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Original
Assessing International Transferability of the Highway Safety Manual Crash Prediction Algorithm and its Components / Sacchi, Emanuele; Persaud, B.; Bassani, Marco. - In: TRANSPORTATION RESEARCH RECORD. - ISSN 0361-1981. - STAMPA. - 2279:(2012), pp. 90-98. [10.3141/2279-11]

Publisher:
Transportation Research Board of the National Academies

Published
DOI:10.3141/2279-11

ASSESSING INTERNATIONAL TRANSFERABILITY OF THE HIGHWAY SAFETY MANUAL CRASH PREDICTION ALGORITHM AND ITS COMPONENTS

Word Count (Abstract 170; Manuscript 4250; Tables and Figures 3000)

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This paper is submitted to the Transportation Research Board (TRB) for publication in the Transportation Research Record.
Re-submission Date: March 15, 2012

ABSTRACT

The Highway Safety Manual (HSM) provides an algorithm, and associated knowledge, for predicting crashes for different facility types. This algorithm requires calibration to current local conditions to enhance transferability, using a procedure that is prescribed in the HSM. However, there is no procedure for assessing transferability. To fill this void, this paper is focused on the methodology for assessing the transferability of the key HSM algorithm components, the baseline Safety Performance Function (SPF) and the Crash Modification Factors (CMFs), using the Italian road network for an illustrative case study. The calibration of the HSM crash prediction model is investigated with a dataset for two-lane two-way rural highways, to demonstrate tools that could be used by jurisdictions around the world for assessing the validity and compatibility of the CMFs and base models, as well as the performance of the complete algorithm. A comparison with the results from a similar study carried out in Canada is provided in supplementing the conclusions on the transferability of the HSM algorithm outside the United States.

BACKGROUND

In Europe and other parts of the world, road safety evaluation methods used by transportation professionals are traditionally descriptive, and are focused on summarizing and quantifying information about crashes that have occurred at a specific roadway site. In Italy, for instance, the official guidelines relating to road safety analysis do not provide analytical tools and techniques for quantifying the potential effects on crashes of decisions made in planning, design, operations, and maintenance of roadways (*1*). Recently the European Commission (EC) has adopted the directive 2008/96/EC that requires the establishment of procedures relating to road safety impact assessments, and the results of its implementation in the member States is forthcoming (*2*).

The recent evolution in road safety analysis from descriptive methods to quantitative and predictive analyses will greatly facilitate the EC directive. New North American initiatives such as the Highway Safety Manual (HSM) (*3*) are providing guidance, based on the best available factual knowledge, to professional engineers for quantitative crash analysis and safety evaluation. The HSM is becoming a standard of practice for highway safety professionals just as the Highway Capacity Manual currently is for traffic engineers, and is being implemented in state and local highway agencies in the US and other countries. A key issue in facilitating the worldwide application of the HSM is the transferability of the predictive models to different road networks in environments that are quite different from those in the US.

While the HSM could be a valuable resource for fulfilling the EC directive, the European roadway systems, weather, animal populations, terrain, driver training and behavior, and crash frequencies and severity patterns can result in problematic crash predictions from the HSM algorithm, which was developed from US data. At a minimum, the algorithms presented in the HSM should be properly calibrated and validated, and, where necessary and possible, new statistically-based algorithms should be developed for environments that are substantially different from the US.

Part C of the first edition of the HSM provides the crash prediction algorithm essentials – base models and CMFs – for segments and intersections for three types of facilities: rural two-lane undivided (2U) highways, rural multilane highways, and urban and suburban arterials (*3*).

According to the HSM procedure, the expected collision frequencies calculated using the baseline SPFs have to be modified, using Crash Modification Factors (CMFs) listed in HSM Part D (*3*), to help account for changes in features from baseline conditions at a specific site, such as lane or shoulder width for two-lane roads. This prediction is refined using the Empirical Bayes (EB) method (*4*) for facilities with a known crash history. Equation 1 summarizes the procedure for predicting the number of collisions ($N_{predicted}$) at a site (before applying the EB method):

$$N_{predicted} = C_x \times N_b \times CMF_1 \times CMF_2 \times \ldots \times CMF_n \qquad (1)$$

where N_b is the number of crashes predicted by the SPF for specified base conditions, and C_x is a calibration factor for applying a base SPF from a different jurisdiction and/or time period. This factor can be simply calculated from the total number of crashes for a sample set from the jurisdiction of interest divided by the sum of the predicted crashes for the sample using Equation 1 without the calibration factor. The HSM documents details of this simple calibration procedure, including minimum sample sizes of 30-50 sites with 100 crashes per year. However, there is no methodology for assessing the validity of the results, i.e., the transferability of the algorithm to a specific jurisdiction.

