Predicting Road ACcidents - a Transferable methodology across Europe

Anastasios Dragomanovits[1], George Yannis[1], Alexandra Laiou[1], Francesca La Torre[2], Lorenzo Domenichini[2], Thomas Richter[3], Stephan Ruhl[3], Daniel Graham[4], Niovi Karathodorou[4]

[1] National Technical University of Athens, 5, Heroon Polytechniou st., 15773, Athens, Greece
[2] University of Florence, Via S. Marta, 3, 50139, Firenze, Italy
[3] Technische Universität Berlin, Gustav-Meyer-Allee 25, 13355, Berlin, Germany
[4] Imperial College London, SW7 2AZ, London, United Kingdom

Abstract

Accident Prediction Models (APMs) and Crash Modification Factors (CMFs) are developed on the basis of usually long-term observational studies examining the statistical correlation between geometric or operational road characteristics and accidents. APMs and CMFs allow Road Authorities, designers and road safety engineers to estimate the safety performance of road projects, analyze potential safety issues, identify safety improvements and estimate potential safety effects. However, the reliability and accuracy of such methods largely depends on available knowledge on existing APMs and CMFs as well as on their transferability to different conditions.

Within PRACT research project new CMFs were estimated and a user friendly online searchable repository was developed with APMs and CMFs that satisfy specific quality criteria, focusing on types that are considered most useful by Road Authorities. Furthermore, a practical tool was developed to assist in the use and transferability evaluation of APMs and CMFs in different countries and road networks.

Keywords: *Accident Prediction Models, Crash Modification Factors, transferability, Europe, PRACT*

1. Introduction

Accident Prediction Models (APMs) and Crash Modification Factors (CMFs) are developed on the basis of usually long-term observational studies that examine the correlation of geometric or operational road characteristics and accidents, using suitable statistical techniques. In recent years, the use of APMs and CMFs is increasing in road safety decision making; the efficiency of an intended policy is determined by the use of efficiency assessment tools, which enable decision-making and identification of the most cost-effective and profitable road safety measures (Yannis et al., 2015). Thus, road safety policy is increasingly dependent on sound indicators of how effective different safety interventions are, in terms of accident or casualties reduction, such as APMs and CMFs.

The use of Accident Prediction Models (APMs) and Crash Modification Factors (CMFs) allows Road Authorities, designers and road safety engineers to estimate the safety performance of road projects, analyze potential safety issues, identify safety improvements and estimate the potential effect of these improvements in terms of crash reduction. However, the reliability and accuracy of such methods largely depends on available knowledge on existing APMs and CMFs as well as on their transferability to conditions different from the ones they were developed.

The PRACT Project (Predicting Road ACcidents - a Transferable methodology across Europe - http://www.practproject.eu/), funded by the Conference of European Directors of Roads (CEDR), aimed at developing a European accident prediction model structure for rural roads that could, with proper calibration, be applied to different European road networks.

The core principles behind the PRACT project structure are that:

- it is unrealistic to think that one unique Accident Prediction Model (APM) with a unique set of Crash Modification Factors (CMFs) can actually be developed and be valid for all Europe and for all the different types of networks;
- the development of a specific APM and a set of CMFs based on local data is extremely time consuming and expensive and requires data and experience that most road administrations do not have;
- the development of "local" CMFs only based on historical local data prevents the possibility of evaluating the effectiveness of new technologies.

The basic assumption is that APMs and CMFs can be transferred to conditions different from the ones for which they have been developed if selected based on scientifically valid criteria and adapted to local conditions based on historical crash data.

The PRACT project aimed at addressing these issues by developing a practical guideline and a user friendly tool that will allow different road administrations to:

- adapt the basic APM function to local conditions based on historical data;
- identify the CMFs that could be relevant for the specific application;
- verify if the selected CMFs are transferable to the specific condition;
- apply the calibrated model to the specific location to be analyzed.

This approach acknowledges that different countries, as well as different road authorities within a country, have different levels of expertise and different data availability, and will allow calibration levels ranging from a total lack of historical data to situations where crash data, traffic data and geometric data are all available.

Furthermore, new CMFs were developed focusing on CMF needs as reported by National Road Authorities. Finally, gathered knowledge on accident prediction (existing and new) was organized in an online searchable database / repository of APMs and CMFs that provides valuable assistance to national road authorities and road safety practitioners in identifying models and data that are most relevant and suitable for specific road safety problems.

2. Overview of existing knowledge and current practices

In order to obtain a clear picture of existing knowledge on accident prediction and on the practices usually followed by National Road Administrations (NRAs) in Europe and worldwide, a two-fold approach was followed; a questionnaire survey accompanied by a detailed review of existing guidelines and research on accident prediction.

