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Passing Opportunity Model of Vehicles on Two Lane Undivided Highways under Mixed Traffic Conditions

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Abstract - *Traffic on Indian roads is heterogeneous in nature with wide variations in the static and dynamic characteristics of vehicles. Overtaking or passing is the act of one vehicle going past another slower moving vehicle, travelling in the same direction, on a road. Road geometry also plays an important role in providing gaps for overtaking. The main objective of the present study is to develop a logit model for passing opportunity. The results showed that passing opportunity depends on parameters like type of overtaking vehicle, speed of both overtaking and overtaken vehicle, density of vehicles in both directions, opposing gap, type of vehicles coming from the opposite direction. Road geometry has less significance.*

Keywords: Overtaking, Passing Opportunity, Moving observer method, Opposing gap, Logit model.

1. INTRODUCTION

Traffic is highly mixed in nature with lack of lane discipline on Indian roads. Traffic compositions mostly comprises of motorized vehicles such as two-wheelers, three- wheelers, cars, trucks, buses and non-motorized vehicles like bicycles, etc. Overtaking in two lane highways is a frequent phenomenon and a major consideration in traffic operations and safety. Characteristics like the dimensions, speed, acceleration, deceleration, clearances and manoeuvrability of these vehicles vary widely and hence, traffic speed is the most important factor affecting the safe movement of vehicles. In mixed traffic, vehicles use the road space more effectively and their movement depends on lateral and longitudinal gaps. The willingness to overtake mainly stems from the speed difference between the subject vehicle and the rest of traffic on the same or opposing travel lane and the tendency of each driver to maintain a desired speed during driving. They are unavoidable especially in the case of mixed traffic conditions where a speed differential always exists between the fast and slow moving vehicles. Also, overtaking is one of the most complex and important manoeuvre on undivided roads where the vehicles use the opposing lane to overtake the slower vehicles with the presence of oncoming vehicles from opposite direction. The ability to pass is influenced by a variety of parameters including the volumes of through and opposing traffic, speed differential between the overtaking and overtaken vehicles, highway geometry particularly available sight distance, and human factors. Hence, the knowledge of overtaking and lane changing behaviour of vehicles is essential in understanding of traffic behaviour on undivided roads. The aim of the study is to evaluate the overtaking behaviour of vehicles on two lane undivided roads with the following specific objectives:

- To identify the factors that influences the overtaking behaviour of different modes of vehicles.
- To develop a passing opportunity model after analyzing the identified factors.

2. LITERATURE REVIEW

Asaithambi, G. et al. [1] carried out similar study on a two-lane two-way national highway (NH 66) of 1.2 km road section in Mangalore, India. The overtaking characteristics of all categories of vehicles under heterogeneous traffic conditions were observed and mathematically modelled. It was concluded that flying overtaking is performed by 62% of drivers and accelerative by 38% of drivers which shows that majority of vehicles are travelling with their current speed without reducing the speed during overtaking. Budhkar, A.K et al. [2] developed a methodology to model overtaking decision- making, based upon longitudinal gap, centerline separation and speeds of leading and following vehicle pairs in weak lane disciplined traffic was Inter-vehicular gaps and speeds were obtained from vehicular trajectories of pairs of leader and follower vehicles by logistic regression. They have concluded that average speed has little or no impact on decision to overtake. Chandra, S. et al [3] have studied the acceleration and overtaking characteristics of different types of vehicles using floating car method. The influence of shoulder condition (paved and unpaved) on the acceleration behaviour during overtaking was presented and found that the overtaking time depends upon the speed differential between the overtaking and overtaken vehicles. Farah, H. et al [4] developed a passing gap acceptance model using the data collected on two-lane highways that were collected with an interactive driving simulator. This model took into account the impact of the road geometry, traffic conditions and driver's characteristics. However, this model did not consider driver's motivation and desire to pass. Farah, H. et al. [5] developed a model that attempted to capture both driver's desire to pass and their gap acceptance decisions to complete a desired passing manoeuver and estimated using data collected with a driving simulator. The estimation results showed that modelling the driver's desire to pass the vehicle in front has a statistically significant contribution in explaining their passing behaviour.

