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AN ITALIAN EXPERIENCE ON CRASH MODELING FOR ROUNDABOUTS

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ABSTRACT

In the last few years a considerable amount of safety models and evaluation tasks have been developed and specifically dedicated to roundabouts. Several safety performance functions (SPFs), indeed, have been implemented for roundabouts worldwide. Since SPFs are developed using crashes, traffic volume and other characteristics of a specific site (or geographical area), their direct transferability to other contexts different from those in which SPFs were calibrated is not always possible and, in any case, it must be done very carefully. A safety performance function cannot be used without a transferability evaluation for sites not included in the geographic area for which it was developed. Starting from these considerations, this paper aims to calibrate a safety performance function for urban roundabouts in Italian context, expanding a sample data already used in a previous work by Giuffrè *et al*. (2007); this SPF is then compared with other safety performance functions found in literature, testing the transferability.

Keywords: safety performance functions, transferability, roundabouts.

INTRODUCTION

The economic and social costs associated with road crashes have led many national and local roads authorities to establish safety engineering and management programs aimed at continually improving the safety performances on the road networks. However, the success of safety improvement programs in reducing number and severity of crashes has to be put in relation to the availability of methods and models being able to reliably predict the safety level of existing road locations or proposed road plans and designs.

In the last few years many Safety Performance Functions (SPFs) have been developed for different road facilities and implemented for a wide range of analysis purposes and applications. Safety performance functions are mathematical models developed through statistical regression modeling by using historical crash data. Unlike models developed for evaluating the potential accident rate (see e.g. Mauro and Cattani, 2004), these functions relate the crash occurrence to the traffic and geometric data of a road entity (segment and intersection); they result more sophisticated than crash frequency (or crash rate) as a predictor, since they account for the regression to the mean bias and random variation in crashes over any time period. SPFs are fundamental in highway safety analyses, both when the expected collision frequency, for new and existing road facilities, have to be predicted and when the safety impacts of alternate design scenarios have to be evaluated; SPFs are used for different applications, i.e., screening of the road network for locations with a potential for safety improvements, selection of countermeasures, cost-benefit analysis for contemplated countermeasures by applying crash modification factors, evaluation of safety improvements (see Sacchi *et al*., 2012). The Highway Safety Manual (2010) provides important information and methodologies including safety performance functions and crash modification factors for segments and intersections on three types of facility: undivided rural two-lane highways, rural multilane highways and urban/suburban arterials. It has to be pointed out that since SPFs are developed using crashes, traffic volume and other characteristics of a specific site (or geographical area), their transferability to other contexts different from those in which SPFs were calibrated is not always possible and, in any case, it must be done very carefully. Indeed, crash frequencies can vary across time and space, even for roads that are similar, because of differences in factors such as crash reporting thresholds and practices, driver population, law enforcement, animal populations, vehicle characteristics, climate, etc. Consequently, a safety performance function cannot be used without a transferability evaluation for sites not included in the geographic area for which it was developed; for issues related to the estimation of SPFs see e.g. Persaud *et al*. (2002), Lord (2006), HSM (2010), Lord and Mannering (2010), Sacchi *et al* (2012), Heydari *et al*. (2014).

Two options are possible for obtaining SPFs for a jurisdiction or a specific geographical area: taking existing SPFs that were developed in other geographic areas and calibrate them for the conditions in the jurisdiction or developing jurisdiction-specific SPFs to improve the accuracy of the predictions. The Highway Safety Manual (2010), as it is well known, has introduced a calibration procedure for adjusting the SPFs so that they can reflect the unlike crash frequencies between different jurisdictions. This calibration can be undertaken for a single state, or where appropriate, for a specific geographic region within a state. According to the HSM (2010) procedure the expected crash frequencies for a "base" condition (for a road or an intersection) are calculated by using the proper safety performance function and then modified with CMFs and a calibration factor (C_x). The HSM (2010) involves the use of CMFs to adjust the predictions for situations other than the base condition (for instance, lane or shoulder width for two-lane roads), whereas the calibration factor (C_x) accounts for differences between: i) the jurisdiction and time period for which the predictive models were developed; ii) the jurisdiction and time period to which they are applied by HSM users. The Highway Safety Manual crash prediction algorithm has the following structure (HSM, 2010):

$$N_{predicted}=N_{SPFx}\times(CMF_{1x}\times CMF_{2x}\times\ldots\times CMF_{yx}) \times C_x \qquad (1)$$

where

$N_{predicted}$ = predicted average crash frequency for a specific year for a site of type x;

