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Comparison between Trucks & Passengers Car by Reliability Theory Application to Highways Horizontal Curves Design in Egypt

[1]Alaa Ahmed Ali Ahmed, [2] Ibrahim Mohammed Ramada, [3]Ahmed Abd El Moamen Khalil, [4]Walid Ahmed Dawoud

[1]M.Sc in Civil Engineering , Faculty of Engineering at Shoubra –Banha University

[2]Associate Prof.Transportation &Highways Eng.-Civil Eng. Department Faculty of Engineering at Shoubra –Banha University

[3]Associate Prof.Railways & Transportation Eng.-Civil Eng. Department Faculty of Engineering at Shoubra –Banha University

[4]Assistant Prof .Geotechnical Eng.-Civil Eng. Department Faculty of Engineering at Shoubra –Banha University

مقارنة بين الشاحنات والسيارات الملاكى خلال تطبيق نظرية الموثوقية فى تصميم المنحنيات الأفقية للطرق السريعة فى مصر

الملخص :

تطبيق نظرية الموثوقية فى التصميم الهندسى للطرق أصبحت من الأمور الهامة فى امان النقل , فى الدراسات السابقة للمنحنيات الأفقية تم أخذ نموذج فى حالة انزلاق المركبات فقط. هذا البحث يوضح 3 نماذج رياضية مستخدمة فى تطبيق نظرية الموثوقية فى تصميم المنحنيات الأفقية وعمل مقارنة بين نتائج الشاحنات والسيارات الملاكى باستخدام الثلاث نماذج. النموذج 1 فى حالة الانزلاق فقط للمركبات والنموذج 2 فى حالة الأنزلاق مع الأنقلاب والنموذج 3 فى حالة الأنقلاب فقط. وأوضحت الدراسة خلال 7 منحنيات للطرق السريعة فى القاهرة الكبرى بمصر , أن نتائج الشاحنات والسيارات متقاربة جدا فى احتمالية تخطى حد الأمان الخاص بتحديد الموثوقية. مما يعنى أن أنصاف الأقطار ءامنة للنوعين.

Abstract:

Reliability-based analysis of road geometric design has been reported in literatures as a trend in transportation safety study. In the reliability analysis of a horizontal curve, the performance function is usually formulated as a function of the failure mode of vehicle skidding only. This paper takes into account the failure modes of vehicle skidding and rollover in formulating the performance functions of cars and trucks, respectively. A comparative study of three different performance functions for calculating the probability of vehicle failure modes is conducted. The results qualitatively show that trucks are more nearly of skid and rollover with on wet pavement. A vehicle's is greatly influenced by vehicle suspension and roll motion.

A sensitivity analysis investigating the influences of vehicle parameters and super elevation on vehicle skidding and rollover follows is done. The probability of failure for the radius from 700m to up by AASHTO at various super elevations and design speeds were more safe design.

Keywords: Reliability- Horizontal curves- Highway safety

1. Introduction

Existing geometric design guides, such as the *AASHTO Green Book (AASHTO, 2011)*, the Canadian design guide by the Transportation Association of Canada (TAC, 1999) and the Egyptian code for urban and rural roads are deterministic and give design requirements using conservative percentile values for uncertain design inputs to account or uncertainty. This deterministic approach For highway design has two main shortcomings (*Ismail and Sayed, 2010*).

Appropriate design of geometric elements in roads is an important feature for safety measures. The stopping sight distance (SSD) and the radius (R) of the horizontal curve are the most important geometric elements at the horizontal curve section. Both SSD and R increase with the increase in speed. However, the available sight distance (ASD) at site can be regulated by varying R and middle ordinate (M) at the curve section. Also, both ASD and R at any given curve section are fixed quantities which are associated with safe movement of vehicles (*Rajbongshi and Kalita,2018).* This study evaluates 7 horizontal curves in great Cairo, Egypt, for the available curve radius of the existing curves by comparing it with the required curve radius, from No.1 to 5 for Ring Road and No.6,7 for Alex. Cairo Road as shown in figure 1,2. Noncompliance occurs whenever the required curve radius exceeds the available curve radius. The inputs of the required radius are the operating speed, the lateral friction and the superelevation. Both of the operating speed and the lateral friction are random variables and the superelevation is deterministic and its value is determined

from data collection. The mean of the lateral friction is obtained based on the previous model and the standard deviation is assumed based on the recommendations of the previous studies. However the mean and the standard deviation of the operating speed are obtained based on spot speed data collected at sites. On another hand the available curve radius is deterministic.

