USE OF THE OUTPUT OF THE DRIVER VEHICLE MODULE OF THE IHSDM AS SURROGATE MEASURES FOR DEPARTURE CRASHES

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ABSTRACT

This paper presents the results of a research that investigates whether four output measures of the IHSDM Driver Vehicle Module (DVM), longitudinal and lateral Friction Ratios, Lateral Offset, and Roll-Over Index, follow the Normal distribution. The research then studies how the lateral offset can be used as a surrogate measure for departure crashes.

The "UNIVARIATE" procedure of SAS software was used in the normality tests. Besides the graphical outputs, the skewness and Kurtosis values as well as the Shapiro-Wilk and the Anderson-Darling tests results were reviewed. For Lateral Offset, we could not reject the hypothesis that these data are normally distributed for results of 95 locations (α=5%). The results for longitudinal and lateral Friction Ratio, and Roll-Over Index were 73, 84, and 83 locations, respectively.

The data used in this study come from running the DVM simulation on stretches of two-lane rural highways from Washington State. For the normality testing the simulation output of 100 randomly selected locations were studied. For studying the lateral offset as a surrogate measure the probabilities of Lateral Offset values exceeding the threshold values (encroachments) were calculated and the relations of these encroachments with departure crashes was studied. In this part of the study it was observed that for highways with narrow shoulders there exists a strong correlation between number of encroachments and the departure crash rates. We concluded that this measure can be used as a surrogate measures for departure crashes for this type of highway.

KEYWORDS: IHSDM, normality, safety, encroachment, departure crashes.

INTRODUCTION

The Federal Highway Administration's (FHWA) Interactive Highway Safety Design Model (IHSDM) is a suite of software analysis tools for evaluating safety and operational effects of geometric design in the highway project development process, FHWA-IHSDM-1 (2010). This software can be downloaded for free from the IHSDM public website at www.ihsdm.org, FHWA-IHSDM-1 (2011). The IHSDM contains six evaluation modules, including the Driver/Vehicle Module (DVM) that micro-simulates the interactions between the driver, the vehicle, and the roadway. Currently available in the IHSDM 2010 Public Release, the DVM is "a computational model of driver behavior that simulates the driver's perceptual, cognitive, and control processes to generate steering, braking, and acceleration inputs to the vehicle. The objective of the DVM is to permit the user to evaluate how a driver would operate a vehicle (e.g., passenger car or tractor-trailer) through a geometric design, and to identify if conditions exist that could result in loss of vehicle control (e.g., skidding or rollover)," FHWA-IHSDM-2 (2010).

This paper presents the results of a research that investigates whether four output measures of the DVM follow the Normal distribution. It then presents an estimation of lane encroachments by using the AADT of the road and the probability that the Lateral Offset exceeds certain thresholds equivalent to the vehicle encroaching out of the lane boundaries.

The four measures under investigation are shown below, FHWA-IHSDM-2 (2010):

- Friction Ratio X: The ratio of longitudinal friction demand to available friction;
- Friction Ratio Y: The ratio of lateral friction demand to available friction;
- Lateral Offset: The distance of the vehicle (cab) center of mass from lane center; and
- Roll-Over Index: The lateral load transfer indicating the fraction of vehicle (cab) weight borne by the right or left tires.

Among the DVM simulation setting options is the Evaluation Mode – either "Stochastic" (multiple runs; many parameters selected randomly from predefined distributions) or "Deterministic" (single run; deterministic parameters used). Other settings include Path Decision – either "Cut Curve" (driver shortens the path by flattening the curve) or "Center" (driver attempts to maintain the center of the lane).

By confirming a normal distribution, the probabilities that threshold values of these measures are exceeded are studied in conjunction with the AADT. Such results can be used to identify locations on new highways (or highways with no available historical crash data) that are vulnerable with respect to departure crashes, and to consider improvements before these crashes occur.

DVM OVERVIEW

The DVM was developed to provide highway designers with a means for: (a) readily evaluating the safety impacts of driver/vehicle/roadway geometry interaction; and (b) enhancing design for highway safety.

The DVM, which is a time-based micro simulation model, estimates the vehicle's speed and path along a rural two-lane highway in the absence of other traffic. These estimates provide for various computational performance measures such as lateral acceleration, friction demand, and rolling moment. Driver performance is influenced by cues from the roadway/vehicle system (i.e., drivers modify their behavior based on feedback from the vehicle and the roadway). Vehicle performance is, in turn, affected by driver behavior/performance.

Stochastic analysis provides statistical results relevant to critical performance variables. In this mode, the model is run multiple times (30 to 40 trials is recommended) to provide moment-to-moment and trial-to-trial variations in driver behavior. The DVM produces the measures of effectiveness discussed in the previous section and, where appropriate, threshold or reference values for comparison purposes, FHWA-IHSDM-2 (2010). The current DVM is limited to simulating a normal driver who always acts in a rational manner (i.e., makes appropriate decisions given good information) and it does not simulate the inappropriate driver decisions or mistakes and short comings that are the source of many crashes.