N_{SPFx} = predicted average crash frequency for base conditions of the SPF developed for site type x;

CMF_{yx} = total number (y) of collision modification factors (CMFs) specific to the SPF for site type x;

C_x = calibration factor to adjust SPF for local condition for a facility type x; it is defined as the ratio of the total number of observed crashes in the calibration sample to the total number of predicted crashes for the homogenous sites.

As introduced above, instead of calibrating existing SPFs, HSM users may prefer to develop their own SPFs with data from their own jurisdiction. The HSM calibration procedure will provide satisfactory results, but SPFs developed directly with data for a specific jurisdiction may provide more reliable estimates for that jurisdiction. The advantages of jurisdiction-specific SPFs are also discussed in previous studies (e.g., Persaud *et al*., 2002). Jurisdiction-specific SPFs also provide the opportunity to examine alternative functional forms (depending on the data) rather than using the default forms in the HSM (2010).

The importance of safety performance function makes it imperative that they be properly calibrated (Persaud *et al*., 2002). Calibrating such models is not straightforward. First high quality data is required for a large enough sample of entities and crashes; moreover, for an actual calibration, the recommended minimum sample size would be 30 to 50 sites that experience at least 100 accidents per year (HSM, 2010). Second, in order to obtain large enough samples of crashes, data consisting of observations over several time periods are used. A data structure of this kind creates a specific problem in safety modeling because of the failure of the independence hypothesis for the variate response; this difficulty is magnified by temporal trends in accident counts (Persaud *et al*. 2002; Giuffrè *et al*., 2013; Mohammadi *et al*., 2014).

Starting from these considerations, this paper aims both to calibrate a safety performance function for urban roundabouts in Italian context, expanding a sample data already used in a previous work by Giuffrè *et al*. (2007), and to compare this SPF with other functions found in literature, testing the transferability.

INTERNATIONAL SAFETY PERFORMANCE FUNCTIONS FOR ROUNDABOUTS

In the last few years there have been implemented several safety performance functions for urban/suburban roundabouts in different countries. Table-1 reports some models selected from five countries: Italy, where one model was implemented in the Province of Trento, Italy, and another model in the Province of Novara, Italy (Giuffrè *et al*., 2007; Sacchi *et al*., 2011), Sweden (Turner *et al*., 2007), New Zeeland (Turner *et al*., 2009), USA (Rodegerdts *et al*., 2007) and Canada (Persaud *et al*., 2010).

Table-1. International models for crashes at roundabouts.

	Models form: crashes/year = $\alpha AADT_i^{\beta}$					
	Trento (IT)	**Novara** (IT)	**Sweden**	**New Zeeland**	**USA**(*)	**Canada**
α	$5.5*10^{-3}$	$2.93*10^{-7}$	$3.08*10^{-6}$	$2.2*10^{-4}$	-	$5.46*10^{-6}$
α_3					$1.8*10^{-3}$	
α_4					$3.8*10^{-3}$	
α_5					$7.3*10^{-3}$	
β	2.146	1.66	1.2	0.710	0.749	1.424
(*)parameter α varying with numbers of roundabout entries						

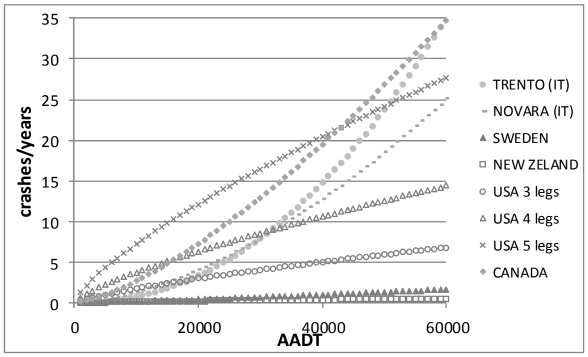

Figure-1. Comparison of safety performance functions for roundabouts from around the world.

