Development of Speed Prediction Models for Day-time Versus Night-time Conditions on Rural Multilane Egyptian Highways

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Abstract: ***This study presents the development of operating speed models for day-time and night-time conditions for highways in Egypt based on a study of 58 horizontal curves at different sites on rural multilane roads. In each horizontal curve, spot speeds at each horizontal curve and tangents between them were collected during the day and night at five points. Spot speeds were collected at the middle of first tangent, point of curve, middle of curve, point of tangent and the middle of second tangent. In the operating speed models, the radius of the horizontal curve was used to estimate the operating speed. The speed models determined that the operating speed correlated with the radius of the horizontal curve. Statistical tests were used to compare daytime and nighttime speeds at the midpoint of each horizontal curve. The comparison reveals that there is no statistical difference between daytime and nighttime speeds at the midpoint of the horizontal curves. Another test was done to investigate the design consistency of the horizontal curves. Comparison between speeds at the main points of the horizontal curve was made. Differences between speeds at point of curve, middle of curve and point of tangent were examined within the tested horizontal curves using ANOVA. The results of ANOVA test for horizontal curves in each group showed that there is no significant difference in speeds between each two successive points within the horizontal curve.***

Index Terms: ***Operating Speed, Design Consistency, Regression Analysis, Daytime & Night-Time Speeds.***

I. INTRODUCTION

Although the number of vehicle miles driven at night generally represents less than 20 percent of the total vehicle miles driven on US highways, between 40 and 50 percent of traffic fatalities occur at night [1]. The National Highway Traffic Safety Administration (NHTSA) reported that 49 percent of passenger vehicle occupant fatalities occur at night, while only 25 percent of travel occur during the night [2].

The severity of the night-time crash problem is further evidenced by nighttime traffic fatality rates, which are more than four times higher than in the day. Night-time traffic fatality rates have traditionally been the highest in rural driving environments. Despite these numbers, current geometric design criteria and knowledge on the operational and safety effects of geometrics seem limited with respect to night-time speeds [1].

Accidents on horizontal curves have presented a safety challenge for many years. Crashes occur on the rural areas due to inconsistency between the geometric elements of the road and the driver expectations, speeding and the driver inattention [3]. At horizontal curves, about 76 percent of the fatal crashes involve single vehicles leaving the roadway and driving into trees or other fixed objects and overturning. Another 11 percent are head on crashes [3].

Studying the night-time speeds was an important issue to be investigated. Transportation Research Circular: Number E-C151 (2011) recommends that operating speed modeling work be designed to develop operating speed models at night-time conditions [7]. However, most of the current studies have been carried out in Europe and North America. The study reported in this paper presents one of only few studies that attempt to develop reliable speed models in a developing country.

II. DATA COLLECTION

One of the most important steps to achieve the objectives of this study is to collect the necessary data with a sufficient degree of accuracy. This section provides a detailed description of the data collection process.

A. Geometry Data

58 Horizontal curves from four multilane rural Egyptian highways were tracked using GPS recorder. After surveying, a best fit was made to these roads using AutoCAD Civil 3D Program ™ to extract the geometric data like horizontal curve radius, curve length, deflection angle and tangent length.

The geometric characteristics of these locations are listed in Table 1.

Table 1. Geometric Characteristics of surveyed Horizontal Curves

	Max.	Min.	Avg.
Curve Radius (m)	10500.0	70.0	2432.1
Curve Length (m)	2561.2	59.9	762.6
Delta Angel (deg.)	79.1	3.4	22.4
Tangent Length (m)	11089.5	327.5	2894.4

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B. Speed Data

In this study, spot speeds were collected in the selected locations using radar gun. The device was calibrated by making a trial runs and comparing the speed of vehicles using the device and the speed record from the vehicle speedometer. The number of speed observations was 40 at each location. It was determined according to the confidence level [4]. It can be calculated from the following equation

$$N = 1.96^2 \frac{s^2}{e^2}$$

Where

The constant = 1.96 as (95% confidence level)
S = Expected standard deviation (3-8kph)
e = Acceptable error in the speed estimate (1-2kph)

Speed data were collected on horizontal curves at day-time and night-time only at the free flow condition. The time headway between consecutive vehicles is required to be at least 5 seconds to collect truly free flow speeds [5]. This concept was taken into consideration during speed data collection.

