study. They investigated one of the Ohio freeways and demonstrated that headway distribution functions at different traffic lanes were the same (Zwahlen et al., 2015). In addition to what has been mentioned, the empirical models are other forms of headway models. These models are introduced by cumulative distribution functions. Some studies, which were focused on the estimating median, the mean and the coefficient of variation had been conducted, that Buckley’s research has been the most reputed one. Also, Breiman et al. (1977) and Griffiths and Hunt (1991) have carried out some researches in this field.

It should be considered that the discrepancy between distribution functions and the research results in different countries and also variety of the proposed models are remarkable problems of the presented models. The reason of the mentioned problem is that the drivers’ behaviors are completely different as well as their sensitivity on time headway. The statistical characteristics of the models have neither been presented comprehensively. In empirical models, determining the statistical characteristics of models are complicated and they cannot be generalized.

DATA COLLECTION

In this research work two types of data, macroscopic and microscopic, have been utilized. The data related to macroscopic parameters are collected from the detectors which are available in Iran’s freeways. These data are mean headway in five minute intervals. According to the current limitations in Iran, the microscopic parameters have been collected by video-recording and image processing. The total time period for surveying the macroscopic parameters is considered in a year and the data was provided in ordinary weather and dry pavement, and for commuters. Microscopic data have been collected in two-hour intervals in the mornings and evenings of the working days in same section as macroscopic data. Three sections in Iran, as basic section characteristics, have been selected, and the related data will be used in this study.

METHODOLOGY

Most accidents on roads are rear-end kind and occurred at capacity level. Capacity of flow in this article in defined as flow before queuing and reaching the capacity level. On the other hand, vehicles at the capacity level cannot maneuver, so they are follower (Branston, 1976; Buckley, 1968). In other words, headway distribution function at the capacity level, are equal to the following vehicles’ headway. This hypothesis has been considered in most headway models. Thus in this study, the following headway of the distribution function at the capacity level will be estimated. While, according to the conducted investigations, the drivers’ behaviors are remarkably different in the time of queuing.

RECOGNIZING THE FOLLOWING VEHICLES

The car-following theories represent how vehicles follow others in an uninterrupted flow. In fact, these models are the most simple and usual way for drivers’ behaviors investigations (Mathew & Krishna Rao, 2006). According to these models, vehicles are categorized in two groups which are following and free or leader vehicles. The following vehicles cannot maneuver or change their directions, and their behavior depends on the leader vehicle. However, free vehicles can maneuver and move freely. Different models have been introduced in this field up to now. Among these models, the most specified ones are Pipes, Forbes and General Motors (GM) models. The GM, presents car-following definition in the form of Eq (1) using two assumptions:

1) The higher speed, longer distance.
2) Safe distance by drivers due to preventing conflict (Maerivoet & De Moor, 2005).

The maximum following time can be estimated using the equations which have been presented by GM and therefore Eq (1) can be presented as:

\[ x_n^f - x_{n+1}^f = \Delta x_{safe} + \tau v_{n+1}^f \]  \hspace{1cm} (1)

The real-time subtraction of Eq (1) is,

\[ v_n^f - v_{n+1}^f = \tau v_{n+1}^{t+1} \]  \hspace{1cm} (2)

Here \( x_n^f - x_{n+1}^f \) is distance between the \((n+1)\) vehicle and its previous vehicle, \( \Delta x_{safe} \) is the safe length distance, \( x_{n+1}^f \) as speed of \((n+1)\) vehicle, \( \tau \) is sensitivity coefficient and \( \tau v_{n+1}^{t+1} \) is desired local distance of follower driver. The decision distance of the following vehicle will be considered as the desired distance if the speed of the leader vehicle is reduced. Therefore, the following time distance can be estimated by Eq (3).

\[ T_f = T_{safe} + \tau \]  \hspace{1cm} (3)

where here \( T_f \) is defined as desired time distance , \( T_{safe} \) as safe time distance and \( \tau \) is sensitivity coefficient. The safe time distance in Eq (3) is the reaction time. Thus, the desired time distance can be estimated by finding the sensitivity coefficient of driver. The sensitivity coefficient of the drivers will be counted by Eq (2) and using collected microscopic data.