Assumption of Normality for DVM Measures

In the current DVM, it is assumed that the “Lateral Offset”, “Friction Ratio X”, “Friction Ratio Y”, and “Roll-Over Index” output measures are normally distributed. Even though the results of this simulation had been validated by comparison to field measurements, the normality assumption had not been tested before. Although it is possible that another distribution might be better fit for DVM output measures, that is beyond the scope of this research to find such distribution.

With the normality assumption, the DVM defines the lower and higher threshold values for each of the main output measures, then estimates the probabilities of exceeding those threshold values at stations along the highway. Threshold values as well as the type of “failure” related to exceeding them are:

- Lateral Offset: Threshold values on each side of the vehicle is half of the difference between the lane width and the vehicle width. Failure occurs when the vehicle encroaches off the lane (encroachment).
- Friction Ratio X: Threshold values are -1 and +1. Failure results in the vehicle skidding longitudinally (along the highway).
- Friction Ratio Y: Threshold values are -1 and +1. Failure results in the vehicle skidding laterally.
- Roll-over Index: Threshold values are -1 and +1. Failure results in the vehicle rolling over on a curve.

For estimating the probabilities of each of the above variables exceeding the threshold values, the DVM calculates the probabilities of these values being above the maximum threshold and below the minimum threshold separately and sums up these two probabilities. In this process, two critical values (Z_1 and Z_2) are calculated from the mean and standard deviation of the variables values based on the following equations:

$$Z_1 = \frac{\mu - LL}{\sigma} \tag{1}$$

$$Z_2 = \frac{UL - \mu}{\sigma} \tag{2}$$

Where:

μ = the mean of the values
σ = the standard deviation of the values
LL = Lower Limit of the boundary value. For Friction Ratio X, Friction Ratio Y and Rollover Index, the lower limits are equal to -1. For Lateral Offset, the lower limit is equal to – (Lane Width – Vehicle Width)/2
UL = Upper Limit of the boundary value. For Friction Ratio X, Friction Ratio Y and Rollover Index, the upper limits are equal to +1. For Lateral Offset, the upper limit is equal to (Lane Width – Vehicle Width)/2

For each critical value, the probabilities that the value exceeds the lower and upper limits can be calculated by estimating the areas of the normal distribution curve and summing these two areas. The DVM estimates these two areas by using the approximation shown in equation (3). M. Albramowitz and I. A. Stegun (1964) have shown that the absolute error of this approximation is less than 0.00025.

$$P_k = (1.0 + 0.196854 \times Z_k + 0.115194 \times Z_k^2 + 0.000344 \times Z_k^3 + 0.019527 \times Z_k^4)^{-4} \tag{3}$$

Where:

P_k = Probability that the value of the variable (each of the four measures reviewed in this study) goes below (or above) the lower (or upper) threshold value.
Z_k = From Equations 1 and 2.
k = 1, or 2 for any of the threshold values. Values of 1 and 2 correspond to the probability of the variable being less than the lower limit and higher than the upper limit, respectively.

The total probability that the value of the variable goes below or above the threshold values (*P*) can be calculated by summing up the above two probabilities:

$$P = P_1 + P_2 \tag{4}$$

For the Lateral Offset variable, the summation of the product of these probabilities by the AADT provides an estimate of the number of encroachments.

More information about the DVM assumptions and models as well as the validation of these models can be found in the DVM Engineer's Manual, FHWA-IHSDM-2 (2010).

DATA SOURCE AND DATA MANIPULATIONS

The data used in this research are from rural two-lane highways in Washington State. Currently, the DVM simulation can only be used for this type of highway. There are over 5000 miles of rural two-lane State highways in Washington whose data are maintained by the FHWA Highway Safety Information System (HSIS), FHWA-HSIS (2010). These data are comprised of over

58,000 segments of highway. From these segments, all continuous stretches of highway were formed. For the normality tests, 44 stretch of highways that had the highest crash cost rates and more than 2 horizontal elements were selected. Our reasoning for choosing highways with the highest crash cost was that the rural two-lane highways are the most common type of highway in the United States and highways of this type that come to the radar for study are in almost all cases the ones with the highest crash costs. The DVM was run on each of these highways for 30 trials, using “Stochastic” trials of “Passenger Cars” with the driver path decisions of “Cut-curve” and “Center.” The lengths of these selected highway stretches were from 1.01 to 15.5 miles, totaling about 170 miles. The minimum and maximum crash cost rates for these highways were 0.38 and 1.72 $M/mile/year respectively.

For the second part of the study, 53 other stretches of highways, each 5+ miles long, were added to the original 44 for estimating the number of encroachments and comparing these values with the observed departure crash rates. Ten years of departure crash records were used in this study to establish the relations between the number of encroachments and number of departure crashes. Table A1 in the Appendix shows information about the 97 stretches of highway used in this study.

METHODOLOGIES

Normality Test

The IHSDM DVM software was used to generate the output measures for the selected highways. The SAS software was used to investigate the normality of the DVM output measures of “Lateral Offset”, “Friction Ratio X”, “Friction Ratio Y”, and “Roll-Over Index.”