Mocsari, T. [6] analysed the overtaking behaviour of vehicles on two-lane rural roads in Hungary using the data collected by an instrumented vehicle. The average time of overtaking for accelerative overtaking was 8.5 s and for continuous overtaking it was 7.9 s. The length of the spacing did not depend on the overtaking vehicle's category and also, spacing was not influenced by the speed of the vehicle to be overtaken, either. Mawjoud, A. et al. [7] has obtained a relation between passing manoeuvres and flow rate for each and both directions and found that the number of passing manoeuvre increases as the flow rate for both the directions increase up to 1500 veh/h flow rate. Relation between the demand of passing and passing supply with flow rate was also calculated and found that the demand of passing increased with increase of flow rate while passing supply increased with a decrease in flow rate in opposite direction.

3. METHODOLOGY FOR DATA COLLECTION

The data for this study was collected on 2 two-lane two-way state highway in Kerala. They were SH22 and SH69. Details of study area is given in table 1. The traffic data were collected for 1 hour moving car method and registration plate method.

Table -1: Details of study area

Designation of Study section	Length of the segment (km)	Pavement width (m)	Shoulder type	Shoulder width (m)	
				Left	Right
SH22 (Thiroor)	1.1	12	Paved	3.1	1.5
SH69 (Parembadam)	1.6	9.5	Unpaved	1.6	2.8

3.1 Moving Car Method and Videography

Moving car method was chosen for the collection of data on overtaking manoeuvre. In this method, test car was driven to make other vehicles to overtake the test car. The data was collected for six categories of vehicles such as cars, Heavy Motor Vehicles (HMV), Buses, Two Wheelers (TW), three wheelers (3W) and Light Motor Vehicles (LMV). The entire process of the overtaking operation was divided into five events and the time taken for each event was recorded with a help of a stop watch. These different events are shown in fig. 1.

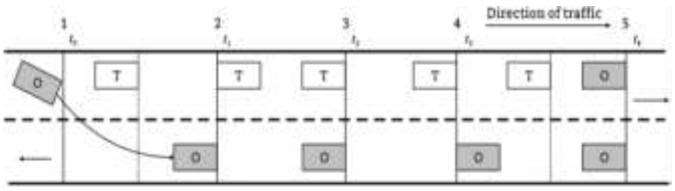

Fig -1: Events during overtaking process[1]

Video cameras were placed at each end of the section to record the passage of vehicles. The flow of vehicles was extracted for each 5 minutes interval from the recorded video. The traffic density is defined as the number of vehicles occupying a unit length of roadway. Density is a key factor in making overtaking decisions. In most of the cases drivers decides to overtake a slow moving vehicle if the density in the opposing direction is less.

4. DATA EXTRACTION AND ANALYSIS

4.1 Density

Traffic density is defined as the number of vehicles occupying a unit length of road- way. It is expressed as veh/km. Video camera was placed at the entrance and exit of the study section and the video was recorded for a time interval of one hour on both the study areas. The flow of vehicles was extracted for every 5 minutes interval. Classified count was taken for both the lanes and density was calculated as given in equation.

Density = Initial volume + Entry flow- Exit f low (1)

The effect of density in the opposite direction in making a successful overtaking and aborted overtaking is shown in fig.5.4. It is clear from the graph that the chances of making aborted overtaking was greater when the density increased as compared to the successful overtaking. This is because the drivers drive carefully in order to avoid the chance of collision.

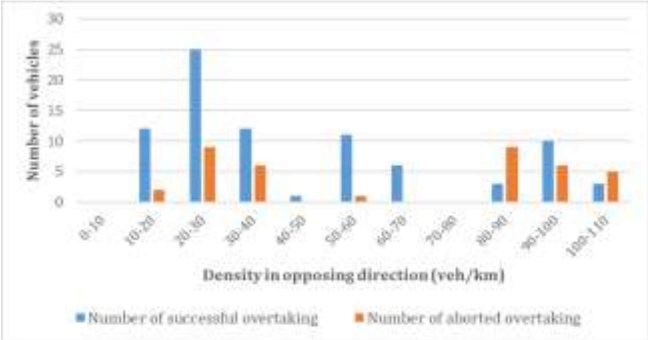

Fig -2: Number of vehicles overtaken Vs Density in opposing direction

4.2 Opposing Gap

The gap between the overtaken vehicle and the opposing vehicle at event 1 (time t_0) in moving car method is the opposing gap available during each overtaking operation. It was extracted from the video. Opposing gap in case of successful and aborted overtaking is shown in fig.3. When opposing gap was more there was no overtaking, which means the chance of overtaking depends on availability of opposing gap.