Figure-1 shows that the model predictions are very different: the 5-leg US model makes the highest predictions for AADT values less than 42,000 veh/h, whereas for AADT values higher than 42,000 veh/h the Canada model sets the upper limit; the Sweden model, instead, gives the lowest predictions over the entire AADT range. In general, only the three US models have downward concavity, while the other models have upward concavity. Regarding the European models, as is evident from the plots, the Italian models predict more crashes than the Swedish model. The Canadian and Trento models seem to be very similar and also the New Zeeland and Sweden models are very similar one from the other.

The main observed differences in the models are due to different characteristics (geometric, traffic, driver behavior, speed limits, operating speeds, climatic conditions, etc...) representative of the specific geographical area for which each model was implemented. Also the definition of crashes occurred at intersection (how close to the roundabout a crash has to be for the inclusion in the model) can be different from a country to another country.

Regarding the crashes reporting rates, there are some important differences that need to be taken into account in comparing models from different countries. In Italy for example PDO crashes are generally underreported; they often are not notified by the police because injured vehicles mindful of insurance or legal repercussions. The fatal reporting rate is conversely close to 100%, because the law constrains the involved parties to notify immediately the police.

It has to be also noted that the two Italian models were implemented from small samples: 21 sites for Trento model and 15 sites for Novara model; this is for the difficulties with the data collection process due to limitations on data availability in computerized records. Therefore, the small sample size used in the studies could have affected the estimation of model parameters. This issue was clearly highlighted by Giuffrè *et al*. (2007), where the small sample was used for demonstration purposes only and it merely served to show the procedural issues in improving the reliability of road safety estimates with temporally correlated data.

DEVELOPMENT OF AN ITALIAN SPF FOR ROUNDABOUTS

Starting from these considerations, expanding the sample of crash and traffic dataset already used (Giuffrè *et al*., 2007), a safety performance function for urban roundabouts was estimated.

To accomplish the study, 156 urban roundabout have been selected in Sicily, Italy; to these were added the 21 roundabouts used for the calibration of the Trento model, so that the entire database consisted of 177 roundabouts. Depending on the service life of each installation, periods of observation may be different. For each roundabout, crashes occurred from 1997 to 2010 were selected and directly collected from reports available at the Municipal Police Force.

The sample characterization required that annual average daily traffic (AADT) data were also collected. Table-2 reports the details of the database used to estimate the models. In order to develop the SPF for urban Italian roundabouts with the expanded database, a generalized linear model through maximum likelihood methods was used; the model parameters were estimated using the GenStat software package (Payne at al., 2013). In this first phase a flow-only model was estimated:

$$\hat{y}_i = \alpha_{legs} \cdot AADT^{\beta} \tag{2}$$

where:

$\hat{y}_i$ = expected number of crashes at roundabout i;

$AADT_i$ = Annual Average Daily Traffic entering the roundabout i;

α_{legs}, β = parameters to be estimated; note that α_{legs} is varying with numbers of roundabout legs.

In highway safety studies, the Poisson distribution remains the most common probabilistic model used for analyzing crash data (Hauer, 2004), (Lord, 2006). Nevertheless, Poisson basic assumption of equidispersion (i.e., equality between mean and variance values) is often too much restrictive for crash counts. In fact this type of

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Table-2. Database used to develop the model.

total round.	arms	n. of round.(%)	crashes					AADT			
			tot	min	max	mean	median	min	max	mean	Median
177	3	47 (27)	157	0	14.00	3.34	3.00	3,330	112,877	20,037	14,435
	4	94 (53)	358	0	17.00	3.81	3.00	3,330	175,000	25,736	20,222
	5	30 (17)	93	0	13.00	3.10	3.00	3,330	80,941	17,771	14,435
	6	6 (3)	25	0	14.00	4.17	2.50	3,330	53,000	24,740	21,492
TOT		177(100)	633	0	17	3.58	3.00	3,330	175,000	22,839	14,435

data has been found to often exhibit overdispersion (i.e., the variance is greater than the mean); in few cases, under dispersion (i.e., the variance is less than the mean) has been found.

