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Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural Roads in Israel and Germany

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Crashes on two-lane rural highways are over-represented at horizontal curves, and speed inconsistency is a common contributing factor to these crashes. Road Consistency reflects the similarity or lack thereof of vehicle performance along an entire road segment. Consistency is measured by estimating the speed variation along successive geometric elements and evaluation of the speed deviation from the average speed. Because it has been shown in the past that speed variability has an impact on safety, it was hypothesized that design consistency is also related to safety. The purpose of this study is to examine the relationship between road design consistency and crash probability on two-lane rural highways. An enhanced consistency model is applied to examine this relationship in Israel and Germany. This consistency model is based on both the horizontal and vertical alignments and takes into account the impact of trucks and grades on road consistency. A statistically significant model that showed a reduction in average crash numbers per year with an increase in consistency is presented and discussed. It was found that the Israeli and German models have a similar trend. The enhanced-consistency model and the software may be used relatively easily to determine consistencies of different alternatives during the planning of new highways or the reconstruction of existing roads. Planners and decision-makers could be advised of potential design deficiencies during the design process and consequently, modify a proposed design and thus improve safety levels and save lives.

Keywords: crash probability; horizontal alignment; road consistency; speed profile; two-lane highways; vertical alignment

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Mattar-Habib, Polus and Farah
Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural
Roads in Israel and Germany

1.   Introduction

A design inconsistency in a roadway segment usually results from geometric features that vary significantly and therefore may cause drivers to make speed errors or unsafe driving maneuvers leading to higher collision risk. Therefore, geometric design consistency is emerging as an important component in highway design (Glennon and Harwood, 1978). Some researchers have explicitly noted that treating any inconsistency in a highway alignment can significantly improve its safety performance (Joanne and Sayed, 2004).

Most consistency concepts today deal with the variation in the speeds of vehicles on segments of highways (Leisch et al., 1977; Lamm and Choueiri, 1995; Al-Masaeid et al., 1995). This speed variation is affected mainly by longitudinal elements of the horizontal alignment. Horizontal elements impact the speeds of cars on curves and tangents; therefore, because highway features change, so do the speeds. The magnitude of this variability of speeds is essentially converted to an estimate of highway consistency. To date, however, this concept does not include the impact of the vertical alignment on speeds and, consequently, on consistency. Therefore, the existing consistency models are applicable mostly to level terrain, where the vertical alignment does not impact vehicles' speeds.

In hilly and mountainous terrain, however, speeds are impacted by both the vertical and horizontal features of the alignment. Influencing parameters include curvature, length of tangents, percentage and length of grades. Furthermore, heavy-vehicle speeds are subject to considerably more fluctuations than are passenger-car speeds, particularly on mountainous roads, because of the vertical alignment features. As a result, the consistency of a design model needs to consider the performance of both cars and trucks when making the consistency estimate. In reality, both the fluctuations in speeds and the difference between the performance of cars and trucks do determine jointly the design consistency of a given highway facility and consequently its safety level. This paper presents the development of an improved model to estimate highway consistency and also the principles of a software package that was developed to estimate this consistency. It also presents a significant relationship between consistency and crashes, in two countries, Israel and Germany.

2.   Background of study

2.1   Definition of Road Consistency

A review of road consistency definition in the literature indicates that researchers have defined the consistency in horizontal alignment as individual speed differentials between two successive elements, mostly without consideration of the overall longitudinal segment features. The following is a summary of previous studies on road consistency which indicates this point.

Leisch et al. (1977) suggested three criteria for consistency of an alignment of a highway which stated generally that: (1) the difference in design speed along the alignment resulting from different topographical conditions should be 10 mph (approx. 15 km/h) or less; (2) the difference in operating speeds of cars should be 10 mph or less, and; (3) the difference in operating speed of cars vs. trucks should be limited to 10 mph or less.

Messer (1980) presented a methodology to evaluate consistency based on driver-behavior principles associated with work-load ratings for different geometric features. For example, because sharper curves are generally more troublesome, a driver's workload increases with the degree of curvature and with the deflection angle of the curve. Messer suggested that excessively long curves are prone to crashes and should be discouraged. Similarly, he proposed some

EJTIR **8**(4), December 2008, pp 320-332
Mattar-Habib, Polus and Farah
Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural
Roads in Israel and Germany

322

general design recommendations for consistent horizontal and vertical alignments and intersections.

