A Comparison of Daytime and Nighttime Operating Speed on Rural Multi- Lane Highway Sections in Egypt

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Abstract

Traditionally, the 85th percentile of observed speeds is used to represent the operating speed associated with a specific site with certain geometric features. The presence of sunlight enhances the vision of drivers during daytime while visibility usually degrades during nighttime, especially on rural roads where no street lighting exists, and drivers would depend solely on their vehicle headlights. Visibility degradation is a safety concern which is magnified on horizontal curves. The objective of this study, therefore, is to compare operating speed in daytime and nighttime conditions on both tangent sections and horizontal curves. The analysis made use of spot speed data collected on horizontal curves of two major rural multilane highway in Egypt. Spot speed data were collected using speed guns during daytime and nighttime. The spot speed data were used to calculate the mean speed, variance of speed, and the 85th percentile speed. Analysis of Variance (ANOVA) was used to compare the speeds in daytime and nighttime. For most cases, it was shown that no significant difference existed in speed for daytime and nighttime. This was mainly attributed to the generous design features of the highway elements (e.g., large radii of horizontal curves, wide lanes, etc.). An attempt was made to develop operating speed models to see which variables impact speed during daytime. The results of operating speed models' development were deemed inappropriate due to the lack of variability in speeds.

1. INTRODUCTION

Speeds on Rural roads depend mainly on the condition of the pavement and its periodic maintenance operations, which improve its performance [1-3]. Many studies are being conducted to improve the condition of the paving, whether by adding polymeric materials, a mixture of nano materials, or even waste materials [4-19]. Also, lighting is one of the important factors affecting speed, as the presence of sunlight enhances the vision of the driver during daytime. In contrast, at night, the driver relies only on the headlights of his car, as there is no street lighting in most cases, especially on rural roads [20]. As a result, for example, on the United States highways the number of deaths at night is 40 to 50 percent more than the number of deaths during the day, despite the number of miles traveled by vehicles during the day is about 20 percent more than the number of miles traveled during the night [21]. The National Highway Traffic Safety Administration (NHTSA) stated that Almost 50% of passenger vehicle occupant fatalities occur at night, while only 25% of travels occur during the night [22]. The death rates from accidents that occur at night are 4 times that of those that occur during the day, and this clearly shows the impact of the problem of night collision [21]. Despite these numbers, current geometric design criteria and knowledge on the operational and safety effects of geometrics seem limited with respect to nighttime speeds [23].

Collisions on horizontal curves have presented a safety challenge for many years. A study conducted near Nashville, Tennessee revealed that crashes occur on rural areas due to inconsistency between the road geometric elements and the expectations of driver, driver's inattention, and speeding. On horizontal curves, about seventy-six percent of fatal crashes involved single vehicles leaving the roadway and driving into trees or other fixed objects and overturning. This is in addition to eleven percent were head-on crashes [23].

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Analyzing the difference between nighttime and daytime speeds, especially on horizontal curves is an important issue that should be studied. The Transportation Research Circular: Number E-C151 (2011) [24] recommended that future operating speed modeling work be designed to develop operating speed models for nighttime conditions. In this study, a comparison is made between daytime and nighttime speeds on a major multilane rural highway in Egypt. As well, an attempt is made to develop operating speed models using speed and geometric information data.

2. LITERATURE REVIEW

2.1. SPEED, VISIBILITY, AND SAFETY

Operating speed is defined as the speed at or below which 85 percent of drivers can drive without being impacted by the road design or traffic conditions [25]. There are various factors that influence operating speed such as weather conditions, road design, the presence of commercial vehicles, speed limit, among other factors (AASHTO 2004). As well, the characteristics of horizontal curves, can have a considerable impact on operating speed.

Intuitively, speeding reduces the available reaction time which leads to higher probability of a crash. An early study by Solomon (1964) [26] used 10,000 crashes to examine the relationship between vehicle speed and crash occurrence on rural highways. The relationship was found to follow a U-shape curve between the deviation from the average travel speed and crash rate per 100 million miles. accordingly, crash rates were the lowest when the travel speeds are close to the mean speed of the traffic. However, as the deviation of the travel speed from the mean speed increases more than 24 km/h, the likelihood of being involved in a crash also increases. In addition, with an increase in speed, the crash rates were decreased. This fact only holds good as the speed of the vehicle is not above 104 km/h. Solomon (1964) [26] also showed that the severity of a crash increased when speeds increase on rural roads. Later, Cirillo (1968) [27] confirmed Solomon's findings by conducting a similar analysis on 2,000 vehicles involved in daytime crashes on Interstate freeways. The analysis was limited to two or more vehicles traveling in the same direction. Another study showed that while the deviation from the mean speed increased with more than 32 km/h, the severity of crashes increases [28].

Driving on a road during the daytime and nighttime can be very different. The absence of the sunlight makes driving very different at night than during the day. In addition, 90 percent of a driver's reaction depends on vision which is limited at nighttime, making it harder to drive at nighttime compared to daytime. Some of the reference points that people use during the day to guide them through the road are no longer visible at night [23]. Fatality rates are approximately three to four times higher at night than during the day. A study carried out in New Zealand found that the chance of getting involved in a crash in terms of distance traveled is higher at night than day [29].

