Modelos de perfil de velocidad para evaluación de consistencia del trazado en carreteras de la provincia de Villa Clara, Cuba

Speed profile models for evaluation of design consistency in road of the province of Villa Clara, Cuba

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Resumen

Entre los aspectos relativos a la carretera que influyen en la accidentalidad, tiene un gran peso el diseño geométrico, internacionalmente el método más empleado para la evaluación del diseño es a partir de la consistencia del trazado con modelos de perfil de velocidades de operación. Cuba no cuenta con modelos propios que consideren las características de las carreteras y los conductores, por lo que es necesario desarrollar modelos de predicción de velocidades para la evaluación de la consistencia del trazado. El desarrollo de modelos de predicción del perfil de velocidades de operación para diferentes condiciones de alineación en carreteras rurales de dos carriles en el contexto de Cuba, se efectúa a partir de características geométricas y velocidades puntuales, con análisis estadístico de las principales variables que relacionan la velocidad con el diseño. Una vez desarrollados los modelos, se aplican a un tramo de carretera declarado como tramo de concentración de accidentes (TCA) de la provincia de Villa Clara localizada en la región central de Cuba, los resultados obtenidos confirman la validez de los modelos desarrollados para determinar los perfiles de velocidad de operación y de esta forma, evaluar la consistencia del trazado, con el objetivo de detectar los lugares de mayores dificultades con relación al trazado.

Palabras Clave: Diseño geométrico, evaluación, consistencia del trazado, modelos de perfil de velocidad

Abstract

Among the aspects that influence road accidents, geometric design is the most relevant. The most used method for evaluating the design all over the world is based on the design consistency with speed profile models of operation. Cuba does not have proprietary models that consider the characteristics of the roads and drivers, so it is necessary to develop predictive models for the evaluation of design consistency. The development of operating speed profile prediction models for different alignment conditions on rural roads with two lanes in the context of Cuba is made from the geometric characteristics and point speeds with statistical analysis of the main variables related with the operating speed. Once models are developed they are applied to a section of road designated as an accident concentration section (TCA) of the province of Villa Clara located in central Cuba, these results confirm the validity of the models developed to determine the operating speeds, thus evaluating the design consistency, with the aim of detecting the locations of greater difficulties with respect to the geometric design.

Keywords: Geometric design, evaluation, design consistency, speed profile models

1. Introduction

In Cuba the accident rate is mainly concentrated in urban areas. The predominance of human factor is recognized as the primary reason for accidents (Albentosa, 2006), although the roads geometric characteristics also influence the accident rate.

In Cuba the causes of accident rate related to highways are higher than the ones reported in other countries, due to roads conditions, present status of elements comprising them and the pavement surface characteristics (García, 2010).

Presently there is a strong worldwide tendency to evaluate road safety based on road consistency. This is defined as the relationship between the road geometrical characteristics and the ones expected by the driver travelling on a roadway (Leisch and Leisch, 1977).

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Several researchers have proposed models allowing the determination of operating speed profiles on two-lane highways. Some of them are listed on Table 1.

Tabla 1. Expresiones para estimar la velocidad de operación
Table 1. Expressions to estimate operating speed

