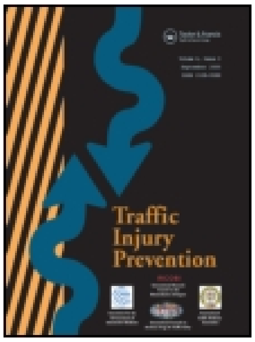

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Identifying Significant Predictors of Head-on Conflicts on Two-Lane Rural Roads Using Inductive Loop Detectors Data

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Objective: *To identify the significant factors that influence head-on conflicts resulting from dangerous overtaking maneuvers on 2-lane rural roads in Iran.*

Methods: *A traffic conflict technique was applied to 12 two-lane rural roads in order to investigate the potential situations for accidents to occur and thus to identify the geometric and traffic factors affecting traffic conflicts. Traffic data were collected via the inductive loop detectors installed on these roads, and geometric characteristics were obtained through field observations. Two groups of data were then analyzed independently by Pearson's chi-square test to evaluate their relationship to traffic conflicts. The independent variables were percentage of time spent following (PTSF), percentage of heavy vehicles, directional distribution of traffic (DDT), mean speed, speed standard deviation, section type, road width, longitudinal slope, holiday or workday, and lighting condition.*

Results: *It was indicated that increasing the PTSF, decreasing the percentage of heavy vehicles, increasing the mean speed (up to 75 km/h), increasing DDT in the range of 0 to 60 percent, and decreasing the standard deviation of speed significantly increased the occurrence of traffic conflicts. It was also revealed that traffic conflicts occur more frequently on curve sections and on workdays. The variables road width, slope, and lighting condition were found to have a minor effect on conflict occurrence.*

Conclusion: *To reduce the number of head-on conflicts on the aforementioned roads, some remedial measures are suggested, such as not constructing long "No Passing" zones and constructing passing lanes where necessary; keeping road width at the standard value; constructing roads with horizontal curves and a high radius and using appropriate road markings and overtaking-forbidden signs where it is impossible to modify the radius; providing enough light and installing caution signs/devices on the roads; and intensifying police control and supervision on workdays, especially in peak hours.*

Keywords Two-lane rural roads; Overtaking maneuver; Traffic conflict technique; Inductive loop detectors; IHSDM

INTRODUCTION

Traffic accidents in Iran result in more than 23,000 fatalities each year (Forensic Medicine Organization of Iran [FMOI] 2009). Two thirds of these fatalities occur on rural roads, and a significant number of these roads are 2-lane roads. According to Kashani et al. (2011a, 2011b), dangerous overtaking is one of the most serious causes of injuries and fatalities on such roads. Because overtaking maneuvers on 2-lane rural roads occur by using the opposite lane, the severity of accidents is considerably high, such that although dangerous overtaking maneuvers account for only 20 percent of accidents in these roads, they are responsible for 30 percent of injuries and 50 percent of fatalities.

Moreover, head-on collisions are one of the most fatal consequences of these maneuvers and due to their seriousness, many studies have been devoted to investigating the factors that influence these crashes. Evans and Wasielewski (1987) examined the relationship between car mass and driver injuries (serious or fatal) in head-on crashes between 2 cars of similar mass and found that the likelihood of driver injury increased with decreased car mass. Zhang and Ivan (2005) performed an analysis to evaluate the effects of roadway geometric features on the incidence of head-on crashes on 2-lane rural roads in Connecticut. The variables speed limit, maximum degree of horizontal curve, and sum of absolute change rate of horizontal/vertical curvature were recognized as significant factors, such that the number of crashes increased with each of these variables except for speed

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limit. In another study, Garder (2006) investigated driver and segment characteristics of head-on crashes on 2-lane rural highways in Maine. According to his results, a majority of crashes were caused by driver error or misjudgment; other important causes were illegal/unsafe speed, driver inattention/distraction, fatigue, using alcohol or drugs, overtaking, and intentionally crossing the centerline. Straight segments with dry pavement, higher speed limits, and more than 2 travel lanes were also found to increase crash severity. In summary, he concluded that there are 2 major reasons why drivers cross the centerline and have head-on collisions: they are (1) going too fast for the roadway conditions or (2) inattentive and cross the centerline without noticing.