Bennet (1994),[30] compared nighttime and daytime speed data for two-lane rural roads. The speeds were found to have a Gaussian distribution and there were limited differences between day and night speeds, thereby allowing both sets of speed data to constitute part of the same population. In other words, it was possible to develop a single speed prediction model valid over a 24-hour period. Similar observations were made by Guzman, (1996) [31], who found no significant differences between day and nighttime speeds. The magnitude of the difference was small for all degrees of curvature.

Assum et al., (1999) [32] tried to explain some previous research findings of no change in operating speed when the road lighting was present. The authors suggested that there is a counterbalance between daylight conditions which are associated with higher driving speed and a larger proportion of more slowly driving groups (elderly people and women).

Bonneson et al., (2007) [33] showed that average nighttime speed tends to be lower for both passenger car and truck drivers compared to average daytime speed. For passenger cars, the nighttime speed was 3.6 km/h lower than daytime passenger car speeds and for trucks the nighttime speed was 1.6 km/h slower than the daytime truck speed.

Bella et al., (2014) [34] used driver's simulator to compare driver's speed behavior during daytime and nighttime. The authors investigated the substantial factors affecting driver's speed behavior. The study was carried out using data collected on 39 tangent-curve configurations by 40 drivers in the same lighting conditions. The authors suggested that a driver does not choose to reduce speed in nighttime unless they did not correctly predict the length of whole segment. Other studies which used a driver's simulator to examine driver's behavior under day and night scenarios include the work of Calvi and Bella (2014) [34] and Valck et al., (2006) [35]. Calvi and Bella (2014) [36] used a driver's simulator to analyze driver's speed during different lighting conditions in terms of speed differential predicted by an experienced driver. Valck et al., (2006) [35] used real traffic data and a driver's simulator to investigate driving behavior during different lighting conditions.

Hashim et al., (2016) and Abdel-wahed et al., 2017) [37-38] developed speed profile models for horizontal curves and tangents on two-lane rural highways for daytime conditions. Their models took into consideration acceleration and deceleration rates before and after horizontal curves. Jägerbrand and Sjöbergh, (2016) [39] studied the relationship between lighting conditions (daylight, twilight, darkness, artificial light) and vehicle

speed. A weak correlation was found between variation in driver speed and lighting conditions. Other factors such as weather conditions, driver distraction, and brightness were found to be more influential on vehicle speed [40].

2.2. OPERATING SPEED PREDICTION MODELS

Driver's gender, age, perceived risks, attitude, road and vehicle characteristics, weather, speed adaptation, and speed zoning can influence operating speed. The most significant road characteristics contributed to the operating speeds include grade, curvature, length of grade, surface condition, number of lanes, sight distance, lateral clearance, number of intersections, and built-up areas near streets and highways. Many studies were developed to investigate Operating speed models for rural highways. Most of the developed models were for rural two-lane highways and suburban/urban roadways, while only a few were developed for rural multi-lane highways. A summary of operating speed models as developed in previous studies can be found in [41-64].

Most of the developed models were based on speed prediction for passenger-car vehicles while only a few were developed for heavy or light trucks. As well, most of the previous studies used the 85th percentile speed to represent the operating speed. In most of these studies, linear and non-linear regression models were developed using ordinary least squares (OLS) method. It was also noted that most of the previous studies used only daytime speeds in the development of operating speed models. Only a few studies investigated the use of nighttime speeds. In most studies, the operating speed predictors mainly consisted of geometric design features, while in a few models, traffic and pavement information was also used. The variables which were found to have significant impact on operating speed included curve radius, curve length, length of the preceding and successive tangents, grade, super-elevation, pavement condition, and speed limit.

3. RESEARCH METHODOLOGY

In this research, a comparison is made between daytime and nighttime speeds on a multilane rural highway in Egypt. The methodology followed in this research can be described by the following steps:
1. Data collection and analysis,
2. Assessment and comparison of daytime and nighttime speeds and speeds at different locations on horizontal curves, and
3. Development of operating speed models.
Each of these steps is described in more detail in the following sub-sections.

4. DATA DESCRIPTION

This study made use of data collected on a major rural multilane highway in Egypt, Cairo-Alexandria desert road. Three types of data were collected: roadway geometry, weather conditions, and vehicle spot speeds in daytime and nighttime. The three datasets were merged into one dataset which was used in the analysis. The data collection plan followed the following stages:
- Roads and sites selection
- Geometric design data collection
- Spot speeds & weather data collection

