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Application of Artificial Intelligence Techniques for Developing Operating Speed Models for Rural Multilane Highways in Egypt

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ملخص البحث

يعتبر عدم التناسق بين السرعة التشغيلية والسرعة القانونية للطرق هو أحد عيوب الطرق في مصر، مما يؤدى الى عدم التناسق بين عناصر الطريق المتتابعة. لذلك تستخدم طرق التصميم المبنية على السرعة التشغيلية لتقييم تناسق التصميم. قامت عدة أبحاث بدراسة السرعة التشغيلية، ولكن تعرض القليل منها للطرق متعددة الحارات. وقد تم بناء معظم نماذج السرعة التشغيلية باستخدام طرق تحليل الانحدار، والتي عانت من عيوب الافتراضات الغير صحيحة جزئيا.

الهدف من ذلك البحث هو بناء نماذج للسرعة التشغيلية للطرق الخلوية متعددة الحارات في مصر، باستخدام أساليب الذكاء الاصطناعي في المنحنيات الافقية والقطاعات المستقيمة، ودراسة تأثير زيادة السرعة القانونية على بعض الطرق. في سبيل ذلك، تمت دراسة 69 قطاع من طريقين خلويين تم رفع كفاءتهم حديثا وأربع طرق خلوية أخرى لم تتم رفع كفاءتهم بعد. في كل قطاع تم جمع بيانات السرعات عند منتصف المنحنى ومنتصف القطاع المستقيم. وُجد ان العوامل المؤثرة على السرعة التشغيلية هي زاوية الانحراف، نصف قطر المنحنى، عرض الرصف، السرعة القانونية، ومتوسط تعدى السرعة القانونية ($V_{exceeeding}$). كما وجد أيضا ان طريقة الشبكات العصبونية تفسر بطريقة أوضح تأثير العوامل ولها قدرة أفضل على التنبؤ بالسرعة التشغيلية.

Abstract:

One of the shortcomings of roads in Egypt is that posted speed and operating speed are not consistent. This may lead to potential inconsistencies among successive sections of a road. So, the operating speed-based method is popularly used for examining design consistency. Numerous studies have been completed on rural two-lane highways for predicting operating speeds. However, little is known for rural multilane highways. Most of the developed operating speed models were based on linear regression models which have some drawbacks such as the flawed assumption of data independence.

The main objective of the current research is to develop operating speed models for rural multilane roads in Egypt using Artificial Neural Network modeling techniques for curve sections and straight sections and to figure out effect of raising posted speed in the new developed multilane roads. A set of 69 sections from two newly upgraded multilane rural roads and four multilane rural roads that did not undergone upgrade works recently. In each section, spot speeds were collected at the middle of the horizontal curve and at the middle of the straight section.

It was found that significant parameters are deflection angle, curve radius, pavement width, posted speed and $V_{exceeding}$. In addition, it was revealed that neural network explains the effect of parameters on operating speed more clearly than regression models with higher predictive power.

Key Words: Operating Speed, Operating Speed Models, Posted Speed, Design Speed Artificial Intelligence, Neural Network.

INTRODUCTION

Speed is considered one of the most important factors assessing the efficiency of a certain route by road users. Other factors such as travel time, route length, traffic volume, and level of service might have a role in drivers' decision to choose a route to reach their destinations. For that reason, designers take into consideration speed as a key to choose route and geometric elements' characteristics so that the designed road could meet a significant level of service which fulfill road users' requirements.

Different types of speeds are used in highway and transportation engineering: design speed, operating speed, and posted speed. Operating speed has many definitions that might differ from each other, but AASHTO, 2011 renders its definition as follows "*it is the speed at which drivers are observed operating their vehicles during free-flow conditions.*". The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature.

Design consistency is deemed an important factor by which highways could be evaluated on safety grounds. The most used criteria for evaluation of highway design consistency are based on evaluation of operating speed (Lamm & Choueiri, 1987). The concept of design consistency dictates that the variations in operating speed between successive elements have to be as minimum as possible. To keep design consistent, a design speed selection procedure was proposed by Andueza, (2000) and Harwood et al., (2000) based on keeping speed differential between design speed and operating speed as minimum as possible. Therefore, there is a need for developing operating speed prediction model.

As most of the developed operating speed models were based on regression models (usually linear) through which researchers assume some relationships and test the satisfaction of the assumption. It could be useful to apply other techniques such as the artificial intelligence (AI) methods to develop operating speed model.

As the Artificial Neural Networks (ANNs) is an AI technique used all over the world for pattern recognition, higher predictive power, and development of models that are difficult to be built using traditional statistical techniques (Semeida, 2013), it is necessary to assess the use of this methodology to predict the operating speed in this research.