Lamm and Choueiri (1995) in Germany analyzed the horizontal alignment of two-lane highways and developed several consistency criteria for the design characteristic. They suggested that the difference between the 85th percentile operating speed and the design speed should be smaller than a set of criteria for good, acceptable, and poor designs. Likewise, the difference in these same two speeds on two consecutive elements should be bounded by similar criteria. The researchers suggested that the sum of curvature change rates (CCR) between the horizontal curves and the adjacent spirals explained most of the change in operating speed along each section. No measure, however, was provided for the entire highway, including the tangent sections.

Krammes et al. (1995) presented several design-consistency models to evaluate design consistency for rural two-lane highways. The 85th percentile speed was predicted on the basis of such independent parameters as the degree of curve, length of curve, and deflection angle. Their speed-prediction model for horizontal curves was utilized in the present study for the development of the speed profile, from which the consistency model subsequently was developed, after the inclusion of the vertical alignment elements.

McFadden and Elefteriadou (1997) used the bootstrapping statistical technique to sample, formulate, and validate the operating speed-prediction models that were previously proposed by Krammes et al. (1995). In all three models tested, they found no significant difference between the 85th percentile speed predicted by the model and the observed 85th percentile speed.

Al-Masaeid et al. (1995) considered the speed reduction between tangent and curve as the consistency measure of a section; speed reduction was found to be highly affected by the radius of the curve. The speed on the tangent was found to be affected mainly by the tangent length.

Polus at al. (2000) developed a family of non-linear models for predicting operating speeds on tangent sections of two-lane highways. These models, jointly with those suggested by Krammes et al. (1995) for estimating operating speed on curves and the AASHTO 2001 models for speeds on grades, were used during the development of speed profiles in this study for formulating a consistency model for two-lane highways. Krammes and Hayden (2003) discussed the Interactive Highway Safety Design Model (IHSDM), which has been in development in the U.S. for several years. This model includes a consistency module with two aspects: large differences between the assumed design speed and the 85th percentile speed and large changes in the 85th percentile speed between tangents and curves.

Hassan and Easa (2003) tested the radius of horizontal curves depending on the overlapping vertical alignment using computer animation and field measurements. The results showed that crest curves cause overlapping horizontal curves to look sharper while sag curves cause overlapping horizontal curves to look flatter than what they actually are.

2.2   Relationship between Road Consistency and Safety

Consistency versus safety has also been studied recently. Polus (1980) investigated the relationship between longitudinal geometric measures (such as the average radius, or the ratio between the minimum and maximum radius of an alignment) and safety levels on two-lane rural highways. He proposed that safety correlated with a similarity in design elements (quantified by the proposed measures) and, therefore, with consistency. He reasoned that drivers tended to build up an expectation of what the upcoming roadway would be like, based on their immediate previous driving experience.

Easa (2003) presented a method to distribute superelevation to maximize highway-design consistency based on safety margins defined as the difference between the maximum-limit safe

EJTIR **8**(4), December 2008, pp 320-332
Mattar-Habib, Polus and Farah
Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural
Roads in Israel and Germany
323

speed and the design speed. Anderson et al. (1999) studied several consistency measures (such as speed reduction on a horizontal curve relative to the preceding tangent) and showed that these measures were significantly correlated with crash-rates. Anderson and Krammes (2000) estimated the reduction in 85th percentile speeds from the approach tangent to the mid-point of the following curve. They found that a statistically significant relationship existed between mean speed reduction and mean crash rate: sites with higher speed reductions showed higher crash rates. This important finding was further investigated in the present research during the development of a relationship between the design consistency of two-lane highways and expected crash-rates.

As can be seen from the studies mentioned above, there is a need to develop a model that takes into account the overall horizontal features as well as the vertical alignments. Moreover, there is a need to re-estimate the relationship between road consistencies calculated according to this developed model and road crashes.