4.1. Roads and Sites Selection

Initially, eight rural multilane highways were selected as potential candidates for data collection. Some of these roads were deemed inappropriate to serve the purpose of this study for the following reasons:
Large percentage of heavy trucks (% HV > 25 %)
Poor pavement condition (PCI between 30% and 50%)
Slight variations in the geometric elements
Existence of maintenance or development works at time of survey
Security and safety issues that impede data collection, especially at night
On that basis, Cairo - Alexandria Desert Road and Katameya - Ain Sokhna Road were selected for data collection. Security clearance to collect data at night was only warranted for Cairo-Alexandria and therefore daytime and nighttime data of this highway was used in the speed comparison. The road exhibited suitable variations in geometric elements such as horizontal curves with different radii, good pavement condition (PCI ranges from 70 – 95 %) and high percentage of passenger cars. This facilitated a proper collection of free flow speeds as well as geometric data. Daytime speed data of both Cairo - Alexandria Desert Road and Katameya - Ain Sokhna Road were used in developing operating speed models for multilane highways. Figure 1 shows the layout of Cairo - Alexandria Desert Road and Katameya - Ain Sokhna Road.
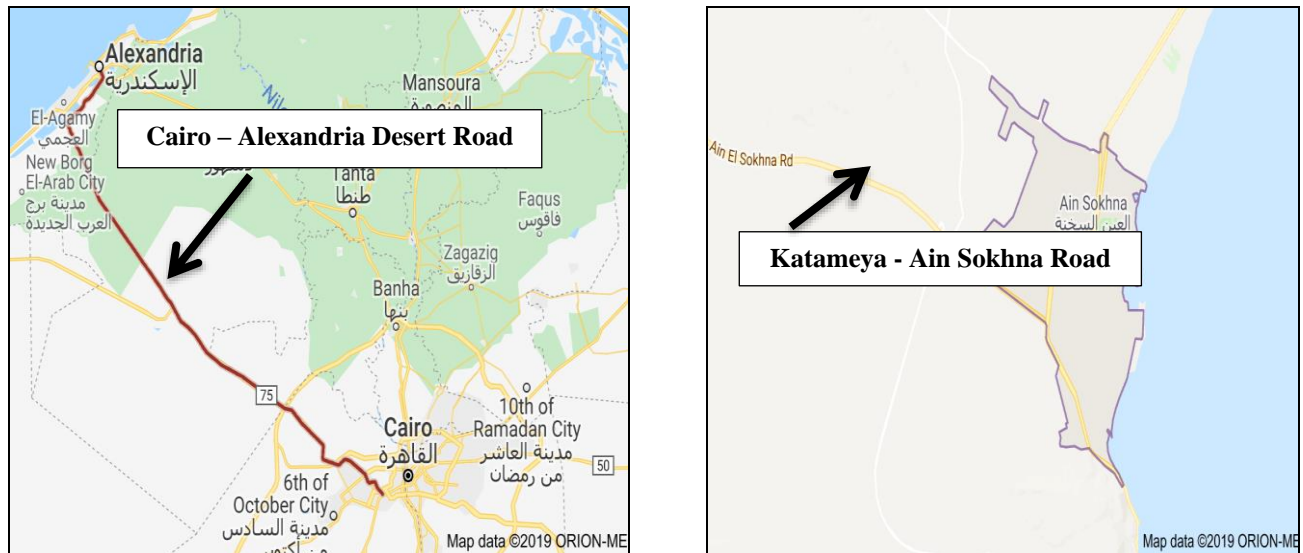
Figure 1: Layout of the Data Collection Roads.

4.2. Geometric Design Data

Geometric design data were collected using portable GPS devices which were installed inside a test vehicle. A road survey was undertaken by driving the test vehicle along the data collection segments. The GPS data collection resolution was set to 1 second to allow for closely spaced points and a continuous trajectory. The collected GPS points were projected in AutoCAD Civil 3D and approximate best fit curves were generated to enable the extrication of geometric design information of the surveyed road sections. The information collected included horizontal curve radius, curve length, deflection angle, tangent length, and coordinates of the points of interest of the roads. Table 1 presents a summary of the attributes of the surveyed segments on the two highways.

TABLE 1 SUMMARY OF THE CHARACTERISTICS OF THE DATA COLLECTION SEGMENTS

Road Name	Section Length (km)	Number of Curves	Min. Radius (m)	Max. Radius(m)
Katameya - Ain El Sokhna	100.4	34	944	10500
Cairo - Alexandria Desert	105.6	20	750	5050