Autor (es)/ Researcher (s)	Expresión/ Expression	Año/ Year	País/ Country
Lamm y Choveiri	$V_{85}=95,78-0,076CCR$ $V_{85}=96,152-0,302GC$	1987	EE. UU./USA
Lamm et al.	$V_{85}=94,398-3188,656/R$	1990	EE. UU./ USA
Kanellaidis et al.	$V_{85}=129,88-623,1/(\sqrt{R})$	1990	Grecia/ Greece
Morrall y Talarico	$V_{85}=\exp(4,561-0,0058GC)$	1994	Canadá/ Canada
Islam y Seneviratne	$V_{85\text{ PC}}=95,41-0,45GC-0,001GC^2$ $V_{85\text{ P1}}=103,03-0,73GC-0,003GC^2$ $V_{85\text{ PM}}=96,11-0,32GC$	1994	EE. UU./ USA
Krammes et al.	$V_{85}=102,44-2471,81/R+0,012Lc-0,10\Delta$	1995	EE. UU./ USA
Voigt	$V_{85}=99,61-2951,37/R+0,014Lc-0,13\Delta-71,82e$	1996	EE. UU./ USA
McFadden y Elefteriadou	$V_{85\text{ reduc}}=-14,90+0,144*V_{85@PC200}+0,0153*Lr+954,55/R$ $V_{85\text{ reduc}}=-0,812+0,0017*Lr+998,19/R$	2000	EE. UU./ USA
Gibreel et al.	$V_{85}=102,2-0,10\Delta$	2001	Canadá/ Canada
Misaghi y Hassan	$V_{85}=91,85+9,81*10^{-3}R$ $V_{85}=94,30+8,67*10^{-6}R^2$	2005	EE. UU./ USA
Castro	$V_{85}=120,16-5596,72/R$	2005	España/ Spain
Fitzpatrick et al.	Varias expresiones, según la pendiente/ Several expressions in according to the slope	2000	EE. UU./ USA
<p>V_{85} - velocidad de operación en un punto (km/h)/ operating speed at a given point (km/hr) CCR - tasa de cambio de curvatura/ curvature exchange rate GC - grado de curvatura/ curvature degree R - radio (m)/radius (m) Lc - longitud de la curva (m)/ curve length (m)</p> <p>Δ - ángulo total girado (°)/ total angle turn (°) e - tasa de peralte (m/m)/ cant rate (m/m) Lr - longitud de la curva circular (m)/ circular curve length (m) $V_{85@PC200}$ - velocidad de operación a 200 m del punto de comienzo de la curva (km/h)/ operating speed at 200 from the curve beginning point</p>			

The experience of roads consistency assessment in Cuba, developed by the Universidad Central de Las Villas (UCLV) by means of expressions by Fitzpatrick et al., (2000) included in the IHSDM 2004 (Interactive Highway Safety Design Model) proves the roads inconsistency for a high percentage of segments lengths; due to differences between speed design and operation design. Above, because models employed in this assessment were obtained for another conditions and they do not reflect the real operating speed in Villa Clara's highways (Raoul 2009).

Based on this situation and considering that the percentages of national interest two-lane rural roads represent a 71.6% of total Villa Clara province, in addition to the high accident and severity rates, it was decided to develop speed predictive models for these kind of rural highways in order to evaluate the roads consistency.

2. Development

The general procedure followed in this research is divided into two stages. The first consists of a bibliographic analysis and the determination of speed profile models. The second stage evaluates the roads consistency for national interest two-lane rural roads. These stages include the following aspects:

Determination of speed profile models

- Assessment of highways within the territory
- Definition of fixed parameters to be researched
- Determination of selected sites
- Complementation of information obtained in the field
- Field work carried out in selected locations
- Development of speed predictive models

Roads consistency evaluation

- Developed models cross-check
- Roads consistency assessment
- Analysis of results obtained by the consistency assessment

Determination of speed profile models

- **Analysis of highways within the territory.** A high percentage of vehicles travel on asphalt highways, among them those declared as national interest highways, having a length of 1,264.49 km in the Villa Clara province. Out of them 1,008.10 km are national interest rural highways and 905.10 km correspond to two-lane rural highways, which include 63.68 km of mountainous highways.

The operating speed profile models are determined as function of multiple combinations of ground plant and cross section alignments, depending on the category, type of ground and design criteria established by regulation NC 53 02 1986.

The alignment combination existing on highways, hereafter designated as "conditions" are determined from the analysis of highways records and inventories filed by the roads governing entities, such as Road Provincial Center (CPV) and the Traffic Engineering Provincial Center (CPIT). Above was fully proven by travelling across highways under study.

Alignment conditions existing on highways of the province are determined by means of regulation NC 53 02 1986, from abovementioned segments and from experiences developed by other researchers (Fitzpatrick et al., 2000). These conditions are grouped into horizontal curve with slope (-9% to -4%), horizontal curve with slope (-4% to 0%), horizontal curve with ramp (0% to 4%), horizontal curve with ramp (4% to 9%), crest horizontal curves; sag horizontal curves, crest horizontal straight-line, sag horizontal straight-line and, straight-line segment on a slope or ramp.