RECOGNIZING DATA BEFORE QUEUING

According to the hypothesis, the headway model will be constructed for the follower vehicles. Since the vehicles headway at the capacity level has been considered, and there has had remarkable discrepancy between drivers’ behaviors before and after queuing, the data related to the queue have to be eliminated. In order to recognize and eliminate the relevant data, the speed parameter is used. Indeed, speed drop is the best factor for the queue recognition (Chung, Rudjanakanoknad, & Cassidy, 2007). The speed-flow curves have been suggested for the sake of recognizing the speed corresponded to the breakdown (Maerivoet & De Moor, 2005).
THEORETICAL MODELING BASES

The renewal hypothesis of statistical modeling is based on accidental input data (Luttinen, 1996). Three tests suggested to determined data trend, are as: 1- Weighted sign test; 2- Kendall rank correlation test and 3- Exponential ordered scores test. In order to trend data, correlation tests are utilized. The pair data are compared in this test (Stuart & Ord, 1991). Here statistical software used because of complicated calculations of the above-mentioned tests. It has to be considered that data collection with a specific trend in traffic data is inevitable (Luttinen, 1996). In order to trendless data observed, the test should be done for data by test series. According to auto-regression series characteristics, which are trendless data, so if the test set be done by test serried, then trendless will be assumed (Stuart & Ord, 1991). The model parameters are analyzed after investigating the data trend. The model parameters estimation is the most vital section in statistical modeling. These parameters can be estimated by several methods. The most well-known methods of model parameters analysis are Moments Method, Maximum Likelihood and Chi-square. The most common methods of parameter estimation, is Maximum Likelihood (Luttinen, 1996). Statistical software (Minitab 16) (Thailand, 2010) is used because of the complicated calculations of the mentioned test.

MODELING

The headway data modeling is conducted in two steps including: 1) Preparing and filtering the input data. 2) Statistical modeling. In the first step, the input data for the follower vehicles are exploited before the queuing by determine the following time and speed-flow curves. In the second step, the statistical models, related to vehicles’ headway and flow rate related to exploited data and separated lanes, and also for the whole section, are fitted and investigated. It should be mentioned that the models have been chosen concerning their applicability attitude.

First Step: Preparing the input data recognizing the follower vehicles

Drivers’ reaction time in Iran has been investigated in Hamedan Medical University (Sohrabi, 2013). This study has been carried out on 46 individuals (including 10 women and 36 men) and has been complemented on each volunteer by a simulation machine for one hour day and night. In addition, the statistical sample contains drivers having driving license who drive professionally and unprofessionally. Also, the sample which has been defined as a representative of the whole society and covered different characteristics including age, gender, the year of getting driver’s license and driving distance. The drivers’ reaction has been recorded by a simulation machine and has been analyzed by SPSS software in the next step.

This study’s results have demonstrated that the mean reaction time of decelerating is 1320 milliseconds. Also, the time of releasing the accelerator has been estimated 559 milliseconds. If the driver’s reaction time is considered as the sum of perception, decision and action time (Elefteriadou, 2014), the sum of releasing accelerator and decelerating will be equal to the driver’s reaction time. Consequently, the driver’s reaction time in Iran has been determined 1879 milliseconds. The equation (4) is used to estimate the driver’s sensitiveness coefficient:

\[ v_n^f - v_{n+1}^f = \tau a_{n+1}^f \]  

Here \( v_n^f, v_{n+1}^f \) and \( a_{n+1}^f \) values have been estimated by collected microscopic data. In the next step, the sensitiveness coefficient can be estimated using regression model. It has to be mentioned that the follower vehicles for surveying has been recognized by engineering judgment and also for unsaturated condition before queuing known as low limitation and level of service C has been defined as high limitation according to Highway Capacity Manual of America. In order to fit the mentioned equation in SPSS software and linear regression model with zero constant value have been applied. The obtained equation has been estimated as Eq (5) and Fig(1).