There has been some research related to the adoption of the HSM predictive techniques in different jurisdictions in the US such as Texas (*5*), Louisiana (*6*), Oregon (*7*), as well as in other countries like Italy (*8*), Canada (*9*) and New Zealand (*10*). With the exception of the Canadian study, these efforts have principally focused on estimating and evaluating the size of the calibration factor for different facility types. The results have shown a wide variability in this factor even across US jurisdictions. The first two calibrations used a complicated, but conceptually more robust calibration procedure outlined in the HSM prototype chapter (*11*). The results of those calibrations indicated a slight under-prediction of the algorithm for Texas (C_x=1.12) and a more marked one for Louisiana (C_x=1.63). The Texas research further analyzed a data subset of two-lane rural horizontal curves. In that case, the results were less encouraging, indicating a C_x that varied between 0.76 and 1.8 across the state, suggesting that the use of the calibrated algorithm for curves in Texas could be problematic. The Louisiana research focused more on comparing observed and predicted number of crashes with and without the EB method which, as noted above, is used to refine the predictions from Equation 1 for facilities with a known crash count. Not surprisingly, the EB method produced better results. The Oregon study (*7*) used the HSM-first-edition simplified calibration procedure (*3*) and estimated calibration factors of 0.74 for total and 1.15 for fatal-plus-injury crashes.

Outside the US, the algorithm was calibrated for a central-Italy dataset for rural two lane undivided (2U) highways (*8*) using the complex HSM prototype chapter procedure. Six calibration factors were estimated, indicating a sizable overprediction. C_x varied between 0.11 and 0.40 when it was estimated section-by-section and between 0.35 and 0.38 when estimated for aggregated segments with averaged CMFs. The New Zealand study also used the complex calibration procedure and estimated a value of C_x of 0.89 for rural 2U roads (*10*).

The variability in the calibration factors across, and even within, jurisdictions suggests that an evaluation not only of C_x, but also of the validity of SPFs as well as CMFs should be conducted when the HSM models are considered for application in another jurisdiction, particularly outside the US. This is because a C_x value that is substantially different from 1.0 may be capturing the crash prediction differences from variability in crash reporting thresholds and road environments as well as a lack of suitability of the baseline SPFs and CMFs.

OBJECTIVES AND METHODOLOGICAL APPROACH

The primary objective of the study was to explore methodology for assessing transferability of HSM algorithm as a whole, as well as its components – the baseline SPFs and CMFs. The main context of this investigation and illustration is a case study for Italian two-lane rural roads.

One secondary objective was a comparison with the results from a similar study carried out in Canada (*9*) to supplement the conclusions on the transferability of the HSM algorithm outside the United States. Another secondary objective was to document the methods and results as an illustration of what it takes for jurisdictions to assess the transferability of the HSM crash prediction algorithm.

The first step in the methodological approach for meeting these objectives was simply the calculation and the analysis of the calibration factor, following the procedure outlined in the HSM 2010 release.

As suggested earlier, baseline models and CMFs should be evaluated separately to assess the transferability of the HSM algorithm as a whole. This goal was pursued with the estimation of a local baseline model and the evaluation of each CMF in turn, followed by a comparison of the results with equivalent HSM information.

To assess the global performance of the recalibrated HSM algorithm, the most appropriate goodness-of-prediction measures were selected based on a literature review and applied. The combination ultimately selected included the Mean Absolute Deviation (MAD) (*12*), the value of the recalibrated dispersion parameter (*9*), and the Cumulative Residual (CURE) plots (*13*). Further discussion of these measures is presented in a later section.

DATASET USED

The dataset used pertains to the Province of Turin, one of the eight Piedmont provinces in North-Western, Italy. It has more than 2 million inhabitants in an area of almost 7,000 km^2 (2,700 mi^2). The topography is characterized by mountainous as well as hilly and plain areas.

The Province of Turin's secondary network contains 3,084 km (1,916 mi) of rural 2U roads. Official data for motor vehicle crashes available from the Italian National Institute of Statistics (ISTAT) pertain to 472 km (293 mi) (*14*) of this network. These are roads with an interprovincial service or those that link cities, large towns and other significant traffic generators, and include freeways and two-lane rural highways. According to the Italian Road Design Standard (*15*), the definition of rural 2U highways in the HSM matches two different typologies: the so-called functional type "C" minor collectors that attract traffic over medium distances, and type "F" local roads that primarily provide access to adjacent land and to the collector network.

Geometric and Traffic data

Geometric characteristics and the annual average daily traffic volumes (AADT) are the main data required for the use of the HSM algorithms. According to the HSM, a highway must be divided into individual homogenous roadway segments with a minimum length of 160 m (0.10 mi) in order to apply Equation 1. Changes in factors such as AADT, lane and shoulder width, the beginning or end of a horizontal curve, and the point of vertical intersection for a crest or sag vertical curve are among the triggers for demarcating consecutive homogeneous roadway segments.

To enable the fragmentation of segments, traffic volume reports and a geographical information system (GIS) provided by the Province of Turin were used. Road network features are expressed as vectors by points and polylines (road centerline). In addition, that database was combined with satellite imagery, aerial photographs, local cartography, and similar mapping sources for estimating parameters like driveway density (DD), roadside hazard rating (RHR), lane width, shoulder width/type, and presence of two-way left-turn lanes (TWLTLs).