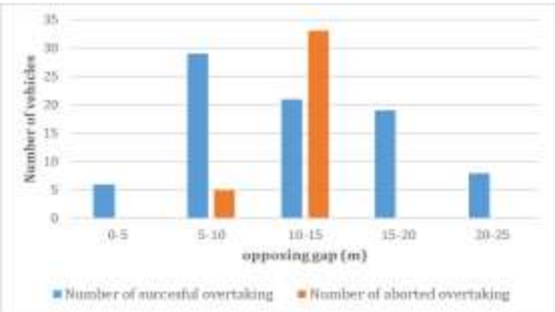

Fig -3: Number of vehicles overtaken Vs Opposing gap

4.2 Effect of Speed of Test Vehicle, Overtaken Vehicle and Opposing Vehicle on Overtaking

Speed of the overtaken vehicle is a controlling element in the determination of overtaking time and distance. Hence, it is worthwhile to determine the effect of speeds of both overtaking and overtaken (test) vehicles. The effect of speed of vehicles on making successful overtaking was studied in case of each vehicles. It was found that the speed of overtaken vehicles and speed of opposing vehicles determined the chances of making successful overtaking. This is shown in fig. 4 and fig. 5.

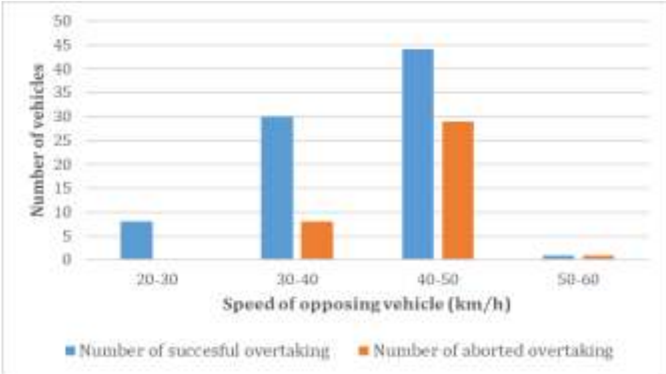

Fig -4: Number of vehicles overtaken Vs Speed of opposing vehicles

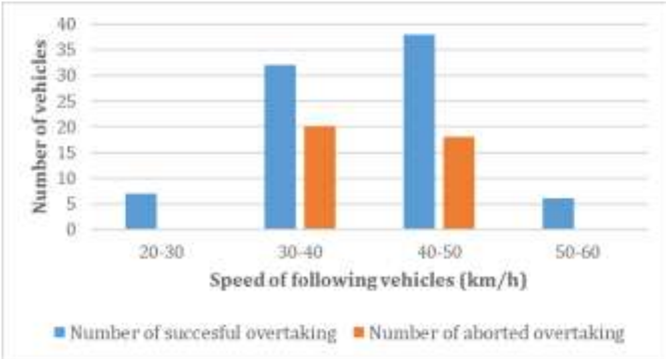

Fig -5: Number of vehicles overtaken Vs Speed of following vehicles

4.2 Effect of type of Opposing Vehicle

The influence of the type of opposing vehicle is studied and it was found in both cases as shown in fig. 6. and fig. 7. Respectively. In case of succesful overtaking the percentage of two wheelers were more. Out of the total number of vehicles participated in overtaking, 48% of vehicles were two wheelers and 28% of cars. The proportion of three wheelers, LMV, HMV and buses were 6%, 9%, 3% and 6% respectively.

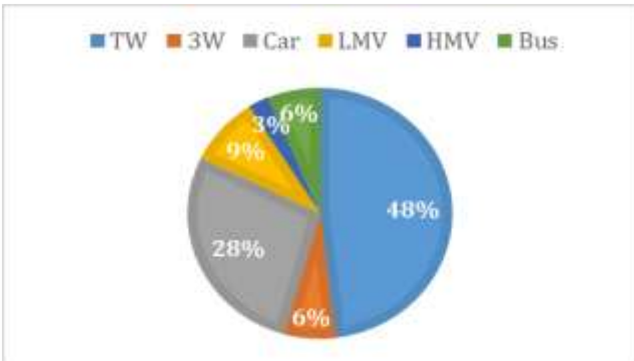

Fig -6: Percentage of vehicles participated in successful overtaking

Similarly in the case of aborted overtaking 48% of cars have decided not to complete the overtaking manoeuver due to the less availability of opposing gap or due to increase in opposing density. The proportion of two wheelers in case of aborted overtaking were only 5% because they require only less gap for completing over- taking. The proportion of three wheelers, LMV, HMV and buses were 13%, 21%, 5% and 11% respectively.