2.1 Questionnaire Survey

The objective of the questionnaire survey was to collect detailed information on APMs developed and used by the NRAs, as well as information regarding data availability, quality and definitions among European countries and worldwide (Yannis et al., 2016). A total of 23 completed questionnaires were received, mostly from National Road Authorities, but also from road managing companies, academia/ research institutes or highway consultants. The questionnaires were received mostly from European countries, namely: Austria, Belgium, Cyprus, Denmark, Finland, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxemburg, the Netherlands, Norway, Slovenia, Spain, Switzerland, UK, as well as from the United States and Australia.

Analysis of the survey responses resulted in the following interesting observations:

The majority (83%) of NRAs and other organizations always or usually use a specific procedure for assessing alternative road safety measures, with safety effectiveness being the most common criterion; however only 30% use APMs or CMFs during the assessment procedure. The use of APMs in decision making is more common in countries that have relevant approved guidelines or manuals, which is normally related to a more advanced road safety culture.

The availability of road design data, road operation data, traffic related data and accident data was reported as adequate, with larger data availability for motorways/ freeways compared to two-way two-lane rural roads. Limited data availability (50% to 60%) was reported on factors relating to user behavior such as alcohol-impaired driving, excessive speeding, seat belt and helmet use.

Respondents were also asked which criteria they use to decide whether a particular CMF or measure assessment is relevant and can be applied to address a specific problem. As far as criteria related to the quality and reliability of the CMF are concerned, NRAs and other organizations responded that they take into account criteria such as date range of data (60%), country / area of data (56%), statistical methodology (63%) and sample size (54%). From the questionnaire survey, it seems that most of the criteria are of similar importance.

The experience of NRAs and other institutions on road safety measures and CMFs was also examined in the questionnaire survey by providing two comprehensive lists of infrastructure road safety measures (different for motorways / freeways and for two-way two-lane rural roads) and requesting to identify: (a) the need to implement the safety measure in the country's road network, (b) the availability of assessment of measure / CMF, and (c) the transferability of safety effect (i.e. if the measure is assessed in a different location, will the safety effect be similar and therefore transferable to the examined country).

According to the questionnaire survey, the countermeasures / CMFs presenting the highest need in motorways and divided freeways are “workzones” (86.7%), “roadside features: clear zone width” (75.0%), “high friction treatments” (73.3%) and “effect of traffic - volume/capacity - % trucks & buses" (68.8%). In two-lane, two way rural roads, the highest need is exhibited by “roadside features: presence of a barrier” (81.3%), “shoulder type - paved/unpaved” (80.0%), “shoulder width” (78.6%) and “workzones” (76.9%).

2.2 Literature Review

A broad overview of pertinent literature reveals that accident prediction modeling has recently been a very active research field. A very comprehensive knowledge source is the Highway Safety Manual (HSM) (AASHTO, 2010; AASHTO, 2014). The Manual includes a predictive method for estimating the expected average crash frequency (by total crashes, crash severity or collision type) of a network, facility or individual site, relying upon models developed from observed crash data for a number of individual sites. Different regression models, called base Safety Performance Functions (SPFs) have been developed for specific facility types and "base conditions". SPFs are typically a function of only a few variables, primarily Average Annual Daily Traffic (AADT) volumes and segment length. SPFs in the HSM have been developed through statistical multiple regression techniques using historic crash data collected over a number of years at sites with similar characteristics and covering a wide range of AADTs. Adjustment to the prediction made by a SPF, in order to account for geometric design or traffic control differences between the base conditions of the model and local conditions of the considered site, is made through the use of CMFs. Finally, a Calibration Factor (C) is used to account for differences between the road network for which the models were developed and the one for which the predictive method is applied. Building on the methodology proposed by the HSM, CMFs for various road safety interventions have been developed by a large number of studies.

Furthermore, regression equation APMs have been developed by various researchers, for the road network of several countries, such as: Austria, Portugal and the Netherlands (RIPCORD 2007), Norway, Austria, Portugal and the Netherlands (Azeredo & Cardoso, 2011; Dietze & Weller, 2011), Italy (Caliendo et al., 2007; Montella et al., 2008; Cafiso et al., 2010), New Zealand (Turner et al., 2012), etc.

However, the existing information on accident prediction is generally not readily available to road safety practitioners and decision makers. Significant amounts of time and effort are required in order to identify related literature sources, examining the APMs and CMFs that have been developed and the conditions for which they have been developed, and decide if they are suitable for use in a specific situation. Existing web-based databases of road safety measures, namely the FHWA CMF Clearinghouse (FHWA, 2016), the SPF Clearinghouse (Tatum Group LLC, 2016), the AustRoads Road Safety Engineering Toolkit (AustRoads, 2016) and the iRAP Road Safety Toolkit (iRAP, 2016), partially address this difficulty. However, all these databases do not provide enough information on the calculation of the safety effect estimate and therefore, usually, it is not possible to reliably judge the suitability of the estimate to different conditions.