The horizontal and vertical alignments as well as the cross section data of the selected highways were input into the IHSDM software. For each of 44 highways used in the normality test, the DVM evaluation was run in the stochastic mode, with 30 as the number of trials. Path Decision of “Cut-curve” and Vehicle Type of “Passenger Car” were the other relevant evaluation attributes set for the simulation. For each highway, at 100 foot intervals, the DVM simulation provided output measures, 30 output values for each measure (30 trials). From all of these locations (over 8800), 100 locations were randomly selected and the normality of the output measures of these 100 locations was put under investigation.

The “UNIVARIATE” procedure of SAS software was run for all four measures and for all 100 locations, each case having 30 output values. In the SAS reports, besides basic statistical measures there are two measures of “Moments” (Skewness and Kurtosis value) as well as four measures from analytical normality tests (Shapiro-Wilk, Kolmogorov-Smirnov, Cramer-von Mises, and Anderson-Darling tests) that can help test the normality of data. There are also two main types of graphs that could be used to investigate the normality. The “Moments” used in the normality test are:

- Skewness: “Skewness is based on the third standardized moment that measures the degree of symmetry of a probability distribution. If skewness is greater than zero, the distribution is skewed to the right, having more observations on the left,” IUIT (2009).

- Kurtosis value: “Kurtosis, based on the fourth central moment, measures the thinness of tails or ‘peakedness’ of a probability distribution,” IUIT (2009). In general, if the Kurtosis value is close to 3 the distribution has the thinness close to a normal distribution. In SAS, the value shown as Kurtosis is actually the value of (Kurtosis -3). Therefore, if this value is close to zero, it means that the thinness is close to that of a normal distribution.

For each of the analytical normality tests, there is a test value that should be compared to a critical value for normality. There is also a “P-value” whose comparison to the test level (i.e., α=0.05 in our tests) can determine whether the sample has a normal distribution or not. The H_0 hypothesis was “The data follow a normal distribution” and the H_A alternative hypothesis was “The data do not follow the normal distribution.” “P-value” is the smallest level of significance at which H_0 would be rejected when a specific test procedure is used on a given dataset. In this study comparison of the P-values to α=0.05 was used, rather than the comparison of the test values to the critical values. For this we use the following cases as our criteria:

$$a : P - value \le \alpha \quad \Rightarrow \quad \text{reject } \mathrm{H}_0 \ \ at \ \ level \ \ \alpha$$

$$b : P - value > \alpha \quad \Rightarrow \quad \text{do not reject } \mathrm{H}_0 \ \ at \ \ level \ \ \alpha$$

As a result, if case *a* holds we conclude that the distribution is not normal and if case *b* holds we conclude that the distribution is normal. The four normality tests reported by SAS and their test values are:

- Shapiro-Wilk: This statistic is positive and less than or equal to one. Being close to one indicates normality, IUIT (2009).
- Kolmogorov-Smirnov test statistic with the theoretical cumulative distribution being a normal distribution, NIST (2008).
- Cramer-von Mises test statistic with the theoretical cumulative distribution being a normal distribution, NIST (2008).
- Anderson-Darling: test statistic with the theoretical cumulative distribution being a normal distribution, NIST (2008).

Besides the above statistics, two types of graphs produced by SAS were also used in the normality test. These graphs are SAS Histogram and SAS Q-Q Plot for normality, as shown in Figures 1 and 2 for Lateral Offset.