- **Definition of fixed parameters to be researched.**

Highways fixed parameters are the characteristics that do not change throughout time, where preservation measures are not applied. The most significant geometric characteristics are slope and horizontal curvature radius, which are determined at selected locations. "Site" is considered as the group of one or several curves with similar geometrical characteristics under the same condition, horizontal curve, vertical curve or the combination of both (Fitzpatrick et al., 2000).

General criteria used to select locations are: rural area, lower functional classification of arterial lane, speed limit between 50 and 90 km/hr, plane and undulated ground, traffic volumes between 100 and 4,000 vehicles/day, carriageway width between 2.75 and 3.75 meters, non-restricted horizontal curves length and, vertical curves length between 40 and 320 meters. These parameters were selected as they represent the most common features of rural highways in the country.

- **Determination of selected sites.** The selection of sites is developed based on the elements that counteract with the effect of centrifugal force in horizontal curves (cant, transverse friction and horizontal radius), which depend on the speed at horizontal curves (Expression 1).

$$R_c = \frac{V^2}{127.14 * (e + \mu)} \quad (1)$$

Where:

e	cant rate (m/m)
μ	coefficient of side friction
V	vehicle speed
R_c	curvature radius (m/m)

Radiuses intervals are determined based on the highway category and ground type. Afterwards the amount of sites is defined by considering that speed values dot not exceed dispersion values, which were assumed in ± 2.5 km/hr.

Table 2 shows the sites obtained from analysis in Formula 1, as function of horizontal curves radius for each existing alignment condition.

Tabla 2. Cantidad de sitios
Table 2. Number of sites

Radio/ Radius	Intervalo de radios (unidad de medida en metros)/ Radiuses Intervals (measurement unit in meters)			
	< 75	75 – 210	211 - 500	> 501
Sitios/ Sites	< de 75	75 – 131	211 - 277	501 - 535
		131 – 159	277 - 318	535 - 591
		159 – 185	318 - 366	591 - 647
		185 – 210	366 - 413	647 - 710
			413 - 458	710 - 782
			458 - 500	782 – 869
				869 - 995
				995 - 1067
				>1067
Total de sitios/ Total sites amount	1	4	6	9

In the case of vertical curves the algebraic difference of slopes is considered, which is conditioned to the curve location at the top or depression, for convex and concave cases thus defining two sites: one for each condition.

Once radiuses intervals are established for each site, it is necessary to determinate their existing amount per condition and which ones are required for models development. Calculation of samples number is carried out by using Formula 2, which is recommended when the population size is already known.

$$n = \frac{Z^2 pqN}{NE^2 + Z^2 pq} \quad (2)$$

Where:

n	sample size
Z	confidence level
p	positive variability
q	negative variability
N	population size
E	accuracy or error

The amount of sites in two-lane rural highways is obtained from a detailed analysis on these kinds of highways in Villa Clara province, where all alignment combinations are present. Afterwards, sites are defined where models are validated. In order to determinate the number of sites required for the development of operating speed predictive models Expression 2 is applied, because the total number of existing sites in the studied rural highways is available per condition and interval radiuses. Results are shown in Table 3.

Tabla 3. Matriz de sitios deseados

Table 3. Matrix of desired sites

Condiciones/ Conditions	Rango de radios (unidad de medida en metros)/ Radiuses Range (measurement unit in meters)					
	> 500	500-211	210-75	<.75)	Tangente/ Tangent	Total
1	2\2\2	4\4\4	1\1\1	0\0\0	-	7\7\7
2	6\6\6	8\7\8	4\4\4	0\0\0	-	18\17\18
3	6\6\6	8\7\8	4\4\4	0\0\0	-	18\17\18
4	5\5\5	4\4\4	1\1\1	0\0\0	-	10\10\10
5	6\6\6	4\4\4	2\2\2	0\0\0	-	12\12\12
6	2\2\2	7\6\7	0\0\0	0\0\0	-	9\8\9
7	-	-	-	-	8\7\8	8\7\8
8	-	-	-	-	9\8\9	9\8\9
Total	27\27\27	35\32\35	12\12\12	0\0\0	17\15\17	91\86\91
Donde: Número existente de sitios \ número real de sitios para el desarrollo de modelos \ número de sitios para la validación de los modelos. Where: number of existing sites / actual number of sites for the development of models / number of sites for validating the models						

The determination of specific speed samples number analyzed for every single site under study, in order to calculate operating speed, is obtained by Expression 3 (Radelat, 2003), which is used when the population size is unknown. The result obtained from the normal distribution parameter, assumed standard variation and the error delivered by measurements is 23 samples.