LITERARTURE REVIEW

Most of operating speed models were developed using traditional regression models and artificial neural network techniques. However, used parameters were different from one model to another. It was apparent that most of the models used horizontal geometry parameters (curve radius, deflection angle, lane width, pavement width) (e.g. Krammes et al., 1993 ; Semeida, 2013). Posted speed limit (e.g. Stokes R. et al., 1998; Singh et al., 2011) also was found to have statistically significant effect on operating speed.

Dixon et al., (1999) tackled the effect of raising the posted speed limit on the vehicles' speed in rural multilane in Georgia. It was found that the observed mean speed was increased by 3.2 mph after raising posted speed limit from 55 mph to 65 mph. A hypothesis was drawn when more time is given to adjust to the higher regulatory conditions, mean speeds will likely continue to increase. However, mean speed will not exceed design speed otherwise traffic safety will be negatively affected.

Jessen et al., (2001) and Schurr et al., (2002) modeled operating speeds of passenger cars on tangents and horizontal curves in Nebraska. For tangents, the authors stated that the approach grade and average daily traffic negatively impacted vehicle's speed. However, the posted speed had the most influence on operating speed. While at midpoint of horizontal curve, it was observed that most influencing factors on operating speed were longitudinal grade, curve length, and deflection angle. Although, the authors used annual average daily traffic as a predictor in the model, the coefficient was very small. Consequently, it has been proved low influence of the annual average daily traffic and higher effect of PSL on the operating speed.

Fitzpatrick et al., (2000) conducted a research to study the factors that affect driver's speed on suburban arterials. Both curved and straight sections are studied. In curve sections, it was found that road alignment properties (curve radius and deflection angle) were responsible for about 21.1 percent of speed variation, while cross section (median presence) was held accountable for 24.1 percent of speed variation. On the other hand, alignment properties (downstream distance to control) in straight section were responsible for about 17.3 percent of speed variation, while cross section (average lane width) was responsible for 24.9 percent of speed variation.

Ali et al., (2007) studied the interrelationship between the free flow speed, posted speed limit, and geometric design variables along 35 four-lane urban street segments in Fairfax County, Virginia. The analysis revealed that land use, access density, and lane width proved to affect free flow speed significantly. Correlation analysis showed that posted speed, median width, and segment length had a significant effect on free-flow speed on urban streets. The coefficients of median width, segment length, and posted speed for the previous variables were +3.6, +13, and +2.1, respectively. This means that a positive correlation between these variables and operating speed was achieved.

Semeida, (2013) had generated Regression and ANN models for operating speed in Egypt to discuss the impact of highway geometry and posted speed on it. Through these models, it was concluded that the most influential variable on V_{85} is pavement width, followed by median width and side area. It was found that increase of pavement width from 6.8 m to 7.1 m increases 85th percentile speed by nearly 40 kph. Besides, it was revealed that existence of side area decreases operating speed. Side area demonstrated by adjacent land use or constructions, limits the road's right of way which consequently has a negative effect on the operating speed. Side area may be considered as a constraint for the drivers to exceed their speed which decrease the effect of posted speed on operating speed. However, the disadvantage of this research was that all the parameters were used in developing the model without correlation analysis prior to developing the model in an exhaustive technique.

Farrag, (2018) conducted a research to develop operating speed models for day-time versus night-time conditions in rural multi lane roads in Egypt. In this research, it was revealed that there is no statistically significant difference between vehicle mean speeds during day-time and night-time conditions at the midpoint of the horizontal curves and in straight sections. However, there was a significant statistical difference in speed variance between daytime and night time at both cases; midpoint of curve and straight sections. Consequently, free flow speeds in Egypt could be collected through all day as it is not affected by darkness.

Operating speed models based on literature are categorized into two categories; traditional regression models and Artificial Intelligence (AI) models. Neural network is most effective methods used in AI-based operating speed models.

McFadden et al. (2001), Mahmoudabadi (2010), Semeida (2013), and Semeida (2014) developed operating speed models utilizing both regression as well as ANN approach and using the same dataset. It was recorded through the above-mentioned studies that ANN's level of prediction power is higher than traditional regression approach. This is because regression cannot capture different patterns of data and cannot deal with nonlinear relationships.

From previous literature it was obvious that most used parameters to predict operating speed were curve radius, deflection angle pavement width, %violated, and posted speed. So, it will be helpful to collect data about these parameters to build the operating speed. Additional parameter (Vexceeding) was measured at each site to represent the behavior of drivers with posted speed. This parameter is the average speed differentials between violated vehicles' speed and posted speed

DATA COLLECTION

This paper used 69 curved section and 66 straight sections from six roads. These roads were divided into two categories:

- Category I: Cairo-Ain Sokhna Desert Road and Cairo Alexandria Desert Road. These roads were newly upgraded to be principal arterials according to national plan for roads development in Egypt. Design and posted speed were raised and trucks have separate service roads. These roads characterized by high radius of curves, wide right of way, and posted speed 120kph.
- Category II: Cairo Alexandria Agricultural Road, Cairo-Belbeis Desert Road, Belbeis Zagazig agricultural road, and Portsaid-Ismailia Agricultural road. All these roads had not undergone upgrade work since last years. Selected sections have posted speed in range of 30kph to 100kph. All agricultural roads characterized by limited right of way which decrease their operating speed.

