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Investigating and modeling speed variability on multilane highways

A.H. Alomari[1] B.H. Al-Omari[2] M.E. Al-Adwan[2] A. Sandt[3]

[1]Department of Civil Engineering, Yarmouk University (YU), P.O. Box 566 - Irbid 21163, Jordan
email: alomarish@yu.edu.jo
[2]Department of Civil Engineering, Jordan University of Science & Technology (JUST),
P.O. Box 3030 - Irbid 22110, Jordan
email: bahomari@just.edu.jo; mhmedwan@yahoo.com
[3]Department of Civil, Environmental, and Construction Engineering,
University of Central Florida (UCF), Orlando, FL 32816-2450, United States
email: adrians2009@knights.ucf.edu

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Abstract

This paper investigated the speed variance on multilane highways, explored the main associated factors, and developed prediction models to help agencies better set speed limits to reduce speed variance and their associated crashes. Speeds of vehicles were measured for twenty-five multilane highways in Jordan. Data were collected during off-peak hours on sunny days with dry pavement conditions. Results indicated the difference between the design speed and speed limit (DS-SL) is the primary factor that affects speed variance. The minimum speed variance occurs when the DS-SL is 10 km/hr. Speed limits more than 10 km/hr below the design speed increase the speed variance, as road conditions (represented by design speed) tend to control vehicle's speeds rather than speed limits in these cases. Additionally, having more highway lanes decreases speed variance, as does having roadside barriers. This paper provides beneficial information to authorities and policymakers who set speed limits on multilane highways.

Keywords - speed variance, speed limit, design speed, multilane highway, regression

1. Introduction

Roadway speed limits are used in most countries to set the maximum (or minimum) speeds at which vehicles can legally travel on a section of roadway. Speed limits can be variable and are typically indicated on traffic signs. Legislative bodies, policymaker specialists, and other authorized agencies usually set speed limits and enforce them by police (patrol vehicles) or automated roadside systems such as speed cameras (visible or hidden). A speed limit of around 30 kilometers per hour (km/hr), or 20 miles per hour (mph), is commonly used in urban residential areas to keep roads within the acceptable safety range [1]. However, Nitzsche and Tscharaktschiew [2] proposed that applying a general speed limit consistently on all urban area roadways is an insufficient way to enhance social welfare. The lowest optimal speed limit was estimated to be 60 km/hr (37 mph) for urban areas in Norway [3]. Although speed limits are a common global policy, there are highway sections in some countries that have high speed limits, such as highway sections in Texas, Unites States, with speed limits of 137 km/hr (85 mph) [4], or even sections with no speed limit, such as the Autobahn in Germany [5]. Moreover, several authorities use variable speed limits (VSL) to control posted speed limits according to the prevailing traffic and weather conditions to improve the level of service and enhance safety [6].

Designing a roadway facility with a desired speed can be achieved by considering the relationship between the posted speed limit, design speed, and operating speed. AASHTO defines design speed as "the selected speed used to determine the various geometric features of the roadway" [7]. In comparison, the operating speed is defined as "the speed at which drivers are observed operating their vehicles during free-flow conditions" [7], which can be affected by grade, radius, and length of road alignments [8]. While the relationship between operating speed and posted speed limit can be well defined, the relationship between the design speed and either operating speed or posted speed limit cannot be determined with the same level of confidence [9]. Himes, Donnell, and Porter [10] suggested that the posted speed limit should be considered as an exogenous variable in operating speed models, speed magnitude, and speed dispersion. They concluded that the posted speed limit had a “positive association with both mean speed and speed deviation” [10]. Similarly, Sun et al. [11] focused on the significance of operating speed and design speed as crucial factors in establishing the speed limit.

While the operating speed does affect the prevalence of crashes, another significant safety factor is the speed variability, or speed variance, between vehicles in the traffic stream. Several studies have shown that higher speed variance is associated with higher accident rates [12]. When all vehicles in a traffic stream are moving at a similar speed, the distance between vehicles stays relatively constant, reducing the chance of the vehicles colliding with each other. If the vehicles are traveling at different speeds (resulting in higher speed variance), the chance of an accident occurring increases due to the interaction between vehicles increasing the opportunities for crashes. Therefore, it is expected that reducing the speed variance can help reduce the accident rate.