Speed observations were recorded at five points for each horizontal curve under free-flow conditions. These five points are as follow:

- Middle of the first tangent (MT1)
- Beginning of curve (BC)
- Middle of curve (MC)
- End of curve (EC)
- Middle of second tangent (MT2)

Figure 1. shows the locations of the five points at each horizontal curve

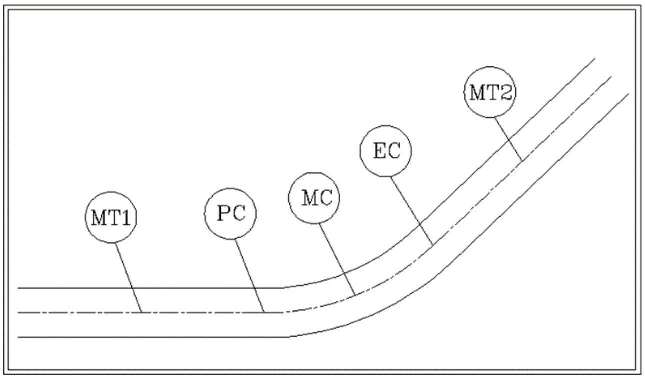

Fig.1. Locations of The Five Points At Each Horizontal Curve

III. SPEED ANALYSIS

Analysis was carried out to compare vehicle mean speeds during day-time and night-time conditions at the midpoint of the horizontal curves to study the effect of light conditions on vehicle speeds. Also, comparison between speeds of each two successive points - point of curve, middle of curve and point of tangent - within horizontal curves of the studied roads was made. These comparisons help to investigate the design consistency of the studied roads and its impacts on vehicle speeds.

A. Comparison of Day-time & Night-Time Speeds

Two tests were developed to compare day-time and night-time speeds. T-test was provided to compare the average speeds at the midpoint of horizontal curves. Also, Analysis of Variance was made to examine the speed variance under different light conditions.

T-test

T-test is one of the statistical tests used to assess whether the difference between average values of two data sets are statistically different from each other. Prior to the analysis, an example of average day-time and night-time speeds for each curve on Cairo-Alexandria Desert Road provided in the following table.

Table 2. Average Day-time and Night-time Speed for Each Curve (Cairo-Alexandria desert road)

Curve ID	Average Daytime Speeds (Km/hr)	Average Nighttime Speeds (Km/hr)
1	106.2	106.5
3	109.4	109.6
4	111	115
5	110	113
8	111.3	107.5
10	112.8	116
11	119.7	114.7
13	114	113.6
15	114	111
16	120	120
17	117	119
18	110	114
19	114.6	117.5
20	118	113
21	124.8	120.2
23	118	115.6
24	122.5	128

T-test was carried out for each curve to compare daytime and nighttime speeds for each curve. The parameter t was calculated from the following equation

$$t = \frac{\mu_1 - \mu_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Where

- μ_1 = The average speed of day-time observations at midpoint of curve
- μ_2 = The average speed of night-time observations at midpoint of curve
- s_1 = Standard deviation of day-time speeds
- s_2= Standard deviation of night-time speeds
- n_1 = Sample size of day-time speeds
- n_2 = Sample size of night-time speeds

The calculated value from the equation was compared with critical value according the t distribution in table 3. The tabulated value of t-test (=1.66) depends on the confidence level (95%). The results from this test will be summarized in Table 3.

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Results showed that there is no significant difference between day-time and night-time average speeds in the observed curves.