Fig(1): Horizontal Curves Studied in Ring Road

Fig(2): Horizontal Curves Studied in Alex.Cairo desert Road

2. Literature Review

Providing an efficient and safe transportation system for road users is a principal objective of transportation engineers. However, hundreds of thousands of people are injured or die from traffic accidents every year. A roadway system consists of the driver, the vehicle, and the road environment. Accidents result from any of these components or a combination of them. Statistics show that the road environment factor is one of factors causing accident, contributing to 30% of accidents (*Sayed et al. 1995*), as shown in Fig.3 As a result, diagnosing deficiencies and improving roadway curve design, including providing adequate sight distance and superelevation, provides an effective way to reduce crash rates.

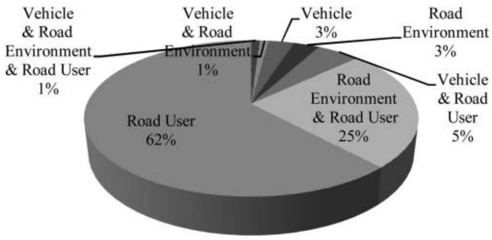

Fig. (3): Attribution of accident responsibility (data from Sayed et al.1995)

Currently, the deterministic method is used in roadway a geometric design. Design requirements are based on a geometric design guide, such as the AASHTO Green Book (2011), which provides deterministic standards (e.g., the minimum radius for the curve to prevent vehicle skidding). Road designers assume that roads meeting current roadway design standards are safe, which is nominal safety. However, several researches have criticized the current roadway geometric design standards for being incapable of providing sufficient safety for road users under certain circumstances (Lamm and Smith 1994; Harwood and Mason 1994; You et al. 2012; Sun et al. 2011) and for providing little knowledge on the safety implications of deviating from standard requirements (Ismail and Sayed 2010). In the roadway design process, many design variables are stochastic in nature, such as vehicle speed, friction coefficient, perception, and brake reaction time (PRT) which involve different levels of variability and uncertainty (Ismail and Sayed 2009). Ignoring stochastic characteristics in current roadway geometric design procedures is detrimental to the capability of providing sufficient consideration for traffic safety (Ismail and Sayed 2009).

The deterministic approach to roadway geometric design also cannot provide an explicit safety margin of design output and value to be targeted (Ismail and Sayed 2010). Reliability-based analysis considers design variables as random. This approach overcomes the previous drawbacks and has widely been used in structural safety (Melchers 1999) and water supply (Li et al. 1993). Navin (1990, 1992) is one of the pioneers, who introduced the concept of reliability analysis into roadway geometric design by outlining a method to estimate the margin of safety as a reliability index for isolated roadway components. The reliability theory is not only useful for the road design stage but also can be used as a risk analysis tool for the road operation stage to diagnose the safety problems (Zheng 1997). The following research in the reliability-based risk analysis of roadway geometric design primarily focuses on two aspects: Stopping sight distance design and horizontal curve design, which is restricted to single design elements, such as the radius of a circular horizontal curve and stopping sight distance. In the reliability analysis of sight distance design. Richl and Sayed (2006) applied first-order reliability analysis for studying the sight distance restriction caused by median barriers on horizontal curves. El Khoury and Hobeika (2007) applied a Monte Carlo simulation to calculate the probability of a passing sight distance limitation; the risk index based on the value of the clearance time between the passing and the opposing vehicles was proposed to measure the risk level of passing maneuvers.

Sarhan and Hassan (2008) applied a Monte Carlo simulation to calculate the probability of three dimensional (3D) sight distance limitations in the design of horizontal curves overlapping with flat grade, crest curve, and sag curves. A probability of hazard (POH) was proposed in the study, which refers to the probability that the design does not satisfy the standard requirement. The study indicated that the current deterministic approach yields very conservative estimates of available and required stopping sight distance, resulting in a very low POH.