Road geometric data were collected surveying the chosen roads by a car carrying a GPS navigator was planned to go through the road, particularly the lane with a uniform velocity. By mean of obtained coordinates form the navigator a best fit alignment for these points was made in an AutoCAD file. Then it becomes an easy to detect coordinates of the desired sections for spot speed data collection. Radius, length, and deflection angle of each curve was obtained. Lane width and pavement width were measured by tape before spot speed data collection step.

Spot speed data were gathered at mid of the curve and mid of straight section under free flow condition with a minimum headway of 5 sec. Radar gun was hidden in a vehicle which was pulled over on the right shoulder while the vehicle's engine hood was opened in order no to affect road users.

Based on following Equation the observer has collected a minimum of 40 free flow vehicle speeds.

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

Where :*S = Expected standard deviation (3-8kph)*

e = Acceptable error in the speed estimate (1-2kph)

In addition to the previous collected data, raw data from a previous research (Abdalla N. et. al. 2010) was handed over by Dr. Nasser Abdallah through a personal review with him in 2018. This data set was a collection of straight sections, horizontal curves, U-turns as well as upgrade and downgrade sections. At each section, vehicle speeds, curve radius, PCI, AADT, truck percent, and structural number were measured. As this research did not target tackling all of these data components, the data was filtered to be used side by side data collected in this research. U-turns, upgrades and downgrades (G>3%) sections, besides sections at acceleration and deceleration lanes were excluded. As shoulder width was not included, recent research could not involve shoulder width in model development stage.

Table 1 depict number of sections studied in each road, minimum and maximum radii, minimum and maximum straight length, and minimum and maximum operating speed.

Regression Analysis

Data collected were used to investigate relationships between operating speed and all the remaining parameters (radius of the curve, length for straight sections, lane width, number of lanes, pavement width, posted speed limit, $V_{exceeding}$, and %Violate) for Category I and Category II roads separately.

Table 1 Number of Sections Studied In Each Road, Minimum And Maximum Radii, Minimum And Maximum Straight Length, And Minimum And Maximum Operating Speed

Road name	Category	Surveyed sections length (Km)	Number of surveyed sections		Max.-Min radii (m)	Max.-Min. Length (m)	Max. – Min V_{85} (kph)
			Curved	Straight			
Cairo -Ain Sokhna Desert Road	Category I	100.4	34	33	10500-944	4655-328	155-113
Cairo Alexandria Desert Road	Category I	108	22	22	5050-468	11090-333	150-115
Cairo Alexandria Agriculture Road	Category II	50	9	11	1211-22	8030-150	100-59
Portsaid-Ismailia Agriculture Road	Category II	0.85	1	-	209	6000-2600	87
Cairo -Belbeis desert Road	Category II	0.5	2	-	300-155	Na	84-73
Belbeis Zagazig Road	Category II	0.1	1	-	70	Na	53
Total		286.5	69	66			

Simple linear regression was used to check the correlation between operating speed (V_{85}) and all the parameters at curved and straight sections separately in order to examine the affinity between dependent (operating speed) and independent (all remaining parameters) variables. The independent variables that have relatively high correlation values were introduced into the multiple linear regression models. Table 2, Table 3, Table 4, and Table 5 show correlation between operating speed and the parameters that have acceptable correlation (r>0.3) with operating speed and have low correlation (r<0.5) with each other. These variables are curve radius, pavement width, and posted speed in Category II roads. While in Category I roads, curve radius, lane width, %Violated, and $V_{exceeding}$ have high correlation with the operating speed. On the other hand, for straight sections, length of straight section, pavement width, posted speed, and $V_{exceeding}$ have high correlation with operating speed in Category II roads. While in Category I roads, shoulder width and %Violated have high correlation with operating speed. This proved that behavior of drivers in upgraded roads was affected by different parameters in curved sections and straight sections. Stepwise regression analysis will be adopted to select the most statistically significant variables.