Building on the above broad review and the findings of the questionnaire survey, it was decided that a more detailed review should focus on the CMFs included in AASHTO's HSM - being of sufficiently high quality since they have been systematically evaluated by expert groups regarding their reliability and quality - along with CMFs that more than 50% of NRAs considered as highly desirable. The questionnaire survey identified 52 high need CMFs (20 for rural motorways and 32 for two-lane roads); taking also into account the HSM CMFs, a total of 92 high priority CMF types was identified. A complete list of the 92 high priority CMF types is available in Yannis et al. (2016). As far as APMs are concerned, the detailed review also focused on the aforementioned categories.

2.2.1 In-depth CMF review

The CMF review focused on presenting a comprehensive overview of different CMFactors and CMFunctions. The 92 different CMF types were grouped in six roadway element categories: (1) Freeway segments, (2) Speed change lanes, (3) Ramp segments, (4) Crossroad ramp terminals, (5) Rural road segments (two-way two-lane), and (6) Rural road intersections. For each of the 92 CMF types a one-page summary was developed, concisely presenting the most important information of the review. An example summary for CMF type no 85: "Rural road intersections - Roundabouts" is presented in Figure 1. A complete presentation of all the CMF review summaries can be found in Yannis et al. (2016).

CMF name & description: *CMF type 85: Rural road intersection - Roundabouts*	
Number of studies: *7 (21 CMFs depending on intersection type, traffic control and crash severity)*	
Number of studies by methodology: *Before - After Study with Comparison Group (2), Empirical Bayes Before-After Study (2), Naive Before - After Study with estimated reduction of effectiveness due to RTM bias and general crash trends (2), Naive Before - After Study (1)*	
Number of studies by country: *Belgium - Flanders (1), UK (1), Australia Nationwide (1), Australia - State of Victoria (1), Australia - State of Western Australia (1), US Nationwide (1), US Maryland (1)*	
Range of estimates: *0.13 - 0.66 (depending on intersection type, traffic control and crash severity)*	Mean value of estimates: *-*
Earliest year of accident data used in studies: *1988*	Latest year of accident data used in studies: *2000*
Comment on the state of the literature: *Several studies exist regarding the safety impacts of converting a standard at- grade intersection to roundabout. There is a wide geographical distribution of relevant CMFs (from Europe, US and Australia) and in at least four studies the applied statistical methods are considered reliable. Furthermore, there are CMFs for both signalized and stop controlled intersections, as well as for all crash severities, or for injury accidents only. In Mountain et al. (1998) there are also specific CMFs for dry/wet crashes and for daytime/nightime crashes.*	
List of studies estimating CMF: *Brabander, B.D. & Lode Vereeck, E.N. (2005). Road safety effects of roundabouts in Flanders, Journal of Safety Research, 36, 289–296.* *BTCE (1995). Evaluation of the black spot program, report 90, Bureau of Transport and Communication Economics (BTCE), Canberra.* *Meuleners, L., Hendrie, D., Lee, A. H. & Legge, M. (2008). Effectiveness of the Black Spot Programs in Western Australia, Accident Analysis and Prevention, 40, 1211–1216.* *Mountain, L., Maher, M. & Fawaz, B. (1998). Improved estimates of the safety effects of accident remedial schemes, Traffic Engineering and Control, 10, 554–558.* *Newstead, S., & Corben, B. (2001). Evaluation of the 1992–1996 Transport Accident Commission funded accident black spot treatment program in Victoria, Report No.182, Monash University Accident Research Centre, Melbourne, Australia.* *Persaud, B. N., Retting, R. A., Garder, P. E., & Lord, D. (2001). Observational Before-After Study of the Safety Effect of U.S. Roundabout Conversions Using the Empirical Bayes Method, Transportation Research Record, No. 1751, Washington, D.C., Transportation Research Board, National Research Council.* *Rodegerdts, L. A., Blogg, M., Wemple, E., Myers, E., Kyte, M., Dixon, M., List, G., Flannery, A., Troutbeck, R., Brilon, W., Wu, N., Persaud, B., Lyon, C., Harkey, D., & Carter, D. (2007). Roundabouts in the United States, NCHRP Report 572, Washington, D.C., Transportation Research Board, National Research Council.*	

Figure 1: *Summary page for CMF type no 85: Rural road intersections - Roundabouts*

The review resulted in a comprehensive inventory of 1,526 CMFs (Factors and Functions), compiling detailed data for each CMF, such as: development information (study design, potential standard errors, sample sizes etc.), information about the study from which the CMF was retrieved, information on the considered road elements, basic accident information (period of accident data, levels of accident severity, accident types, number of involved vehicles, weather and lighting conditions, road user types), etc.