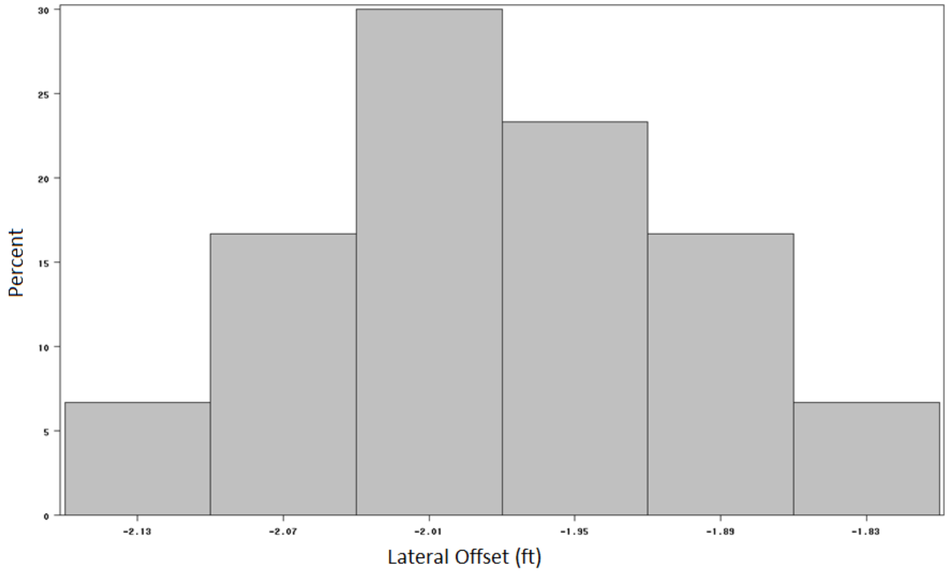

Figure 1 – SAS Histogram Sample for Normality Test

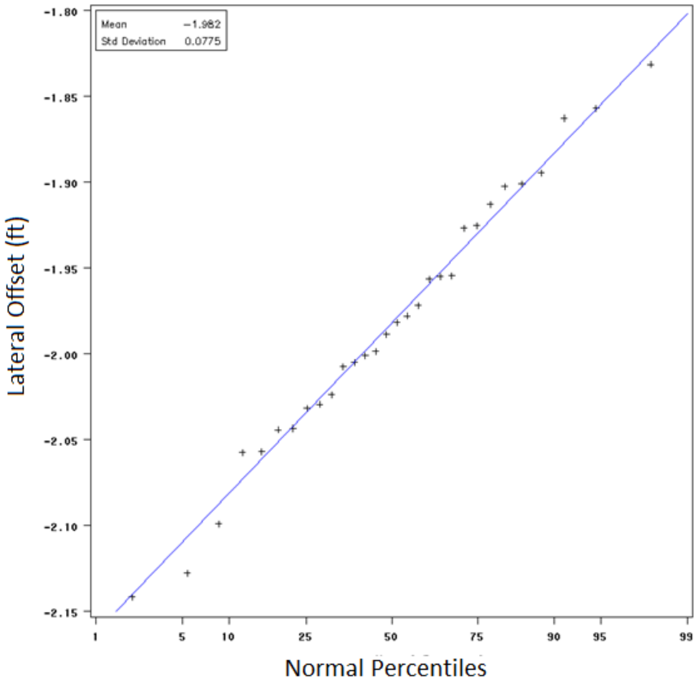

Figure 2 – SAS Quantile-Quantile (Q-Q) Plot for Normality Test

When the results of the above four analytical tests were in conflict, in almost all cases the results of the Shapiro-Wilk test were in conflict with the results of the other three. Therefore, the Anderson-Darling test results were selected as the main criteria in the normality testing. This was in line with the number of data points (30) in each sample, because the Anderson-Darling test is more appropriate for this size of sample than other tests, Jorge Luis Romeu (2003-2005).

The skewness and Kurtosis values were used as well as the graphic outputs as tools to confirm the results of the Anderson-Darling test.

Relationship between Encroachments and Departure Crashes

For studying the relations between encroachments and departure crashes, all 97 stretches of highway prepared for this study were used. The DVM was run on these stretches of highways with both Path Decision options (“Center” and Cut-Curve”). Probabilities of Lateral Offset values exceeding the threshold (i.e., an encroachment) are among the output of the DVM. These probabilities were multiplied by the AADTs and number of days in a year, producing estimations of the number of encroachments for the year for both “Center” and Cut-Curve” Path Decisions. Based on a study conducted by P. Spacek (2005), on average a certain percentage of drivers would attempt to cut curves on two-lane highways. Spacek’s estimations are 32% for left-hand curves and 22% for right-hand ones. In this study, an average of these values was used to assume that 27% of drivers cut the curves and 73% do not. Therefore, 27% of the estimated encroachment for “Cut-Curve” Path Decision plus 73% of the estimation for “Center” Path Decision options builds up estimation of total encroachment for the highway for the whole population. The DVM simulates driving on the pavement (not including shoulder). Once the vehicle leaves the pavement, the simulation stops. Table A2 in Appendix shows the values for “Departure Crashes / Year / Mile” and “Encroachments / Year / Mile” for all 97 cases, sorted by shoulder width.

The relations between encroachment estimates and departure crashes were studied for different ranges of shoulder width: values between 0 and 3-ft, between 3-ft and 6-ft, and more than 6-ft. First, the correlations between encroachment estimates and departure crashes were studied. Table 1 shows this correlation. Then, for data corresponding to the first group (Shoulder Width <= 3 ft), linear regression analysis was used to establish relations between these two variables.

Table 1 – Correlation between Departure Crashes and Number of Encroachments for Cases within Different Shoulder Width Groups

	Shoulder Width (ShW) Group		
	ShW <= 3-ft	**3-ft < ShW <= 6-ft**	**ShW > 6-ft**
Correlation between “Departure Crashes / Year / Mile” and “Number of Encroachments / Year / Mile”	0.73	0.39	0.30

SUMMARY OF THE RESULTS

Normality Test

The “p-values” for different normality tests for all 100 samples were compared to the value of α (0.05). Figures 3, 4, 5, and 6 show how these values for the 100 samples are compared to α for the Anderson-Darling test. Results for other tests were almost identical.