3.   Data collection

In order to examine the relationship between road consistency and crash occurrence, it was necessary to find a set of road segments in which data on the horizontal and vertical alignment and their history of crashes were available. Two datasets on two-lane rural highways were accessible for this study. The first dataset included 26 road segments from northern Israel and the second dataset included 83 road segments from Saxony province in Germany derived from "Road View" software (Dietze and Ebersbach, 2006). All segments selected connect two major intersections although typically there were several minor intersections in between them. Road segments that had significant infrastructure changes (e.g., widening and paving of shoulders, construction of long guardrails, or intersection control and channelization changes) during the years for which the crash data were collected were eliminated from the dataset.

Data on crash history and traffic volumes of the same road segments were also required for the analysis of the relationship between crash occurrence and road consistency. Crash and traffic data on the Israeli road segments were acquired from the Israeli Central Bureau of Statistics which included the number of crashes and traffic volumes for 5 consecutive years, 1997 through 2001. Crash and traffic data of the German road segments, crash data where extracted from the "Road View" software for 3 consecutive years, 2003 through 2005.

All crashes in the dataset involved casualties categorized as light, serious, and fatal crashes. Damage only crashes were not included in this study. It was not possible to conduct the different statistical analyses for each severity level or for each type of crash separately, since the number of crashes over a period of three to five years would not be sufficient for attaining statistically significant results. Moreover, in order to make international comparisons, a similar classification of crashes is needed, as well as the use of the same definitions (for example: died within 30 days, serious injury, slightly injured). Crashes are classified as "serious" in Israel when the victims stay in the hospital for more than 24 hours, and not just for observation. According to IRTAD (1998) - International Road Traffic and Accident Database, in Germany "serious" crash is a crash where victims were taken to hospital for in-patient treatment (of at least 24 hours). Crashes are classified as "light" in Israel when the hospital stay is less than 24 hours. In Germany, "light" injury includes all injured road users who are not seriously injured. Fatal crashes has the same definition in Israel and Germany and it is classified when at least one person who was killed outright or who died within 30 days as a result of the crash.

It is concluded that the Israeli and German definitions of "light" and "serious" crashes are very similar. Yet, this study took into account all crashes with casualties (light, serious and fatal) and therefore differences in definitions, if any, between countries are not affecting the overall results.

EJTIR **8**(4), December 2008, pp 320-332
Mattar-Habib, Polus and Farah
Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural
Roads in Israel and Germany

324

4.   The basic consistency model

The basic consistency model was presented in a previous study (Polus et al., 2004). This model was based on two main parameters: (1) the bounded area between the profile and the average speed; (2) the standard-deviation of speeds along a two-lane highway segment. The basic model is presented in Equation1:

$$C = 2.808 \cdot \exp^{(-0.278 \cdot Ra \cdot \sigma)} \tag{1}$$

Where:

C   basic consistency of a highway segment

Ra   normalized area bounded by the average speed profile of cars and the average operating speed (m/sec.)

σ   standard deviation of cars speeds (m/sec.)

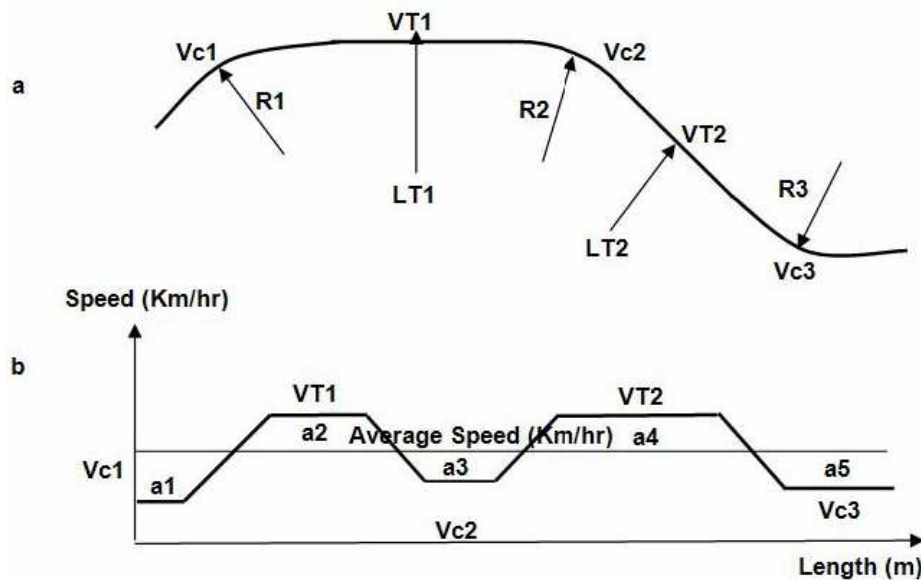An example of a road segment and its speed profile is presented in Figure 1.