2.2.2 In-depth APM review

The APM review was conducted in a similar way to the aforementioned CMF review. Models were also grouped into the six roadway element categories: (1) freeway segments, (2) speed change lanes, (3) ramp segments, (4) crossroad ramp terminals, (5) rural road segments (two-way two-lane), and (6) rural road intersections. Also, a second level grouping considered the form of the model: Regression Equation APMs are stand-alone models that are able to predict accidents based on a series of road and traffic related data (independent variables). On the other hand, SPF and CMF APMs (such as the HSM models), use a Safety Performance Function (SPF) to calculate an initial accident frequency by a very limited number of parameters (e.g. AADT and segment length), for specific 'base' conditions. At a second stage, CMFs are used to account for geometric design or traffic control features differences between the base conditions of the model and local conditions of the site under consideration.

Within the APM review, a total of 146 different Accident Prediction Models were examined; 85 Regression Equation models and 61 SPF & CMF models. The models were also grouped into categories, based on the considered road elements: freeway segments, freeway speed change lanes, freeway ramps, crossroad ramp terminals, two-way two-lane rural roads and two-way two-lane rural road intersections. As in the case of CMF types, a one-page summary was developed for each of the six APM categories, concisely presenting the most important information of the review. A complete presentation of all the APM review summaries can be found in Yannis et al. (2016).

The review resulted in an APM inventory of 273 entries (several models were compiled as more than one entry, in order to properly handle complex parameters, e.g. parameters included in a tabular form in the model). The inventory includes detailed data for each APM, such as: model structure (Regression Equation APMs or SPF & CMF APMs, roadway element category, variables of the models), development information (study design, sample sizes etc.), information about the study from which the APM was retrieved, information on the considered road elements, basic accident information (period of accident data, levels of accident severity, accident types, number of involved vehicles, weather and lighting conditions, road user types), etc.

3. Estimation of new CMFs

Considering the CMF needs and lack of availability identified in the questionnaire and data availability, 13 new CMFs were developed within the project (see Table 1). Two distinct methodological approaches were used, depending on the type of CMF to be estimated and data limitations.

When a countermeasure had been implemented, the treatment year/ date was known, and data on accident rates and traffic volumes were available both for the period before and after implementation, CMFs were developed using an Empirical Bayes Before-After (EB) approach (Hauer, 1997). The advantage of the approach is that it controls for the effects of regression to the mean. Countermeasures tend to be implemented in sites where high accident rates have been recorded. This non-random allocation of countermeasures can lead to self-selection bias, including the so-called regression to the mean (RTM) effect. The RTM effect arises because observed high accident rates may simply be due to random variation. If this is the case, they will tend to be closer to the mean value in future observations. Thus, a reduction in accident rates may be observed that is however random rather than due to the implemented countermeasure. Because of its ability to deal with RTM, the EB approach is currently widely used for CMF development (example of studies include Harkey et al. (2008); Khan et al. (2015); Lyon & Persaud (2008), Park et al. (2012); Persaud et al. (2012)). In the PRACT project it was used to estimate the effect of work zones, high friction wearing courses and average speed enforcement (section control) on accident rates on rural motorways based on data from Italy.

When no suitable data to employ the Empirical Bayes approach are available, multivariate regression models can also be used to estimate CMFs. The approach is useful when only cross-sectional data are available for estimation. However, it is not suitable for countermeasures that have been implemented to road segments because of high accident rates. When countermeasures have been allocated at hazardous locations, the countermeasure variable will be endogenous in the model (i.e. correlated with the error term) leading to biased estimates; more advanced modeling techniques (e.g. instrumental variables) are needed to obtain unbiased estimates of the effect of the treatment. On the other hand, multivariate regression models are suitable for CMF estimation when countermeasures are independent of accident rates (e.g. blanket treatments) and for road features such as the number of lanes or the traffic composition that typically do not depend on the accidents occurred in the analyzed section. Care should be taken to include a detailed set of explanatory variables in the model to avoid issues relating to omitted variable bias; variables omitted from the model that do affect accidents and are correlated with the error term can also lead to biased estimates. An advantage of using multivariate regression models for CMF estimation is that they can provide CMF estimates as a function of the countermeasure of interest. This can be helpful for countermeasures/road features that are represented by continuous variables such as the percentage of heavy goods vehicles in traffic.

Using negative binomial models and data from England and Germany, CMFs were estimated for traffic volume, traffic composition, lane width, horizontal curvature and vertical curvature. Such features are unlikely to depend on accident rates and hence the methodology should provide unbiased estimates of their effect on accident rates.

More details on the CMFs developed in the PRACT Project can be found in Karathodorou et al, (2015) and Karathodorou et al. (2016).