The objective of this study is to identify the significant factors influencing head-on conflicts resulting from dangerous overtaking maneuvers on 2-lane rural roads using data from inductive loop detectors and based on a traffic conflict technique.

A traffic conflict technique is a useful method for studying traffic safety and is used to determine potential accident situations. A traffic conflict is a visible situation where 2 or more road users are so close to each other that unless they change their positions, an accident is inevitable (Rumar et al. 2004). Measuring conflicts on rural roads is more difficult than on urban roads because monitoring the whole road is impossible. Therefore, traffic conflict techniques have been usually used to study the safety of urban roads and intersections. There are only a few studies concerning this technique as applied to rural roads, which are limited to specific sections of a road. For example, Campbell and Ellis King (1970) investigated the application of a traffic conflict technique to 2 rural Y-type roadway intersections and showed an association between accidents and different forms of conflict. Farah et al. (2008) presented a decision-making model for overtaking on 2-lane rural roads. Using a driving simulator, they determined that important factors in making such decisions are the size of the passing gap, vehicle speed, and distance from the vehicle ahead. In a similar research, Farah et al. (2009) analyzed dangerous overtaking maneuvers on 2-lane roads and found that the speed of the overtaking vehicle and the one being overtaken influenced the occurrence of dangerous overtaking. They also determined that for low traffic volumes, dangerous overtaking occurs less, and with increasing wait time to find a suitable passing gap, the possibility of dangerous overtaking increased. In addition, inappropriate geometric design of the road has a contributing effect on the occurrence of dangerous overtaking.

Inductive loop detectors provide useful data that have been used for various purposes and in different fields, such as traffic safety. For example, Dia and Thomas (2011) used simulated data derived from inductive loop detectors and probe vehicles to develop an incident detection model for urban arterial roads. In research carried out by Oh et al. (2006), a traffic conflict technique combined with inductive loop detector data was used to evaluate rear-end collision potentials on freeways. However, all of these studies were conducted in urban areas. A useful aspect of these data for rural roads is that they can show whether overtaking maneuvers have occurred. Using these data, we are able to identify factors that influence the occurrence of head-on conflicts resulting from dangerous overtaking maneuvers, which are of particular concern on rural roads.

In this research, using inductive loop detector data, we applied a traffic conflict technique to a wide range of 2-lane rural roads in Iran to identify factors that influence the occurrence of head-on conflicts resulting from vehicle overtaking maneuvers.

METHODS

A traffic conflict technique is a common method used to study traffic safety whereby, instead of investigating the accident data, the potential situations for accidents to occur are investigated. In this study, we applied this technique in order to identify geometric and traffic factors that influence the occurrence of traffic conflicts resulting from overtaking maneuvers on 2-lane rural roads in Iran.

Determining Traffic Conflicts Resulting From Overtaking

There are many criteria for identifying traffic conflicts, including time to collision (TTC), deceleration rate, and postencroachment time. Time to collision is a useful criterion for identifying traffic conflicts and is defined as the expected time for 2 vehicles to collide if they continue to move at the same speed and in the same direction. It has an inverse relationship to the risk of the accident, and less time to collision results in a more hazardous situation.

In this research, we have used this criterion identify traffic conflicts resulting from overtaking. Some researchers, including Farah et al. (2009), have suggested 3 s for TTC to identify such conflicts on 2-lane roads. The same value has also been recommended by the American Association of State Highway and Transportation Officials (AASHTO 2004). Moreover, in a related study investigating driver assistance systems for safe overtaking, Hegeman (2008) stated that a TTC less than 3 s is unsafe and inappropriate. Therefore, in this research a TTC value of 3 s is used and overtaking maneuvers in which the TTC for 2 vehicles is less than 3 s are considered traffic conflicts resulting from overtaking.