- **Completion of information obtained in the field.** Data completion required for the elaboration of operating speed predictive models is carried out by means of direct measurements taken from the longitudinal slope field and the horizontal curves radiuses, in case of lacking of information on CPV and CPIT files or when there are doubts about the information reliability.
- **Field work carried out in selected sites.** Speed samples are taken from free-flow travelling light weight vehicles, at day, on dry and well conditions asphalts by using a laser gun. Speed studies shall be developed at the curve site where the operating speed is increased (Fitzpatrick et al., 2000). According to developed studies, these sites are located in the centerline of horizontal curves and vertical curves.
- **Development of speed predictive models.** Once measurements and checking of fixed parameters and speed are completed, the normality, homogeneity and independency of data groups are tested in order to conduct a parametric test and variance analysis.

Now the operating speed is calculated by considering two variables per sites (radius and speed), which are employed for models development.

Operating speed prediction profiles for two-lane rural highways are obtained by the application of regression techniques. The statistical processing of the variables employed is developed by the SPSS 16.0.1 software.

Models development considers logarithmic, exponential and linear regressions including several variables. The most fitted models are the linear ones that relate speed and radius for horizontal curves (1, 2, 3, 4, 5, and 6). As unique independent variable, the inverse radius was introduced in the specific case of horizontal curves and, for the case of horizontal curves the slopes algebraic difference was considered.

Table 4 shows the results from statistical tests, obtained by employed variables (inverse radius, slope algebraic difference and operating speed). There are no self-correlation, multiple co-linearity and significance levels lower than 0.05, with adjustments of curves higher than 0.693; therefore, it can be concluded that these are high quality models.

Tabla 4. Resumen de pruebas estadísticas**Table 4.** Statistical tests summary

No	Condición/ Condition	R ²	d	i _c	Significación constante/ Constant Significance	
					1/R	kv
1	Curva horizontal en pendiente/ Horizontal curve with slope (-9% -4%)	0,833	1,786	5,691	0,004	-
2	Curva horizontal en pendiente/ Horizontal curve with slope (-4%- 0%)	0,766	1,995	3,194	0,000	-
3	Curva horizontal en rampa/ Horizontal curve with ramp (0% - 4%)	0,851	2,108	3,194	0,000	-
4	Curva horizontal en rampa/ Horizontal curve with ramp (4% - 9%)	0,706	2,160	4,484	0,002	-
5	Curva horizontal con acuerdo convexo/ Crest horizontal curves	0,733	2,015	3,257	0,000	-
6	Curva horizontal con acuerdo cóncavo/ Sag horizontal curves	0,772	2,027	5,171	0,002	-
7	Recta con acuerdo convexo/ Crest horizontal straight-line	0,799	2,106	5,742	-	0,003
8	Recta con acuerdo cóncavo/ Sag horizontal straight-line	0,693	1,859	6,178	-	0,005

From the verification of statistical results and models quality, the equation for each condition is established as well as the number of sites where tests were applied for models development. The results are shown in Table 5.