\[ v_n^f - v_{n+1}^f = (1.646) a_{n+1}^f \]  

Table 1. The Result of Model Statistical Tests

<table>
<thead>
<tr>
<th>Model</th>
<th>( R^2 )</th>
<th>P-value model (F)</th>
<th>P-value</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.933</td>
<td>0.00</td>
<td>0.00</td>
<td>1.646</td>
</tr>
</tbody>
</table>

Fig 1. The Equation of Estimated Regression in Order to Determining the Driver’s Sensitivity Coefficient

According to software’s outputs, the value of \( R^2 \) has been determined 0.985. Also, according to Table 1, the sensitivity coefficient in this equation has been meant with 95% confidence level. The model coefficient (F) has been meant with 95% confidence level.
As it was mentioned, the desired time distance is sum of the reaction time and driver’s sensitivity coefficient. Therefore, this value is determined as 3.525, which is meant the vehicles that have time headway less than 3.525 are follower or following vehicles and the vehicles that have more headway are free ones and can maneuver.

RECOGNIZING DATA BEFORE QUEUING
Speed and flow data of the study section in one year are fitted for five minute periods as shown in Figure 2.

This is obviously clear that congestion in data drop happened in speed of 71(km/h). So data by mean speed by of 71(km/h) assumed for base of study and modeling and done for speed of more than 71(km/h).

Second Step: Modeling
In this step, the filtered data have been extracted according to maximum vehicles’ headway and minimum vehicles’ mean speed, and modeling has been conducted by statistical software, Minitab16. As it was mentioned before, modeling has been carried out for each lane and the whole section. Table 2 to 5, shows the headway distribution function parameters for each lane of freeway and whole section.

Table 2. Parameters of the Headway Model for First Lane Data

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameter</th>
<th>Threshold</th>
<th>Scale</th>
<th>Shape</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma</td>
<td></td>
<td>0.146</td>
<td>11.067</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3- parameter Gamma</td>
<td>0.928</td>
<td>0.368</td>
<td>1.881</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td></td>
<td>0.549</td>
<td></td>
<td>1.620</td>
<td></td>
</tr>
<tr>
<td>Exponential</td>
<td></td>
<td>1.620</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lognormal</td>
<td></td>
<td>0.289</td>
<td>0.437</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3- Parameter Lognormal</td>
<td>0.837</td>
<td>0.634</td>
<td>-0.448</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weibull</td>
<td></td>
<td>1.810</td>
<td>2.928</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3- parameter Weibull</td>
<td>0.935</td>
<td>0.752</td>
<td>1.354</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Parameters of the Headway Model for Second Lane Data

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameter</th>
<th>threshold</th>
<th>scale</th>
<th>shape</th>
<th>location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma</td>
<td></td>
<td>0.193</td>
<td>1.236</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3- parameter Gamma</td>
<td>0.834</td>
<td>0.359</td>
<td>3.184</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td></td>
<td>0.669</td>
<td></td>
<td>1.979</td>
<td></td>
</tr>
<tr>
<td>Exponential</td>
<td></td>
<td>1.979</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lognormal</td>
<td></td>
<td>0.307</td>
<td>0.633</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3- parameter Lognormal</td>
<td>0.586</td>
<td>0.451</td>
<td>0.228</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weibull</td>
<td></td>
<td>2.212</td>
<td>2.997</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3- parameter Weibull</td>
<td>0.874</td>
<td>1.245</td>
<td>1.753</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Parameters of the Headway Model for Third Lane Data

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameter</th>
<th>threshold</th>
<th>scale</th>
<th>shape</th>
<th>location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma</td>
<td></td>
<td>0.228</td>
<td>11.963</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-parameter Gamma</td>
<td></td>
<td>-7.450</td>
<td>0.056</td>
<td>181.803</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td></td>
<td>0.743</td>
<td></td>
<td>2.732</td>
<td></td>
</tr>
<tr>
<td>Exponential</td>
<td></td>
<td>2.732</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lognormal</td>
<td></td>
<td>0.301</td>
<td>0.962</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-parameter Lognormal</td>
<td></td>
<td>-0.561</td>
<td>0.001</td>
<td>6.335</td>
<td></td>
</tr>
<tr>
<td>Weibull</td>
<td></td>
<td>3.011</td>
<td>4.372</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-parameter Weibull</td>
<td></td>
<td>-3.077</td>
<td>6.132</td>
<td>9.492</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Parameters of the Headway Model for Whole section