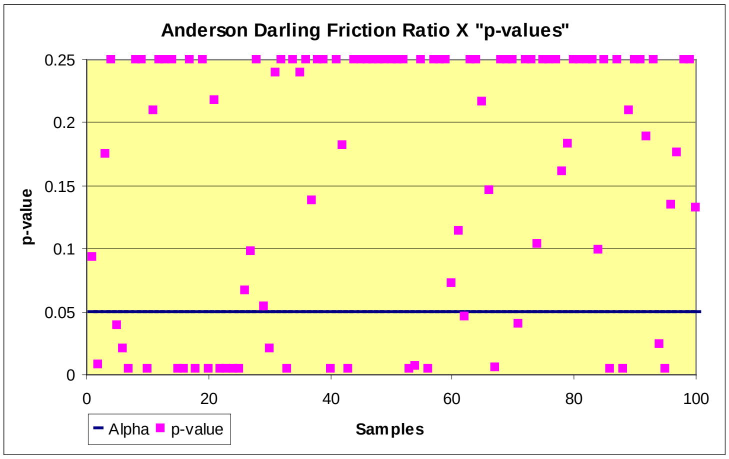

Figure 3 – “p-values” for Anderson-Darling test for Friction Ratio X

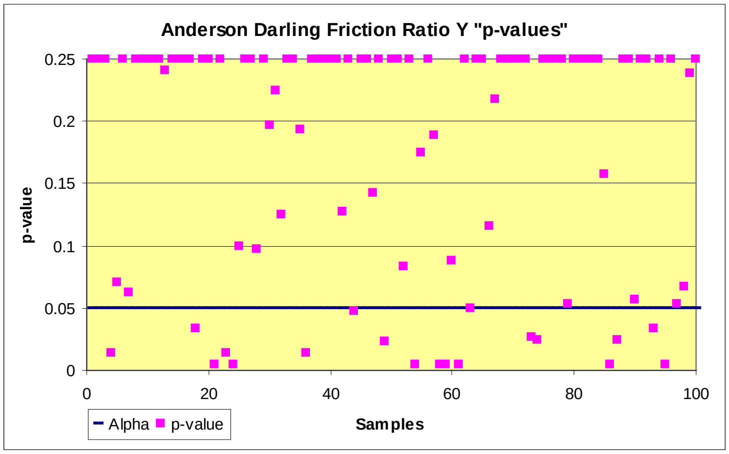

Figure 4 – “p-values” for Anderson-Darling test for Friction Ratio Y

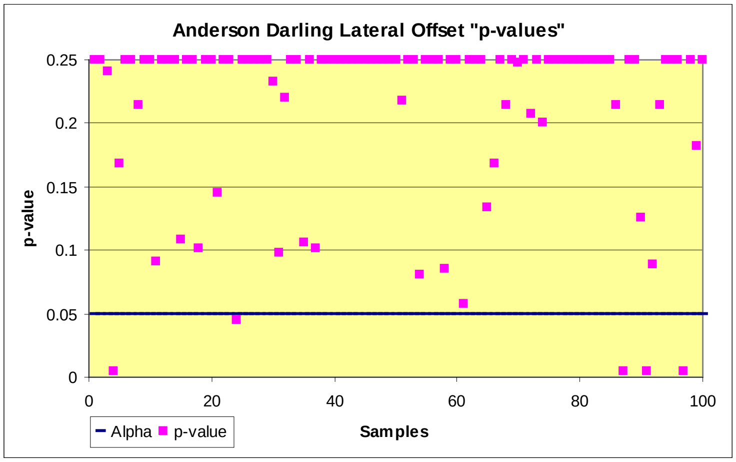

Figure 5 – “p-values” for Anderson-Darling test for Lateral Offset

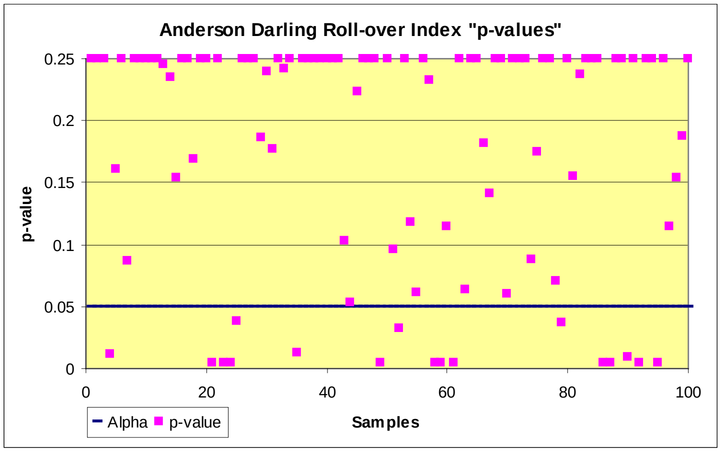

Figure 6 – “p-values” for Anderson-Darling test for Roll-over Index

Table 2 shows the number of samples with “p-values” greater than 0.05 for four different DVM measures and for four different tests. As this table shows, the results of different tests for each of the measures are almost identical.

Table 2 – Number of Cases out of 100 with p-values Greater Than 0.05

Test	**Number of cases with p-value greater than 0.05**			
	Friction Ratio X	**Friction Ratio Y**	**Lateral Offset**	**Roll-over Index**
Anderson-Darling	73	81	95	83
Cramer-von Mises	72	81	95	82
Shapiro-Wilk	74	85	93	81
Kolmogorov-Smirnov	74	82	92	80

From all four measures that were studied, the distribution of “Lateral Offset” is closest to a normal distribution (i.e., most cases with p-value > 0.05). “Roll-over Index” and “Friction Ratio Y” are the next closest measures to a normal distribution; they can be used to calculate the probability of rolling over and skidding laterally on sharp horizontal curves, respectively. The measure furthest from a normal distribution is “Friction Ratio X.”