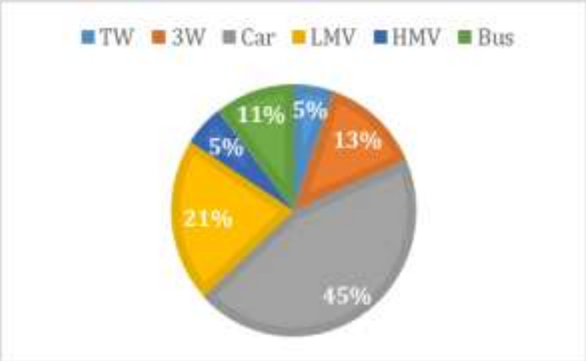

Fig -7: Percentage of vehicles in aborted overtaking

5. MATHEMATICAL MODELING

Statistical modeling was done in SPSS (Statistical Package for Social Science) by Binary Logistic Regression and Linear Regression after conducting Spearman's correlation test. Regression analysis is widely used for prediction and forecasting, where its use has substantial overlap with the field of machine learning. Regression analysis is also used to understand which among the independent variables are related to the dependent variable, and to explore the forms of these relationships.

Overtaking decision model was developed using binary logistic regression after identifying the influencing variables from the collected set of data. The passing opportunity was chosen as the dependent variable and was coded as 1 for successful overtaking and 0 for aborted overtaking. The independent variables selected were the speed of test vehicle (overtaken vehicle), overtaking vehicle and opposing vehicle; traffic density in both subject direction and opposite direction; opposing gap; type of opposing vehicle; pavement width; type and width of the road. Out of these 10 variables 5 variables namely density in the opposite direction, speed of overtak- ing vehicle and opposing vehicle, opposing gap and type of opposing vehicles were found to be correlated with the dependent variable after conducting spearman's cor- relation test. The predicted probability (p) of overtaking can be calculated by,

$$P\ (succesful\ overtaking) = \frac{e^{u_x}}{1+e^{u_x}} \qquad (1)$$

Where,

$$u_x = \ln\left(\frac{probability\ to\ follow}{probability\ to\ overtake}\right)$$

$$= \beta_0 + (\beta_1 * k_{opposing}) + (\beta_2 * VT_{opposing}) + (\beta_3 * v_{opposing}) + (\beta_4 * G_{opposing}) + (\beta_5 * v_{followingvehicle}) \qquad (2)$$

Using equation 1 and 2, one can obtain the probability to overtake depending on various predictor variables. Probability to follow is obtained by subtracting probability to overtake from unity. The coefficients $\beta_0, \beta_1, \ldots, \beta_5$ express the effects of the predictor variables namely density in the opposite direction ($k_{opposing}$), type of opposing vehicle ($VT_{opposing}$), speed of opposing vehicle ($v_{opposing}$), opposing gap ($G_{opposing}$), and speed of following/overtaking vehicle ($v_{following\ vehicle}$); on the log odds of following versus overtaking (u_x).

Utility equation obtained is in the form,

$$u_x = 19.116 - (0.09 * k_{opposing}) + (2.129 * VT_{opposing}) - (2.698 * v_{opposing}) + (1.601 * G_{opposing}) + (1.362 * v_{followingvehicle}) \qquad (3)$$

The model obtained is thus in the form,

$$P\ (succesful\ overtaking) = \frac{e^{19.116-(0.09*k_{opp})+(2.129*VT_{opp})-(2.698*v_{oppveh})+(1.601*G_{opp})+(1.362*v_{folloveh})}}{1+e^{19.116-(0.09*k_{opp})+(2.129*VT_{opp})-(2.698*v_{oppveh})+(1.601*G_{opp})+(1.362*v_{folloveh})}} \qquad (4)$$

The accuracy of the model in equation (4) is evaluated by both the Nagelkerke R^2 (NRS) and the overall prediction accuracy, which are 0.922 and 83%, respectively. The result shows that density in opposite direction, Type of vehicle coming from the opposite direction, speed of opposing vehicle, opposing gap and speed of following/overtaking vehicle are statistically significant factors that impact the drivers decision to make an overtaking manoeuver

The model variables and coefficients are shown in table 2.