Table 2 High Correlation Parameters for Curved Sections in Category I Roads

	V85	Curve Radius	Lane Width	%Violated	$V_{exceeding}$
V85	1.00				
Curve Radius	0.30	1.00			
Lane Width	0.36	0.30	1.00		
%Violated	0.91	0.25	0.36	1.00	
$V_{exceeding}$	0.66	0.28	0.32	0.42	1.000

Table 3 High Correlation Parameters for Curved Sections in Category II Roads

	V85	Curve Radius	PW	PSL
V85	1.00			
Curve Radius	0.35	1.00		
PW	0.70	0.22	1.00	
PSL	0.76	0.10	0.38	1.00

Table 4 High Correlation Parameters for Straight Sections in Category I Roads

Linear Correlation Table	v85	Shoulder Width	%Violated
v85	1.00		
Shoulder Width	-0.51	1.00	
%Violated	0.91	-0.55	1.00

Table 5 High Correlation Parameters for Straight Sections in Category II Roads

	V85	Straight length	PW	PSL	$V_{exceeding}$
V85	1.00				
Straight length	0.43	1.00			
PW	0.33	0.045	1.00		
PSL	0.310	0.46	0.34	1.00	
$V_{exceeding}$	0.32	-0.11	-0.04	-0.77	1.00

Stepwise linear regression was performed on the two categories and Equation 1, Equation 2, Equation 3, and Equation 4 represented as following:

$V_{85c} = 107.45 + 0.45$ %Violated $+ 0.593\ V_{exceeding}$ PSL=120kph $R^2=0.92$ …………………………... Equation 1

$V_{85c} = 14.863 + 3.496\ PW + 0.327\ PSL$ PSL<120kph $R^2=0.71$ ……………………………. Equation 2

$V_{85T}= 112.25+0.57$ %Violated PSL=120kph $R^2=0.82$ …………………………… Equation 3

$V_{85T}= -13.28+0.92\ PSL+2.75\ V_{exceeding}$ PSL<120kph $R^2=0.56$…………………………… Equation 4

Where:

- **V_{85C}: Operating Speed on Curved section**
- **V_{85T}: Operating Speed on Straight section**
- **%Violated: percent of drivers that exceed posted speed (%)**
- **PW: Pavement width (m)**
- **PSL: Posted Speed Limit**
- **$V_{exceeding}$: average speed deferential between PSL and vehicle speeds at that section**

Figure 1 and Figure 2 show actual versus predicted operating speed for curved sections and straight sections respectively. For Category I roads, in Equation 1 and Equation 3, as posted speed is not varied through the sample, it does not appear as a variable. High value of constant indicates that these variables cannot explain variation in operating speed. In addition, presence of positive sign for all variables releases that operating speed in these roads is always higher than 107.45 kph. Since, lane width in the developed roads was more than 3.6m, it has no sensible effect on the operating speed. However, posted speed limit effect and pavement width effect could not be figured out as all samples had same posted speed and almost same values for pavement width.

While for Category II roads, in Equation 2 and Equation 4, posted speed appears to have less influence in curved sections on operating speed than straight sections. However, pavement width has higher effect on operating speed of curved section that its coefficient is 3.5. Therefore, operating speed is affected by the narrower lane width in older roads. Lower coefficient of posted speed means that posted speed was not set in a correct way in these roads. In other words, posted speed has no relation with design speed. The disadvantage is that R-squared for straight section in low posted speed roads is low giving low accuracy for the model. This might be due to small data set for low posted speed roads.

Therefore, at high posted speed limit roads, operating speed has higher values as design speed was raised and was not a cause of raising posted speed. Presence of about 80% of drivers violated posted speed proves this finding. While for Category II roads, drivers' speed is affected by posted speed as well as pavement width. This returns to that; driver's speed is more related to cross section geometry than posted speed at low posted speed.

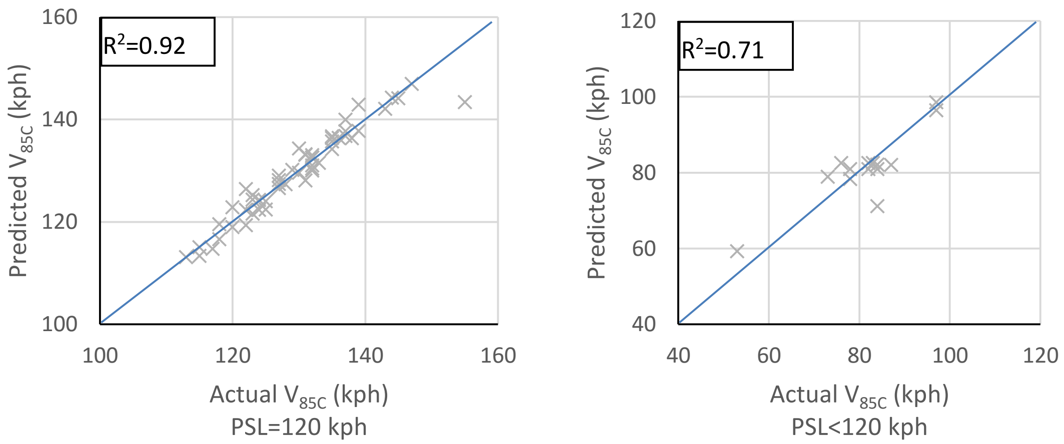

Figure** 1 **Actual Versus Predicted Operating Speed for Curved Sections in a) Category I Roads And b) Category II Roads