Tabla 5. Modelos de predicción de velocidades de operación**Table 5.** Operating speed predictive models

Condiciones/ Condition	Expresión/ Expression	R ²	Sitios/ Sites
Curva horizontal en pendiente / Horizontal curve with slope (-9% a -4%)	$V_{85}=76,587-1305,731/R$	0,833	7
Curva horizontal en pendiente/ Horizontal curve with slope (-4% a 0%)	$V_{85}=77,43-1206,266/R$	0,766	18
Curva horizontal en rampa/ Horizontal curve with ramp (0% a 4%)	$V_{85}=77,212-1435,599/R$	0,851	18
Curva horizontal en rampa/ Horizontal curve with ramp (4% a 9%)	$V_{85}=79,977-2410,793/R$	0,706	10
Curva horizontal con acuerdo convexo/ Crest horizontal curves	$V_{85}=79,883-1744,898/R$	0,733	12
Curva horizontal con acuerdo cóncavo/ Sag horizontal curves	$V_{85}=83,599-2247,827/R$	0,772	9
Recta con acuerdo convexo/ Crest horizontal straight-line	$V_{85}=83,332-0,157/kv$	0,799	8
Recta con acuerdo cóncavo/ Sag horizontal straight-line	$V_{85}=84,018-0,177/kv$	0,693	9

Roads consistency assessment

- **Developed models cross-check.** Models cross-checking is performed by measuring speeds on the field site and later applying the corresponding expression at the laboratory. Difference must be approximately of ± 2.5 km/h to prove the model efficiency. The cross-checking number is defined in Table 3. Results are satisfactory for all conditions.
- **Roads consistency assessment.** Roads consistency assessment is developed in accordance with Table 6, based on the difference of operating speed obtained when applying the speed profile together with design speed and, the difference of operating speed among consecutive elements. The results assess the roads consistency in accordance with criteria proposed by Lamm and Choueiri, 1987,

which are still in force and have been employed by several researchers (FHWA; Castro and Sanchez, 2008; and Sanchez, 2008).

Tabla 6. Intervalos y calificación de la consistencia del trazado

Table 6. Intervals and qualification of roads consistency

Intervalo/ <i>Interval</i>	Clasificación de la consistencia/ <i>Consistency qualification</i>
Comparando con la velocidad de diseño (V_d)/ <i>Comparing to design speed (V_d)</i>	
$V_{85} - V_d \leq 10 \text{ km/h}$	Buena/ <i>Good</i>
$10 \text{ km/h} < V_{85} - V_d \leq 20 \text{ km/h}$	Regular
$20 \text{ km/h} < V_{85} - V_d$	Mala/ <i>Poor</i>
Comparando velocidad entre elementos consecutivos/ <i>Comparing speed between consecutive elements</i>	
$\Delta V_{85} \leq 10 \text{ km/h}$	Buena/ <i>Good</i>
$10 \text{ km/h} > \Delta V_{85} \leq 20 \text{ km/h}$	Regular
$\Delta V_{85} > 20 \text{ km/h}$	Mala/ <i>Poor</i>
Donde/ <i>Where:</i> V_{85} : velocidad de operación en un punto dado de la vía (km/h)/ <i>operating speed at a given road point (km/h)</i> V_d : velocidad de diseño (km/h)/ <i>design speed (km/h)</i> ΔV_{85} : diferencia de velocidad de operación entre dos elementos consecutivos (km/h)/ <i>operating speed difference between two consecutive elements (km/h)</i>	

The obtained results define the sites having difficulties regarding roads consistency, provoked by one or maybe by two causes. Therefore, actions are focused to such critical points so as to eliminate the potential accident causes.

- **Analysis of results obtained by the consistency assessment.** Roads consistency assessment is developed on a two-lane rural highway segment, called Santa Clara-Hatillo. This segment was rated as the most dangerous in the country.

The segment under analysis is a national interest two-lane road, belonging to Santa Clara – Sitiecito highway, located at the southeast of Santa Clara City, which is the entrance to the provincial capital from Cifuentes, Sagua la Grande, Quemado de Guines and Coralillo city councils and it holds strong pendulum-like-movements among population settlements. From above, the social and economic relevance is deduced for the segment to be assessed (Figure 1).

The ground plant and cross section of highway segment are now available, as well as speed design (60 km/hr), determining its alignment conditions, which are used in order to apply operating speed predictive models.

Tables 7 and 8 show the design of an Excel sheet created for the calculation of roads consistency assessment, where different characteristics of ground plant and cross section alignments are depicted for the studied segment. Besides, an operating speed graph is obtained as well as operating speed differences between consecutive elements (Figures 2 and 3), which enable us to notice the most critical points for both circulation directions.