The proposed study was unique because a reliability analysis was recommended as the only valid quantitative analysis of road safety and was accepted by the project owner. *Ibrahim and Sayed (2011)* conducted the research to make the link between the safety measures based on reliability analysis and the measures based on cash frequency. Total, severe, and property damage only collisions of three safety performance functions, incorporating the probability of noncompliance, were developed. The study showed that predicted collisions have a statistically significant positive relationship with the probability of noncompliance. In the reliability analysis of horizontal curve design, *Emmanuel (1996)* and *Zheng (1997)* applied a reliability analysis to curve radius design based on the failure mode of vehicle skidding without involving roll motion.The stopping sight distance (SSD) and the radius (R) of the horizontal curve are the most important geometric elements at the horizontal curve section. Both SSD and R increase with increase in speed. However, the available sight distance (ASD) at site can be regulated by varying R and middle ordinate (M) at the curve section. Also, both ASD and R at any given curve section are fixed quantities which are associated with safe movement of vehicles (*Rajbongshi and Kalita,2018)*.

Easa et al. (2016) demonstrates the application of multi-mode reliability analysis to the design of horizontal curves. The process is demonstrated by a case study of Sea-to-Sky Highway located between Vancouver and Whistler, in southern British Columbia, Canada.

Osama El shotairy,Ibrahim Hashim and Ahmed Abu El-maaty (2019) presented evaluation of 12 horizontal curves for two way two lane highway and The results showed that about 85% of studied curves have probability of non-compliance (Pnc) less than 10% for ASD and The results showed that about 85% of studied curves have probability of non-compliance (Pnc) less than 10%.

4. Reliability Theory

Reliability is defined as the ability of a system or component to perform its required functions under stated conditions for a specified period of time *(Kottegoda and Rosso 1997).*

A design situation can be described mathematically in terms of a performance function

$$Z = G(x_1,x_2,x_3,\ldots..,x_n) \qquad (1)$$

where X =($x_1,x_2,x_3,\ldots..,x_n$) = N-dimensional vector of design variables. Noncompliance or failure to meet some criteria of the system will be indicated by all those combinations of the variables. The case of Z < 0 corresponds to demand exceeding supply, whereas the case of Z > 0 corresponds to performance as intended or survival of the system. The case of Z= 0 describes a limit state between survival and failure. Accordingly the probability of failure is given by

$$p_f = \int_{G(x_1,\ldots,x_n)<0} \cdots \int f_{X_1,\ldots,X_n}(x_1,\ldots,x_2)dx_1,\ldots,dx_n \qquad (2)$$

where f $_{x1,\ldots xn}$ (x1 , ….,xn) = joint probability function of the input variables(x1,…,xn) The corresponding non failure probability is

$$r = \int_{G(x_1,\ldots,x_n)>0} \cdots \int f_{X_1,\ldots,X_n}(x_1,\ldots,x_2)dx_1,\ldots,dx_n \qquad (3)$$

In a simple two-variable system, the performance function Z is written as

$$Z=G(X,Y)= X- Y \qquad (4)$$

where variable X = supply; and Y = demand, so the safety and failure of the system are represented by two regions in the plane(X, Y) as shown in Fig. 4(a).

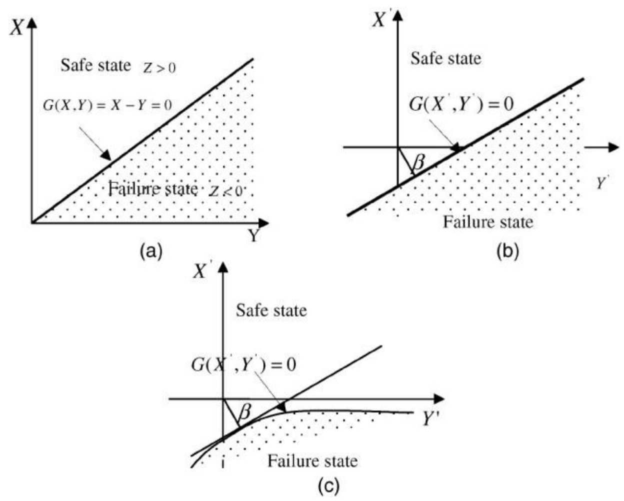

Fig. (4): Failure state, safe state, and limiting state of interest

The reliability index of a system is denoted by β, when X and Y are normally distributed; β is defined as the ratio between the mean and standard deviation of the safety margin of the system:

$$\beta = \frac{E(X) - E(Y)}{\sqrt{\mathrm{Var}(X) + \mathrm{Var}(Y)}} \qquad (5)$$

where β = reliability index; E(X) and (Y) = expected values of the supply and the demand, respectively; and Var(X) and Var(Y) = variance of the supply and the demand, respectively.

In a reduced coordinate system, as shown in Fig. 4(b), the shortest distance from the origin to the line G(X', Y')= 0 is equal to the reliability index β, which can be extended to any performance function in linear form; However, if the limiting state is a nonlinear function of reduced variables, it does not hold for a strictly monotonic G(X', Y')= 0, and the reliability index β corresponds to the shortest distance from the origin, as shown in Fig. 4(c) (*Kottegoda and Rosso 1997*).

5. Reliability Analysis of Horizontal Curves

Reliability analysis for horizontal curve design can be interpreted as follows. When a vehicle travels along a circular horizontal curve with the radius of R, it is subjected to a centrifugal force acting at the center of gravity of the vehicle outward from the center of the circle. The higher the speed of vehicle, the greater the lateral force will be. The radius of the circular curve thus represents supply, denoted by RS. The demand can be represented by radius RD, which is the value demanded by the driver to make the vehicle stable along the road centerline when the vehicle is traveling on the curve at speed V. The performance function in this case can be written as Z = G(RS, RD)= RS - RD. The failure model is stated as RS - RD < 0.

6. Performance Function uses for Reliability

This study focuses on three modes of noncompliance in horizontal curve design for the radius according to skid without roll ,with rool and rollover . the mode of noncompliance occurs when the required horizontal curve radius ($Rdemand$) exceeds the available horizontal curve radius (Rav). Figure (5) shown that.

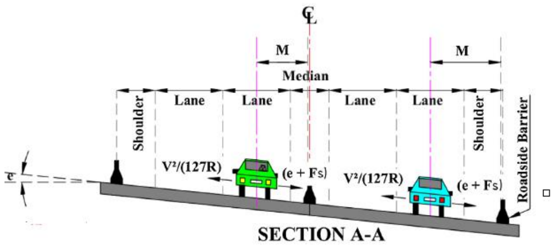

Fig.(5): Horizontal curve design elements used in the analysis

6.1 The first mode accorording to Radius of Horizontal Curve

Mode 1, Failure Mode of Vehicle Skidding without Involving Roll Motion Effect As shown in Fig. 6, a vehicle travels along a circular curve with the radius of R and superelevation of e. The variable W is vehicle weight; Fzo and Fzi are normal forces of the inner wheel and outer wheel, respectively; FYi and FYo are friction forces of the inner wheel and outer wheel, respectively. The minimum radius demanded by the vehicle can be given by Eq. (6) using Newton's laws of motion (*Emmanuel 1996*):

$$R_D = \frac{V^2}{g(e + f_y)} \qquad (6)$$

The performance function of the failure mode of vehicle skidding without involving roll motion effect is given by

$$Z_1 = G_1(X) = R_S - \frac{V^2}{g(e + f_y)} \qquad (7)$$

where f y = lateral friction coefficient; and V = operating speed of vehicle.

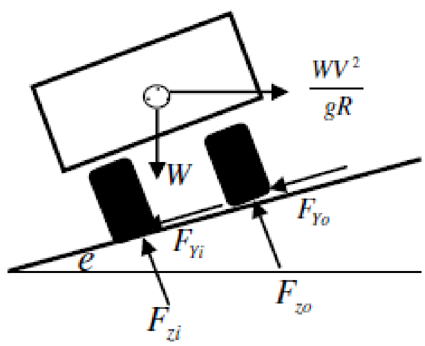

Fig. 6: Vehicle in superelevated horizontal curve

Mode 2, Failure Mode of Vehicle Skidding Involving Roll Motion Effect

Chang (2001) used a deterministic method to investigate the minimum radius computed from the vehicle model with a suspension system to compare with the minimum radius recommended by AASHTO. The same vehicle model is used in this study to establis the performance function of the failure mode of vehicle skidding involving roll motion effect. As shown in Fig. 7, the vehicle consists

of sprung mass and unsprung mass. When it travels on the circular curve, the sprung mass will experience a roll motion with respect to the roll center O. Based on the laws of physics, the demand of radius to avoid vehicle skidding is described as