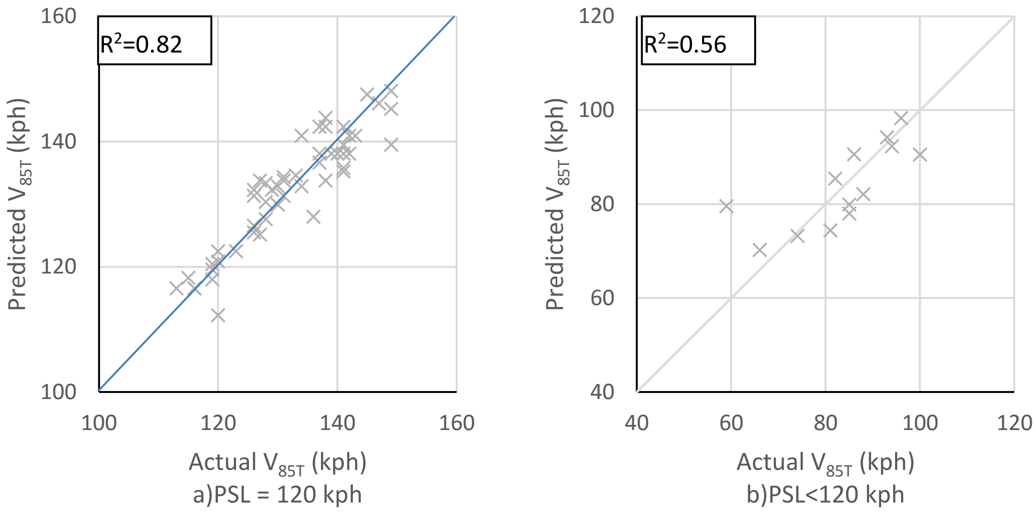

Figure 2 Actual Versus Predicted Operating Speed for Straight Sections in a) Category I Roads And b) Category II Roads

Neural network modeling

Usually neural network consists of input layer and output layer and number of hidden layers between them according to complexity of the problem. In this study one hidden layer is sufficient as dataset is relatively not big enough. The network used is a multi-layer feed forward neural network, a typical architecture of the network is shown in Figure 3. The number of nodes in input layer depends on independent parameters used for the network (4 nodes for curved sections – 3 nodes for straight sections), while only one node in output layer (V85).

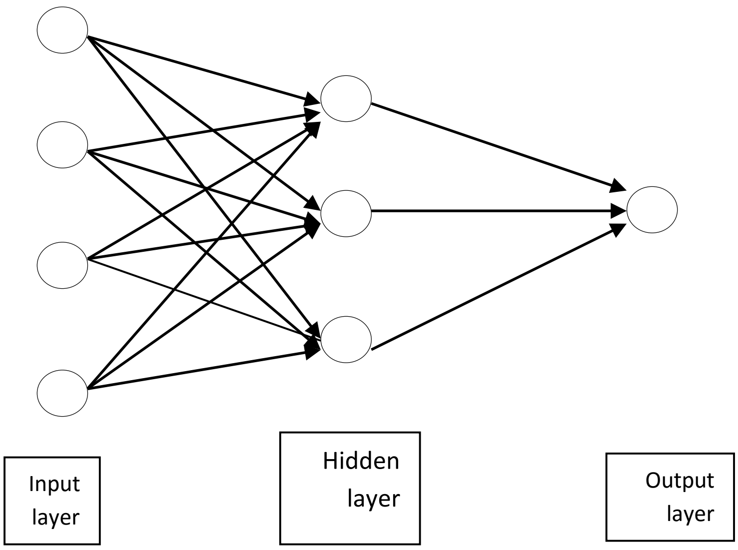

Figure 3 Architecture of Multi Layer Feedforward Neural Network

5.1 Approach

In this approach, roads datasets were assumed to be one dataset as neural network model needs large dataset to be developed. Variables that were chosen to build the networks were deflection angle, curve radius, posted speed, and $V_{exceeding}$ for curved sections. While for straight sections, posted speed, $V_{exceeding}$, and pavement width were chosen to build the network. All of these variables had suitable correlation high correlation with operating speed($r>0.3$) and correlation between them was relatively low ($r<0.5$). Percentage of training and testing was determined by trial and error. Best network for curved section model was 85% training and 15% testing with 5 nodes in the hidden layer. While for straight section model, best network was 90% training and 10% testing with 4 nodes in the hidden layer.

5.2 Neural Network Models Results

Table 6 demonstrates results of networks including root mean square error (RMSE), mean absolute error (MAE), and standard deviation of absolute error (STDAE) for horizontal curved sections and straight sections.