Figura 1. Esquema del tramo de carretera Santa Clara - Hatillo

Figure 1. Drawing of the Santa Clara – Hatillo highway segment

Tabla 7. Evaluación de la consistencia del trazado. Tramo Santa Clara – Hatillo >>>

Table 7. Roads consistency assessment. Santa Clara – Hatillo Segment>>>

Santa Clara – Hatillo Segment – traffic direction>>>											
Tramo (Santa Clara - Hatillo) Dirección del tránsito >>>											
Tramo Segment	Alineación en planta Ground plant alignment		Alineación en perfil/Cross section alignment				Condición Condition	V85 (A- B/R) (km/h)	V85-Vd (km/h)	ΔV85 (km/h)	Longitud Length (m)
	Tipo Type	Radio Radius (m)	Pendiente Slope (%)	Estación/Station		Lv					
				Inicial/Initial	Final						
1	recta	0	1,7	0+0.00	45+0.00		9	77,21	17,21	0,00	450
2			-0,9	45+0.00	89+0.00	80	8	87,04	27,04	9,83	440
3			1,8	89+0.00	111+5.00	80	7	79,90	19,90	7,14	225
4			2,9	111+5.00	150+0.00	120	8	84,90	24,90	5,00	385
5	curva	694	2,9	150+0.00	167+6.31	0	3	75,14	15,14	9,76	176,31
6	recta	0	2,9	167+6.31	191+0.00		9	77,21	17,21	2,07	233,69
7			2,1	191+0.00	228+5.00	40	7	82,40	22,40	5,19	375
8			-1,2	228+5.00	272+5.00	80	8	84,64	24,64	2,25	440
9			1	272+5.00	312+0.00	40	7	76,06	16,06	8,58	395
10			-0,85	312+0.00	329+0.00	40	8	82,73	22,73	6,66	170
11			-0,4	329+0.00	341+0.00	40	8	93,91	33,91	11,18	120
12			0,8	341+0.00	368+0.00	40	7	80,59	20,59	13,32	270
13			-0,46	368+0.00	371+7.18	40	8	87,36	27,36	6,77	37,18
14	curva	489	-0,46	371+7.18	382+0.00	0	5	76,36	16,36	11,00	102,82
15		489	-0,8	382+0.00	384+5.26	0	5	76,36	16,36	0,00	25,26
16	recta	0	-0,8	384+5.26	422+0.00		9	77,43	17,43	1,07	374,74
17			1,2	422+0.00	430+0.00	40	7	76,97	16,97	0,46	80
18	curva	606,54	1,2	430+0.00	440+5.86	0	3	74,85	14,85	2,12	105,86
19	recta	0	1,2	440+5.86	498+0.00		9	77,21	17,21	2,36	574,14
20			-1,1	498+0.00	518+0.00	40	8	79,05	19,05	1,84	200
21			-1,2	518+0.00	545+0.00	40	7	81,49	21,49	2,44	270
22			-2	545+0.00	570+0.00	40	8	91,03	31,03	9,54	250
23			3,8	570+0.00	608+7.74	120	7	77,33	17,33	13,71	387,74
24	curva	406,54	3,8	608+7.74	613+0.00	0	6	76,55	16,55	0,78	42,26
25		406,54	-1,1	613+0.00	622+2.49	0	6	76,55	16,55	0,00	92,49
26	recta	0	-1,1	622+2.49	627+0.00		9	77,43	17,43	0,88	47,51
27			1,2	627+0.00	632+7.16	40	7	78,23	18,23	0,80	57,16
28	curva	545,66	1,2	632+7.16	646+0.00	0	2	75,22	15,22	3,02	132,84
29	recta	0	1,2	646+0.00	673+5.00		9	77,21	17,21	1,99	275
30			-1,3	673+5.00	720+0.00	80	8	87,52	27,52	10,31	465
31	curva	254,58	-1,3	720+0.00	732+0.00	0	2	72,69	12,69	14,83	120
32	recta	0	-1,3	732+0.00	736+0.00		9	77,43	17,43	4,74	40
33			0,8	736+0.00	769+5.00	40	7	76,52	16,52	0,91	335
34			-0,4	769+5.00	789+0.00	40	8	87,84	27,84	11,32	195
35			1,3	789+0.00	803+5.00	40	7	78,33	18,33	9,51	145
36			-1,8	803+5.00	832+5.00	80	8	84,96	24,96	6,64	290

Leyenda: En color verde se muestran las consistencias del trazado evaluadas como buena, en amarillo las evaluadas como regular y en rojo las evaluadas como malas.