4.3. Spot Speeds & Weather Data

The last stage in data collection was to collect spot speed data, weather conditions, pavement marking condition and other geometric data, number of lanes, lane width and shoulder width. The coordinates of data collection points were specified based on the horizontal alignment of the road segments. The location of a data collection point was then determined using a GPS device. The data collection took place in the summer of 2015. Five data collection points were specified for each horizontal curve. Spot speeds were collected using a radar speed gun. The device was checked for accuracy by comparing the recorded speeds using the speed gun and speed readings from vehicle's odometer. Figure 2 shows an example of the locations and geometric data of the five points on one horizontal curve. Speed data were collected on horizontal curves in free flow conditions where a time headway threshold of five seconds was used to specify vehicles running in free flow conditions.
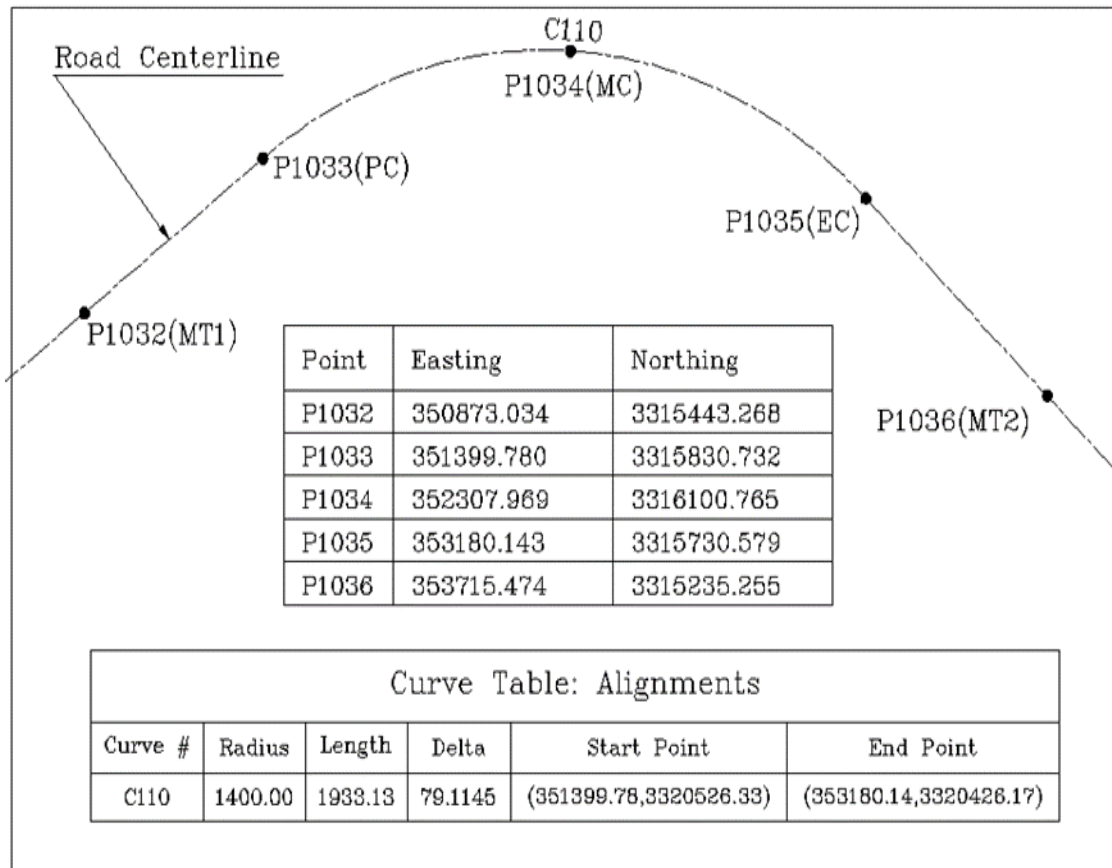
Point	Easting	Northing
P1032	350873.034	3315443.268
P1033	351399.780	3315830.732
P1034	352307.969	3316100.765
P1035	353180.143	3315730.579
P1036	353715.474	3315235.255

Curve Table: Alignments

Curve #	Radius	Length	Delta	Start Point	End Point
C110	1400.00	1933.13	79.1145	(351399.78,3320526.33)	(353180.14,3320426.17)

Figure 2 location and geometric data of the five points on a horizontal curve.

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

In the curved sections, precaution was used to minimize errors in recording spot speeds. The radar gun was aligned with the centerline of curves to gain maximum line of sight with the recorded vehicle and to prevent any deflection with radar waves. Weather data such as temperature in degrees, humidity percentage and wind speed were detected using GIS-based weather application and recorded in the data sheet. Table 2 shows a sample of the data collected at each point on the horizontal curves of the selected road. The speed limit of the two highways is 120 km/h. For Cairo Alexandria Desert Road, the speed measurements were conducted during daytime and nighttime at the same stations, in good weather, and for points with good road surface condition. As built drawings from General Authority for Roads, Bridges and Land Transport (GARBLT) were used to supplement all geometric data of studied segments. For all the data collection points, the cross section of each travel direction consisted of four travel lanes with an average lane width of 3.6 m and a paved shoulder of 3.3-2.6 m in width.

TABLE 2 A SAMPLE OF DATA COLLECTED AT ONE CURVE ON CAIRO – ALEXANDRIA DESERT ROAD

Cairo – Alexandria desert road					
Date	26-8-2015	Daytime		Road Name	
Start Time	11:00 PM	Nighttime	√	Design Speed	
Direction	To Alex	Tangent Length			
Section Number	C14	Curve Length	227 m		
Terrain Type		Curve Radius	2400 m		
Number of Lanes	4				
Shoulder Condition		Marking Condition			
Paved	-	Marked	-	Lane Width	3.6m
Unpaved		Not Marked		Shoulder Width	2.6m
Weather Condition	Partly cloudy				
Temperature (C)	30				
Humidity	52%				
Wind Speed	3 kph				
Speeds (KPH)					
MT1(P54)	PC(P55)	MC(P56)	PT(P57)	MT2(P58)	
111	116	125	115	107	
120	130	120	127	171	
108	111	129	125	106	
114	111	102	116	111	
99	120	114	106	134	
105	98	98	142	102	
103	108	108	125	118	
117	112	114	114	123	

MT1   Middle of the first tangent
PC   Beginning point of curve
MC   Middle of curve
EC   End of curve
MT2   Middle of second tangent
P.55   Point ID