The purpose of this research is to study the main factors that could potentially affect speed variance in traffic streams on multilane highways. This research also aims to develop statistical models to predict this variance and to represent the relationships between speed variance and influencing factors. One of the primary factors considered is the difference between design speed and speed limit to see if roadways with higher differences have higher speed variance. Understanding the factors that influence speed variance and the relationship between speed variance, design speed, and the posted speed limit are important to effectively set speed limits and make roadway modifications to reduce speed variance. The results of this research can be used by policymakers and transportation authorities to improve safety on existing and future multilane highways.

2. Literature review

This paper investigates the influence of geometric and traffic characteristics on speed variance using different analytical and modeling techniques. To assist in this investigation, previous research on speed variance was reviewed. This literature review focused on studies about the influence of speed variance on accidents and safety, as well as studies on the relationship between speed variance, speed limit, geometric characteristics, and weather conditions.

2.1. Studies on speed variance and speed limit and their effects on traffic safety

Speed is a crucial factor in accident rates, affecting the occurrence of crashes and their severity [13, 14]. Speed is responsible for 20 to 30% of all fatal traffic accidents [13]. Ambros & Kysely [14] stated that the difference in speed between the free-flow vehicle and the car-following vehicles might significantly impact safety. Garber and Gadiraju [12] studied the traffic factors that affect speed variance and its degree of influence on accident rate for several types of highways in Virginia, United States. Results showed that accident rates increase with an increase in speed variance for all types of roads. If the average speed increases, speed variance will decrease if the average speed is between 40 and 112 km/hr, (25 to 70 mph). The difference in speed between posted speed and design speed also has a significant effect on speed variance, with the speed variance being lowest if the difference between the posted speed and design speed is within 8 to 16 km/hr (5 to 10 mph). Similarly, Pisarski [15] pointed out that there is a significant statistical relationship between speed variance and accident rate. Wang et al. [16] also confirmed that speed variation is observed to have a significant positive impact on crashes. Furthermore, Jiang et al. [17] concluded that an increase in access density of minor roads would lead to a decrease in the speed variance and traffic accidents.

Several studies investigated the effect of changing the speed limit on speed variance, accident rate, and severity. Graves et al. [18] concluded that a higher speed limit might be optimal in reducing the variance of highway speeds, which can reduce accident externalities. However, Rock [19] showed that raising the speed limit from 88 to 105 km/hr (55 to 65 mph) on rural interstate highways caused 300 additional accidents per month on rural highways in Illinois, with increases in injuries and deaths as well. Similarly, Malyshkina and Mannering [20] determined that, for some non-interstate highways, increased speed limits are associated with higher accident severities. Hu [21] also provided sufficient evidence that increasing the speed limit from 120 to 129 km/hr (75 mph to 80 mph) leads to an increase in travel speed and accidents. On the other hand, Islam et al. [22] stated that a residential speed limit reduction from 50 to 40 km/hr was effective for all of the performance indicators such as free-flow speed and speed variance, and they were significantly reduced.

While reducing the speed limit can be a good way to reduce speed variance [22], this approach can have negative consequences. Feng [23] advised that only decreasing the speed limit is not the right way to reduce speed variance and encourages authorities not to do this because an inappropriate speed limit is easily violated. Besides, the capacity of a roadway can be negatively influenced due to the low level of driver compliance for a given posted speed limit [24]. Additionally, Cheng et al. [25] concluded that when a speed limit is not set realistically or does not represent an acceptable speed for most drivers on the roadway, the risk for vehicles conflict escalates. The basis for enforcement by law officers is also seen as illegitimate, which creates areas known informally as “speed traps”. Another approach being utilized by several countries is the use of minimum speed limits on highways to reduce speed variance and minimize the interruption caused by slow-moving vehicles which contribute to undesirable lane changing or passing maneuvers [26]. For example, a 64 km/hr (40 mph) speed limit has been used as a minimum speed on several highways in the United States. However, minimum speed limits cannot always be implemented and enforced on all roadway types because drivers who drive at low speeds might feel insecure or vulnerable if they are forced to drive faster.

Speed variance can also have a significant safety impact for highway workers. These workers repeatedly work close to live traffic in highway work zones, meaning that traffic accidents can have severe effects on the workers’ safety. To reduce work zone accidents, advisory signs and increased police presence have been used to limit accident risks. Hou et al. [27] showed that reducing the posted speed limit was effective in decreasing expected speeds and speed variance in short-term work zones in rural Missouri, United States. Ravani and Wang [28] illustrated the extent of the speeding problem near highway work zones by studying the effects of various levels of police presence. Results showed that the presence of police at all levels contributed to statistically significant enhancements in one or more of the studied Measures of Effectiveness (MOEs), which are average speed reduction, speed variance, 85th percentile speed, and proportion of high-speed vehicles.