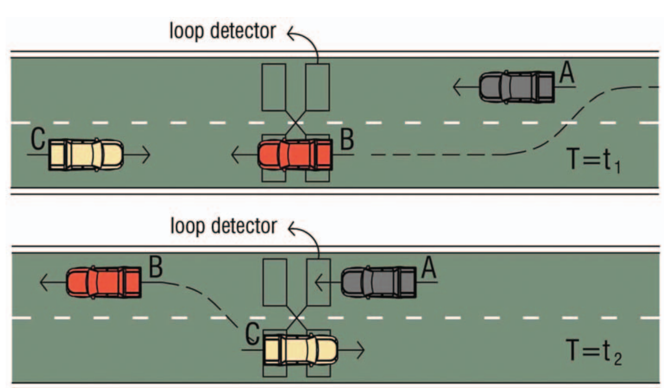

Figure 1 How to determine a traffic conflict (color figure available online).

Figure 1 shows how to determine a traffic conflict. In this figure, vehicles A and B are moving in the same direction, and vehicle C is moving in the opposite direction. At time t_1, vehicle A passes vehicle B and crosses the loop detector. If vehicle C crosses the loop detector at time t_2, where the difference between t_2 and t_1 is no greater than 3 s ($t_1 < t_2 \leq t_1 + 3$), the overtaking maneuver of vehicle A is considered a traffic conflict. If a vehicle crosses the loop detector in its own lane, the detector codes this as 0; if the vehicle enters the opposite lane for passing, the detector codes this as a 1. In this way, the position of a vehicle while overtaking is identified.

Statistical Tests

The main objective of this research is to identify factors that have a significant influence on the occurrence of traffic conflicts. To achieve this, each of the independent variables studied was categorized, and Pearson's chi-square test (χ^2) with a *P*-value of .05 was used to evaluate the relationship between each independent variable and traffic conflict.

DATA DESCRIPTION

In this research, we have studied the data related to 12 two-lane rural roads, enumerated in Table I. The traffic data of these roads were obtained from permanent inductive loop detectors installed on rural roads of Iran by the ministry of road and transportation. These detectors provide data related to speed, passing time, type of vehicle, and overtaking or no–overtaking condition for every vehicle, and are installed at specified locations such that they will be a good representation for traffic of the whole road. Geometric characteristics of the studied road sections were also recorded via field observations. Our 12-road sample for conducting this study is made up of 4 roads for each of the 3 different terrain conditions in Iran: level, rolling and mountainous. Moreover, the characteristics of those roads selected for each terrain condition is that there is no marginal access near the loop detector installed on the road; loop detectors are installed on the main road axis; and the individual records for all vehicles are available via the detector. In order to verify the correctness and accuracy of loop detector data, a field investigation was conducted on one of the studied roads: Roodehen-Amol. Traffic flow on this road was videotaped for 2 h during the morning peak time. The number and type of vehicles, number of vehicles following others at headways of 3.0 s or less, and number of overtaking maneuvers were counted manually for each 5-min interval and in each direction. The data related to video counts were then compared to those extracted from the loop detectors. The comparison showed only a slight difference between the corresponding values, so the reliability of loop detectors data was verified.

Loop detectors for rural roads are installed at locations where factors like residential areas and pedestrians have the least effect on traffic flow. The study was performed on 2228 h of data from loop detectors, classified in 15-min intervals. Evaluation of the data collected revealed that of the 8907 15-min intervals, about 7667 (86.1%) had no conflict, 458 (5.1%) had only 1 conflict, and 782 (8.8%) had more than 1 conflict. This means that in about 91.2 percent of the studied period, traffic conflict had a binary status: occurrence or nonoccurrence. Therefore, we defined the dependent variable of traffic conflict into 2 classes.

Ten independent traffic and geometric variables were studied and are listed in Table II. In order to investigate the correlation between these variables, Pearson's parametric test (for continuous variables) and Kendall non-parametric test (for discrete variables) were used. The results showed that all variables have a correlation coefficient less than 0.5, and thus are considered uncorrelated to each other. Table II presents considered categories for these 10 independent variables along with the number of occurrences or nonoccurrences recorded. The variables percentage of time spent following (PTSF), percentage of heavy vehicles, directional distribution of traffic (DDT), mean speed (in one direction), and standard deviation of speed are traffic variables; section type, road width, and longitudinal slope (low slope or level) are geometric variables. Finally, the variables type of day (workday or holiday) and lighting condition (day or night) are associated with time and condition of utilization.