***Table 1:** CMFs developed within the PRACT project*

Country	Crash Modification Factor	Road Type
Italy	Work zones	Motorway (rural)
Italy	Average speed enforcement (section control)	Motorway (rural)
Italy	High friction wearing course	Motorway (rural)
Germany	AADT (*)	Two-way two-lane rural road
Germany	Traffic composition	Two-way two-lane rural road
Germany	Number of lanes	Two-way two-lane rural road
Germany	Lane width	Two-way two-lane rural road
Germany	Horizontal curvature	Two-way two-lane rural road
Germany	Vertical curvature	Two-way two-lane rural road
England	AADT (*)	Two-way two-lane rural road
England	Traffic composition	Two-way two-lane rural road
England	Horizontal curvature	Two-way two-lane rural road
England	Vertical gradient	Two-way two-lane rural road

4. Repository development

The aforementioned APM and CMF inventories were further elaborated to develop a free access online searchable database / repository with the most important Accident Prediction Models (APMs) and Crash Modification Factors (CMFs) respectively. In order to ensure the quality of the repository data, a set of minimum criteria were established and all CMF inventory entries, prior to inclusion in the repository, were evaluated accordingly. On the other hand, since APM repositories are not generally available and the number of available APMs, according to the literature review, is limited, all identified APMs were included in the repository.

4.1 Criteria for CMF data inclusion

The quality criteria for CMF inclusion in the repository focused on: (a) statistical design, (b) testing for statistical significance, and (c) sample size. Taking into account that CMFs included in the Highway Safety Manual - Part C have been thoroughly examined through a systematic review procedure regarding their reliability and quality, all CMFs originating from the HSM were included in the repository, even if the detailed information on the applied statistical design, statistical significance and sample size are not known. The rest of the CMFs were assessed prior to inclusion in the repository, on the basis of fulfilling all of the following quality criteria.

4.1.1 Statistical design

The statistical design of the original research is critical as far as the reliability of the CMF estimate is concerned. The most commonly used approaches are: naive before - after analysis, simple cross - sectional analysis, before - after analysis with comparison group, Empirical

Bayes before - after analysis and Poisson/negative binomial/quasi - Poisson regression modeling. Other, less common approaches were considered in a case by case basis:

- Naive before - after analysis (without comparison group): CMFs developed from such studies were not included in the repository, since they are considered of low quality and vulnerable to several types of biases.
- Simple cross - sectional analysis: also leading to low quality CMFs, not included in the repository.
- Before - after with comparison group: CMFs from such studies were accepted in the repository, provided that the comparison group is comparable to the treated group, it is properly selected to address the most common biases and that there are sufficient controls to deal with time trends in accidents.
- Empirical Bayes before - after analysis: in general, CMFs from such studies were included in the repository, provided that there are no evident problems in the choice of the reference group.
- Poisson / Negative Binomial / Quasi - Poisson Regression modeling: these types of statistical analysis are considered suitable for road design features or treatments with random treatment allocation (e.g. blanket treatments), and not suitable for treatments applied to high risk sites. Furthermore, locations where a road feature has been changed because of a factor related to accidents should not be included in the dataset (e.g. when considering the effect of side slopes, the dataset should not include sites where side slopes have been decreased to reduce fatal accident risk). Finally, in order to include such analyses in the repository, they should control for segment length (or use segments of fixed length) and traffic volume, and, if time series data are used, for time effects in the model.

4.1.2 Testing for statistical significance

CMF values or functions to be included in the repository should be statistically significant at 5% level (preferably) or 10% level (as a minimum), or the 95% confidence interval does not include 1. If the 95% confidence interval includes 1 and all other criteria are met, the CMF was included in the repository with the code "not significant" instead of the CMF value, as an indication that the treatment has no significant impact to accidents.

4.1.3 Sample size (sites and years)

Studies based on before - after analysis were included in the repository if at least ten treated sites were examined and at least three years of data, both for the before and the after period were used. Exceptions were considered only for specific types of treatments (e.g. for workzones) for which the above criterion cannot be met.

For multivariate cross-sectional models (Poisson / Negative Binomial / Quasi-Poisson Regression), the inclusion criteria depended on the number of explanatory variables and on whether observations for each year are treated as separate observations in the model. Specifically:

- If observations for each year are treated as separate observations in the model:
  - for models with 5 or less explanatory variables, the criterion is:

    sites x years > number of explanatory variables + 50
  - for models with 6 or more explanatory variables, the criterion is:

    sites x years > number of explanatory variables x 10

The observation year should be treated as an explanatory variable to account for time trends in the model.

- If average / mean values of variables overall years are used in the model:
  - for models with 5 or less explanatory variables, the criterion is:
    sites x years > number of explanatory variables + 50
  - for models with 6 or more explanatory variables, the criterion is:
    number of sites > number of explanatory variables x 10

Out of a total of 1,526 CMFs (Factors and Functions) that were included in the CMF inventory, 889 entries were found to satisfy the quality criteria and were finally included in the repository.