Although it is reasonable to conclude that accident rates increase with an increase in speed variance for all roads, it should be remarked that a high percentage of these accidents were property-damage-only [13]. Moreover, Davis [29] pointed out that the positive correlations between speed variance and traffic accidents can be suspected in conditions where specific crash risk increases or decreases. However, the correlations themselves present no indication or support about the relation between speed variance and crash risk for individuals [29].

2.2. Studies on speed variance, geometric conditions, and weather

A study by Elmberg [30] on new reconstructed highways examined the effect of posted speed limit on drivers' speed without any restrictions. This study showed that drivers chose the speed which they considered the most appropriate for the prevailing geometric conditions. Therefore, geometric characteristics do have a major effect on the operating speed. Ma et al. [31] analyzed the relationship between free-flow speed on urban road segments and lane width using data obtained by video cameras and image identification software. They concluded that lane width affects the variance of vehicle speed differently at points close to intersection exits compared to mid-block points. There was no noticeable impact of lane width on speed variance near intersection exits, while the variance of speed increased as the lane width increased at mid-block points.

Weather and environmental factors could also affect the average speed and speed variance of the traffic stream due to differences in driver experiences and characteristics. Liang et al. [32] found that the standard deviation of speed doubles during fog events and triples during snow. They also found that drivers reduce their speeds an average of 1.1 km/hr (0.7 mph) for every 1.6 km/hr (1 mph) that the wind speed exceeds 40 km/hr (25 mph). Rama [33] investigated the effects of weather-controlled speed limits and signs for slippery road conditions on driver behavior at interurban highways and found that these systems decreased both the mean and standard deviation of speed.

2.3. Summary of literature review

This literature review showed that many studies have found that increased speed variance increased the accident rate. Additionally, higher speed limits tend to result in higher speed variance and more accidents. One study looked at the relationship between speed variance and the difference between posted speed limit and design speed, with the results indicating that a smaller difference corresponded to a smaller speed variance. Only a few studies considered other factors that could affect speed variance, such as geometric characteristics and weather conditions, and no previous study considered these other factors along with the difference between speed limit and design speed. Previous studies also did not develop statistical models to predict speed variance based on these factors. This paper analyzed and modeled various factors affecting the speed variance, including the difference between speed limit and design speed.

3. Methodology

The methodology to achieve the above objectives is shown in Figure 1. Data collected in this study were obtained through field measurements during off-peak periods [34]. In addition to the speeds, further field data were recorded to cover roadway characteristics such as lane width, number of lanes, grade, sight distance, speed limit, and presence of roadside barriers. The materials required to perform this study included measuring tape, odometer, stopwatch, radar gun, and statistical software package.

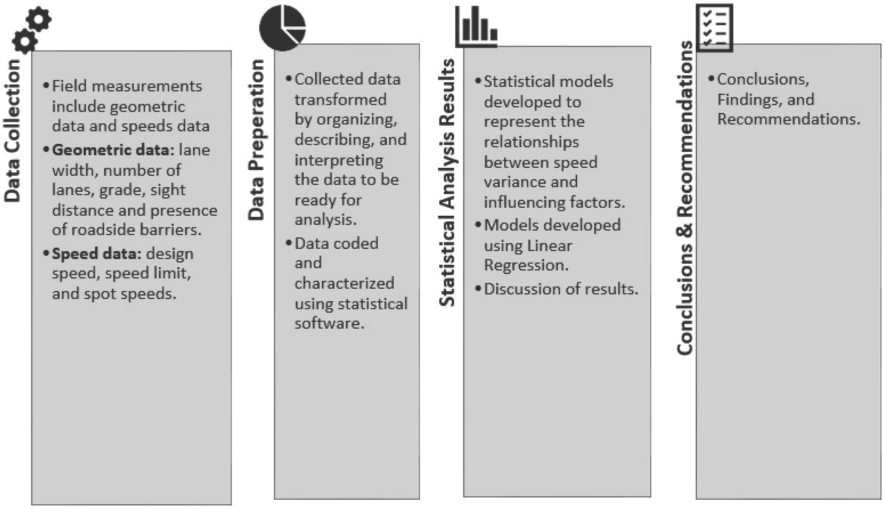

Fig. 1 - Research methodology

Twenty-five divided multilane highways were selected from five major governorates in Jordan: Amman, Irbid, Jerash, Mafraq, and Zarqa. All highways in these five governorates were scanned to locate a mix of highways with different geometric and control characteristics (such as the number of lanes, lane width, design speed, and speed limit). Even though these highways had different geometric and operational characteristics, they were all from locations with good pavement conditions, level grade, and clear sight distance. The selected highway segments were free of interruptions, vertical and horizontal traffic calming measures (such as speed humps, raised crosswalks, raised intersections, and traffic circles/roundabouts), and vertical and horizontal curves.