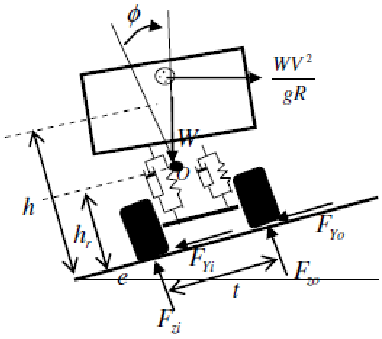

Fig. (7): Vehicle with suspension in superelevated horizontal curve

$$R_D = \frac{V^2}{g[(1-\frac{h_r}{h})e + f_y]}\left[1 + R_\theta\left(1 - \frac{h_r}{h}\right)\right] \qquad (8)$$

where h = height of center of gravity above the ground; hr = height of the roll center above the ground at the longitudinal center of gravity location; and Rθ = roll rate (rad⁄gravity), expressed by Eq. (9):

$$R_\theta = \theta / a_y \qquad (9)$$

where ay = lateral acceleration; and θ = roll angle.
The performance function of the failure mode of vehicle skidding involving roll motion effect is given by

$$Z_2 = G_2(X) = R_S - \frac{V^2}{g[(1-\frac{h_r}{h})e + f_y]}\left[1 + R_\theta\left(1 - \frac{h_r}{h}\right)\right] \quad (10)$$

Mode 3, Failure Mode of Vehicle Rollover

Vehicle rollover is one of the most common types of vehicle accidents, especially for vehicle with a high center of gravity, such as a sport utility vehicle (SUV) or truck. The vehicle experiences a lateral load transfer from inner wheels to the outer wheels when traveling on the curved road. As a result, vertical forces Fzi of the inner wheel roads declines. Once the two wheels lift off, vertical forces Fzi will diminish to zero, and rollover then easily occurs (*Taehyun and Chinar 2007*).

Assume that the vehicle moves on a curve of a radius R and superelevation e. External forces acting on the vehicle are also shown in Fig. 5. Considering the equilibrium of moments about the outer tire–pavement contact point, the following is obtained:

$$F_{zi}.t + \text{Weh} - \frac{WV^2}{gR}h - W(h - h_r)\phi = 0 \qquad (11)$$

where Fzi = vertical force of the inner wheel; t = track width; W = weight of the vehicle; h = height of the center of gravity above the ground; hr = height of the roll center above the ground at the longitudinal center of gravity location; and Rθ = roll rate (rad/g).

When two wheels lift off, the vertical force Fzi is equal to zero, and the demanded radius to avoid vehicle rollover is calculated as

$$R_s = \frac{V^2}{g[e + \frac{t}{2h}]}\left[1 + R_\theta\left(1 - \frac{h_r}{h}\right)\right] \qquad (12)$$

The performance function of vehicle rollover is thus given by:

$$Z_3 = G_3(X) = R_S - \frac{V^2}{g[e + \frac{t}{2h}]}\left[1 + R_\theta\left(1 - \frac{h_r}{h}\right)\right] \qquad (13)$$

7. Data Collection Program

7.1 General

The objective of this part is to explain the process that has been followed in the data collection. Therefore, this part contains an explanation of the traffic survey procedure using a digital camera, considered hump in the study, computations used in data processing.

7.2 Traffic Survey Procedure

The traffic was recognized in video films by digital camera. This camera was supported on that tripod in fixed locations. The recorded observation has been carried out along holiday days. Moreover, the vehicles motion was recorded for one as out of peak, from 10.00 am to 11.00 am.