4.2 Repository features

The online repository (http://www.pract-repository.eu/) includes the following five basic sections:

- a "HOME" section with basic information about the repository and about PRACT project,
- a "SEARCH FOR APMs" section that allows the user to search for APMs with specific characteristics,
- a "SEARCH FOR CMFs" section that allows the user to search for CMFs with specific characteristics,
- a "GLOSSARY" section, with the definition of the most commonly used terms in the repository, and
- a "CONTACT" section, which allows the user to contact (via email) the partners responsible for the operation and maintenance of the website.

The core of the repository is the "SEARCH FOR APMs" and "SEARCH FOR CMFs" sections that provide access to the respective searchable databases. The user may search the database for APMs by providing any of the following:

- APM type: SPF or Regression Equation
- APM applicability: Motorway Segments, Motorway Speed Change Lanes, Interchange Ramps, Interchange Ramp Terminals, two-way two-lane Rural Road Segments, Rural Road Intersections
- Road Elements involved
- Road Type involved: Two-lane two-way rural road, Motorway, Ramp Terminal
- Study information: study name, range of years for the publication date, name of authors, geographic data origin
- Inside / outside of Tunnel
- Type of Intersection or Interchange
- Type of traffic control at intersections
- Characteristics of the accidents predicted by the model: severity, accident type and number of vehicles involved

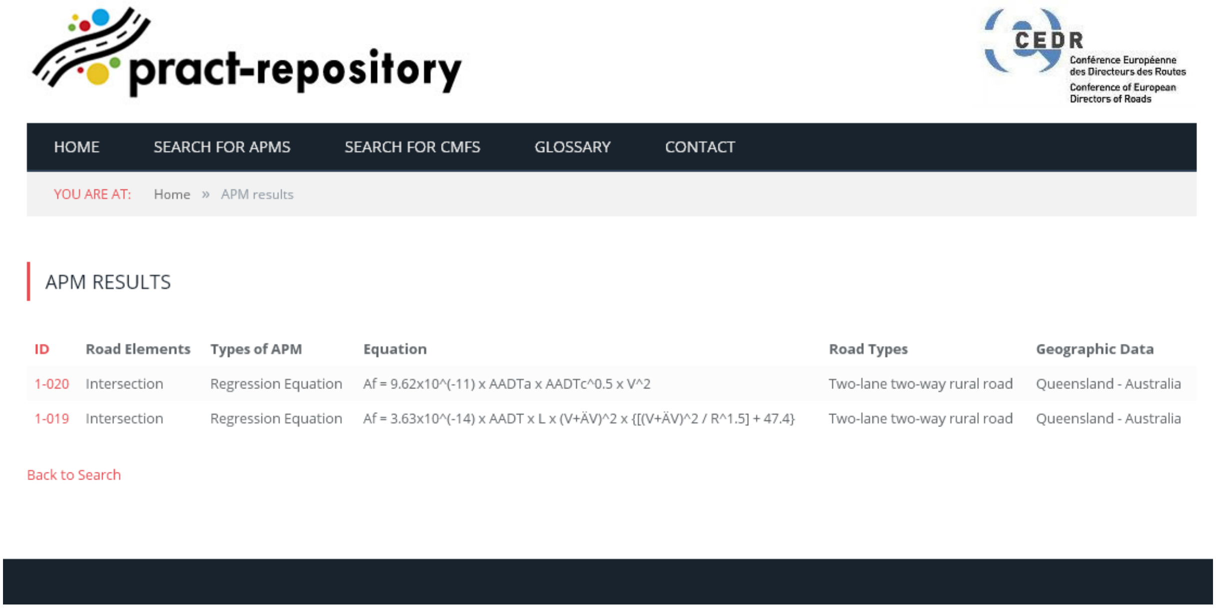


Figure 2: *Indicative results of a search for APMs in the repository, with the following criteria: Road Element = "Intersection" & Geographic Data Origin = "Australia".*

Execution of the search provides the user with a results page (see Figure 2) with a list of the APMs in the database that meet the search criteria and their most basic characteristics (ID number, Road Element, Type of APM, Equation, Road Type and Geographic Data Origin). Further clicking on any specific ID number from this list provides the user with all the available data related to the particular Accident Prediction Model (Figure 3).