5.   COMPARISON OF DAYTIME AND NIGHTTIME SPEEDS

A comparison is made between daytime vehicle speeds and nighttime speeds for different points. The middle point of the second tangent of a horizontal curve was treated as the middle point of the first tangent of the following curve with exactly the same data. As such, the speed comparisons focused only on four points MT, PC, MC, and MC. For 20 horizontal curves, the total number of data collection locations should be 80 (4 points and 20 curves). Nevertheless, data collection at 11 of these locations was not possible due to various reasons. As such, the final dataset included data collected at 69 locations classified as follows: PC: 19 locations, MC: 17 locations, EC: 15 locations, and MT: 18 locations. For each of these points, speed statistics were calculated including V85, V50, V15, and speed variance. An Analysis of Variance (ANOVA) was used to compare the speeds during daytime and nighttime. The null hypothesis (Ho) of the ANOVA was that both the spot speeds collected during daytime and nighttime are drawn from the same statistical distribution. In other words, there is no statistically significant difference in daytime and nighttime speeds. The alternate hypothesis (HA) is that there is a statistically significant difference between daytime and nighttime speeds. Tables 3 through 6 show summary statistics of speeds as well as the results of ANOVA test for the four analysis points.

TABLE 3 SUMMARY STATISTICS OF SPEEDS AS WELL AS THE RESULTS OF ANOVA TEST ON TANGENT POINTS

Type	Daytime				Nighttime				ANOVA Results	
	V85	V50	V15	Variance	V85	V50	V15	Variance	Statistically Different (Y/N)	p-value
MT	138.00	119.00	105.67	353.50	162.50	140.00	131.50	188.06	Yes	0.00
	119.00	109.50	104.50	102.36	120.50	110.00	100.00	69.88	Yes	0.00
	122.00	111.00	102.33	158.98	142.00	132.00	98.00	327.57	Yes	0.01
	129.00	116.00	106.00	141.13	142.00	127.00	114.00	154.04	Yes	0.01
	115.00	103.50	96.00	72.42	105.00	98.00	89.50	46.62	Yes	0.03
	141.00	114.00	106.25	230.20	146.50	126.00	111.00	275.34	No	0.05
	142.00	115.00	106.00	324.69	137.00	129.00	106.50	236.62	No	0.10
	136.00	123.50	107.33	291.17	129.50	112.00	98.00	167.51	No	0.10
	134.50	118.50	106.00	232.10	120.50	110.00	104.50	77.43	No	0.14
	144.00	118.33	109.00	293.89	149.50	123.00	110.50	294.01	No	0.21
	129.50	117.50	106.00	105.01	129.50	119.00	107.00	281.43	No	0.31
	141.00	121.00	109.00	308.36	163.50	131.50	112.00	678.82	No	0.44
	118.00	108.00	99.67	72.64	116.00	110.50	99.00	79.78	No	0.55
	130.00	115.00	107.00	243.43	138.00	119.00	109.25	261.12	No	0.58
	146.00	117.50	110.00	365.66	142.00	113.00	96.50	848.72	No	0.60
	133.00	114.75	104.00	277.32	132.50	119.00	112.50	111.29	No	0.78
	138.00	116.00	103.00	286.11	128.00	124.00	105.00	122.10	No	0.92
	124.00	113.00	99.50	156.92	125.00	112.00	97.50	152.23	No	0.94

TABLE 4 SUMMARY STATISTICS OF SPEEDS AS WELL AS THE RESULTS OF ANOVA TEST ON PC POINTS

Type	Daytime				Nighttime				ANOVA	
	V85	V50	V15	Variance	V85	V50	V15	Varianc	Statistic	p-value
PC	124.00	114.00	103.67	113.98	161.00	125.00	109.00	371.36	Yes	0.02
	124.00	113.75	100.00	106.23	113.50	104.00	97.50	49.88	Yes	0.05
	126.00	113.50	103.00	127.52	113.50	104.00	98.00	65.66	No	0.07
	145.50	115.00	105.00	517.48	149.50	115.00	105.50	463.73	No	0.11
	120.00	109.00	99.67	132.40	128.50	115.00	99.00	322.99	No	0.17
	131.00	115.67	103.00	203.38	149.00	120.00	103.50	558.90	No	0.43
	135.00	115.00	107.00	246.36	133.00	112.00	104.50	175.49	No	0.46
	130.00	111.00	103.00	181.04	122.50	110.00	104.00	100.46	No	0.47
	125.00	112.00	103.00	146.33	125.00	116.50	104.00	85.79	No	0.48
	132.00	115.33	104.00	140.34	128.00	112.00	97.50	195.51	No	0.61
	126.00	112.33	104.00	172.15	128.00	115.00	104.50	163.79	No	0.64
	125.00	115.00	102.00	191.75	121.50	112.00	102.00	96.10	No	0.70
	120.50	111.00	101.50	84.42	121.00	112.00	95.00	143.07	No	0.76
	114.33	105.67	98.00	289.89	111.50	101.00	92.50	104.99	No	0.81
	117.67	109.75	103.33	75.05	125.25	104.00	97.50	202.28	No	0.82
	123.00	111.50	104.00	80.86	121.50	113.00	103.25	68.22	No	0.87
	132.00	115.00	108.00	217.30	125.50	120.00	107.00	145.07	No	0.92
	124.00	111.00	104.00	119.92	127.50	108.00	100.50	172.71	No	0.93
	13	11	10	24	12	11	10	51	N	0.