Since misspecification of the distribution of the response variable can have important consequences on estimates of regression parameters, tests for overdispersion were preliminarily implemented. Tests started by estimating the basic Poisson regression in the GLM context and then calculating fitted values $\hat{y}_i$; GenStat software was used for this purpose (see Table-3).

Table-3. Basic Poisson model.

	Model: $\hat{y}_i = \alpha AADT_i^{\beta}$			
	estimate (antilog est.)	**s.e.**	**t**	**t pr.**
lnα	-5.641 (0.0035)	0.487	- 11.58	< .001
β	0.696	0.047	14.60	< .001

The following auxiliary ordinary (linear) least-squares (OLS) regressions were then performed:

$$OLS_1 = \frac{(y_i - \hat{y}_i)^2 + y_i}{\hat{y}_i} = \gamma \cdot \hat{y}_i + u_i \quad (3)$$

$$OLS_2 = \frac{(y_i - \hat{y}_i)^2 + y_i}{\hat{y}_i} = \gamma + u_i \quad (4)$$

where

$\hat{y}_i$ = expected number of crashes at roundabout i obtained by GLM regression using the Poisson basic model;

y_i = crash observed at roundabout i;

γ = parameter to be estimated by means of OLS regression;

u_i = error term.

According to Cameron and Trivedi (1998), the t-statistics for γ (in each auxiliary regression) are asymptotically normal under the null hypothesis of no overdispersion against the alternative of overdispersion of the Negative Binomial 2 (NB2) form (for OLS_1) or the NB1 form (for OLS_2). In other words, the auxiliary regression tests are used to discriminate the more appropriate form of the response variable distribution in the negative binomial family.

The results of overdispersion tests, summarized in Table-4, show that the null hypothesis of no overdispersion must be accepted against the alternative of overdispersion for both the NB2 and NB1 forms.

In Table-5 are reported the parameter estimates for the Trento model as performed by Giuffrè *et al*. (2007) and the new extended model implemented assuming a Poisson error distribution; for each model the standard errors of parameters estimates are provided.

Table-4. Summary of auxiliary regression test results.

	Auxiliary OLS_2 (poisson vs NB_1)			
	est.	**s.e.**	**t**	**t pr.**
Constant	-5.641	0.195	-1.45	0.149
Fitted	-	-	-	
	Auxiliary OLS_1 (poisson vs NB_2)			
Constant	-	-	-	-
Fitted	0.056	0.046	1.23	0.221

As it is possible to notice the new extended model shows better estimates of parameters, i.e. standard errors are less and the *t* values are greater than for the Trento model.

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Table-5. Parameters estimates and GOF for Trento and new extended models.

	Trento model			New extended model		
Variables	**est.** (a log)	**s.e.**	**t**	**est.** (a log)	**s.e.**	**t**
lnα	-5.19 (0.0055)	0.92	-5.64	-	-	-
$ln\alpha_3$				-5.66 (0.0034)	0.49	-11.50
$ln\alpha_4$				-5.71 (0.0033)	0.50	-11.40
$ln\alpha_5$				-5.65 (0.0035)	0.49	-11.48
$ln\alpha_6$				-5.60 (0.0037)	0.53	-11.46
β	2.15	0.285	7.53	0.701	0.05	14.48
MPB	0.352			0.000		
MAD	1.556			0.930		
MSPE	6.133			4.970		

(*) parameter α varying with numbers of roundabout legs

To compare the two models by the point of view of the goodness-of-fit, the indicators listed below (Oh *et al*., 2006) were calculated and reported in Table-5:

- **Mean Prediction Bias** (MPB)

MPB gives a measure of the magnitude and direction of the average model bias. If MPB>0 then the model over-predicts crashes, whereas MPB<0 then the model under-predicts crashes. MPB is computed using the following equation:

$$MPB = \frac{1}{N}\sum_{i=1}^{N}(\hat{y}_i - y_i) \qquad (5)$$

where N is the sample size, $\hat{y}_i$ and y_i are the predicted and observed crashes at site *i*, respectively;

- **Mean Absolute Deviance** (MAD)