1-020

BY PRACT REPOSITORY ON FEBRUARY 29, 2016

APM ID: 1-020

Type of APM	Regression Equation
Is applicable to Motorways Segments?	No
Is applicable Motorway Speed Change Lanes?	No
Is applicable to Interchange Ramps?	No
Is applicable to 2-way 2-lane Rural Road Segments?	No
Is applicable to Rural Road Intersections?	Yes

For Regression Equation

APM variable 1	Traffic Volume in approach AADTa (veh/day)
APM variable 2	Traffic Volume in circulating carriageway AADTc (veh/day)
APM variable 3	85th percentile speed (approach) V (km/h)
APM variable 4	-
APM equation	Af = 9.62x10^(-11) x AADTa x AADTc^0.5 x V^2

APM development information

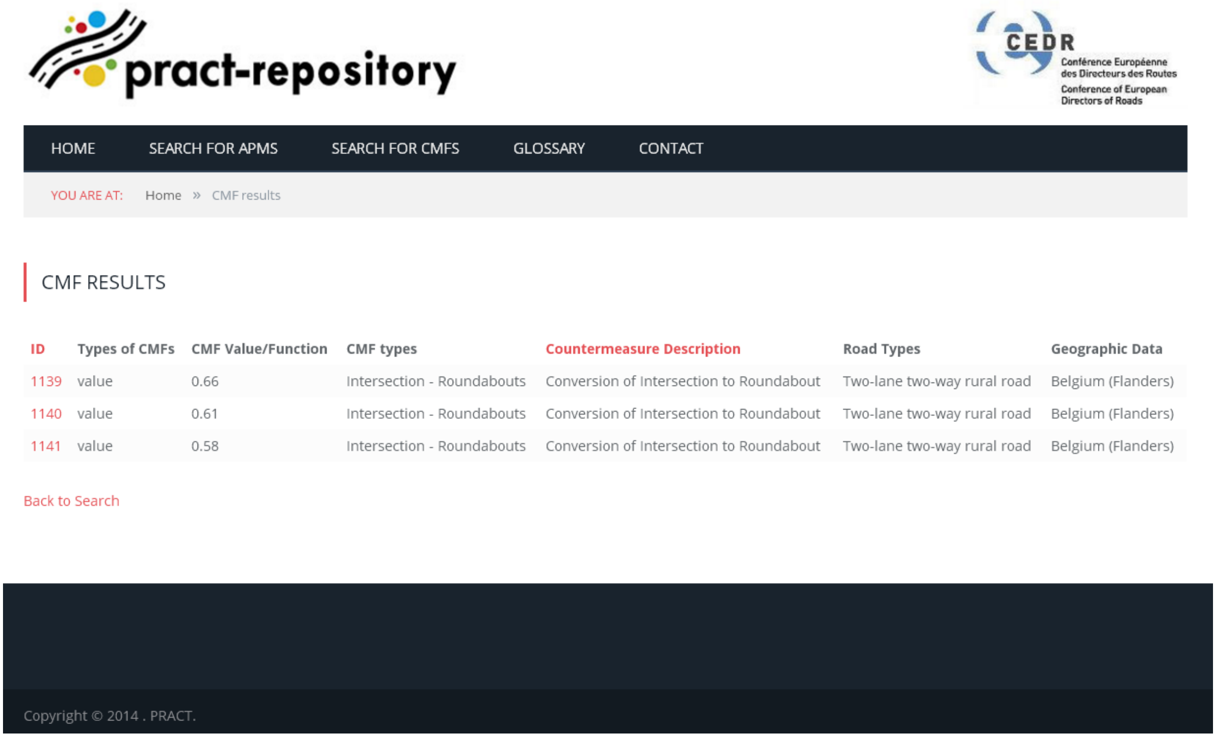
Study Design	Stepwise Multiple Linear Regression
Sample Size – No of sites	
Sample Size – No of years	
Sample Size – No of crashes	

Figure 3: *Part of the detailed results page for APM with ID number 1-020.*

Similarly, the CMF search function provides access to the searchable CMF database. The user may search for CMFs by providing any of the following:

- Type of CMFs
- CMF applicability: Motorway Segments, Motorway Speed Change Lanes, Interchange Ramps, Interchange Ramp Terminals, Two-way two-lane Rural Road Segments, Rural Road Intersections
- Road Elements involved
- Road Type involved: Two-way two-lane rural road, Motorway, Ramp Terminal
- Countermeasure categories involved
- Countermeasure description (free keyword search)
- Study information: study design, study name, range of years for the publication date, name of authors, geographic data origin
- Type of Intersection or Interchange
- Type of traffic control at intersections
- Characteristics of the accidents included in the study: severity, accident type and road user type

Execution of the search provides the user with a results page (see Figure 4) with a list of the CMFs in the database that meet the search criteria and their most basic characteristics (ID number, Type of CMF, CMF Value / Function, CMF type, Countermeasure Description, Road Type and Geographic Data Origin). Further clicking on any specific ID number from this list provides the user with all the available data related to this specific CMF, in a similar way to the APM search function.