The skewness and Kurtosis values, as well as the graphic outputs confirmed the results of the Anderson-Darling test to the same degree of certainty. Figure 7 shows the Shapiro-Wilk “W” ratio for lateral offset. In almost all of the samples, the ratio is very close to one, which confirms the normality of the distribution of this data. For the other three measures, the “W” ratio confirms the conclusions made from reviewing the “p-values” with almost the exact same certainty.

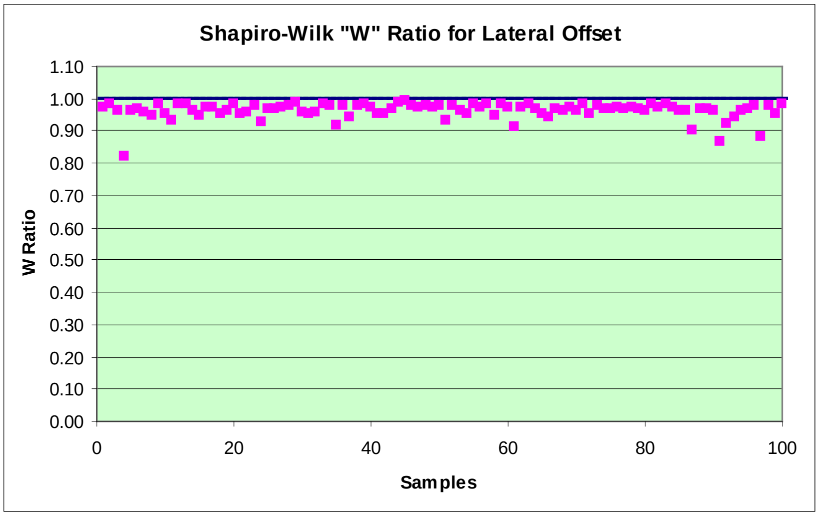

Figure 7 – Shapiro-Wilk “W” Ratio for Lateral Offset

Relationship between Encroachments and Departure Crashes

As for the relations between the number of encroachments and the number of observed departure crashes on these highways, the correlations shown in Table 1 indicate that shoulder width has a strong effect in this relationship. The correlation between number of departure crashes and number of encroachments for these cases becomes much stronger as the shoulder width becomes narrower. Linear regression results show that departure crash rates are linearly related to the number of encroachments for highways with shoulder width less than or equal to 3 ft. The regression results are shown in Table 3.

Table 3 – Departure Crash Rates as a Function of the Number of Encroachments

Regression Statistics						
Multiple R	0.73					
R Square	0.53					
Adjusted R Square	0.51					
Standard Error	0.22					
Observations	21					
ANOVA						
	df	**SS**	**MS**	**F**	**Significance F**	
Regression	1	1.00	1.00	21.4	0.0002	
Residual	19	0.89	0.05			
Total	20	1.89				
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
Intercept	0.248	0.052	4.79	0.00013	0.14	0.36
Encroachment/Year /Mile	0.00006	0.00001	4.63	0.00018	0.00003	0.00008

A preliminary estimation of the expected number of departure crashes for a highway can be gained by using the following equation:

$$N_{DC} = 0.248 + 0.00006 \times N_E \qquad (5)$$

Where:

N_{DC} = Predicted number of departure crashes per year per mile

N_E = Number of encroachments calculated from the DVM outputs per year per mile for the highway’s AADT

The constant value in Equation 5 shows that even if there is no encroachment estimated by the DVM there would be a minimum expected number of departure crashes for the highway. This minimum number of crashes expected for the project has two main sources: (1) the combined effect of all roadway/environment factors not considered in the DVM simulation and; (2) the consequences of non-rational driving behavior (which is not simulated by the DVM).

To further study the relations between this surrogate measure and observed crash rates, averages of the values of this measure and departure crash rates for highways with narrow shoulders (i.e., Widths <= 3 ft; see Table 4) were examined. The averages are reflected in Table 4.

Table 4 – Averages of Departure Crash Rates and Encroachment

	Average of Departure Crash Rates (Crashes / Year / Mile)	**Average Number of Encroachments / Year / Mile**
All highways with Shoulder Width Equal to or Less Than 3 ft (21 highways)	0.35	1808
Highways with Crash Rates Less Than Average (13 of 21 highways)	0.17	457
Highways with Crash Rates Greater Than Average (8 of 21 highways)	0.64	4004

The relationship between Number of Encroachments and Departure Crashes in Table 4 suggests that using DVM Lateral Offset output to estimate encroachments could be a useful surrogate measure to evaluate the safety of a highway. For example, the number of expected encroachments on a highway with a certain traffic volume could be estimated for a variety of alignment/lane width alternatives. Then, by applying Equation 5, a preliminary estimate of the effect of changing the alignment and lane width on departure crashes for the given design and traffic volume (exposure) could be obtained.