Figure 1. (a) Example of Road Segment; (b) Example of Speed Profile
Vci = speed on curve i, (km/h)
VTi = speed on tangent i, (km/h)
ai = area bounded by average speed and the speed profile

This model consisted of two measures. The first measure was the relative normalized area (per unit length), bounded between the average speed profile and the average speed line. The average operating speed, V_{avg}, was computed as the average weighted speed, by length, along the entire segment. If the areas bounded between the speed profile and the average operating speed line are denoted by a_i, as shown in Figure 1, then the first consistency measure is given as:

$$Ra = \frac{(\Sigma a_i)}{L} \tag{2}$$

Where:

Ra   relative area (m/sec) measure of consistency

EJTIR **8**(4), December 2008, pp 320-332
Mattar-Habib, Polus and Farah
Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural
Roads in Israel and Germany

$\sum a_i$ sum of i areas bounded between the speed profile and the average operating speed (m^2/sec)

L   entire segment length (m.)

The second measure of consistency was σ, the standard deviation of speeds along the highway segment. The standard deviation is the most appropriate statistical measure of data distribution around the mean value. The standard deviation of the operating speeds was defined as:

$$\sigma = \left\{ \frac{(V_j - V_{avg})}{n} \right\}^{0.5} \tag{3}$$

Where:

σ   standard deviation of operating speeds (km/h)

V_j operating speed along the jth geometric element (tangent or curve) (km/h)

V_{avg} average weighted (by length) operating speed along a highway segment (km/h)
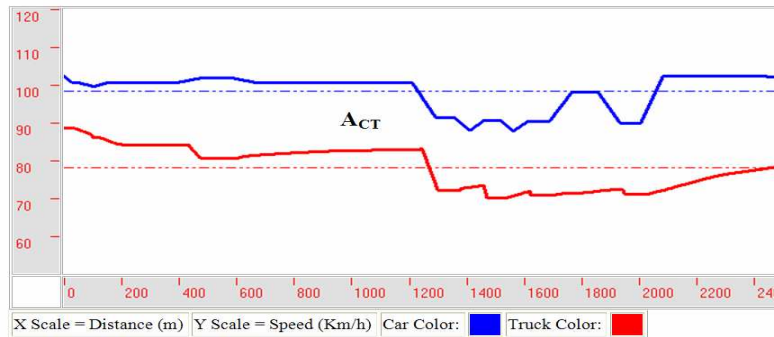
n   number of geometric elements along a segment (km/h)

The basic model is based only on the speed variability of cars in mostly level terrain. When evaluating the consistency of mountainous roads, as well as many hilly or winding highways, it becomes necessary to consider the speed performance of trucks and to estimate the consistency of the speed profile of heavy vehicles. To achieve that, an enhanced integrated model was developed by Polus et al. (2005).

5.   The enhanced integrated-consistency model

The new integrated-consistency model is applicable to any two-lane highway, including mountainous terrain, where it is imperative to incorporate the impact of the speed profile of trucks on design consistency in conventional traffic and safety evaluations. The model takes into account the combined effect of the horizontal and vertical alignments. For horizontal curves, the speed was determined by models developed by Krammes (1995), and for horizontal tangents, the models of Polus, Fitzpatrick, and Fambro (2000) were used. Further discussion of these models was provided by Polus and Mattar-Habib (2004). For the vertical alignment, the speed was determined on the basis of AASHTO (2001) speed curves for different grades. Both horizontal and vertical speeds were calculated at 1m (3 ft.) intervals by a software called HSPC (Highway Speed Profile and Consistency), that was developed specially for that purpose. The development of improved speed-profile models and plots made it possible to compare the variability of car speeds (Ra and σ; note Equations 2 and 3, respectively) to the area (A_{CT}) bounded between the speed profile of cars and trucks (see Figure 2).