TABLE 5 SUMMARY STATISTICS OF SPEEDS AS WELL AS THE RESULTS OF ANOVA TEST ON MC POINTS

Type	Daytime				Nighttime				ANOVA Results	
	V85	*V50*	*V15*	*Variance*	*V85*	*V50*	*V15*	*Variance*	*Statistically*	*p-value*
MC	123.00	112.0	101.50	119.50	125.00	117.00	105.75	65.16	Yes	0.04
	128.00	115.7	107.00	171.32	158.50	119.00	100.00	808.84	Yes	0.04
	130.00	113.5	104.00	269.82	128.50	111.50	97.00	145.36	No	0.07
	122.50	109.0	98.00	110.51	135.00	111.00	102.00	292.06	No	0.08
	133.00	119.0	108.70	185.07	139.00	124.00	112.00	393.73	No	0.14
	120.50	109.0	100.00	126.56	121.25	102.00	95.00	112.28	No	0.34
	119.00	108.5	99.33	100.35	124.50	107.00	102.50	116.10	No	0.43
	116.00	110.0	99.50	135.68	128.50	113.00	101.00	191.07	No	0.44
	133.00	114.0	104.00	171.15	131.50	110.00	98.00	321.16	No	0.46
	144.00	121.0	108.00	140.34	130.00	115.00	104.50	170.84	No	0.49
	122.00	111.0	104.00	112.97	116.50	109.50	105.00	35.88	No	0.50
	137.00	111.3	104.25	501.46	122.50	117.00	96.00	134.90	No	0.50
	130.00	110.6	103.00	182.10	128.50	115.00	103.00	107.17	No	0.70
	130.50	116.0	105.00	227.05	143.50	127.00	104.00	280.18	No	0.86
	114.00	104.5	97.00	65.84	115.00	103.50	98.50	51.61	No	0.91
	115.00	108.5	100.67	64.71	120.00	102.00	97.50	115.60	No	0.95
	142.00	115.0	104.50	215.37	123.00	119.00	108.00	121.73	No	0.95

TABLE 6 SUMMARY STATISTICS OF SPEEDS AS WELL AS THE RESULTS OF ANOVA TEST ON EC POINTS

Type	Daytime				Nighttime				ANOVA Results	
	V85	*V50*	*V15*	*Variance*	*V85*	*V50*	*V15*	*Variance*	*Statistically Different (Y/N)*	*p-value*
EC	126.00	112.00	100.00	227.07	123.25	114.00	104.00	87.51	Yes	0.01
	127.00	114.00	104.00	163.64	137.50	123.00	110.50	250.06	Yes	0.03
	126.00	112.00	102.00	145.01	129.50	120.00	113.50	73.16	Yes	0.03
	122.00	111.33	101.50	118.66	131.25	115.00	95.50	219.34	No	0.05
	143.00	120.50	110.00	247.38	126.50	117.00	100.50	118.89	No	0.11
	134.00	111.00	103.00	315.22	140.00	120.00	109.00	234.54	No	0.13
	122.00	112.00	99.00	139.62	127.00	117.50	104.50	110.62	No	0.20
	137.00	111.33	104.25	501.46	143.50	119.00	104.00	585.82	No	0.27
	117.00	109.00	101.00	87.17	120.00	113.00	104.00	44.01	No	0.30
	132.00	115.00	106.00	297.81	125.50	117.00	100.00	134.93	No	0.56
	130.00	113.33	103.50	209.19	133.00	118.50	104.50	150.40	No	0.58
	145.00	114.67	103.75	308.67	126.50	115.00	106.25	130.32	No	0.66
	132.00	116.50	106.33	259.71	140.00	115.50	98.67	491.42	No	0.71
	122.00	111.00	102.00	138.67	116.00	109.00	102.00	386.77	No	0.77
	114.00	104.33	97.00	65.84	118.50	99.00	95.50	163.16	No	0.86

The results of ANOVA show that, for most cases, there was no statistical evidence to reject the null hypothesis that the daytime and nighttime speed come from the same population. In other words, there is no evidence that daytime and nighttime speeds are different. The number of locations which showed a statistically significant difference in speed were 5, 2, 2, and 3 for MT, PC, MC, and EC points, respectively. It was also noted that the difference is not always in the same direction (i.e., nighttime speed is not always lower than daytime speed). These results might be explained by the generous design features of the highway where the minimum curve radius was 750 m, and a cross section that comprised four lanes per direction with a paved shoulder. Finally, for most of the locations, the 85th percentile speed was higher than the limit speed of 120 km/hr. This can be attributed again to the generous design of the highway, good pavement conditions, favorable weather, and lighting conditions along with the lack of proper speed enforcement on the highway.