MAD gives a measure of the average mis-prediction of the model. The model that provides MAD closer to zero is considered to be the best among all the available models. It iscomputed using the following equation:

$$MAD = \frac{1}{N}\sum_{i=1}^{N}\left|\hat{y}_i - y_i\right| \qquad (6)$$

- **Mean Squared Predictive Error** (MSPE)

MSPE is typically used to assess the error associated with a validation or external data set. The model that provides MSPE closer to zero is considered the best among all the available models. It can be computed using the following equation:

$$MSPE = \frac{1}{N}\sum_{i=1}^{N}(\hat{y}_i - y_i)^2 \qquad (7)$$

The goodness-of-fit indicators in Table-5 show that the new extended model fits the data better than the Trento model: i) the MPB value equal to zero for the extended model indicates that the model well estimates crashes; ii) the MAD and the MSPE values for the extended model, closer to 0 than the Trento model, indicate that the model has better prediction capacity.

TRANSFERABILITY OF A US SPF MODEL FOR ROUNDABOUT IN THE ITALIAN CONTEXT

Starting from these considerations, expanding the sample of crash and traffic dataset already used (Giuffrè *et al*., 2007), a safety performance function for urban roundabouts was estimated.

Since the new extended model was very similar to the USA model for roundabouts, Figure-2a shows the comparison of the two models for a given number of legs and the differences in the crashes estimates. It is possible to notice that: i) differences between models rise for increasing AADT; ii) there are slight differences in crashes estimates of the 3-leg models; iii) the differences between the Italian and the USA models rise for increasing numbers of legs.

Figure-2b compares the trend of the extended Italian model with the 3-leg US model. It can be easily seen that model predictions are very similar; the new 6-leg extended model is at the upper limit (i.e. it makes the highest predictions), whereas the 3-leg US model is at the lower limit.

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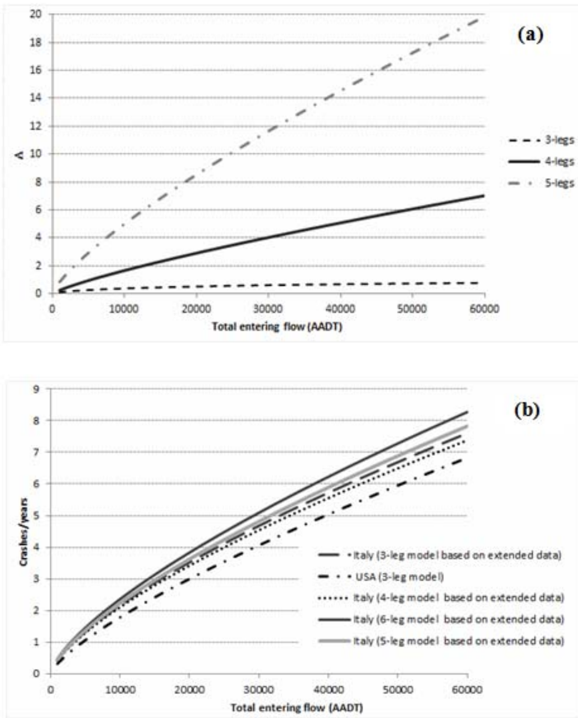

Figure-2. Comparison of Italian and US safety performance functions for roundabouts.

On the basis of the previous results it was decided to test the transferability of the USA model in the Italian context using the HSM (2010) calibration procedure. The Authors wanted to verify whether it is better to develop SPFs with data from their own jurisdiction than use the HSM calibration procedure. In fact in HSM it is said that SPFs developed directly using data for a specific jurisdiction may provide more reliable estimates for that jurisdiction; therefore HSM encourages jurisdictions that have the capability to develop their own model.

For this purpose the USA transferred model, developed with the HSM calibration procedure, reported in the introduction section, has been compared with the Italian extended model. To establish how well the two models fit the observed data, the Cumulative Residuals (CURE) method was used (see Hauer and Bamfo, 1997). This method consists of plotting the cumulative residuals (the difference between the observed and predicted values of crashes for each site) against values of the model covariate (in this case the AADT). According to Hauer and Bamfo (1997), the fit is very good for the covariate if the adjusted cumulative residuals oscillate around the value of zero and lie between the two standard deviation boundaries (±2σ*).

Figure-3 shows the results after applying the CURE method for the two models. As it is possible to see both the two models oscillate around the value of zero, but the Italian extended model has a lower boundary width.