Table I Description of studied sites

Terrain type	Site	Flow rate (veh/h)			Road width (m)	Section type	Duration (hr)
		Min	Max	Ave			
Level	Zahedan-Khash	27	248	113	7.0	Straight	184
	Yazd-Tabas	16	149	55.5	6.8	Straight	186
	Eslamshahr-Qom	44	1511	683.6	6.8	Straight	184
	Gonbad-Incheh Beron	7	253	102.6	7.0	Straight	186
Rolling	Zanjan-Miyaneh	11	134	60	7.2	Curve	186
	Damghan-Cheshme Ali	15	354	90.6	6.8	Straight	186
	Amlash-Shalman	33	292	173.6	7.2	Straight	186
	Borojen-Mobarakeh	21	250	105.2	7.2	Straight	186
Mountainous	Ardebil-Khalkhal	24	316	182.1	7.0	Straight	186
	Karaj-Chalus	34	629	162.9	7.4	Curve	186
	Sanandaj-Divan dareh	44	336	136.9	7.0	Straight	186
	Roodehen-Amol	99	845	373.9	7.1	Curve	186
Total Duration							2228

Table II Number of occurrences or nonoccurrences of traffic conflicts for each classified variable

Variable	Variation intervals	Observed count: Nonoccurrence of traffic conflict	Observed count: Occurrence of traffic conflict
PTSF (%)	0–20	5007	226
	20–40	2101	389
	40–60	392	242
	60–80	151	339
	80–100	16	44
Percentage of heavy vehicles (%)	0–20	4326	835
	20–40	2104	343
	40–60	667	49
	60–80	422	11
	80–100	148	2
Road width (m)	6.8–7.1	4506	684
	7.1–7.4	3161	556
Section type	Straight	5950	728
	Curve	1717	512
Lighting condition	Night	2439	431
	Day	5248	809
Standard deviation of speed (km/h)	0–10	583	244
	10–20	5844	925
	20–30	1199	69
	30–40	39	2
Mean speed (in one direction) (km/h)	<50	763	81
	50–75	2215	1020
	75–100	4428	139
	>100	261	0
DDT (%)	0–20	110	11
	20–40	1435	211
	40–60	4635	814
	60–80	1384	195
	80–100	103	9
Slope	Level	3762	684
	Low slope	3907	556
Type of day	Holiday	2312	165
	Workday	5355	1075

The variable PTSF is defined as the average percentage of total travel time that a vehicle has to travel in platoons behind slower vehicles, due to inability to pass (Transportation Research Board [TRB] 2000). Though the concept of PTSF is sound, it is difficult or even impossible to measure this variable in the field. Therefore, the HCM (2000) suggests a surrogate measure for that, which is "the percentage of vehicles following others at headways of 3.0 s or less" (p. 12-12).

Prior to use of the above surrogate measure for the present study, the validity of this measure was investigated. To do so, first of all, the percentage of headways equal to 3 s or less was estimated for 3 of the studied roads and 50 15-min intervals. In the next step, the studied situations were simulated by the use of a traffic analysis module (TAM) from the Interactive Highway Safety Design Model (IHSDM) software collection. The TAM module calculates PTSF values in a time range by geometric simulation and traffic flow. Finally, comparing the percentage of vehicles with headway less than 3 s (obtained from loop detector data) to the corresponding PTSF values resulting from TAM road simulation, the differences were calculated and are presented in Table III. There was no significant difference between the 2 measures, so we replaced the PTSF variable with its surrogate measure.

Table III Differences between PTSF values resulting from TAM road simulation and its surrogate headway measure

Variation (%): Ave.	Variation (%): Max	Variation (%): Min	Site
3.4	12.2	0	Eslamshahr-Qom
4.9	15.0	0	Karaj-Chalus
1.9	8.7	0	Zanjan-Miyaneh
3.4	15.0	0	Total

The variables mean speed and standard deviation of speed resulted from considering all vehicles and the 15-min intervals. Finally, traffic flow volumes and the geometric variables road width and section type for each of the studied roads are shown in Table I.

RESULTS AND DISCUSSION

In this research, the effect of each variable on the occurrence of traffic conflicts was evaluated independently, and results of Pearson's chi-square test (χ^2) for each variable are presented in Table IV. The results show that there is a significant difference between the two classes, and for all variables the *P*-value were close to zero, which means that there is a meaningful relationship between the independent variables and the dependent variable traffic conflict.