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameter</th>
<th>threshold</th>
<th>scale</th>
<th>shape</th>
<th>location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma</td>
<td></td>
<td>0.186</td>
<td>9.644</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-parameter Gamma</td>
<td></td>
<td>0.873</td>
<td>0.391</td>
<td>2.367</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td></td>
<td>0.638</td>
<td></td>
<td>1.800</td>
<td></td>
</tr>
<tr>
<td>Exponential</td>
<td></td>
<td>1.800</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lognormal</td>
<td></td>
<td>0.313</td>
<td>0.535</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-parameter Lognormal</td>
<td></td>
<td>0.755</td>
<td>0.576</td>
<td>-0.121</td>
<td></td>
</tr>
<tr>
<td>Weibull</td>
<td></td>
<td>2.016</td>
<td>2.859</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-parameter Weibull</td>
<td></td>
<td>0.877</td>
<td>1.032</td>
<td>1.556</td>
<td></td>
</tr>
</tbody>
</table>

EVALUATING THE MODELS

Concerning the presented descriptions, the distribution function and the possibility density will be determined for the headway in basic capacity on the basis of the problem’s theoretical bases and for the sake of solving the mentioned obstacles. Thus, models have been evaluated by three principles and the best model has been determined. These three principles are:

1- Applicability: the suggested model has to be simple mathematically and model parameters can be estimated by a specific process. Statistical attitudes of the model can be also estimated.

2- Validity: the produced model has to be checked by statistical tests and has to be valid.

3- Reasonability: the produced and investigate model has to be compatible to traffic flow theory and has to be justifiable.

APPLICABILITY

The applicable model should have not only simple structure and definition, but also specific statistical attitudes. In addition, this model can be reviewed and the model parameters can be estimated. Therefore, the well-known statistical models in this study are considered and experimental models are not investigated. According to the conducted studies up to now, in this study 4 models are investigated and are as,

1-Normal distribution function and exponential distribution function.
2-Lognormal distribution function and 3-parameter lognormal distribution function.
3- Weibull distribution function and 3-parameter Weibull distribution function.
4- Gamma distribution function and 3 parameter gamma distribution function

VALIDITY

In modeling, validating models is the most prominent step. In this study, the models’ goodness of fit is investigated and the best model will be determined. The goodness of fit is considered due to validating statistical models. The goodness of fit tests can be applied in order to investigating the hypothesis of equality in data distribution with specific distribution. The zero hypothesis of this test (H₀) depicts the equality of fitted distribution function on data and the reputed distribution function. The contrast hypothesis (Hₐ) illustrates the inequality of the models. In order to testing the goodness of fit, tests can be used like: Chi-Square test, Kolmogorov-Smirnov and Anderson & Darling tests. Although all the methods have balanced hypotheses, it has been demonstrated that Anderson & Darling test or A-D will have better results concerning headway data essence. In this method, the maximum value will be estimated as the minus model and data distribution function. This discrepancy is belonged markedly to middle part of function and the discrepancies are slight in the first and last of the function. These discrepancies are weighted according to the locating place in function and each point has a specific weight (Luttinen, 1996). In this
study, the A-D method will be applied in order to check the model goodness of fit. The goodness of fit and P indicator have been illustrated with 0.05 meaning level in Table 6.