The summary statistics in Table 1 indicate the range of values for the key variables obtained for this study. Table 1 also indicates if data for a certain variable are required or are just desirable for the HSM calibration procedure.

Overall, 242 homogeneous sections, totaling 115.35 km (71.67 mi), were defined. The freeway network was omitted from the 472 km of data mentioned above. Moreover, it was decided to omit segments in more mountain environments. This enabled closer matching of the radii of horizontal curve range with that for the data used for estimating the rural 2U segment SPFs that were used to derive the base models provided in the HSM (*16*). In addition, sites with an AADT of more than 20,000 were omitted to match the domain of the HSM baseline SPF.

Motor vehicle collision data

The main source was the official collision data provided by ISTAT, which contains only those crashes involving at least one vehicle traveling on the road network and a personal injury, i.e., fatal plus injury crashes (F+I). The data are assembled by progressive kilometric stations, and no information is provided on whether or not a collision is intersection-related. That missing information was obtained from a second database provided by the Province of Turin (on which the ISTAT report is based on). The analysis period adopted, 2005 to 2008, had a total of 236 collisions recorded, and was the most recent one for which data were available.

HSM CALIBRATION EFFORT

As mentioned earlier, the C_x can be calculated when observed crashes are known for a specific site. Equation 2 recaps what was already stated, but also shows the parameters estimated from the segment homogenization process discussed above:

$$C_x = \Sigma\, N_{observed} / \Sigma\, N_{predicted} \qquad (2)$$

where $\Sigma\, N_{observed}$ is the sum of the observed number of crashes, and $\Sigma\, N_{predicted}$ is the sum of predicted crashes for the homogenous segments. The prediction for each segment comes from two basic steps: the estimate of N_b (from Equation 1), and then the adjustment of N_b by multiplying by the appropriate CMF values if there are differences from baseline conditions.

Table 2 depicts the results of that procedure for a study period of four years. The HSM recommends use of between three to five years of data and the random selection of between 30 and 50 sites, but since this is a research investigation rather than an actual HSM application, all available sites have been used for the calibration. In fact, due to the inability to meet the recommended minimum of 100 observed crashes per year in the calibration data, that choice was consistent with other HSM calibration studies (*7*) (*17*). (The HSM recommendations are somewhat arbitrary and, if nothing else, this study and the others mentioned, do provide the basis for fine-tuning the HSM recommendation in future editions, in particular, for the fatal plus injury collisions used in this study, for which smaller samples may suffice, given that these data are more reliable than those based on all crashes.)

The estimated C_x shows an overprediction of collisions by the HSM model by a factor larger than two. This overestimation was also found in the Canadian research cited earlier, which was based on 77.9 km of rural 2U roads in Ontario, and which estimated a fatal plus injury (F+I) calibration factor equal to 0.74 (*9*).

A visual overview of predicted-versus-observed collisions for the data used in this calibration procedure is shown in Figure 1, disaggregated by AADT ranges. Since AADT is the only covariate of the HSM baseline model, it stands to reason that it will affect the predictive ability of the algorithm as a whole.

The analysis of the plot reveals that the predictive ability for higher AADTs is not so good. Also, in accord with results from other studies (*5*) (*8*), it is evident that the HSM model tends to overestimate crash frequency for sections with few collisions and to underestimate it for those ones with more collisions. So it is not surprising that some authors have concluded that a constant value of C_x is not a suitable option for valid model transferability (*8*). However, for this case study, the use of a calibration function rather than a constant factor does not appear necessary since the majority of data are above the best fit line, as highlighted by the ellipse in Figure 1. The data points outside the ellipse are likely due to the extreme random fluctuation in the recorded collision count, an intrinsic feature of collision data. (The apparent outlier, with 19 observed crashes and just 3.10 predicted, does not materially affect the results or conclusions, so has been retained for the remaining analysis.)

TRANSFERABILITY ASSESSMENT

As suggested earlier, baseline models and CMFs should be evaluated separately to assess the transferability of the HSM algorithm as a whole.

Local baseline model estimation and evaluation

For this exercise, a model directly estimated from local data, considering only base conditions (such as absence of horizontal curvature, RHR=3, DD=5 per mile), was compared to the equivalent HSM base model. The data used are the same as that for applying the HSM calibration procedure, but this time the sites with AADTs higher than those applicable for the HSM baseline model were used to enlarge the dataset. Generalized linear modeling through maximum likelihood methods was chosen to estimate local model coefficients, using the Statistical Analysis System (SAS) software package and assuming the negative binomial error distribution for the observed crashes. The dispersion parameter of that distribution, which applies to a unit length of road according to the most recent literature (*12*), was also estimated in this process for use, as noted earlier, as a goodness of fit measure.