For horizontal curve model, the performance indicator MARE for the training dataset was found to be 1.83%. This trained model was tested for 10 sites (testing dataset) that were not used in the training process. The performance of this model for the testing dataset proved to be excellent, with a MARE value of 3.39% (96.61% degree of accuracy). The MARE value for all datasets recorded 2.05% (97.95 ≈ 98% degree of accuracy).

Table 6 Results of The Developed Networks for Horizontal Curve's and Straight Sections

		HZ Curve	***Straight***
Architecture		***4-5-1***	***3-4-1***
Training	***RMSE***	2.607	4.071
	MAE	2.072	3.091
	STD AE	1.582	2.650
Testing	***RMSE***	4.760	1.907
	MAE	3.336	1.662
	STD AE	3.395	0.933

While for the straight section model, the performance indicator MARE for the training dataset was found to be 2.55%, which implies that this model is well trained to calculate V85 with 97.45% average degree of accuracy. This trained model was tested for 7 sites (testing dataset) that were not used in the training process. The performance of this model for the testing dataset proved to be excellent, with a MARE value of 1.52% (98.48% degree of accuracy). Then model was tested for all sites to evaluate its overall accuracy. The MARE value for all datasets recorded 2.44% (97.56% degree of accuracy). Therefore, if this network predicts V85 = X kph, then the actual speed may lie within X [1 ± (overall MARE/100)].

Figure 4 shows predicted operating speed versus actual operating speed for horizontal curve and straight section model. It dictates that predictive power of that model is very high that R squared is 0.984 and 0.968 for horizontal curve and straight section model respectively which obviously exceeds the regression model results.

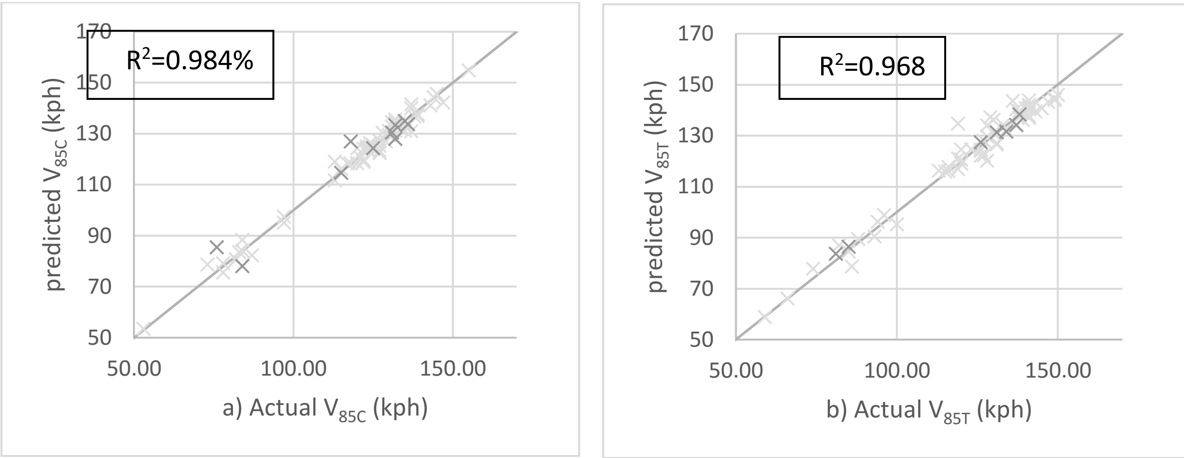

Figure 4 Actual Versus Predicted V85 for a) Curved Sections and b) Straight Sections

5.3. Sensitivity Analysis

5.3.1. Curved Sections Model

Figure 5 illustrates the variable impact analysis which shows relative influence of variables utilized in network on operating speed. It indicates that deflection angle has the greatest effect on operating speed relative to the remaining variables. Posted speed limit comes in the second order with only 5% difference in effect with a deflection angle.