6. VI. DEVELOPMENT OF OPERATING SPEED MODELS

One of the objectives of this research is to develop operating speed models for multilane highways in Egypt in daytime and nighttime. Based on the previous analysis, it was found that there is no significant difference between speeds during daytime and nighttime. As such, it was decided to develop operating speed models using the data collected in daytime only. Using daytime data for model development enabled the inclusion of Katameya - Ain El Sokhna data which increased the available sample size.

The relationship between operating speed and geometric and weather variables was assessed using correlation analysis and stepwise linear regression models. The correlation analysis enabled gaining a general overview of the most influential factors on speeds as well as how strong the relationship between the dependent and independent variables is. The correlation analysis was carried out for the four analysis points: MT, PC, MC, and EC. The results of the correlation analysis are shown in Table 7.

TABLE 7 CORRELATION BETWEEN SPEEDS AND DIFFERENT VARIABLES

	V85				V50				V15				Speed Variance			
	MT	PC	MC	EC	MT	PC	MC	EC	MT	PC	MC	EC	MT	PC	MC	EC
TL1	0.05	-0.06	0.07	0.19	0.21	0.11	0.10	0.17	0.27	0.23	0.26	0.28	-0.12	-0.30	-0.08	-0.07
TL2	0.19	0.05	0.01	-0.04	0.27	0.10	0.05	-0.04	0.32	0.19	0.22	0.07	-0.11	-0.12	0.03	-0.10
Delta	-0.18	-0.11	-0.27	-0.13	-0.12	-0.02	-0.22	-0.08	-0.19	-0.06	-0.27	-0.17	-0.17	-0.01	-0.15	-0.11
CL	0.00	0.04	0.17	0.27	-0.01	0.07	0.06	0.22	-0.07	0.06	0.03	0.09	0.09	-0.01	-0.10	-0.08
CR	0.20	0.23	**0.35**	**0.43**	0.21	0.18	**0.25**	**0.43**	0.12	0.15	**0.30**	**0.42**	0.21	0.03	0.11	0.01
SW	-0.52	-0.40	-0.45	-0.46	-0.61	-0.52	-0.56	-0.62	-0.61	-0.62	-0.58	-0.55	-0.34	-0.11	0.11	-0.14
LW	**0.31**	**0.36**	**0.36**	0.36	0.20	0.22	0.31	0.35	0.03	0.08	0.13	0.15	0.43	0.42	-0.07	0.14
Temp	0.05	0.07	0.04	0.15	0.14	0.19	0.03	0.08	0.19	0.24	0.11	0.07	-0.04	-0.07	-0.33	0.11
Hum	-0.15	-0.19	0.05	-0.19	-0.24	-0.24	-0.01	-0.13	-0.25	-0.27	-0.09	-0.14	0.10	-0.11	**0.28**	-0.14
WS	0.17	0.14	0.19	0.16	0.08	0.01	0.30	0.20	0.13	0.02	0.19	0.20	0.02	0.01	-0.03	-0.16
LnTemp	0.05	0.07	0.04	0.15	0.14	0.20	0.04	0.09	0.19	0.24	0.12	0.07	-0.02	-0.07	-0.36	0.11
LnHum	-0.10	-0.17	0.07	-0.17	-0.21	-0.19	0.04	-0.10	-0.21	-0.23	-0.04	-0.11	0.12	-0.11	0.24	-0.14
LnWS	0.17	0.10	0.14	0.12	0.16	0.05	0.27	0.24	0.10	0.00	0.13	0.09	0.16	0.12	0.02	-0.04

The existing literature shows that the most significant variables that impact operating speeds typically include horizontal curve radius, curve length, deflection angle, number of lanes, among others. Nevertheless, the correlation analysis undertaken in our study showed very weak dependence between speed and other variables. As shown in Table 7, the correlation coefficient between any of the speed variables and geometric characteristics never exceeded 0.5. Apparently, the comfortable driving environment caused by the generous design led to very little variability in speed. A scatter plot of the relationship between V85 and curve radius on curve midpoint is presented in Figure 3. The figure shows that the V85 almost follows a horizontal line with a very mild slope. This indicates that the V85 is almost constant and only varies within a tight range.