Note: good road consistencies are shown in green color, regular road consistencies are shown in yellow color and poor road consistencies are shown in red color.

Figura 2. Consistencia del trazado. Tramo Santa Clara – Hatillo >>>**Figure 2.** Roads consistency. Santa Clara – Hatillo Segment>>>**Tabla 8.** Evaluación de la consistencia del trazado. Tramo Santa Clara – Hatillo <<<**Table 8.** Roads consistency assessment. Santa Clara – Hatillo Segment<<<

Santa Clara – Hatillo Segment – traffic direction>>> Tramo (Santa Clara - Hatillo) Dirección del tránsito <<<													
Tramo Segment	Alineación en planta Ground plant alignment		Alineación en perfil/Cross section alignment				Condición Condition	V85 (A- B/R) (km/h)	V85-Vd (km/h)	ΔV85 (km/h)	Longitud Length (m)		
	Tipo Type	Radio Radius (m)	Pendiente Slope (%)	Estación/Station		Lv							
				Inicial/Initial	Final								
37	urb.Hatillo	0	0	0+0.00	177+5.00	0	9	77,21	17,21	0,00	1775		
36	recta	0	1,8	177+5.00	206+5.00		9	77,21	17,21	0,00	290		
35			-1,3	206+5.00	221+0.00	80	8	84,96	24,96	7,75	145		
34			0,4	221+0.00	240+5.00	40	7	78,33	18,33	6,64	195		
33			-0,8	240+5.00	274+0.00	40	8	87,84	27,84	9,51	335		
32			1,3	274+0.00	278+0.00	40	7	76,52	16,52	11,32	40		
31	curva	254,58	1,3	278+0.00	290+0.00	0	3	71,57	11,57	4,94	120		
30	recta	0	1,3	290+0.00	336+5.00		9	77,21	17,21	5,64	465		
29			-1,2	336+5.00	364+0.00	80	8	87,52	27,52	10,31	275		
28	curva	545,66	-1,2	364+0.00	377+2.84	0	3	74,58	14,58	12,94	132,84		
27	recta	0	-1,2	377+2.84	383+0.00		9	77,43	17,43	2,85	57,16		
26			1,1	383+0.00	387+7.51	40	7	78,23	18,23	0,80	47,51		
25	curva	406,54	1,1	387+7.51	397+0.00	0	6	76,55	16,55	1,68	92,49		
24			-3,8	397+0.00	401+2.26	0	6	76,55	16,55	0,00	42,26		
23	recta	0	-3,8	401+2.26	440+0.00		9	77,43	17,43	0,88	387,74		
22			2	440+0.00	465+0.00	120	7	77,33	17,33	0,10	250		
21			1,2	465+0.00	492+0.00	40	8	91,03	31,03	13,71	270		
20			1,1	492+0.00	512+0.00	40	7	81,49	21,49	9,54	200		
19			-1,2	512+0.00	569+4.14	40	8	79,05	19,05	2,44	574,14		
18	curva	606,54	-1,2	569+4.14	580+0.00	0	2	75,44	15,44	3,61	105,86		
17	recta	0	-1,2	580+0.00	588+0.00		9	77,43	17,43	1,99	80		
16			0,8	588+0.00	625+4.74	40	7	76,97	16,97	0,46	374,74		
15	curva	489	0,8	625+4.74	628+0.00	0	5	76,36	16,36	0,61	25,26		
14			0,46	628+0.00	638+2.82	0	5	76,36	16,36	0,00	102,82		
13	recta	0	0,46	638+2.82	642+0.00		9	77,21	17,21	0,85	37,18		
12			-0,8	642+0.00	669+0.00	40	8	87,36	27,36	10,15	270		
11			0,4	669+0.00	681+0.00	40	7	80,59	20,59	6,77	120		
10			0,85	681+0.00	698+0.00	40	8	93,91	33,91	13,32	170		
9			-1	698+0.00	737+5.00	40	8	82,73	22,73	11,18	395		
8			1,2	737+5.00	781+5.00	40	7	76,06	16,06	6,66	440		
7			-2,1	781+5.00	819+0.00	80	8	84,64	24,64	8,58	375		
6			-2,9	819+0.00	842+3.69	40	7	82,40	22,40	2,25	233,69		
5			curva	694	-2,9	842+3.69	860+0.00	0	2	75,69	15,69	6,70	176,31
4			recta	0	-2,9	860+0.00	898+5.00		9	77,43	17,43	1,74	385
3	-1,8	898+5.00			921+0.00	120	8	84,90	24,90	7,47	225		
2	0,9	921+0.00			965+0.00	80	7	79,90	19,90	5,00	440		
1	-1,7	965+0.00			1010+0.00	80	8	87,04	27,04	7,14	450