7.3 Considered Horizontal Curves in the Current Study

As the rural freeways highways were targeted by the study, a pilot survey had been carried out for the existing horizontal curves in the scoped roads in Greater Cairo. Results of this survey are listed in Table 1. This survey was aimed to detect the most suitable horizontal curves to study evaluation the safety of available radius (R_{av}) .Based on results of this survey, 7 horizontal curves were chosen to be studied lies in Ring highway(no 1 to 5), Alex. Cairo highway (no 6,7).

NO	lanes	Shoulder Width (m)	R (m)	e %	Δ^0	L (m)
1	8	2.50	700	6	105	1283
2	8	2.50	800	5	72	1000
3	8	2.50	1000	4	34	600
4	8	2.50	1250	3.5	57	1240
5	8	2.50	2000	2	60	2070
6	6	12.50	1000	5.6	54	950
7	6	12.50	750	6	77	1000

Table 1: Statistical Summary of Data Set of horizontal curves studied

7.4Data Processing

Video tapes were processed using computer, the data had been recorded for each vehicle when it is crossing stations from the beginning to the end of 9 horizontal curves. In particular, the data were collected while processing the video tapes are the time between each two station (PC and PT of curve) in out of peak. The collected data was arranged in spread sheets to be prepared for analysis.

7.5 Computations used in data processing

The collected data from the camera was gathered in Excel sheets and then processed in order to obtain the operating speed. The adopted procedure to get the three parameters is discussed in the following sections.

7.5.1 Operating Speed Calculation (V)

In characterizing the speed of a traffic stream, the mean speed is used It is the most statistically relevant measure in relationships with other variables, (*HCM2011*). Space mean speed is computed by dividing the length of the highway section by the average travel time of vehicles traversing it. Travel time (T) of each vehicle is calculated by subtracting the entering time from the exiting time.

7.5.2 Side Friction (Fs)

This study will use data collected by *Himes (2013)* on 15 horizontal curves (16 measurements per curve) as shown table 2. The pavement friction was measured using a Dynamic Friction Tester (DFT), and is controlled mainly by the micro-texture of the pavement surface. The Circular Texture Meter (CTM) was used to measure the pavement macro-texture in terms of mean profile depth (*Himes 2013*).

For the purpose of this research, the values shown in Table 2are interpolated from the results by *Himes (2013)* to correspond to 10 km/h increments using the cubic spline interpolation in Matlab. It should be noted also that the distribution of available lateral friction corresponds to wet pavement conditions, and therefore would correspond only to a specific weather condition.

Table 3 represents the Mean and the Standard Deviation of the Required Lateral friction Each Curve of study

Curve Speed (km/h)		Lateral Friction	
Mean	Standard Deviation	Mean	Standard Deviation
20	2.09	0.6294	0.1112
30	2.92	0.5550	0.0950
40	3.62	0.4885	0.0773
50	4.19	0.4296	0.0640
60	4.61	0.3793	0.0551
70	4.90	0.3341	0.0489
80	5.06	0.2956	0.0461
90	5.07	0.2630	0.0437
100	4.95	0.2310	0.0429
110	4.70	0.2058	0.0431
120	4.31	0.1771	0.0420

Table 2: Lateral Friction Coefficients for Different Curve Speeds- Reproduced from Himes (2013).

Curve No.	Mean of Operating Speed(km/hr)	Standard Deviation of speed	Mean of fs (Himes 2013)	Standard Deviation of fs
1	87.79	7.5270	0.2600	0.0237
2	93.27	8.9553	0.2400	0.0265
3	96.24	8.9590	0.2300	0.0255
4	97.69	5.2498	0.2300	0.0149
5	101.44	5.5293	0.2200	0.0150
6	118.66	7.4007	0.1728	0.0162
7	113.74	4.4706	0.1837	0.0106

Table 3:the Mean and the Standard Deviation of the Required Lateral Friction for Each Curve of study

8. Results and Discussion

8.1 Probability Distributions for the Random Input Parameters

In this study Minitab software is used to calculate the probability of non-compliance by using Monti Carlo simulation method for evaluating the studied horizontal curves. For each curve there is a specific value for the available radius (Rav) and a corresponding value of Pnc. A Monte-Carlo simulation Performed by Minitab was carried out to investing between (Rav) and ($Rdemand$) according to Eq 7, 10 and 13 , random samples were generated from the probability density functions defined in Table 4.