Table 3 summarizes the results and the domain of validity of the local model. It also provides a comparison between the model estimated and the HSM one (with segment length converted to SI units). The local base model has an AADT exponent significantly larger ($p=0.09$) than the value of 1.0 that was assumed, a priori, in the HSM model estimation.

The local and HSM models are visually depicted in Figure 2. In calibrating the HSM baseline model, the multiplier, 0.440, from Table 2, was applied. Since the SPF domains are different, a comparison can only be made for AADTs between 5,000 and 17,800. The HSM baseline model, as expected, shows an over-prediction compared to the local one, and this bias is reduced when the calibration factor is applied. But the trend of the recalibrated HSM model appears similar to the estimated local one only for low AADTs. This is evidently due to the difference in AADT exponents.

Evaluation of CMFs

The procedure, which has been used for the Canadian study (*9*), consists of a separate evaluation of each CMF in turn. For this case study, it was possible to evaluate the CMFs related to the length, radius, and the presence or absence of spiral transitions for horizontal curves (CMF_{3r}), driveway density (CMF_{5r}), and roadside design (CMF_{10r}) (*3*). As is evident in Table 1, other road features were considered in the segment homogenization, so the CMFs for such features could not be evaluated.

For this procedure as applied, sites were initially grouped by the levels of the CMF in question, such as 1.0, 1.1, 1.2, etc. Then, to remove the “effect” of the CMF, its value was changed to

1.0 for all sites and new values of predicted collisions were estimated. With these new results, for each level, the sum of observed collisions was divided by the sum of predicted collisions (just estimated). This derived multiplier for each level was divided once again by the multiplier for the base condition level to normalize the result. The resulting ratio simply represents the influence of omitting the proper CMF value from the prediction algorithm for that specific level. A comparison between the normalized multiplier and the original CMF than indicates the suitability of the HSM CMF to describe local conditions for that specific level. When "the ratio compared to baseline" matches "the original CMF", the CMF is suitable. However, these comparisons should be interpreted in the context of the standard deviation of the ratio of observed to predicted crashes, which was also calculated. Table 4 shows the results of applying the procedure. The highlighted columns indicate the values that are being compared.

It is difficult to come to conclusions given the relatively small number of collisions for most CMF groups and the high standard deviation of the ratio of observed to predicted crashes. Nevertheless, it is still informative to present and discuss the results, especially in the context of those from the Canadian study, which are reproduced in Table 5.

For the Italian case study, for horizontal curvature, only the middle range of ratio (1.544) was consistent with the CMF value ($1<\text{CMF}\leq 2$); the ratio of 1.159 is consistent with the CMF indication that increased grade is associated more collisions, although the magnitude is not close to the CMF value ($2<\text{CMF}\leq 3$). Finally when the CMF is more than 3, there is no consistency with the ratio. The results for CMF_{3r} are consistent with those for the Canadian study (Table 5).

For all CMF levels related to driveway density and RHR variables, the ratios for the Italian case study are not consistent with the original CMFs, suggesting that the CMFs may be unsuitable for local Italian roadway characteristics. On the other hand, for the Canadian roadways, which may be closer in nature to the US ones used to derive the HSM CMFs, there is somewhat more consistency, as is evident in Table 5.

GOODNESS-OF-FIT EVALUATION

Several goodness-of-fit (GOF) measures can be used to assess performance of the recalibrated HSM algorithm. The combination of methods found in the literature as the most significant and appropriate for such an evaluation are Mean Absolute Deviation (MAD) (*12*), value of the recalibrated dispersion parameter (*9*), and Cumulative Residual (CURE) plots (*13*). The same indicators were used in the Canadian study (*9*).

MAD is simply the average of the absolute values of observed ($\hat{Y}$) minus predicted (Y) crashes frequencies as shown in Equation 3, where n is the data sample size:

$$\text{MAD}=\sum_{i=1}^{n}\frac{\left|\hat{Y}_i - Y_i\right|}{n} \tag{3}$$

The recalibrated model predicts the observed data well, on average, when MAD is close to 0. However, MAD close to zero could still be obtained by a model that systematically under and over-predicts for wide ranges of a variable. The CURE method (*17*) addresses this issue by providing the means to assess how well a model fits the observed data over the entire range of each independent variable. This requires the plotting of the cumulative residuals, defined as the difference between the observed and predicted values for each site, for values of a model's variables. A good fit is indicated if, for the range of each covariate, or for the other CMF related variables, the adjusted cumulative residuals oscillate around the value of zero and lie between the two standard deviation boundaries that indicate a 95% confidence limit.

The other GOF measure, the dispersion parameter, is such that larger its value, the more the crash data vary as compared to a Poisson distribution with the same mean. The dispersion parameter was calibrated for local conditions using a specially written maximum likelihood procedure detailed in (*9*).