Table 1 shows a list of variables used in this study with their respective symbols, units, and ranges. The speeds of vehicles (passenger cars only) were detected using speed traps and radar throughout sunny days with dry pavement conditions. At each selected site, 150 passenger car speeds were collected. To ensure the independence of individual speed observations, no speed readings were taken for successive vehicles, with the speeds for every tenth car past a certain point taken by the observers. Average speed, standard deviation, and speed variance were then computed from the measured field data. The geometric and control characteristics included the number of lanes, lane width, design speed, speed limit, and presence of roadside barriers. Speed limits ranged from 60 km/hour to 100 km/hour (with values of 60, 70, 80, 90, and 100 km/hour), while design speeds ranged from 80 to 120 km/hr. Additionally, all segments had either 2 or 3 lanes with lane widths varying from 3.5 to 3.65 meters.

Tab. 1 - List of variables used in the study

Variables	Symbol	Units	Range
Number of Lanes	No. L	Count	2 or 3
Lane width	LW	meter	3.5m to 3.65m
Design speed	DS	km/hr	80 to 120
Speed limit	SL	km/hr	60 to 100
Barrier Presence	B	Yes/No	Yes or No
Design Speed – Speed Limit	DS-SL	km/hr	10 to 40

The collected speed data were only for passenger cars during the summer season with dry weather and sunny days. Data were only collected during the daylight, not at night, because drivers drive more carefully and reduce their speed at night with limited visibility and sight distance. Also, when measuring speeds of vehicles, some drivers change their behavior when they see the radar. So, these cases were excluded from the data to study actual driver behavior. When measuring speeds at locations with roadside barriers, the speed was hard to measure because there was no place to stand and measure the data, so pedestrian bridges were used to measure the speeds. Traffic volumes were not considered as a potential factor in this research because data were collected during off-peak periods, where the drivers can drive their vehicles at free-flow conditions. One potential limitation of this study is the low number of sites with three lanes and sites with barriers; future research could be conducted on these types of sites to account for this limitation.

Table 2 shows the data sheet for the collected data from all 25 highway segments. Since one of the main factors that impacts speed variance is speed itself (as shown in previous studies), the design speed minus speed limit was considered as a variable to investigate speed variance. All geometric and traffic data were considered carefully to explore the main possible factors that affect speed variance and to develop statistical models that can represent the relationships between speed variance and influencing factors.

Tab. 2 - Data sheet for collected data

SN	No. of Lanes	LW (m)	DS (km/hr)	SL (km/hr)	DS – SL (km/hr)	Average Speed (km/hr)	Standard Deviation (km/hr)	Speed Variance SV $(km/hr)^2$	Barrier Presence (B)
1	2	3.60	100	90	10	89.7	11.1	123.2	No
2	2	3.60	100	80	20	86.3	12.9	166.4	No
3	2	3.60	120	100	20	93.6	12.6	158.8	No
4	2	3.50	100	70	30	86.0	13.6	184.9	No
5	2	3.55	100	70	30	85.1	13.9	193.2	No
6	2	3.60	100	60	40	79.6	14.9	222.0	No
7	2	3.60	100	80	20	85.1	13.0	169.0	No
8	2	3.60	100	80	20	86.7	12.5	156.3	No
9	2	3.55	100	80	20	78.8	12.5	156.3	No
10	2	3.60	100	70	30	87.0	14.2	201.6	No
11	3	3.55	100	70	30	89.0	13.0	169.0	No
12	2	3.60	100	90	10	88.6	10.7	114.5	No
13	2	3.65	100	90	10	90.0	10.5	110.3	No
14	3	3.60	110	80	30	89.1	12.5	156.3	No
15	2	3.60	90	70	20	76.0	12.8	163.8	No
16	2	3.65	100	80	20	85.2	13.2	174.2	No
17	2	3.60	80	70	10	69.7	9.6	92.2	No
18	2	3.60	100	80	20	86.5	10.9	118.8	Yes
19	2	3.60	100	80	20	86.0	10.4	108.2	Yes
20	2	3.60	100	60	40	77.3	13.5	182.3	No
21	2	3.60	100	90	10	84.3	10.8	116.6	No
22	2	3.60	100	90	10	85.0	11.3	127.7	No
23	2	3.60	110	100	10	89.9	11.0	121.0	No
24	2	3.60	110	100	10	86.5	11.5	132.3	No
25	2	3.60	100	90	10	86.8	11.2	125.4	No

Data were coded, characterized, and statistically analyzed using SPSS statistical software package [35]. Data were checked by various tests to explore the main possible factors that affect speed variance. Linear regression models were developed to describe and represent the relationship between geometric characteristics, traffic conditions, and speed variance. These modeling and analysis results are discussed in the next sections.