Param-eter	**Mean**	**Standard Deviation**	**Distributi-on**	**Reference**
V	as calculated	as calculated	Normal	---
fs	as calculated	as calculated	Normal	*Himes 2013*

Table 4:the Probability Distributions for the Random Input Parameters

It is noteworthy that the superelevation and vehicle parameters are assumed to be deterministic, as resented in Table 5, for a typical car and truck (*Chang 2001*).

Vechicle	**h_r/h**	**$R\theta$(rad/g)**	**t/2h**
Car	0.50	0.10	1
Truck	0.25	0.05	0.31

Table 5:Deterministic Variables for Comparative Study

8.2 Calculation of Probability of Non-Compliance

By Minitab program 1000 runs were performed. In each run, the model samples a different value for each random variable and calculates the $Rdemand$. There is no strong theoretical support behind the distribution selection for $Rdemand$ for each curve, the distribution selections were instead guided by empirical testing as well as the practicality of implementing the distributions in the Monte-Carlo method.

The empirical tests done for the distribution selection included the Anderson-Darling test and the Pearson Correlation coefficient test. The data were input into Minitab and AD and P-values were determined for all the distributions. A distribution with a relatively lower AD value and a higher P-value indicated a better fitting distribution, given that the P-value is greater than 0.05.The goodness of fit test (i.e., AD and P-value test). A distribution is considered to be the best fit if the data points exactly follow the straight line in as shown in Figure (8).The finalized statistical distributions for available radius for the three mode obtained from the analysis in Minitab are shown in Figure(9). The Probability of non-compliance (Pnc) can be calculated by Minitab for curves studied.

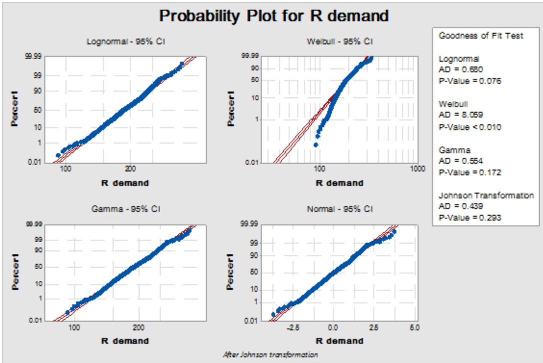

Fig. (8): Probability Plot for R demand for Different Probability Distributions Curve NO.1

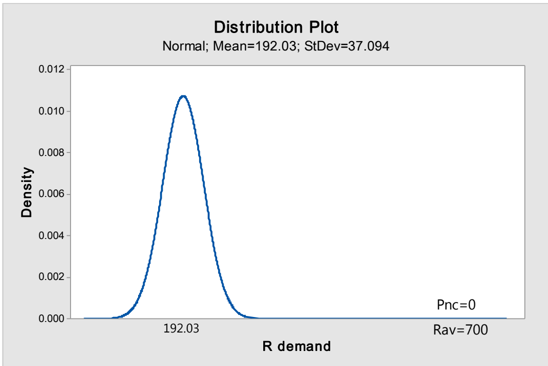

Fig.(9): the Probability of Non – Compliance (Pnc) of Rav for Curve NO.1

8.3 Results of Probability of Non-Compliance and Reliability Index and Discussion

The table 4 shows values of probability of non-compliance and reliability index as shown eq(14) on three modes that 7 horizontal curves in freeways. Overall, it is evident that all The results showed that all curves satisfy the demand radius by users which have a reliability equal 100% for truck and vehicle.
This results shows that no difference between truck and vehicle according to skid without roll,skid with roll and rollover.
The value of high available radiuses is cause for its results according to truck and vehicles.