The HSM and local baseline model dispersion parameters, which were estimated along with the coefficients of the regression equation, are presented in Table 3. Table 6 shows the MAD and dispersion parameter values, along with the calibration factors, for rural 2U highway segments for both the Italian and Canadian datasets. It is evident that, for Italian segments, MAD and the recalibrated dispersion parameter are higher than for Canada. (Surprisingly for Canada the recalibrated dispersion parameter is even lower than for the HSM base model; see Table 3.) These results suggest a lower reliability of the recalibrated HSM model when applied to predict crashes for Italian rural 2U segments. This conclusion is consistent with the relative sizes of the calibration factors themselves, when compared to 1.0.

CURE plots could be constructed for any variable in the dataset, even if it is not in the crash prediction model. Thus, for the Italian dataset, it was feasible to construct them for AADT (Figure 3), as well as the variables related to the CMFs for horizontal curve (Figure 4), driveway density (Figure 5), and grade (Figure 6).

The plot of cumulative residual for AADT does not stray outside of the two standard error boundaries, so this bias is not significant. However, for higher AADTs, the residuals stray close to the lower two standard deviation boundary, in confirmation of the pattern indicated in Figure 1.

For the other variables, all related to the CMFs, the fit is very poor, especially for driveway density (DD). However, in confirmation of the results in Table 4 for CMF_{3r}, when DEG is approximately equal to zero (i.e., for a straight segment), the fit is better.

CLOSING DISCUSSION

The objective of the paper was as much on exploring HSM algorithm transferability assessment methodology as it was in investigating its transferability to Italian 2U rural roads as a case study.

The first step of this assessment compares the HSM base model to a local one estimated on baseline conditions. For the Italian case study, the local base model had an AADT exponent significantly larger than the HSM value of 1.0 ($p<0.1$), so it is not surprising that the relative difference in predictions between the two models increased with increasing exposure.

The second step assesses the transferability of the CMFs. This was done for individual variables for which CMFs were available. This analysis revealed some demonstrable bias, indicating that the CMFs could be improved upon for application in Italy. For example, the CMF for considering curvature increases with decreasing radius.

The final step involves the application of several well-known goodness-of-prediction measures that are recommended for use in assessing the performance of the recalibrated HSM algorithm as a whole. Suggested measures are the Mean Absolute Deviation (MAD), the value of the recalibrated dispersion parameter, and the Cumulative Residual (CURE) plots for AADT and for variables related to the CMFs. The Italian case study results for this assessment are naturally consistent with the results for the base model and CMF assessments.

The results obtained for Italy suggest that the implementation of the HSM techniques in road safety impact assessments across Europe, now promoted with the adoption of the directive 2008/96/EC, should be oriented towards the developing of local SPFs/CMFs for the European context.

The transferability assessment techniques are relatively complex and require substantial data and analytical resources. Thus, they are not intended for routine use by practitioners who, in the absence of such an assessment in an application context, should still apply the universal baseline HSM SPFs (with local calibration) and CMFs.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Department of Civil Engineering at Ryerson University (Toronto, Canada) for hosting Emanuele Sacchi as a visiting scholar. Thanks to this arrangement, and to a discovery grant (to Bhagwant Persaud) from the Natural Sciences and Engineering Research Council of Canada, this research has been made possible. The cooperation of dr. Giovanna Lenti from the Traffic Planning Service of the Province of Turin (Italy), who kindly made the datasets available to the authors, is gratefully acknowledged.

REFERENCES

1. *Circolare 8 giugno 2001 n. 3699: Linee guida per le analisi di sicurezza delle strade* (in Italian). Ministero delle Infrastrutture e dei Trasporti, Rome, Italy, 2001.

2. *Directive 2008/96/EC on road infrastructure safety management*. European Parliament and Council. Brussels, Belgium, 2008.

3. American Association of State Transportation Officials. *Highway Safety Manual*. AASHTO, Washington, D.C., 2010.

4. Hauer, E. *Observational Before-After Studies in Road Safety*. Pergamon Press, Elsevier Science Ltd., Oxford, England, 1997.

5. Fitzpatrick, K., Schneider IV, W., and J. Carvell. Using the Rural Two-Lane Highway Draft Prototype Chapter. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1950, Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 44–54.

6. Sun, X., Li, Y., Magri, D., and H. Shirazi. Application of Highway Safety Manual Draft Chapter: Louisiana Experience. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1950, Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 55–64.

7. Xie, F., Gladhill, K., Dixon, K., and C. Monsere. Calibrating the Highway Safety Manual Predictive Models for Oregon State Highways. Presented at 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 2011.

8. Martinelli, F., La Torre, F., and P. Vadi. Calibration of the Highway Safety Manual's Accident Prediction Model for Italian Secondary Road Network. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2103, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 1–9.

9. Persaud, B., Lyon, C., Faisal, S., Chen, Y., and B. James. *Adoption of Highway Safety Manual methodologies for safety assessment of Canadian roads*. Report prepared for Transport Canada, Ryerson University, Toronto, Canada, 2011.