CONCLUSIONS AND FUTURE DIRECTIONS

It was shown that DVM measures reviewed in this study have a normal distribution. This would help the users of the IHSDM software to estimate the probabilities of these measures exceeding certain thresholds. The probabilities that the values of these measures go below or above their threshold values can be studied in conjunction with the crash experiences along the highways. For lateral offset, exceeding the thresholds creates encroachments. The number of encroachments - estimated using DVM "Lateral Offset" output - was studied in conjunction with departure crashes. The results suggest that the DVM output can be used to identify highways with increased potential for departure crashes - especially for highways with narrow shoulder widths. This can be useful especially if other more relevant information and measures for estimating crashes are lacking.

Encroachments can be used as a surrogate measure to estimate departure crashes in the absence of predictive models (such as those presented in Part C of the Highway Safety Manual and implemented in the IHSDM Crash Prediction Module). In that case, using encroachments to estimate the predicted number of departure crashes per mile (Equation 5) can provide highway engineers with a preliminary tool for safety evaluation.

On the other hand, when results from crash prediction models are available, DVM output can serve as a diagnostic tool to help "explain" those results. Measures such as encroachments are then another "line of evidence" to support the findings suggested by crash prediction models and other sources.

In the future, the estimated average number of encroachments could be considered as an additional DVM output measure. In addition, other types of crashes (i.e., non-departure crashes) could be studied with respect to their relationship with other DVM output measures. Also, the current DVM is limited to simulating a normal driver who always acts in a rational manner (i.e., makes appropriate decisions given good information). This simulation could be expanded to account for inappropriate driver decisions. Expanding this model to the stage of simulating driver mistakes is one of the main directions for future modeling.

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findings and conclusions are of the authors, and do not necessarily reflect the points of view of FHWA.

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APPENDIX

Table A1 – 97 Highway Stretches Used in the Study

Test Case Number	Original Database Highway Number	Start Milepost	End Milepost	Length (mile)	10 Years of Departure Crashes
1	2	39.07	40.16	1.09	32
2	2	72.78	79.62	6.84	147
3	2	93.44	99.13	5.69	69
4	2	298.24	300.88	2.64	41
5	2	303.93	306.96	3.03	51
6	3	3.58	6.59	3.01	52
7	3	26.63	33.64	7.01	146
8	4	6.1	7.11	1.01	5
9	6	46.67	49.46	2.79	32
10	12	71.25	72.93	1.68	28
11	12	308.55	311.15	2.60	20
12	12	341.69	343.92	2.23	23
13	14	24.68	29.01	4.33	78
14	14	37.67	40.23	2.56	12
15	17	0.05	1.28	1.23	8
16	17	25.95	40.6	14.65	137
17	18	17.38	19.89	2.51	35
18	20	25.58	29.31	3.73	134
19	20	135.81	137.92	2.11	8
20	22	3.92	9.05	5.13	24
21	28	14.36	19.92	5.56	60
22	97	0	2.84	2.84	30
23	97	32.74	35.84	3.10	41
24	97	135.05	137.7	2.65	50
25	97	202.4	204.36	1.96	14
26	101	130.34	132.15	1.81	9
27	101	257.48	259.19	1.71	26
28	101	265.95	281.45	15.50	263
29	101	305.75	311.36	5.61	66
30	103	2.93	10.85	7.92	90
31	109	1.84	6.39	4.55	114
32	162	4.45	7.06	2.61	21
33	169	16.02	19.21	3.19	64
34	195	61.48	63.71	2.23	18
35	195	65.31	68.69	3.38	33
36	202	19.22	21.51	2.29	26
37	202	27.65	29.57	1.92	16
38	223	0	2.46	2.46	23
39	507	30.04	35.52	5.48	99
40	507	35.9	38.44	2.54	24
41	507	38.45	43.52	5.07	101
42	522	20.82	22	1.18	22
43	542	28.32	35.71	7.39	101
44	903	0	1.44	1.44	3
45	2	147.002	152.002	5.00	8
46	2	152.002	157.002	5.00	6
47	2	157.002	162.002	5.00	5