4. Regression modeling

The independent variables considered for potential inclusion in the Multiple Linear Regression (MLR) models were lane width, number of lanes, presence of roadside barriers, design speed, speed limit, and design speed minus speed limit. Using linear regression, stepwise analysis eliminated all variables except design speed minus speed limit, barrier presence, and number of lanes. This was expected since variables with high collinearity were automatically excluded from the model. Based on this stepwise analysis, three different MLR models (1A, 1B, and 1C) were obtained as follows:

$$SV = 90.645 + 2.956\ (DS\text{-}SL) \tag{1A}$$

$$SV = 93.799 + 2.956\ (DS\text{-}SL) - 39.426\ (B) \tag{1B}$$

$$SV = 91.51 + 3.176\ (DS\text{-}SL) - 41.525\ (B) - 24.132\ (No.\ L) \tag{1C}$$

where:

- SV = Speed Variance $(km/hr)^2$.
- DS-SL = Design Speed – Speed Limit (km/hr).
- B = Roadside Barriers (binary: 0 = without barriers; 1 = with barriers).
- No. L = Number of Lanes (binary: 0 = 2 lanes; 1 = 3 lanes).

The regression model, intercept and variables were found to be significant at 95% confidence, with the following regression results:

- $R^2_{adj} = 0.702$ and standard error of estimate (SEE) =18.29 for Model 1A.
- $R^2_{adj} = 0.804$ and SEE =14.83 for Model 1B.
- $R^2_{adj} = 0.835$ and SEE = 13.59 for Model 1C.

The ANOVA results for these models (Table 3) show that their F values are 57.461, 50.238, and 41.589, respectively, with p-values less than 0.001. Thus, they are all significant at 95 % confidence.

Tab. 3 - ANOVA[a] for developed MLR models

Model		Sum of Squares	df	Mean Square	F	Sig.
1A	Regression	19228.189	1	19228.189	57.461	.000[b]
	Residual	7696.561	23	334.633		
	Total	26924.750	24			
1B	Regression	22088.315	2	11044.158	50.238	.000[c]
	Residual	4836.435	22	219.838		
	Total	26924.750	24			
1C	Regression	23045.858	3	7681.953	41.589	.000[d]
	Residual	3878.892	21	184.709		
	Total	26924.750	24			

a. Dependent Variable: Speed Variance

b. Predictors: (Constant), Design Speed - Speed Limit

c. Predictors: (Constant), Design Speed - Speed Limit, Barriers

d. Predictors: (Constant), Design Speed - Speed Limit, Barriers, Number of lanes

Tab. 4 - Coefficients[a] for developed MLR models

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1A	(Constant)	90.645	8.616		10.521	.000	72.822	108.467					
	DS-SL	2.956	.390	.845	7.580	.000	2.150	3.763	.845	.845	.845	1.000	1.000
1B	(Constant)	93.799	7.038		13.328	.000	79.204	108.394					
	DS-SL	2.956	.316	.845	9.352	.000	2.301	3.612	.845	.894	.845	1.000	1.000
	Barriers	-39.426	10.931	-.326	-3.607	.002	-62.095	-16.757	-.326	-.610	-.326	1.000	1.000
1C	(Constant)	91.51	6.529		14.016	.000	77.932	105.087					
	DS-SL	3.176	.305	.908	10.400	.000	2.541	3.811	.845	.915	.861	.900	1.111
	Barriers	-41.525	10.062	-.343	-4.127	.000	-62.449	-20.600	-.326	-.669	-.342	.992	1.008
	No. L	-24.132	10.599	-.199	-2.277	.033	-46.173	-2.091	.116	-.445	-.189	.894	1.119

a. Dependent Variable: Speed Variance

Table 4 shows the coefficients, significance, and multicollinearity parameters for these models. This table shows that tolerance is greater than 0.1 and the Variation Inflation Factor (VIF) is less than 10 for all three models, indicating there is no collinearity in either of the three models.