Figure 2 presents the percentage of occurrences and nonoccurrences of traffic conflicts within the determined intervals for each variable. According to Figure 2a, there is a direct relationship between PTSF and occurrence of traffic conflict, and increasing PTSF increases the possibility of a traffic conflict. Increasing PTSF means increasing the time spent in platoons. In this situation, drivers tend to release themselves from the slower vehicles ahead by overtaking to move at their desired speed, which increases the possibility of dangerous overtaking. This confirms the results of Farah et al. (2009) that with increasing wait time to find a suitable passing gap, the possibility of

Table IV Results of Pearson's chi-square test for independent variables

Variable	Pearson Chi-Square value	Degree of freedom	Significant level
PTSF	2145.240	4	<0.001
Percentage of heavy vehicles	118.538	4	<0.001
Slope	15.922	1	<0.001
Road width	5.721	1	0.017
Section type	203.117	1	<0.001
Lighting condition	4.492	1	0.034
Standard deviation of speed	246.785	3	<0.001
Mean speed (in one direction)	1343.374	3	<0.001
DDT	15.223	4	0.004
Type of day	150.931	1	<0.001

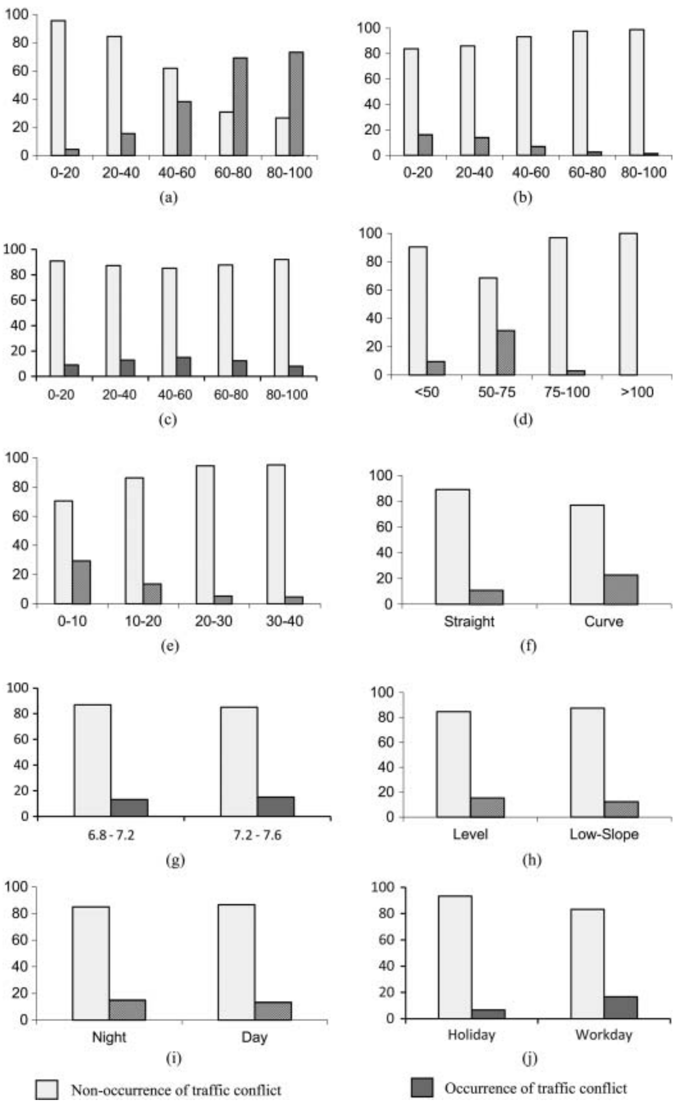

Figure 2 Percentage of occurrences and nonoccurrences of traffic conflicts: (a) PTSF (%); (b) percentage of heavy vehicles (%); (c) DDT (%); (d) mean speed (in one direction) (km/h); (e) standard deviation of speed (km/h); (f) section type; (g) road width (m); (h) slope; (i) lighting condition; and (j) type of day (holiday or workday).