<table>
<thead>
<tr>
<th>Model</th>
<th>Lane one A-D</th>
<th>P Indicator</th>
<th>Lane two A-D</th>
<th>P Indicator</th>
<th>Lane three A-D</th>
<th>P Indicator</th>
<th>Whole section A-D</th>
<th>P Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma</td>
<td>49.780</td>
<td>0.005&lt;</td>
<td>42.457</td>
<td>0.005&lt;</td>
<td>29.915</td>
<td>0.005&lt;</td>
<td>49.780</td>
<td>0.005&lt;</td>
</tr>
<tr>
<td>3- parameter Gamma</td>
<td>12.640</td>
<td>0.000</td>
<td>10.662</td>
<td>0.000</td>
<td>17.554</td>
<td>0.000</td>
<td>12.640</td>
<td>0.000</td>
</tr>
<tr>
<td>Normal</td>
<td>109.603</td>
<td>0.005&lt;</td>
<td>76.219</td>
<td>0.005&lt;</td>
<td>57.733</td>
<td>0.005&lt;</td>
<td>109.603</td>
<td>0.005&lt;</td>
</tr>
<tr>
<td>Exponential</td>
<td>617.820</td>
<td>0.003&lt;</td>
<td>336.036</td>
<td>0.003&lt;</td>
<td>319.189</td>
<td>0.003&lt;</td>
<td>617.820</td>
<td>0.003&lt;</td>
</tr>
<tr>
<td>Lognormal</td>
<td>28.258</td>
<td>0.005&lt;</td>
<td>28.550</td>
<td>0.005&lt;</td>
<td>20.236</td>
<td>0.005&lt;</td>
<td>28.258</td>
<td>0.005&lt;</td>
</tr>
<tr>
<td>3- parameter Lognormal</td>
<td>5.156</td>
<td>0.000</td>
<td>3.731</td>
<td>0.000</td>
<td>13.963</td>
<td>0.000</td>
<td>5.156</td>
<td>0.000</td>
</tr>
<tr>
<td>Weibull</td>
<td>107.168</td>
<td>0.010&lt;</td>
<td>77.992</td>
<td>0.010&lt;</td>
<td>57.236</td>
<td>0.010&lt;</td>
<td>107.168</td>
<td>0.010&lt;</td>
</tr>
<tr>
<td>3- parameter Weibull</td>
<td>26.916</td>
<td>0.005&lt;</td>
<td>16.931</td>
<td>0.005&lt;</td>
<td>25.938</td>
<td>0.005&lt;</td>
<td>26.916</td>
<td>0.005&lt;</td>
</tr>
</tbody>
</table>

**REASONABILITY**

Concerning to statistical data characteristics and traffic flow theory, the gained model should be compatible to users’ behavior. The last step of headway modeling is investigating the models with the purpose of compatibility to drivers’ behaviors.

**CONCLUSION**

According to model evaluations, the lognormal model is introduced as the best distribution function of the headway data for first, second, third lanes and the whole section. This function has been utilized in many headway studies. Figure 3 illustrates lognormal distribution function of 3 parameters and headway data for the whole sections.

According to characteristics of lognormal distribution function, median and average of headway illustrates in Table 7.

<table>
<thead>
<tr>
<th>Index</th>
<th>First Lane</th>
<th>Second Lane</th>
<th>Third Lane</th>
<th>Whole section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>2.228</td>
<td>2.092</td>
<td>2.426</td>
<td>2.245</td>
</tr>
<tr>
<td>Median</td>
<td>1.476</td>
<td>1.842</td>
<td>1.922</td>
<td>1.641</td>
</tr>
</tbody>
</table>

It is patently clear that driver's behavior in Iran's freeways is risky and more than 50% of drivers selected headway of less than minimum safe headway which is 1.879 sec. It should be mentioned that, the minimum headway value is estimated for normal population of gender and driving experiences and it can slightly differ from this survey. As it is shown in Table 7, drivers’ headway increase from lane one to lane three is because of using second and third lane of freeway by drivers and vehicles with lower performance and larger size. Results of this survey can be used in safety studies and considering safety policies for freeways. For instance, restricting vehicle distances in freeways and assigning penalties to avoid accidents. For later studies, It is suggested to investigate relation between the estimated risk and accident rates in particular freeway section, as well as analyzing the rear-end accidents.
REFERENCES