10. Koorey, G., Calibration of Highway Crash Prediction Models for other Countries - a Case Study with IHSDM. Proceedings of the *4th International Symposium on Highway Geometric Design*, Valencia, Spain, June 2010.

11. Hughes, W. E., K. Eccles, Harwood, D. W., Potts, I., and E. Hauer. Appendix C: Prototype Chapter on Two-Lane Highways. In *NCHRP Web Document 62: Development of a Highway Safety Manual*, Transportation Research Board of the National Academies, Washington, D.C., March 2004.

12. Hauer, E., Overdispersion in Modelling Accidents on Road Sections and Empirical Bayes estimation. *Accident Analysis and Prevention*, Vol. 33(6), 2001, pp. 799-808.

13. Hauer, E., and J. Bamfo. Two Tools for Finding What Function links the Dependent Variable to the Explanatory Variables. Proceedings of the *ICTCT 1997 Conference*, Lund, Sweden, 1997.

14. Localizzazione degli incidenti stradali 2005, 2006, 2007, 2008 (in Italian). CD-ROM. Automobile Club d'Italia (ACI) and Istituto Nazionale di Statistica (ISTAT), 2009.

15. *Decreto Ministerile 5 novembre 2001 n. 6972: Norme Funzionali e Geometriche per la Costruzione delle Strade* (in Italian). Ministero delle Infrastrutture e dei Trasporti, Rome, Italy, 2001.

16. Vogt, A., and J. Bared. Accident Models for Two-Lane Rural Segments and Intersections. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1635, Transportation Research Board of the National Academies, Washington, D.C., 1998, pp. 18–29.

17. Sun, X., Magri, D., Shirazi, H., Gillella, S., and L. Li. Application of the Highway Safety Manual: Louisiana Experience with Rural Multilane Highways. Presented at 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 2011.

18. Oh, J., Lyon, C., Washington, S., Persaud, B., and J. Bared . Validation of FHWA Crash Models for Rural Intersections. Lessons Learned. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1840, Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 41–49.

List of Tables and Figures

TABLE 1 Details of the database used

Data element	HSM Data need	Value in the database				Details
		Min.	Max.	Mean	Standard deviation	
Segment Length (m)*	Required	160	1,066	426	530	-
AADT	Required	4,743	18,954	11,471	5,165	-
Lane Width (m)*	Required	-	-	-	-	Used default value Italian design standards (3.50 m ***)
Shoulder Width (m)*	Required	-	-	-	-	Used average default value Italian design standards (1.1 m ***)
Shoulder Type	Required	-	-	-	-	Found only composite shoulders (paved/unpaved)
Radii of horizontal curves (m)*	Required	93	3,857	659	661	-
Superelevation variance for horizontal curves	Desirable	-	-	-	-	Not available; used HSM default assumption
Vertical Grades (%)	Desirable	0.1	4.7	1.4	1.0	-
DD (driveways/km)**	Desirable	0.8	20.6	6.8	5.5	-
Centerline Rumble Strips	Desirable	-	-	-	-	Not present; used HSM default assumption
TWLTLs	Required	-	-	-	-	Found 1 segment for a length of 1,819 m
RHR	Desirable	3	5	3.7	0.7	-
Lighting	Desirable	-	-	-	-	Not available; used HSM default assumption
Passing lane/short four-lane section	Desirable	-	-	-	-	Found 11 segments for a length of 9,380 m
Automated Speed Enforcement	Desirable	-	-	-	-	Not present; used HSM default assumption

* 1 m = 3.28 ft ** 1 km = 0.62 mi ***rural 2U roads, type C2 and F1, according Italian standards

TABLE 2 Calibration result for rural 2U highway segments using the HSM procedure

number of homogeneous segments	242
number of observed crashes (F+I)	193
number of predicted crashes (F+I)	438.71
Calibration factor (2005-2008)	0.440

TABLE 3 Estimated models compared to the HSM baseline one (in SI units)

	Model form for F+I crashes/year = α L c_i (Total AADT) $^{\beta}$ with: L=segment length in km			Dispersion parameter	AADT validity range
	ln(α) (standard error)	β (standard error)	c_i adjustment coefficient		
baseline conditions	-11.152 (6.35)	1.1 (0.64)	-	0.56/L L in km	4,743 to 36,700
HSM baseline model	-0.312	1	c_1= 365×10^{-6} * c_2= 0.62 ** c_3= 0.321 ***	0.15/L L in km	0 to 17,800

* factor not applied when AADT is in [millions of vehicle per year;
** conversion factor from km to mi
*** HSM default proportion of F+I crashes for rural 2U segments

TABLE 4 Recalibration of HSM CMFs (Italian study)