Table 3. Comparison Results between Day-time & Night-time Using T-test

Curve ID	Day-time Condition			Night-time Condition			$t_{Calculated}$	Statistical difference
	Avg. Speed (km/hr)	SD	N	Avg. Speed (km/hr)	SD	N		
1	106.2	8.1	40	106.5	6.9	40	-0.1783	Not significant
3	109.4	8.0	40	109.6	10.4	40	-0.0964	Not significant
4	111	10.5	40	115	16.5	40	-1.2935	Not significant
5	110	10.0	40	113	10.4	40	-1.3151	Not significant
8	111.3	11.3	40	107.5	10.2	40	1.5788	Not significant
10	112.8	10.9	40	116	7.8	40	-1.5100	Not significant
11	119.7	22.4	40	114.7	11.2	40	1.2627	Not significant
13	114	11.0	40	113.6	12.7	40	0.1506	Not significant
15	114	10.6	40	111	5.8	40	1.5703	Not significant
16	120	14.7	40	120	10.6	40	0.0000	Not significant
17	117	13.1	40	119	12.3	40	-0.7039	Not significant
18	110	11.6	40	114	13.3	40	-1.4335	Not significant
19	114.6	13.5	40	117.5	10.0	40	-1.0917	Not significant
20	118	16.4	40	113	11.7	40	1.5697	Not significant
21	124.8	17.5	40	120.2	12.6	40	1.3491	Not significant
23	118	13.1	40	115.6	17.3	40	0.6995	Not significant
24	122.5	13.6	40	128	19.1	40	-1.4835	Not significant

Analysis of variance

Although there is no significant difference between day-time and night-time average speeds at the midpoint of horizontal curves, the day-time and night-time average speeds on horizontal curves exhibit a different variance values. Analysis of speed variance was provided to investigate this difference. ANOVA test was used to assess the difference between the variance of day-time and night-time speeds for horizontal curves. Table 4 shows the results of ANOVA test using SPSS software for one curve.

Table 4. Analysis of variance between day-time & night-time speeds for curve.4

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1140.05	1	1140.05	5.999	0.017
Within Groups	14823.9	78	190.05		
Total	15963.95	79			

The following figures illustrate the relationship between speed variance and horizontal curve radius in day-time and nighttime conditions. In most of horizontal curves surveyed, there is significant difference in the variance between day-time and night-time speeds.

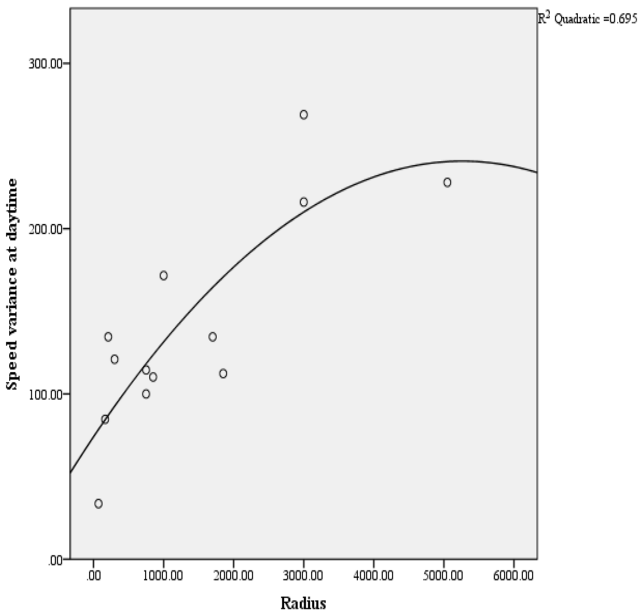

Fig. 2. The Relationship Between Curve Radius and Speed Variance at Day-Time

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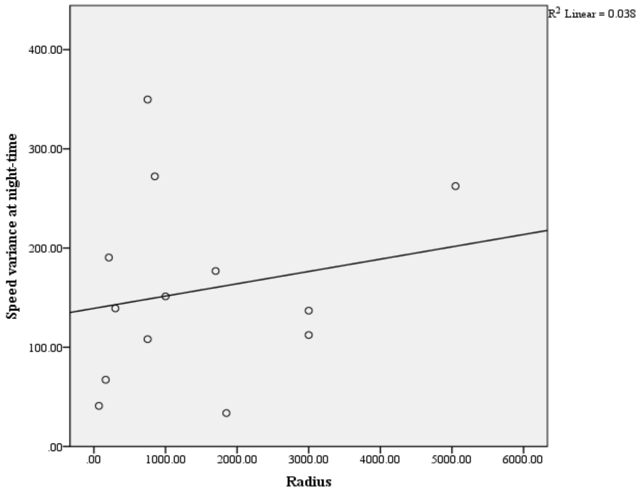

Fig.3. The Relationship Between Curve Radius and Speed Variance at Night-Time

From the previous figures, it can be concluded that as the curve radius increases, the speed variance increases in both day-time and night-time conditions. The impact of horizontal curve radius on the speed variance is higher at day-time conditions showing the different speed behavior between day-time and night-time conditions. This should be taken into consideration when estimating operating speeds on roads.