EJTIR **8**(4), December 2008, pp 320-332   326
Mattar-Habib, Polus and Farah
Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural
Roads in Israel and Germany

GENERAL ROAD DATA
NUMBER OF LANES: 2
ROAD COEFFICIENT: 1.00
LENGHT: 2486 m
TERRAIN: Level
SPEED PROFILE PARAMETERS - CARS
AVERAGE SPEED: 98.23 km/hr
RELATIVE AREA (Ra): 0.97 m/sec
STANDARD DEVIATION (STD): ±5.96 km/hr
CONSISTENCY: 1.79
CONSISTENCY EVALUATION: Acceptable Consistency
SPEED PROFILE PARAMETERS AND CONSISTENCY - TRUCKS
AVERAGE SPEED: 78.05 km/hr
RELATIVE AREA (Ra): 1.40 m/sec
STANDARD DEVIATION (STD): 5.49 km/hr
CONSISTENCY: 1.55
CONSISTENCY EVALUATION: Acceptable Consistency
INTEGRATED CONSISTENCY MODEL
BOUNDED AREA BETWEEN PROFILES (ACT): 5.89 m/sec
OVERALL CONSISTENCY: 1.69
OVERALL CONSISTENCY EVALUATION: Acceptable Consistency

Figure 2. HSPC Program Output of a German Two-Lane Highway Segment with Acceptable Consistency

The A_{CT} is conversely related to the improvement in the design consistency; put differently, the smaller the bounded area, the better is the design.

Adding the bounded area (A_{CT}) to the consistency concept provides an additional measure of the impact of the entire alignment, including both horizontal and vertical elements, on the steady (i.e., consistent) performance of both cars and trucks. Along a given segment, the smaller the bounded area, the greater is the resemblance between the speed performance of cars and speed performance of trucks. Larger differences between the speed profiles, particularly in mountainous terrains, lead to higher speed differentials, and hence a higher likelihood of crashes and a lower operational consistency.

The integrated-consistency model is presented in Eq. 4:

$$IC = [2.808 \cdot \exp^{(-0.278 \cdot Ra \cdot \sigma)}] \cdot \exp^{(-0.01 \cdot ACT)} \tag{4}$$

Where:

IC   integrated consistency of a highway segment

Ra   normalized bounded area by the speed profile of cars and the average operating speed, defined in Eq. 2 (m/sec.)

EJTIR **8**(4), December 2008, pp 320-332   327
Mattar-Habib, Polus and Farah
Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural
Roads in Israel and Germany

σ   standard deviation of car speeds, defined in Eq. 3 (m/sec.)

A_{CT} normalized bounded area between the speed profiles of cars and trucks (m/sec).

The threshold values to distinguish among good, acceptable, and poor design consistencies are presented in Table 1 and are not changed relative to the basic model (Polus et al., 2004).

Table 1. Thresholds for the Determination of Design-Consistency Quality

Design-consistency quality		
Good	Acceptable	Poor
C > 2	1 < C ≤ 2	C ≤ 1 (m/sec)

These values were determined based on consultation with experienced highway engineers, which included an examination of numerous segments and their qualities and based on utilization of engineering judgment.

The HSPC (Highway Speed Profile and Consistency) software program developed by Polus et al. (2005) and described extensively in a previous article was used to assess the consistency measures. The horizontal alignment input includes the radius and length of curves and the length of tangents. The vertical alignment input includes the slope and length of each grade. The program calculates the operating speed of cars and trucks, separately for horizontal and vertical alignments. The output of HSPC includes a plot of the speed profiles of cars and trucks and their computed average operating speed, standard deviation of operating speeds, and three types of normalized "bounded area": between the speed profile of cars and their average operating speed (Ra, Eq. 2), between the speed profile of trucks and their average operating speed (calculated in same way as Ra), and between the speed profiles of cars and trucks (A_{CT}) as noted above. Figure 2 is an example of the output of HSPC of a German road.

6.   Relationship between road consistency and crash safety

The occurrence of road crashes is known as random, discrete, and rare. Therefore, the idea of applying the Poisson distribution in modeling the occurrence of crashes overcomes the shortcoming of conventional regression models, such as the linear regression.