To further examine the relationship between operating speed from one side and geometric design elements and weather variables from the other, stepwise regression was used to develop operating speed models. Four groups of operating speed models were developed for MT, PC, MC, and EC points. In all models, three dependent variables were used; 85th, 50th, and 15th percentile speed while covariates included geometric design and weather conditions in addition to a location-specific dummy variable (1 for Cairo-Alexandria Road, 0 Otherwise) and a marking condition dummy variable. The final models of the V85 are presented in Table 8 for the four analysis points: MT, PC, MC, and EC.
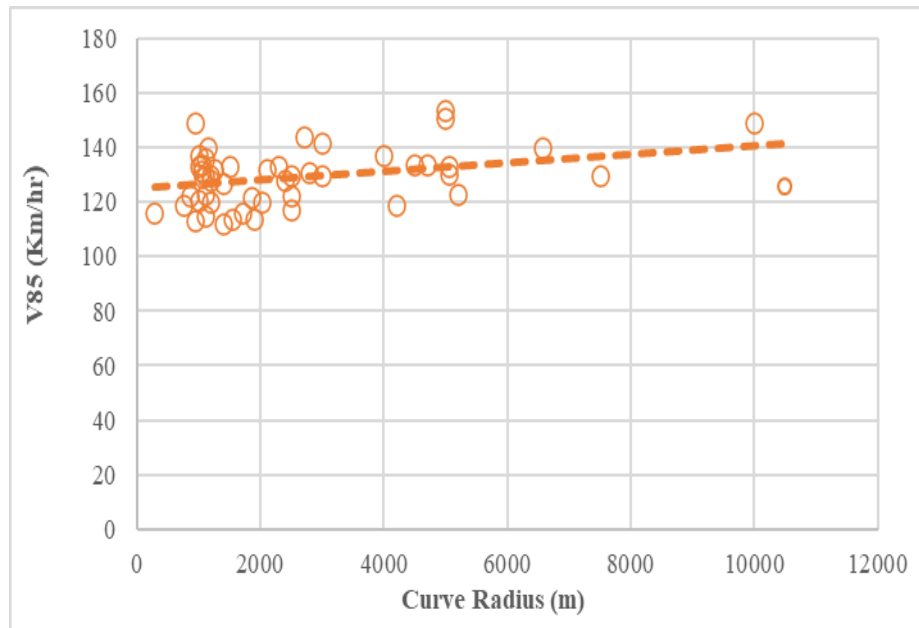
Figure 3 Relationship between Operating Speed and Curve Radius on MC.

TABLE 8 FINAL MODELS OF THE V85

	Tangent		PC		MC		EC	
	Coefficient	*T-Stat*	*Coefficient*	*T-Stat*	*Coefficient*	*T-Stat*	*Coefficient*	*T-Stat*
Base Speed (Constant)	157.515	26.25	67.487	1.98	64.053	1.62	144.568	21.27
TL1								
TL2								
Delta								
CL								
CR							0.002	2.75
SW	-9.080	-4.31	-4.982	-2.76	-6.378	-3.10	-6.877	-3.09
LW			20.046	2.29	22.238	2.19		
LnTemp								
LnHum								
LnWS								
Highway Dummy								
Marking Dummy								
Goodness of Fit Measures								
Number of Observations	51		53		51		48	
Root MSE	9.25		7.84		8.90		8.82	
Model R²	0.27		0.24		0.27		0.33	
Adjusted R²	0.26		0.21		0.24		0.30	
AIC	281.8		276.2		278.9		261.9	
BIC	231.1		223.9		228.4		214.3	

The models confirm the previous findings of no strong relationship between the speeds and the independent variables. Some of the coefficients even appear with illogical signs. For example, shoulder width (SW) appeared with a negative sign on Tangent's V85 model indicating that the 85th speed decreases when the shoulder width increases. Some geometric design variables such as first and second tangent length, deflection angel and curve

length were not included in any of the four models. Curve radius only appeared in the EC model with a very small coefficient of 0.002 which means an increase of 2 km/hr. in operating speed for each 1000 m increase in curve radius. All weather variables were shown to have no impact on speed which is intuitive. Weather is Egypt in the summer is always favorable (i.e., sunny and clear) with no impact on visibility or pavement surface condition. In all models, the coefficient of determination (R2) was less than 0.4 indicating weak relationship. All the other models where other speed parameters were used as dependent variables showed very similar results. As such, the developed models were deemed inappropriate and cannot be used to express a solid relationship between operating speed and other variables.

7. SUMMARY AND CONCLUSIONS

In this study, a comparison is made between daytime and nighttime speeds on a rural multilane highway in Egypt. Several criteria were specified to select the most suitable roads for data collection. Two major multilane highways were selected namely Cairo- Alexandria Desert Road and Katameya - Ain El Sokhna Road. Geometric data was collected via road trips while using in-vehicle GPS devices with a data collection resolution of one second. The data was then used to plot best-fit curves and accordingly extract geometric design information. The security clearance did not allow for nighttime data collection on Katameya - Ain El Sokhna Road. As such, daytime speed data was collected on the two highways while nighttime data was only collected on Cairo - Alexandria Desert Road. Spot speed data was collected using a speed gun for four different points; mid-tangent, point of curve (PC), mid-curve point (MC), and end of curve points (EC). The collected speed data was supplemented by weather information collected using a mobile application. The collected spot speeds were used to calculate the main speed parameters; 85th percentile speed, 50th percentile speed, 15th percentile speeds, and speed variance. An analysis of variance (ANOVA) was used to test whether daytime and nighttime speeds are statistically different on the four analysis points. The results showed that, for most curves, there was no difference between daytime and nighttime speeds. These results were attributed to the generous design elements of all curves and good weather conditions. An attempt was made to develop operating speed models for daytime using the data collected on the two highways. Correlation and stepwise regression analyses were employed, and both showed very little dependence of speed on geometric design and weather variables. Again, this was explained by the high-standards of the design (e.g., large radii, large curve length, wide lanes and shoulders, and good pavement conditions) as well as clear-favorable weather. The results of models' developments were deemed inconclusive, and more data is needed with a wide range of design values to show how operating speed could be impacted by lower design standards and pavement conditions. An ongoing data collection effort is currently in place with focus on roads with these characteristics. The modeling effort will be repeated once these data become handy.

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