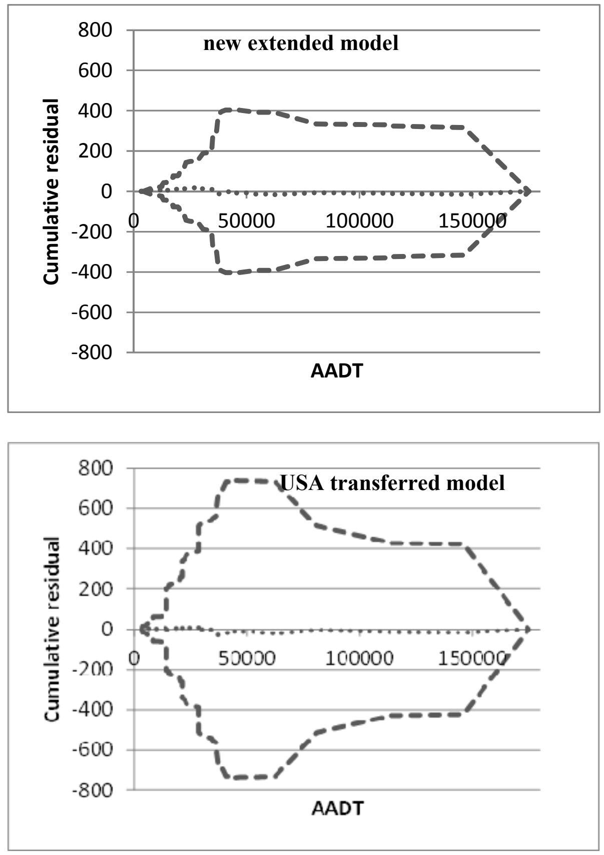

Figure-3. CURE plots for the new extended and USA transferred models.

In order to further compare the two models, GOF indicators (Oh *et al*., 2006) were calculated, as reported in Table-6; they show that the new extended model fit the data better than the USA transferred model:

- the MPB value equal to zero for both models indicates that the two models well estimates crashes,
- the MAD and the MSPE values for the new extended model, closer to 0 than the USA transferred model, indicate that the model has better prediction capacity.

These results suggest that the USA transferred model could be applied in the Italian jurisdiction, but the SPF developed directly with data for the Italian context provides more reliable parameters estimates.

CONCLUSIONS

Transferability of safety performance functions in contexts other than those in which they have been calibrated it is not always possible and in any case must be done very carefully. The Highway Safety Manual (2010) has introduced a calibration procedure to adjust the SPFs to reflect the differing crash frequencies between different

Table-6. GOF of new extended and USA transferred models.

	new extended model	USA transferred model
MPB	0.00	0.00
MAD	0.93	1.64
MSPE	4.57	8.33

jurisdictions. HSM calibration procedure can provide satisfactory results, but SPFs developed directly with data for a specific jurisdiction may provide more reliable estimates for that jurisdiction.

Starting from these consideration a safety performance function for urban roundabouts in Italian context was estimated, expanding a little sample dataset (Trento) already used by Giuffrè *et al*. (2007). The model form used is a "flow-only" model implemented in GLM context using a Poisson distribution. Since misspecification of the distribution of the response variable can have important consequences on the estimates of regression parameters, over dispersion tests was preliminarily implemented; it confirmed that the Poisson distribution is the most appropriate for the new extended model.

In order to verify the goodness-of-fit of the two models, "Oh GOF indicators" were used; they showed that the new extended model fits the data better than the Trento model. Since the new extended model is very similar to a USA model for roundabouts as found in literature, the two models were compared and the transferability of the USA model in the Italian context using the HSM calibration procedure was tested. To establish how well the two models fitted the observed data, the Cumulative Residuals (CURE) method was used. The results showed that both the two models oscillate around the value of zero, but the new extended model had a lower boundary width. To further compare the two models "Oh GOF indicators" were used again; they showed that the new extended model fitted the data better than the US (transferred) model. Therefore the US (transferred) model could be applied in the Italian jurisdiction, but the SPF developed directly with data from the Italian context can provide more reliable parameters estimates.

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