B. Comparison of Speeds within Horizontal Curves

In this section, comparison between speeds of the main points of the horizontal curve is made. Difference between speeds at point of curve, middle of curve and point of tangent were investigated within horizontal curves.

As in day-time and night-time testing. T-test and Analysis of Variance (ANOVA) were used to compare mean speeds. P-value of all curves shows that speeds of each two points in horizontal curves were not statistically different. An example of analysis of variance is seen in Table 5.

Table 5. Analysis of Variance of Curve 121

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	2	125.9	62.93	0.35	0.707
Error	118	21354.4	180.97		
Total	120	21480.3			

Another table provided from ANOVA test was Tuckey pairwise comparisons which group information using the Tukey method and 95% confidence. In this table, comparison between means of each two groups was provided. Means that do not share the same letter are significantly different. Table 6 shows sample of Tukey pairwise comparisons.

Table 6. Tuckey Pairwise Comparison Curve 121

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
MC121	40	116.70	A
PC121	40	115.22	A
PT121	41	114.22	A

Means that do not share a letter are significantly different.

Another plot was provided- in the output of the comparison of each curve- which compare between each two groups in this test as in Figure 4

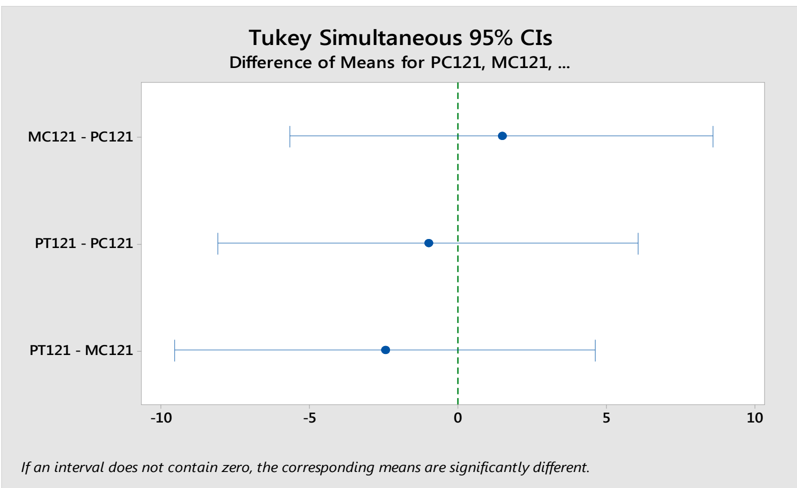

Fig.4. Tuckey Simultaneous 95% Confidence Interval (Comparison of Means)

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From the previous figure, if an interval does not contain zero, the corresponding means are significantly different. The results of ANOVA test for all horizontal curves show that there is no significant difference between speeds of each two successive points within the horizontal curve even in relatively small radius as long as proper geometric design standards are followed in horizontal curve design which was the case in tested roads.

IV. DEVELOPMENT OF OPERATING SPEED MODELS

In this section, regression analysis was used to develop different operating speed models as a function of the geometric features of the studied roads (curve radius, curve length, deflection angle and tangent length) on the midpoint of tangents and curves at day-time and nighttime conditions. The analysis used spot speed data to determine, the dependent variable, operating speed (85^{th} percentile speed). Speed observations at each location were checked by Chi-Square test to verify the fitting of Statistical Normal Distribution in order to extract the 85^{th} percentile speed at each location.

The following criteria were used to determine the best predictor of the independent variables and to assess the accuracy of the developed models:

- A correlation analysis was made to judge the independent variables. Also, scatter plots were used to identify possible relationships between the independent variables and the operating speed (85^{th} percentile speed). Correlation coefficient must be high as possible to indicate higher effect on the developed models.
- The models with higher coefficient of determination R^2 and lower percent standard error of estimate PSEE usually indicate better fit regression models.