	Original CMF	Observed crashes	Predicted crashes	Ratio	Standard deviation of ratio	Ratio compared to baseline
Horizontal Curve - CMF$_{3r}$	1.0	31	136.79	0.444	0.566	1
	1< CMF ≤ 2	97	141.61	0.685	0.556	1.544
	2< CMF ≤ 3	37	71.95	0.514	0.634	1.159
	3< CMF	14	37.13	0.377	0.215	0.850
Driveway Density - CMF$_{5r}$	1.0	148	403.43	0.459	0.687	1
	1.1	37	674.84	0.460	0.558	1.003
	1.2	8	21.69	0.369	0.472	0.804
	≥1.3	4	10.92	0.366	1.956	0.798
Roadside Design - CMF$_{10r}$	1.0	118	191.07	0.618	0.900	1
	1.1	58	190.99	0.304	0.301	0.492
	1.2	17	43.67	0.389	0.580	0.630

TABLE 5 Recalibration of HSM CMFs rural 2U segments in Ontario, Canada (*9*)

	Original CMF	Observed crashes	Predicted crashes	Ratio	Ratio compared to baseline
Horizontal Curve	1.0	95	95.02	1.00	1
	1< CMF ≤ 2	44	42.37	1.04	1.04
	2< CMF	2	3.61	0.55	0.55
Driveway Density	1.0	103	85.01	1.21	1
	1.1	13	13.23	0.98	0.81
	1.2	6	12.51	0.48	0.40
	1.3	8	5.03	1.59	1.31
	1.4	11	25.23	0.44	0.36
Roadside Hazard Rating	1.0	54	62.55	0.86	1
	1.1	82	75.97	1.08	1.25
	1.2	5	2.47	2.02	2.34

TABLE 6 Recalibrated HSM algorithm goodness-of-fit: comparison between Italy and Canada

Country	Total observed F+I crashes	F+I calibration factor	MAD	Recalibrated dispersion parameter for F+I
Italy	193	0.44	1.661	0.97/L[km]
Canada	141	0.74	0.384	0.11/L[km]

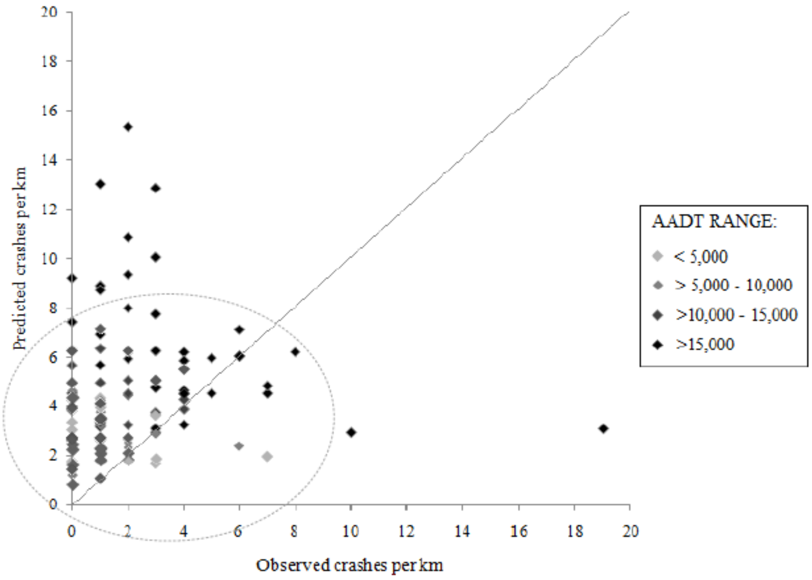

FIGURE 1 Observed versus predicted crashes by AADT variability.

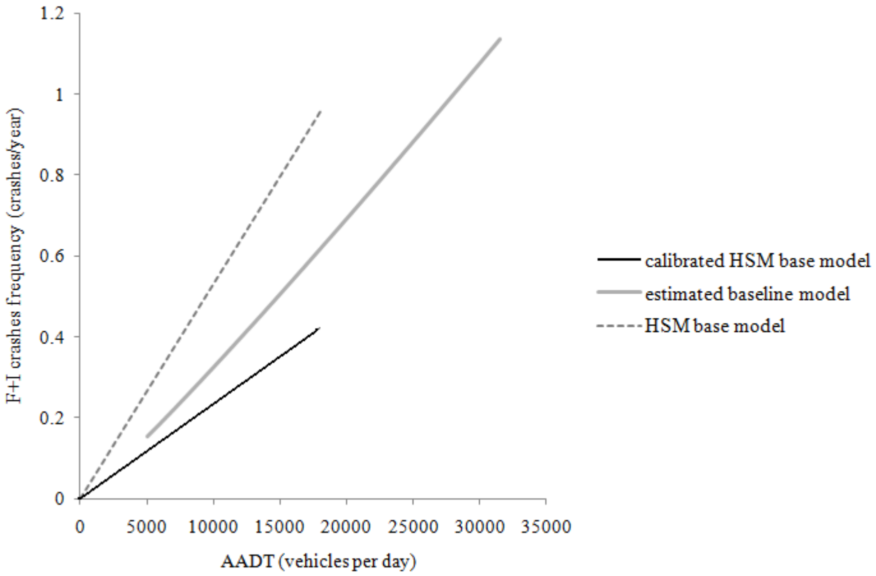

FIGURE 2 Comparison between the estimated models and the HSM baseline one.