dangerous overtaking increases. Figure 2b shows that an increase in the percentage of heavy vehicles decreases the occurrence of traffic conflicts because in the presence of heavy vehicles, drivers take more precautions in overtaking and the occurrence of overtaking maneuvers generally decreases. Hence, there is an inverse relationship between these 2 variables. About DDT, with an increase in DDT in the range of 0 to 60 percent, the percentage of traffic conflict will also increase, whereas increased DDT over 60 percent will decrease this percentage (Figure 2c). A similar trend was seen for the mean speeds: as can be seen in Figure 2d, increasing mean speed up to 75 km/h increases the percentage of traffic conflicts, but increased mean speed over 75 km/h this percentage decreases. This can be explained by the fact that drivers want to overtake others to reach their desired speed, but when the mean speed reaches 75 km/h, overtaking is no longer necessary. On the other hand, standard deviation of speed has an inverse relationship with occurrence of traffic conflicts; with increased standard deviation of speed the rate of traffic conflicts decreases (Figure 2e). Moreover, according to Figure 2f, traffic conflicts in curve sections are more frequent than in straight ones, because deceleration, decreased overtaking sight distance, and movement limitations in curves lead to dangerous overtaking maneuvers and, consequently, the occurrence of more traffic conflicts. This agrees with the study of Zhang and Ivan (2005), who found that the maximum degree of horizontal curve and sum of absolute change rate of horizontal/vertical curvature influenced the incidence of head-on crashes. Figure 2g shows the effect of road width, such that by increasing road width beyond its standard value (3.6 m), the percentage of traffic conflicts slightly increase, because drivers feel safer in performing overtaking maneuvers on wider roads and so are more willing to undertake risky maneuvers that result in more traffic conflicts. Therefore, 2-lane roads should not be constructed with road widths greater than the standard value. This outcome confirms the results of Roess et al. (2004).

Road slope (Figure 2h) has a minor inverse relationship to the occurrence of traffic conflicts, because on a road with a low slope the possibility of increasing speed to perform an overtaking maneuver decreases, and consequently drivers undertake fewer risky behaviors compared to level roads. Finally, about the type of day (holiday or workday) and lighting conditions, Figures 2i and 2j indicate that traffic conflicts occur more often at night and on workdays. The former is because of the visibility and other issues with night driving, and the latter is due to fatigued drivers who may be in a rush, which makes them impatient in following and more willing to pass.

CONCLUSION

In this study, using a traffic conflict technique, 12 two-lane rural roads in Iran were studied in order to analyze the relationship between the occurrence of overtaking head-on conflicts and traffic/geometric conditions and to identify the factors that influence these behaviors. Traffic data were collected via inductive loop detectors installed on the roads, and geometric characteristics were obtained through field observations. Two groups of data were analyzed using statistical tests.

The results revealed that increased PTSF and decreased mean vehicle speeds, which are mainly caused by driving in platoons, increases the possibility of traffic conflicts. Therefore, not constructing long "No Passing" zones and constructing passing lanes where necessary are highly recommended. This research proved that PTSF is not only an index for road level of service but for measuring the safety of roads with regards to overtaking maneuvers.

According to the findings, increasing road width beyond its standard value (3.6 m) slightly increases the possibility of traffic conflicts. Therefore, in resurfacing, restoration, and rehabilitation projects on these roads, the road width should not be constructed greater than the standard value. Sometimes, the soil shoulder of the road is asphalted as an inexpensive option for broadening the road, though this is proven to have negative consequences.

The results also indicated that the possibility of traffic conflicts in curved sections is greater than in straight sections. So, the use of horizontal curves with a high radius is recommended in order to provide a better field of view. In cases where it is impossible to modify the radius, appropriate road markings and the posting of overtaking-forbidden signs are suitable alternatives. Moreover, the results showed that the possibility of conflicts at night is a little greater than in the daytime, which is due to lower visibility at night and the consequent driving problems. In order to resolve this issue and increase traffic safety at night, lighting or the installation of caution signs/devices such as centerline rumble strips are a less costly alternative to raise drivers' awareness on rural roads.

The last variable of influence was type of day (holiday or workday), and the results showed that traffic conflicts occur more often on workdays than on holidays. Therefore, police control and supervision should be intensified on workdays and especially in peak hours. Speed cameras and mobile patrol vehicles are some of the options that can be helpful in this regard.

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