The histogram of standard residuals is presented in the left side of Figure 2, where it can be noticed that the observed and expected cumulative probabilities are almost normally distributed. The right side of Figure 2 shows a scatter plot between the normal score versus the residuals. This plot is approximately a straight line, indicating that the normality assumption is reasonable. Therefore, the developed models are appropriate and valid conclusions can be drawn from them. The coefficients of the models show that speed variance increases as the difference between design speed and speed limit increases, while speed variance decreases for roads with roadside barriers present or more lanes. This information is useful for transportation planners and operating agencies so they can modify existing highways and better design future highways to proactively reduce speed variance.

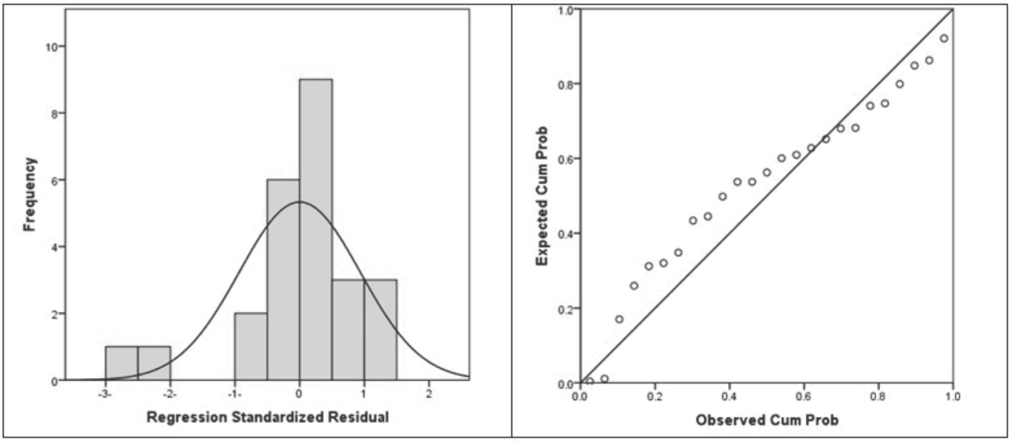

Fig. 2 - Regression standardized residual histogram (left),
and normal P-P plot of regression standardized residual (right) for MLR model 1

A linear regression model with a quadratic form was used to improve the relationship between the dependent variable and the independent variables. Based on previous studies discussed in the literature review [12, 30], and the developed MLR models, the dependent variable (speed variance) is primarily dependent on one variable (difference between design speed and speed limit). The best fit quadratic curve between SV and (DS-SL) is shown in Figure 3. The developed model is shown in Equation 2. It can be seen from Figure 3 that speed variance tends to be low when the DS-SL is 10 km/hr, whereas speed limits more than 10 km/hr below the design speed increase the speed variance as indicated in the plot.

$$SV = 77.16 + 4.412\ (DS\text{-}SL) - 0.32\ (DS\text{-}SL)^2 \qquad (2)$$

This model has $R^2_{adj} = 0.697$ and SEE = 18.452. The quadratic model, intercept, and variables were found to be significant at 95% confidence level. Table 5 shows the ANOVA results on this model. These results indicate that the quadratic model is significant since F = 28.54 and its p-value less than 0.001.