Figura 3. Consistencia del trazado. Tramo Santa Clara – Hatillo <<<

Figure 3. Roads consistency. Santa Clara – Hatillo Segment <<<

The summarized results of design consistency assessment are shown on Table 9, for Santa Clara – Hatillo segment, considering both traffic directions.

Tabla 9. Resumen de la evaluación mala de la consistencia del trazado Santa Clara - Hatillo

Table 9. Summary of poor road consistency assessment on Santa Clara – Hatillo segment

Tramo Segment	Evaluación de la consistencia del trazado mala Poor road consistency assessment				Consistencia mala por ambos criterios	
	$V_{85} - V_d$		ΔV_{85} elementos consecutivos consecutive elements		Poor consistency due to both criteria	
	Cantidad de lugares Sites amount	Longitud Length (m / %)	Cantidad de lugares Sites amount	Longitud Length (m / %)	Cantidad de lugares Sites amount	Longitud Length (m / %)
Santa Clara - Hatillo	Sentido/Direction >>>					
	13	3 707 / 36,7	-	-	-	-
	Sentido/ Direction <<<					
	13	1 161 / 11,1	-	-	-	-
	Evaluación de la consistencia del trazado regular Regular road consistency assessment				Consistencia regular por ambos criterios	
	$V_{85} - V_d$		ΔV_{85} elementos consecutivos consecutive elements		Poor consistency due to both criteria	
	Cantidad de lugares Sites amount	Longitud Length (m / %)	Cantidad de lugares Sites amount	Longitud Length (m / %)	Cantidad de lugares Sites amount	Longitud Length (m / %)
	Sentido/ Direction >>>					
	24	6 393 / 63,3	7	576 / 5,7	-	-
	Sentido/ Direction <<<-					
	24	8 939 / 88,5	7	593 / 5,9	-	-

In Santa Clara – Hatillo traffic direction, roads consistency assessments deliver poor and regular results for both concepts, in four alignments totalizing 349.86 meters, which represent a 3.5% of total segment length. Contrarily, in the opposite direction, the results of five alignments totalizing 442.55 meters represent a 4.4% of total segment length. Poor and regular consistency assessment remains for both criteria, same traffic direction, for one single condition, with 80.59 meters; which represent a 0.8% of total segment length.

Obtained results have proven that there is a higher amount of locations wrongly assessed due to operating speed and project speed differences. Above, because the allowed limit speed is determined according to vehicles potential speed without considering geometric characteristics of analyzed segments.

3. Conclusions

Specific operating speed predictive models are developed for alignment conditions existing in Santa Clara province, for two-lane rural highways of national interest.

The application of such models enables the localization of roads weakness points as well as the determination of roads consistency assessment for a highway segment with two circulation directions.

In a simple way, the elaboration of an Excel sheet allows determining roads consistency assessment by using operating speed predictive profile models developed for two-lane rural highways in Villa Clara province.

It is proven that in Santa Clara – Hatillo segment there is a road safety risk factor represented by roads consistency assessment for both traffic directions, thus proposing measurements that contribute to decrease accident rate becomes necessary.

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