In a Poisson regression model, the probability of segment i having y_i accidents per year (where y_i is a non-negative integer) is given by Eq. 5:

$$P(y_i) = \frac{EXP(-\lambda_i) \cdot \lambda_i^{y_i}}{y_i!} \tag{5}$$

Where P(y_i) is the probability of segment i having y_i accidents per year and λ_i is the Poisson parameter for segment i, which is equal to the expected number of accidents per year at segment i, E(y_i). Poisson regression models are estimated by specifying the Poisson parameter λ_i (the expected number of events per period) as a function of explanatory variables. The most common relationship between explanatory variables and the Poisson parameter is the log-linear model given by Eq. 6:

$$\lambda_i = E(y_i) = \alpha \cdot (AADT_i)^{\beta} \cdot e^{\sum_{j=1}^{k} \gamma_j \cdot x_{ij}} \tag{6}$$

The estimated expected number of accidents, E(y_i), is a function of traffic volume AADT, and a set of risk factors, X_j (j = 1, 2, 3, … n) where γ_j is the coefficient for the jth independent variable.

EJTIR **8**(4), December 2008, pp 320-332
Mattar-Habib, Polus and Farah
Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural
Roads in Israel and Germany

328

The effect of traffic volume on accidents is modeled in terms of an elasticity that is a power of β, to which traffic volume is raised. This elasticity shows the percentage change of the expected number of accidents, which is associated with a 1 percent change in traffic volume. If the value of β is 1.0, the number of accidents is proportional to traffic volume, and in this case using accident rates is acceptable in road safety analysis. If the value of β is less than 1, the number of accidents increases by a smaller percentage than traffic volume. If the value of β is greater than 1, the number of accidents increases by a greater percentage than traffic volume. This model is estimable by standard maximum likelihood method.

The relationship between crash numbers and road design consistency assuming the Poisson distribution was examined based on the data base of each country in separate.
The following equations (7 and 8) present the calibrated models which describe the average estimated crash numbers as a function of road consistency, road length and traffic volume:
The Israeli model:

$$LOG(\lambda_i) = LOG(1.256 \times 10^{-5}) + 1.677 \cdot LOG(AADT) + 0.061 \cdot Length - 0.228 \cdot RC \qquad (7)$$

The German model:

$$LOG(\lambda_i) = LOG(6.902 \times 10^{-3}) + 0.635 \cdot LOG(AADT) + 0.226 \cdot Length - 0.144 \cdot RC \qquad (8)$$

A Summary of the criteria for assessing goodness of fit of the Poisson regression models are presented in Table 2.

Table 2. Summary of the Criteria for Assessing Goodness of Fit of the Poisson Regression Models

	Israeli model			German model		
	Criteria For Assessing Goodness Of Fit					
Criterion	**DF**	**Value**	**Value/DF**	**DF**	**Value**	**Value/DF**
Deviance	22	21.40	0.97	79	30.94	0.39
Scaled Deviance	22	21.40	0.97	79	79.00	1.00
Pearson Chi-Square	22	20.71	0.94	79	31.19	0.39
Scaled Pearson X2	22	20.71	0.94	79	79.62	1.00
Log Likelihood		186.86			-140.58	

The Poisson regression model assumes that the variance of the dependent variable is equal to the mean. A preliminary examination of the Poisson model revealed an evidence of underdispersion in the German data, which indicate inadequate fit of the Poisson model. Corrective measures for the underdispersion include using the deviance or Pearson Chi-Square divided by degrees of freedom as an estimate of the dispersion parameter instead of setting it to 1. A reanalysis, using the deviance divided by the degrees of freedom, is presented in Table 2. As can be seen the deviance and the Pearson statistic divided by the degrees of freedom for both models is now approximately one indicating an adequate fit of the Poisson model. The Deviance and Pearson Chi-Square have approximately Chi-square distribution with the number of degrees of freedom printed in column titled DF. Both values indicate an adequate fit.

A summary of the statistical significance of the estimated coefficients in Eqs. 7 and 8 is presented in Table 3.