Table -2: Model varibles and coefficients

Factor	B	SE	Wald	df	Sig.	Exp(B)
k_{oppo}	-0.090	0.044	4.216	1	0.040	0.914
VT_{oppo}	-2.129	0.989	4.634	1	0.031	0.119
v_{oppo}	-2.698	1.320	4.175	1	0.041	0.067
G_{oppo}	1.601	0.614	6.806	1	0.009	4.957

$V_{folloveh}$	1.362	1.288	1.118	1	0.290	3.906
Constant	19.116	10.019	3.641	1	0.056	

Table 1 states the values of estimated coefficients ($\beta 0$ to $\beta 5$) as per logistic regression technique. Higher absolute value of coefficient indicates higher increase per unit change of the corresponding predictor variable. Negative value indicates decrease of the odds to follow, upon increase of corresponding predictor variable. Density in opposite direction, type of opposing vehicle and speed of opposing vehicle are negatively related which means that the chance to overtake decreases with an increase in these sets of values. Whereas the chances to overtake increases with an increase in the value of the speed of following/overtaking vehicle and opposing gap. The third set of rows gives the standard error of these coefficients. Statistical significance of individual predictors is tested using the Wald chi-square statistic. Those predictors whose p-values are smaller than 0.05 are significant. A p-value less than 0.05 indicates that the data for corresponding predictor variable, separated as per decision to overtake and decision to follow; are significantly different. It implies that drivers maintain statistically different behavior in terms of these predictor variables during overtaking and during following. Thus all the predictor variables are stastically significant with $p<0.05$ except for speed of following vehicle which is slightly significant ass compared to other variables. The significance of that variable will be hence less as compared to other variables. Exp(B) means "e to the power B" or e^B called the "odds ratio". In logistic regression, e^B is the factor by which the odds change when X increases by one unit. The coefficient 0.090 implies that a one unit change in density results in a 0.090 unit change in making successful overtaking or in other words it has an odds ratio of 0.914 in making successful overtaking to aborted overtaking at 95% condifidence interval.

Similarly, the variable type of opposing vehicle has a negative coefficient of 2.129. The effect of type of opposing vehicle on making successful overtaking is negatively related, which means that the chances to make a successful overtaking decreases when heavy vehicles and buses are coming from the opposite direction. It can also be inferred that when the variable type of opposing vehicle changes by one unit, the chances to make successful overtaking changes by a factor 0.119. When the speed of opposing vehicle changes by one unit, the chance for making a success- ful overtaking changes by a factor of 0.067. The variable opposing gap is positively related to the dependent variable and hence a unit increase in the value of opposing gap makes an increase in the chance of making successful overtaking by a factor of 4.957. Similarly, when the speed of following vehicles increases by one unit, the resulting increase in chance of making successful overtaking is 3.906 times.

5.1 Validation

One third of the data was selected for validation of the model. The model was applied to the remaining data set and predicted probability was obtained. Prediction accuracy was 82.5 % which is a good result.

6. CONCLUSIONS

It was observed that majority of the vehicles were intending to overtake the test vehicle when the speed of the test vehicle was between 35 km/h and 45 km/h. The number of overtaking increases with increase density rate in on-going direction and decreases with increase in density in opposite direction. The chances for successful overtaking depends on the density in opoosite direction, opposing gap, type of opposing vehicle, speed of opposing vehicle and speed of following vehicle. As density in the opposite increases chance to overtake successfully decreases and viceversa. Similarly type of vehicle is also a governing factor and it can also be related to density. Small sized vehicles can overtake even if the density is more due to their smaller size and higher manoeuveribility. Overtaking probability increases only if sufficient opposing gap is available and also the speed of vehicles coming from the opposite direction is also to be considered before taking a decision to overtake a slow moving vehicle in front.

Simulation model of the traffic pattern including overtaking behaviour can also be developed in future. The study can be extended to divided highways too. The presence of median can be chosen as a variable.

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