R=1-Pnc (14)

									Reliability-Z1			
	Speed - V (km/hr)				Side Friction Fs				car		Truck	
Curve No.	Car	SD	Truck	SD	Car	SD	Truck	SD	Pnc	R	Pnc	R
1	87.79	7.5270	81.18	6.2807	0.26	0.0237	0.28	0.0226	0	100	0	100
2	93.27	8.9553	84.09	4.7907	0.24	0.0265	0.27	0.0166	0	100	0	100
3	96.24	8.9591	87.64	4.9985	0.23	0.0255	0.26	0.0166	0	100	0	100
4	97.69	5.2499	91.12	4.1611	0.23	0.0149	0.25	0.0132	0	100	0	100
5	101.44	5.5293	95.99	2.4399	0.22	0.0151	0.23	0.0073	0	100	0	100
6	118.66	7.4007	107.48	4.4961	0.17	0.0163	0.20	0.0117	1.65E-12	100	0	100
7	113.74	4.4707	105.37	3.5514	0.18	0.0107	0.20	0.0093	2.49E-04	99.96	0	100

									Reliability-Z2			
	Speed - V (km/hr)				Side Friction Fs				car		Truck	
Curve No.	Car	SD	Truck	SD	Car	SD	Truck	SD	Pnc	R	Pnc	R
1	87.79	7.5270	81.18	6.2807	0.26	0.0237	0.28	0.0226	0	100	0	100
2	93.27	8.9553	84.09	4.7907	0.24	0.0265	0.27	0.0166	0	100	0	100
3	96.24	8.9591	87.64	4.9985	0.23	0.0255	0.26	0.0166	0	100	0	100
4	97.69	5.2499	91.12	4.1611	0.23	0.0149	0.25	0.0132	0	100	0	100
5	101.44	5.5293	95.99	2.4399	0.22	0.0151	0.23	0.0073	0	100	0	100
6	118.66	7.4007	107.48	4.4961	0.17	0.0163	0.20	0.0117	5.58E-05	1.00E+00	0	100
7	113.74	4.4707	105.37	3.5514	0.18	0.0107	0.20	0.0093	1.56E-04	100	0	100

									Reliability-Z3			
	Speed - V (km/hr)				Side Friction Fs				car		Truck	
Curve No.	Car	SD	Truck	SD	Car	SD	Truck	SD	Pnc	R	Pnc	R
1	87.79	7.5270	81.18	6.2807	0.26	0.0237	0.28	0.0226	0	100	0	100
2	93.27	8.9553	84.09	4.7907	0.24	0.0265	0.27	0.0166	0	100	0	100
3	96.24	8.9591	87.64	4.9985	0.23	0.0255	0.26	0.0166	0	100	0	100
4	97.69	5.2499	91.12	4.1611	0.23	0.0149	0.25	0.0132	0	100	0	100
5	101.44	5.5293	95.99	2.4399	0.22	0.0151	0.23	0.0073	0	100	0	100
6	118.66	7.4007	107.48	4.4961	0.17	0.0163	0.20	0.0117	0	100	0	100
7	113.74	4.4707	105.37	3.5514	0.18	0.0107	0.20	0.0093	0	100	0	100

Table 4: summary of Reliability Results of Horizontal Curves Elements

9. Conclusions

From the analysis of the results, the following conclusions were obtained as follows:

- This study using traffic data collection from sites to calculate the mean operating speed instead of the previous operating speed prediction models as in the previous works.
- This work was tested using the data from great Cairo, Egypt. Data were obtained from 7 sites. This study considers the design of nine horizontal curves in Cairo, Egypt, where non-compliance occurs whenever the available horizontal curve radius (Rav; supply) falls short of the required radius (R demand). Then, the contributions of uncertainty in the geometric variables were evaluated. The results showed that all curves satisfy the demand radius by users which have a reliability equal 100%.
- Monte-Carlo simulation was an effective method for implementing the robabilistic analysis approach by using Minitab program. As applied in this case, the Monte-Carlo simulation generated 1000 sets of random input values based on the selected statistical distributions of geometric and traffic characteristics that were developed to obtain a distribution of the SSD and demand radius.

6. Recommendation

The following list contains a number of recommendations for future work:

- More research is needed to study the reliability analysis in different areas of highway design for low available radices.
- More required roll and rollover modes to compare between truck and vehicles.
- More required friction models should be considered in future analysis.
- More research is needed to study relationship between Pnc and collisions, this can be useful for cost benefit analysis and highway safety.

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