EJTIR **8**(4), December 2008, pp 320-332
329
Mattar-Habib, Polus and Farah
Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural
Roads in Israel and Germany

Table 3. Analysis of Parameter Estimates of the Poisson Regressions Models

Israeli model							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence	Limits	Chi-Square	Pr > ChiSq
Intercept	1	-4.901	1.257	-7.365	-2.436	15.190	<.0001
AADT	1	1.677	0.322	1.045	2.308	27.070	<.0001
Length	1	0.061	0.028	0.006	0.116	4.740	0.030
Rc	1	-0.228	0.085	-0.395	-0.061	7.140	0.008
Scale	0	1	0	1	1		
German model							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence	Limits	Chi-Square	Pr > ChiSq
Intercept	1	-2.161	1.053	-4.223	-0.098	4.21	0.040
AADT	1	0.635	0.287	0.074	1.197	4.91	0.027
Length	1	0.226	0.038	0.151	0.300	35.16	<.000
Rc	1	-0.144	0.072	-0.284	-0.003	3.99	0.046
Scale	0	0.626	0	0.626	0.626		

The explanatory variables, AADT, length and road consistency are statistically significant as shown in Table 3 (P-value < 0.05). The scale row indicates the value of the overdispersion scale parameter used in adjusting output statistics. It was estimated by the square root of the deviance divided by its degrees of freedom (Deviance/DF).

It can be seen from Table 3 that when road consistency improves (increases) the estimated average crash number decreases. When road segment length is longer the estimated average crash number is expected to be higher and when the traffic volume increases the estimated average crash number is expected to be higher. The coefficient β, which reflects the elasticity (the percentage change of the expected number of accidents, which is associated with a 1 percent change in traffic volume) is greater than 1 for the Israeli model, which means that the number of accidents increases by a greater percentage than the traffic volume and less than 1 for the German model which means that the number of accidents increases by a smaller percentage than traffic volume.

Figure 3 illustrates the relationship between the estimated average number of crashes, calculated according to equations 7 and 8, and road consistency under the assumption of an average daily traffic volume of 4500 vehicles per day and a road segment of 5 kilometers.
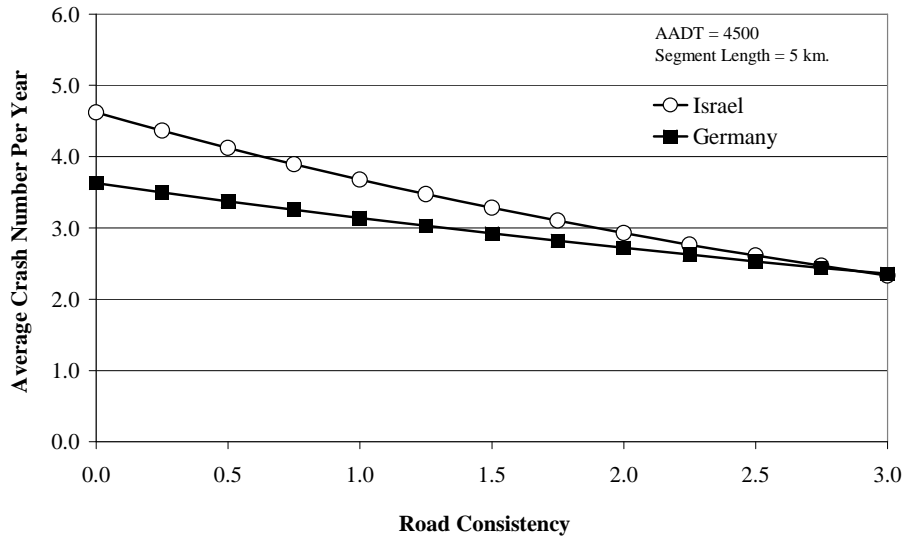
EJTIR **8**(4), December 2008, pp 320-332
Mattar-Habib, Polus and Farah
Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural
Roads in Israel and Germany