Test Case Number	**Original Database Highway Number**	**Start Milepost**	**End Milepost**	**Length (mile)**	**10 Years of Departure Crashes**
48	2	162.002	167.002	5.00	11
49	2	167.002	172.002	5.00	12
50	2	172.002	177.002	5.00	5
51	2	177.002	182.002	5.00	10
52	2	213.892	218.892	5.00	24
53	2	218.892	223.892	5.00	19
54	2	223.892	228.892	5.00	13
55	2	228.892	233.892	5.00	23
56	2	233.892	238.892	5.00	26
57	4	11.262	16.262	5.00	61
58	4	16.262	21.262	5.00	27
59	4	21.262	26.262	5.00	58
60	4	26.262	31.262	5.00	15
61	4	31.262	36.262	5.00	17
62	14	155.08	160.08	5.00	13
63	14	160.08	165.08	5.00	13
64	14	165.08	170.08	5.00	21
65	14	170.08	175.08	5.00	24
66	14	175.08	180.08	5.00	41
67	17	91.392	96.392	5.00	10
68	17	96.392	106.392	5.00	14
69	17	106.392	111.392	5.00	2
70	17	111.392	116.392	5.00	9
71	17	116.392	121.392	5.00	16
72	17	121.392	126.392	5.00	13
73	17	126.392	131.392	5.00	6
74	17	131.392	136.392	5.00	4
75	20	201.592	206.592	5.00	28
76	20	206.592	211.592	5.00	22
77	20	211.592	216.592	5.00	22
78	20	216.592	221.592	5.00	33
79	20	221.592	226.592	5.00	24
80	20	226.592	231.592	5.00	30
81	20	269.002	274.002	5.00	16
82	20	274.002	279.002	5.00	41
83	20	279.002	284.002	5.00	9
84	20	284.002	289.002	5.00	12
85	20	289.002	294.002	5.00	10
86	20	294.002	299.002	5.00	10
87	20	309.482	314.482	5.00	20
88	20	314.482	319.482	5.00	37
89	20	319.482	324.482	5.00	23
90	20	324.482	329.482	5.00	28
91	20	329.482	334.482	5.00	7
92	20	334.482	339.482	5.00	22
93	21	28.802	33.802	5.00	5
94	21	33.802	38.802	5.00	6
95	21	38.802	43.802	5.00	9
96	21	43.802	48.802	5.00	5
97	21	48.802	53.802	5.00	2

Table A2 – Departure Crashes, Encroachments, and Shoulder Widths

Test Case Number	Departure Crashes / Year / Mile	Encroachments / Year / Mile *	Shoulder Width (ft)	Test Case Number	Departure Crashes / Year / Mile	Encroachments / Year / Mile *	Shoulder Width (ft)
72	0.260	<1	1.4	**2**	2.149	7150	5.4
89	0.460	580	1.8	**19**	0.379	904	5.4
88	0.740	3637	1.8	**54**	0.260	<1	5.5
87	0.400	8843	2.0	**8**	0.495	3	5.5
96	0.100	267	2.0	**3**	1.213	3025	5.7
67	0.200	27	2.0	**36**	1.135	2	5.9
68	0.140	<1	2.0	**53**	0.380	<1	5.9
69	0.040	<1	2.0	**5**	1.683	<1	6.0
95	0.180	141	2.0	**23**	1.323	7336	6.0
97	0.040	1651	2.0	**80**	0.600	413	6.0
91	0.140	84	2.3	**18**	3.592	62113	6.2
79	0.480	287	2.4	**9**	1.147	2611	6.4
81	0.320	3	2.4	**25**	0.714	26	6.4
43	1.367	17010	2.6	**48**	0.220	2	6.5
78	0.660	634	2.6	**47**	0.100	238	6.8
92	0.440	313	2.7	**46**	0.120	<1	7.0
90	0.560	728	2.8	**49**	0.240	<1	7.0
71	0.320	<1	2.8	**56**	0.520	<1	7.0
83	0.180	76	2.8	**11**	0.769	25	7.0
70	0.180	103	2.9	**50**	0.100	3	7.1
93	0.100	3588	3.0	**16**	0.935	3	7.1
77	0.440	5708	3.1	**20**	0.468	1	7.2
6	1.728	13513	3.1	**51**	0.200	1	7.2
26	0.497	7889	3.1	**45**	0.160	3950	7.3
75	0.560	2928	3.1	**15**	0.650	19	7.5
57	1.220	3215	3.2	**61**	0.340	91	7.7
30	1.136	<1	3.2	**73**	0.120	1	7.8
31	2.505	267141	3.2	**4**	1.553	23	7.9
40	0.945	<1	3.2	**33**	2.006	1	7.9
29	1.176	12887	3.3	**63**	0.260	<1	7.9
1	2.936	7499	3.4	**62**	0.260	3	8.0
76	0.440	12	3.5	**64**	0.420	<1	8.0
37	0.833	<1	3.5	**65**	0.480	<1	8.0
94	0.120	1298	3.6	**66**	0.820	4	8.0
82	0.820	5482	3.8	**74**	0.080	<1	8.0
13	1.801	76764	3.9	**12**	1.031	45	8.0
32	0.805	13418	3.9	**24**	1.887	11650	8.0
85	0.200	348	4.0	**27**	1.520	2	8.0
86	0.200	297	4.0	**34**	0.807	20	8.0
39	1.807	9040	4.0	**35**	0.976	37	8.0
22	1.056	131648	4.5	**28**	1.697	192	8.3
41	1.992	1346	4.5	**38**	0.935	53405	8.5
7	2.083	5	4.6	**14**	0.469	19	8.6
58	0.540	16	4.9	**44**	0.208	73757	9.0
59	1.160	1669	5.0	**42**	1.864	3657	9.7
52	0.480	<1	5.0	**10**	1.667	1	10.0
84	0.240	1743	5.0	**17**	1.394	41	10.0
60	0.300	9	5.0	**21**	1.079	1	10.0
55	0.460	<1	5.4				

** Values of "<1" correspond to cases in which the probabilities of the lane offsets exceeding the thresholds are so low that they do not generate even one expected encroachment in a year.*