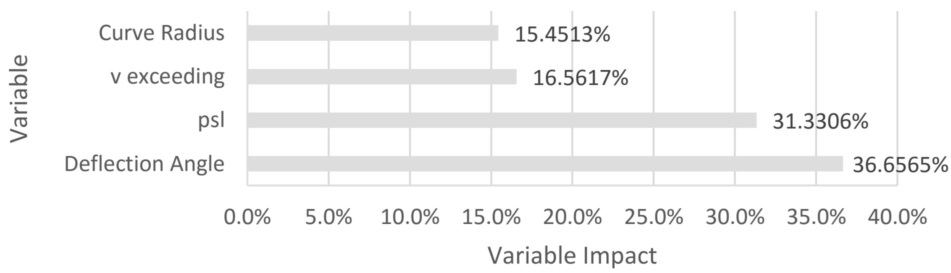

Figure 5 Variable Impact on Operating Speed of Horizontal Curves

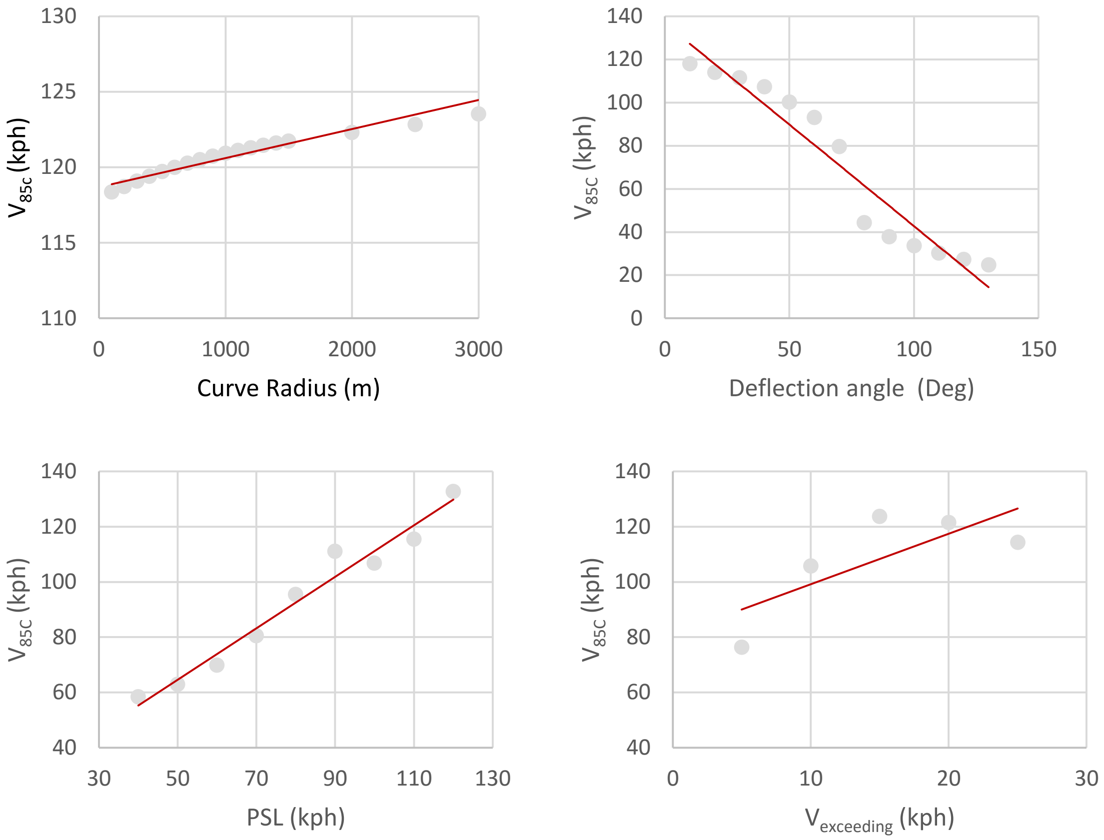

Figure 6 Relation Between Curved Section Operating speed and Variables

Figure 6 shows the relationship between each variable and operating speed on curved section. It shows that operating speed increase with the increase of curve radius, posted speed and Vexceeding. While for Deflection angle, Operating speed decreased as it increased. These findings are compatible to previous studies (McFadden et al. 2001, - Nie and Hassan 2007)

5.3.2. Straight Sections Model

Figure 7 illustrates the variable impact analysis which indicates the relative impact of variables used in network on operating speed. It reveals that PSL has the greatest effect on operating speed on straight sections and V exceeding comes in the second rank, while pavement width was the least.

Figure 8 shows the relationship between each variable and operating speed on straight section. It shows that operating speed on straight sections increase with the increase of posted speed, Vexceeding and pavement width. When pavement width increases from 11m to 11.5m, operating speed increases by almost 15 kph.