Figure 5 shows one of the scatter plots of the relation between the 85^{th} percentile speed and square root of the curve radius on point of middle of curve at day-time

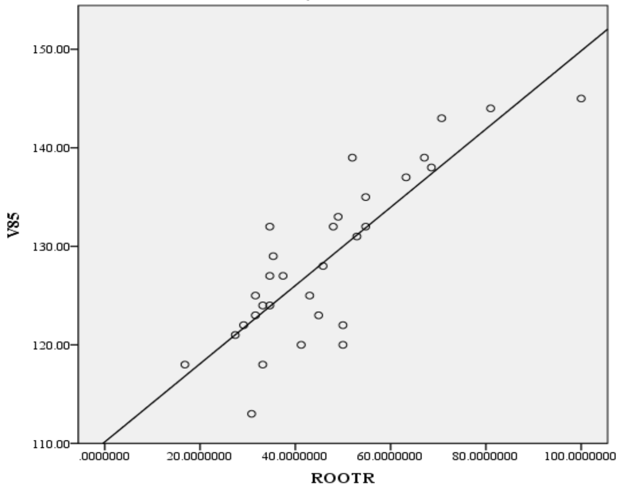

Fig.5. Operating Speed and Square Root of Curve Radius

Table 6 summarizes the best developed operating speed models on middle of tangent and middle of curve locations at day-time and night-time conditions.

Table 7. Summary Table of the Developed Operating Speed Models at Different Point Locations on the Tested Horizontal Curves

Model Number	The operating speed Model	Point Location	Time Condition	R^2	PSEE
1	$V_{85} = 110.114 + 0.397 \sqrt{R}$	Middle of Curve	Day-time	0.705	3.58%
2	$V_{85} = 145.645 – 977.16/\sqrt{R} + 7802.585/\sqrt{R^2}$	Middle of Tangent	Day-time	0.523	4.23%
3	$V_{85} = 125.986 + (6.876*10^{-7})\ R^2$	Middle of Curve	Night-time	0.648	4.05%
4	$V_{85} = 154.764 – 21086614.2/R^2$	Middle of Tangent	Night-time	0.682	6.08%

Where:
V_{85} = operating speed in (km/h)
R = curve radius in (m)

The models in Table 7 confirm that curve radius is the best predictor of the operating speed in the middle of curves. This could be evidenced be the sign of the square root of curve radius in model 1 and square of curve radius in model 3. In other words, a higher curve radius leads to a higher operating speed.

In the tangent models, the best model observed at day-time conditions -model 2-was nonlinear model and related the operating speed with inverse square root of the curve radius prior to the tangent $(1 / \sqrt{R})$ as the tangent speeds are affected by the previous curve, provided that the distance between the 2 consecutive curves is not higher 11089.534 m This model has a logical explanation sign for the effect of the independent variable $(1 / \sqrt{R})$ on the prediction of operating speed on tangent on the following curve. As the curve radius increases, The speed of vehicles will be higher at the curve and the tangent on the closely following curve. In model 4, the sign of the inverse of square of curve radius $(1 / R^2)$ was logical and explain the fact as in model 2.

Finally, it is worth mentioning that R^2 and *PSEE* values in the previous models were reasonable good compared with the values in the previous researches as reported by Hatem et al. [6]. This reflects the accuracy of these models to be used in prediction of operating speed.

V. CONCLUSIONS

From this work, we can conclude the following:

- There is no statistical significant difference between vehicle mean speeds during daytime and night-time conditions at the midpoint of the horizontal curves.

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- There is significant difference in speed variance of horizontal between daytime and night-time conditions at the midpoint of the horizontal curves.
- The impact of horizontal curve radius on the speed variance in day-time is higher than night-time.
- The analysis of variance (ANOVA) showed that there is no statistical significant speed difference between each two consecutive points – point of curve, middle of curve and point of tangent - within the horizontal curve. This indicates the design consistency of the horizontal curves of the investigated roads and that proper geometric design standards were followed in horizontal curve design.
- Different operating speed models were developed at tangent and middle of curve points. These models are very useful and can be used to assess design consistency of roads.
- In the models developed, the horizontal curve radius had the biggest impact on the operating speed among the independent variables.
- Day-time models gives better values of R^2 and PSEE in operating speed prediction models. It is recommended to use day-time models in prediction of operating speed.

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