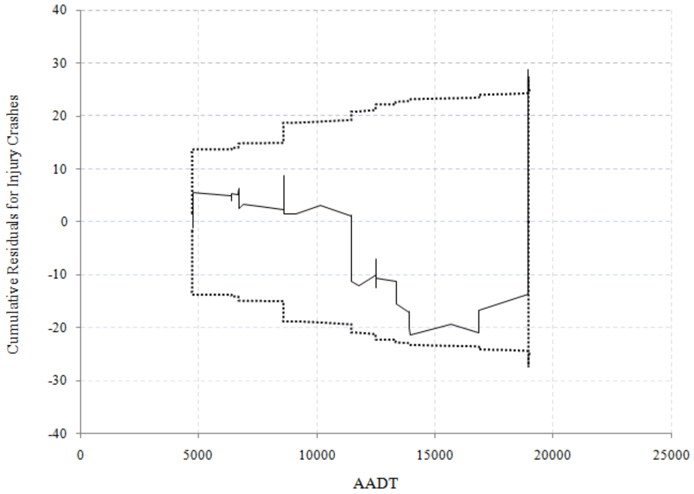

FIGURE 3 CURE plot for F+I collisions versus AADT.

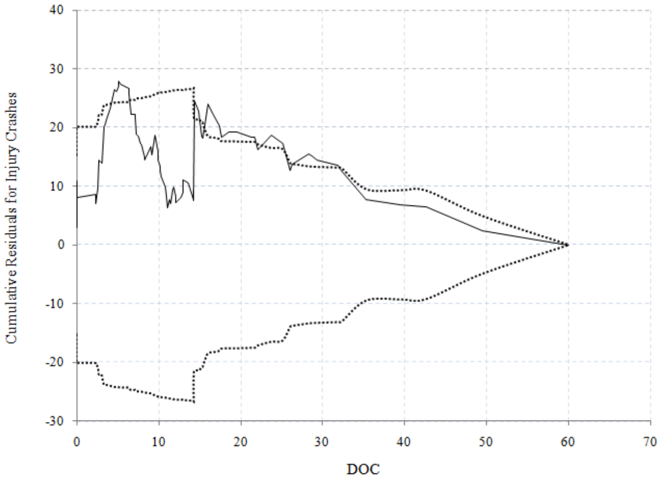

FIGURE 4 CURE plot for F+I collisions versus degree of curvature (DEG).

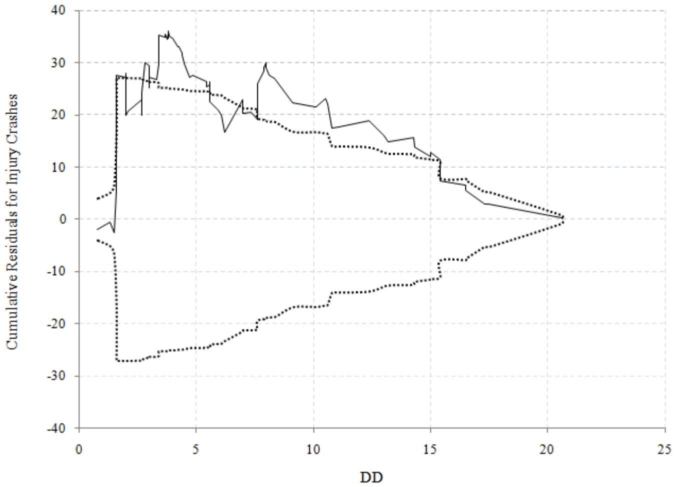

FIGURE 5 CURE plot for F+I collisions versus driveway density per kilometer (DD).

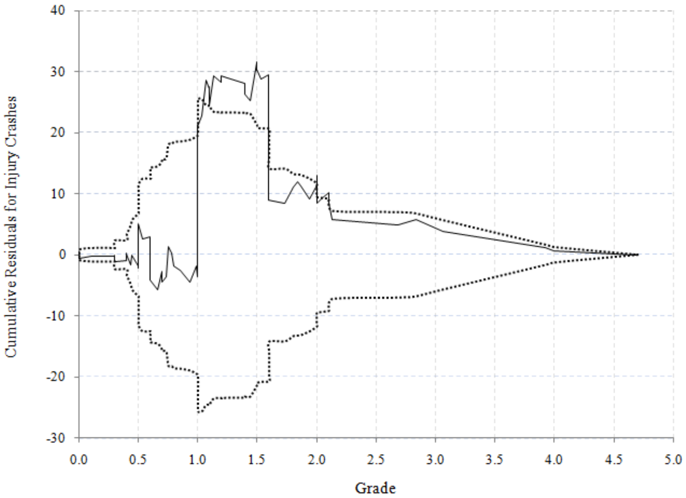

FIGURE 6 CURE plot for F+I collisions versus grade (%).