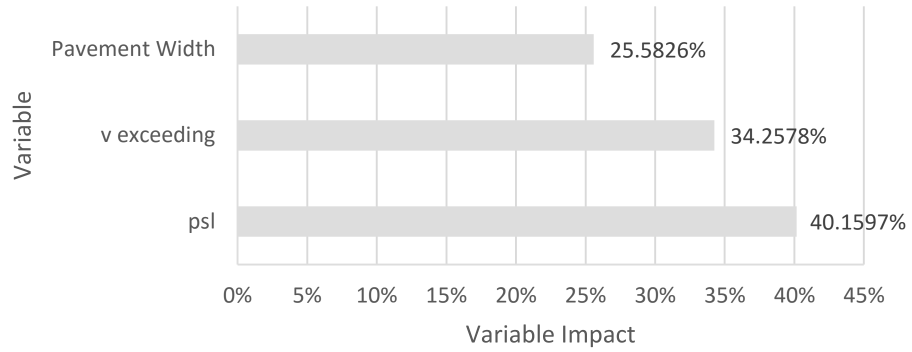

Figure 7 Variable Impact on Operating Speed for Straight Sections

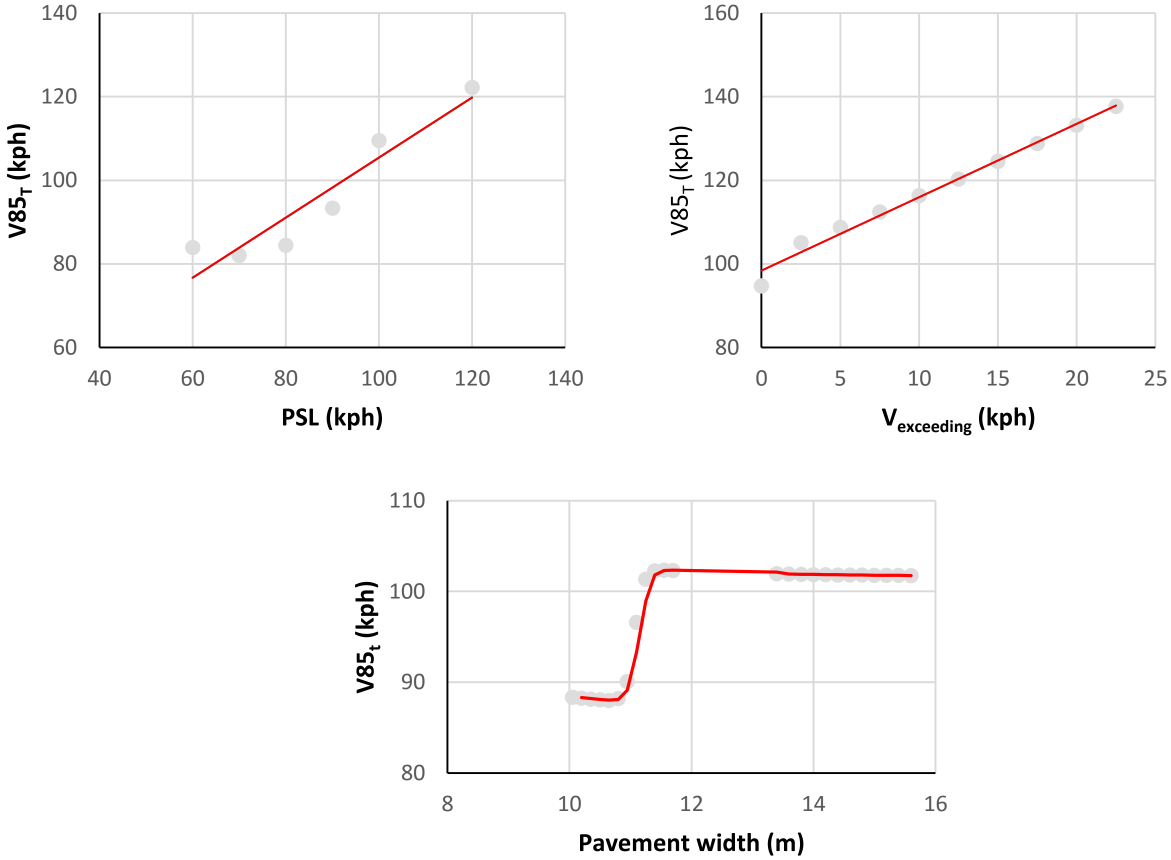

Figure 8 Relation Between Straight Section Operating Speed and Variables

Conclusion

This study examined speed characteristics in straight sections and horizontal curved sections for newly upgraded multilane rural roads and other multilane rural roads that did not undergone upgrade works recently in Egypt. The following results were concluded:

- Neural network model gives best results for predicting operating speed models with higher predictive power than regression models (R^2=0.984)

- It was revealed that neural network explains the effect of parameters on operating speed more clearly than regression models. Neural network considers the effect of variables which was considered insignificant by regression (e.g. deflection angle)

- By reviewing two main datasets, regression models proved that at PSL<120kph, posted speed has a greater effect on straight sections than on curved sections. Operating speed on curved sections are strongly affected by pavement width than posted speed. While in newly upgraded roads, operating speed is mostly affected by Vexceeding and %Violated drivers.

- As long as posted speed was not set inconsistent with design speed, percent of vehicle speeds that exceed posted speed limit were high even for high posted speed. This problem appeared in newly upgraded roads (e.g. Cairo Alexandria desert road) which needed higher posted speed closer to the design speeds and more strict speed enforcement to limit speed violation.

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