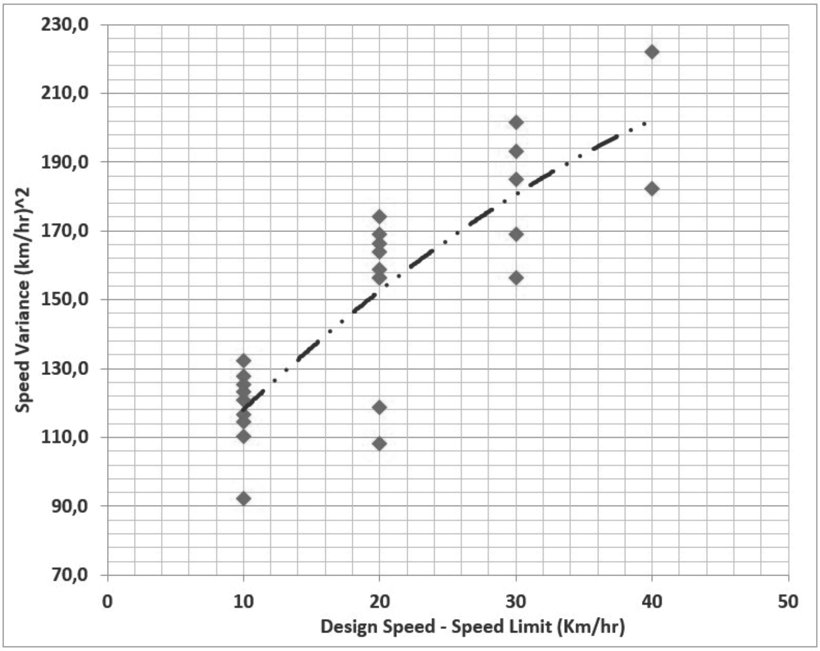

Fig. 3 - Best fit line for quadratic model

Tab. 5 - ANOVA for developed quadratic model

Type	Sum of Squares	df	Mean Square	F	Sig.
Regression	19434.246	2	9717.123	28.540	.000
Residual	7490.504	22	340.477		
Total	26924.750	24			

* The dependent variable is Speed Variance and independent variable is (Design Speed - Speed Limit).

5. Conclusions

Speed variance has been shown to affect crashes, with higher speed variance typically resulting in more crashes. However, limited research has been done on the factors that affect speed variance, especially the relationship between speed variance, design speed, and speed limits. This study analyzed potential factors that could affect speed variance on multilane highways in Jordan and developed models to predicting speed variance based on geometric, operating, and traffic characteristics.

Field data were collected at 25 multilane highway segments throughout Jordan. These data included speed data, geometric factors (number of lanes, lane width), and other roadway characteristics (speed limit, presence of roadside barriers). Using these data, multiple linear regression (MLR) models were developed with speed variance as the dependent variable. The MLR models showed that the speed variance is mainly dependent on design speed minus speed limit (DS-SL), the presence of roadside barriers, and number of lanes. To further understand the relationship between speed variance and DS-SL, a linear regression model with a quadratic form was developed. Based on the developed models and statistical analyses conducted in this paper, the following conclusions can be made:

1. The minimum speed variance occurred when the DS-SL was equal to 10 km/hr.
2. Speed limits more than 10 km/hr below the design speed increase the speed variance. This is likely due to motorists tending to drive their vehicles based on road condition, which is controlled by the design speed, regardless of the speed limit.
3. As the difference between design speed and speed limit increases, the speed variance increases. Based on the quadratic model, the increase in speed variance gets smaller as DS-SL continues to increase.
4. The presence of roadside barriers decreases speed variance.
5. As the number of lanes increases, the speed variance decreases.

This paper provides beneficial information to authorities and policymakers who set speed limits on multilane highways. The discussed analyses and results expand the understanding of speed variability and how speed policy decisions should be made using real world data and suggest how the consequences of speed variance may be improved by observing the principal factors that affect speed variance on multilane highways. The research discussed in this paper provides a significant understanding of the major factors that impact speed variance. However, further research is needed to find the effect of the pavement condition and other possible factors on speed variance. Based on the data collection, analysis, results, and comparisons made in this study, the following recommendations are suggested:

1. It is recommended to decrease the difference between design speed and speed limit to 10 km/hr for multilane highways in rural areas to increase safety by reducing speed variance.
2. It is recommended to use roadside barriers, especially at segments near urban areas, to reduce speed variance and increase traffic safety.

By following these recommendations, transportation agencies can reduce the number of crashes caused by speed variance, saving lives, and reducing delay.

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Investigation of operational performance on 2+1 highways

A. Jafari[1] A. Al-Kaisy[2] S.S. Washburn[3]

[1]I.S. Engineers, 7700 San Felipe St # 485, Houston, Texas, USA
email: amir.jafari@is-engineers.com
[2]Depart. of Civil Engineering, Montana State University, 213 Cobleigh Hall, Bozeman, Montana, USA
email: aalkaisy@ce.montana.edu
[3]Depart. of Civil and Coastal Engineering, University of Florida, 365 Weil Hall, Gainesville, Florida, USA
email: swash@ce.ufl.edu

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Abstract

Two-lane highways constitute a large proportion of the US road network. Limited passing opportunities on these highways could lead to poor driving conditions and risky passing maneuvers. One of the alternative means to improve passing opportunities and level of service on two-lane highways is the use of the 2+1 design concept. In this design, the highway cross section consists of three lanes: a single lane in each direction of travel and a middle passing lane alternating between the two directions. Two plus one highways are very common in Europe, but have not seen broad application in the US, with the exception of reported implementations in a couple of states. This study aims at investigating the primary design parameter of 2+1 highways, i.e. the length of passing section alternating between the two directional lanes. Field data from two passing lane study sites in Oregon were used to calibrate and validate a traffic simulation program, SwashSim. The calibrated model was subsequently used in examining the passing section length under different traffic levels, percentage of heavy vehicles, and free flow speed of the highway network. The optimal length of passing lane was found using average performance over the linear study network. The results showed that free-flow speed is the major determinant of the optimal length of passing section on a 2+1 highway. As the free flow speed increases, longer passing sections are required for an optimal performance on the highway network. This research only investigated the operational performance of 2+1 highways and safety issues were not studied.