Figure 3. Average Crash Number per Year vs. Road Consistency

The two models illustrated in Figure 3 for the Israeli and German data are showing the same trend and relatively close, with the Israeli model having a bit higher average crash values than the German model. Figure 4 present the probability of crash occurrence both in Israel and Germany for a road segment of 5 kilometers in length, average traffic volume of 4500 and a road consistency of 2.
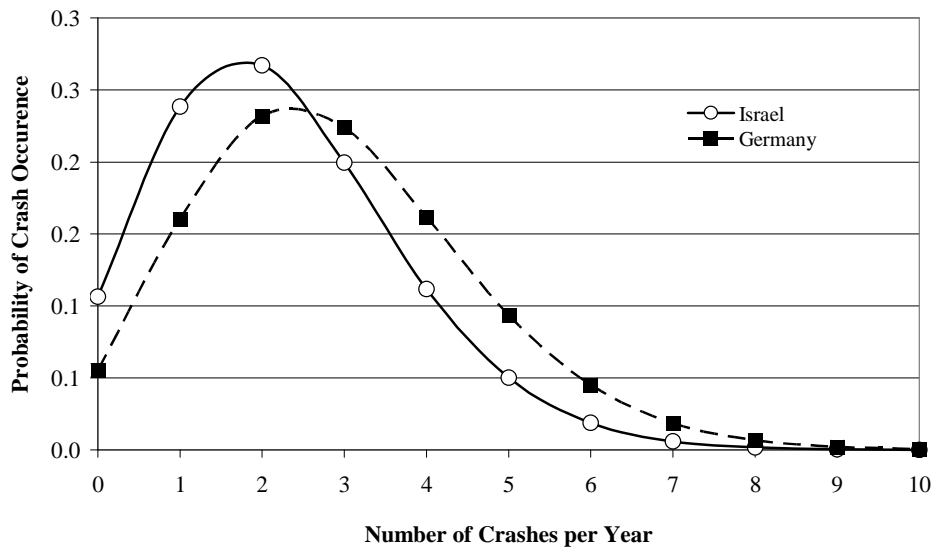

Figure 4. Probability of Crash Occurrence

In order to understand and explain the similarity of the Israeli and German consistency models, it is necessary to examine other infrastructure characteristics of the road in both countries and other variables that are related to the human and vehicle factors. These factors are known of their contribution to crash occurrence beside the infrastructure factor.

EJTIR **8**(4), December 2008, pp 320-332
Mattar-Habib, Polus and Farah
Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural
Roads in Israel and Germany

331

Generally, the alignments of highways in the two countries comply with dynamic design criteria such as minimum radius, slopes, etc. However, a very common characteristic of the German rural two-lane roads in the province of Saxony is the existence of trees along the roads from both sides and the very narrow shoulder width; these two features jeopardize roadside safety. In northern Israel though, the relatively poor quality of pavement maintenance and the accelerated deterioration of pavements decrease the safety level of two-lane roads. Therefore, it is hypothesized that these shortcomings of the roads in both regions may have similar effects on safety.

Further analysis of preliminary comparison of the average vehicle age and distribution of drivers' age showed that the average vehicle age in Israel is slightly less than the average vehicle age in Germany for the years 1995-2006 (Kraftfahrtbundesamt, 2007). Similarly, the distribution of drivers' age in the two countries (although not the two regions) was found to be very similar. These results give only a preliminary explanation of the similarity between the two models. Yet, it was not possible to identify the exact differences between the two regions, northern Israel and the province of Saxony in Germany, which might but not necessarily have particular characteristics that differ from the average characteristics of the whole country. Therefore, more microscopic research and microscopic comparisons of the different factors that contribute to crash occurrence is proposed in order to further investigate the similarity of the Israeli and German consistency models for the two regions studied.

7.   Summary and further research

This paper presents the calibration of an enhanced-consistency model which was developed initially by Polus et al (2005). The values of the consistency were calculated using data collected from two countries: Israel and Germany. 26 Israeli road segments and 83 German road segments were investigated in order to examine the relationship between crash occurrence and road consistency.

The relationship between crash probabilities and road consistency was described by a Poisson model. The model's parameters were calibrated using maximum likelihood method. It was found that the German and Israeli calibrated models were relatively close to each other. It can be noticed clearly that the trend of the two calibrated models is similar; as road consistency improves, the average crash numbers estimated decrease significantly.

The enhanced-consistency model and the software may be used to determine consistencies of different alternatives during the planning of new highways or the reconstruction of existing roads. Adherence to high consistency levels adds another dimension to the planning process, beyond the use of minimum criteria of geometric design, and therefore consequently assures a higher level of safety.

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EJTIR **8**(4), December 2008, pp 320-332   332
Mattar-Habib, Polus and Farah
Further Evaluation of the Relationship between Enhanced Consistency Model and Safety of Two-Lane Rural
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