Keywords – two-lane highways, operational performance, 2+1 road, passing lane

1. Introduction

Two-lane highways constitute a large proportion of the highway network in the US, especially in rural areas. On these highways, there is only one lane provided in each direction of travel. Passing maneuvers usually occur on the opposing lane of traffic. There should be adequate gap and sight distance in the opposing direction that enables a driver to do the passing maneuvers. In the absence of passing opportunities, vehicles start to move in platoons with speeds less than the drivers' desired speeds. As traffic volume and geometric restrictions increase, opportunities to pass decrease. There are different alternatives to increase passing opportunities on two-lane highways, such as passing lanes and turn-outs [1], which consequently improve operational performance. Another alternative is the use of a three-lane cross-section design, commonly referred to as 2+1 highways.

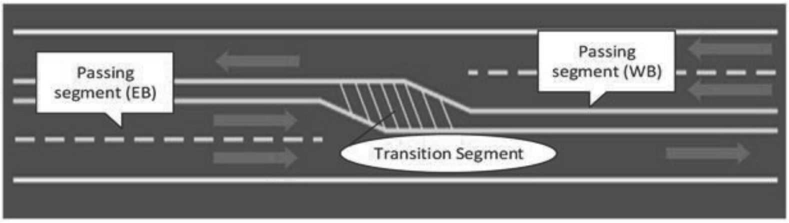

Fig. 1 - 2+1 highway segments

On these highways, there is one lane per each direction of travel and a middle lane that alternates between the two directions and is primarily intended for passing. This configuration may be a suitable treatment for roadways with traffic volumes higher than can be served by isolated passing lanes, but not high enough to justify a four-lane roadway [2]. The American Association of State Highway and Transportation Officials (AASHTO) Green book reports at least two levels of service improvement for 2+1 highways compared to conventional two-lane highways with the same traffic volume [2]. The Green book (Chapter 3) also recommends using these facilities for flow levels less than 1200 veh/h in level or rolling terrain. Further, these facilities are potentially applicable to locations where environmental or fiscal constraints, or both, make provision of a four-lane highway impractical [2]. The economic considerations could be another effective parameter for highway agencies to prefer these highways to four-lane highways. Figure 1 shows a general schematic of 2+1 highway design. The striping on the pavement identifies the passing lanes in each direction. This figure also shows different segments of a 2+1 highway including passing segments and transition segment which lies at the end of passing segments on each direction.

The Highway Capacity Manual (HCM) is the standard reference used in the US for operational analysis of two-lane highways [3]. The current manual lacks a procedure or design guidelines for 2+1 highways. While this type of facility is common in Europe, it is very rare in the US. It should be noted that there are some installations in the US of what are referred to as ‘Super 2’ highways [4,5], but these designs can be quite variable with respect to the frequency, spacing, and length of the alternating passing lanes. To address this limitation, this study investigated the operational performance on 2+1 highways and developed guidelines regarding the optimal length of the alternating passing sections in the middle lane. This information is critical for the planning and design of 2+1 highways, which are expected to see wider application in the US.

2. Background

A summary of several studies in the literature that address the 2+1 highways is provided in this section.

Kirby et al. [6], through a literature review, found that the following countries were using 2+1 highways: Austria, Denmark, Finland, France, Germany, Ireland, Italy, Poland, Netherlands, South Korea, Spain, Sweden, United Kingdom and USA.

Bergh et al. [7] investigated the use of 2+1 roads in Sweden. The first 2+1 road was opened in Sweden in 1998 and by 2016, there were around 1,700 miles (2736 km) of 2+1 median barrier roads in Sweden. Around 70 % of these roads had a speed limit of 63 mi/h (100 km/h). The study reported that the level of service on these facilities depends on the share of two-lane segments as well as how the share of two-lane segments are divided (few and long sections compared to many and short sections). Simulation experiments showed that a length of 0.93 mi (1.5 km) for the overtaking segments is reasonable. Moreover, an increase from 20 to 30 overtaking lane percentage would reduce the delay up to 2.4 s/mi.