ID	Types of CMFs	CMF Value/Function	CMF types	Countermeasure Description	Road Types	Geographic Data
1139	value	0.66	Intersection - Roundabouts	Conversion of Intersection to Roundabout	Two-lane two-way rural road	Belgium (Flanders)
1140	value	0.61	Intersection - Roundabouts	Conversion of Intersection to Roundabout	Two-lane two-way rural road	Belgium (Flanders)
1141	value	0.58	Intersection - Roundabouts	Conversion of Intersection to Roundabout	Two-lane two-way rural road	Belgium (Flanders)

Figure 4: *Indicative results of a search for CMFs in the repository, with the following criteria: "Roundabouts" in Countermeasure Description & Geographic Data Origin = "Europe".*

5. Accident prediction models for Europe and the PRACT Tool

5.1 Accident prediction models development and calibration

In order to obtain a prediction of crash frequency potentially suitable for all the European road network, an Accident Prediction Model structure was assumed that allows a good flexibility and adaptability to local conditions. The models have the following formulation:

$$N_{(predicted,x)} = N_{spf,x} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{ix}) \times C_x \qquad \textbf{(1)}$$

where:
$N_{(predicted,x)}$ = predicted average crash frequency for a specific year for site type x
$N_{spf,x}$ = predicted average crash frequency determined for base conditions for site type x
CMF_{ix} = crash modification factors specific to SPF for site type x
C_x = calibration factor to adjust SPF for local conditions for site type x

Following the Highway Safety Manual (HSM) approach (AASHTO, 2010), the "base" crash frequency is determined by means of regression models developed from data for a number of similar sites. These regression models, called base Safety Performance Functions (SPFs), have been developed for specific site types and "base conditions" that are the specific geometric design and traffic control features of a "base" site, as a function of annual average daily traffic (AADT) volume and roadway segment length. Crash Modification Factors (CMFs) are then used as multiplicative factors to account for the specific site conditions which vary from base conditions. The CMFs presented in this section have the same base conditions as the base SPFs; therefore, CMF is equal to 1.00 when the specific site conditions are the same as the SPF base conditions. A calibration factor (C) is then used to account for differences in the general level of crash frequency, which may vary substantially from one country to another because of differences in climate, driver populations, crash reporting threshold, and crash reporting system procedures.

Within PRACT project, a set of base SPF models were estimated for:

- fatal and injury accidents in freeway segments, both for single vehicle and multi vehicle accidents (two models), using data from Germany, Italy and the Netherlands.
- fatal and injury accidents in two-lane two-way rural roads, for single vehicle and multi vehicle accidents (one model), using data from Germany, Italy and the United Kingdom.

In analyzing the data collected for a country, when the sample of data available was not large enough to develop a new base SPF, a SPF developed for another jurisdiction was selected. Nevertheless, the calibration of the full APM with local data allowed to obtain reliable results even when the base SPF was the one developed in another European country.

Furthermore, specific guidelines for the evaluation of the transferability of the models to different conditions were developed, assisting practitioners to implement a specific treatment on a road segment in their local area where no CMFs based on the local conditions are available. More details on the developed models, SPFs and CMFs can be found in La Torre et al. (2016).

5.2 PRACT Tool

A user-friendly tool (Figure 5) was built around the aforementioned European Accident Prediction Models, to allow practitioners to easily implement them. The tool includes the freeway and two-lane two-way models, a set of commonly used CMFs and a set of transferability checks. It also incorporates a direct link to the PRACT online repository to retrieve further CMFs.

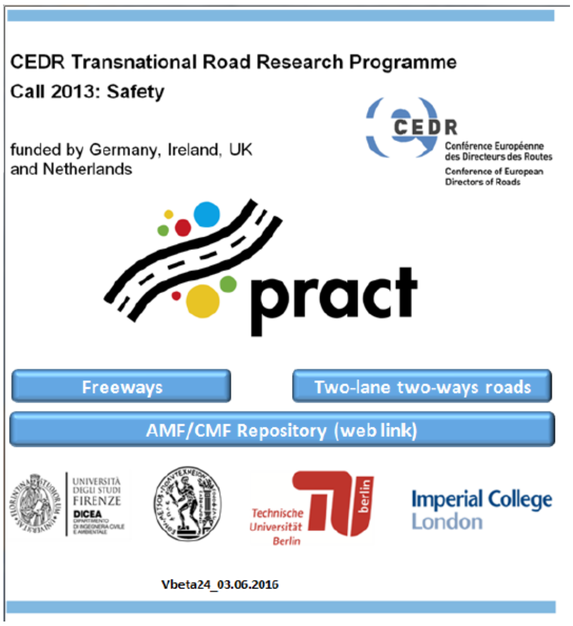


***Figure 5:** PRACT Tool.*

The tool assists road safety practitioners throughout the process of accident prediction; selection of a suitable "base" model, implementation of one or more CMFs according to the characteristics of the examined road section, evaluation of CMFs transferability and calibration of the total model. Its design is flexible in order to produce results even in cases of very limited local data availability; yet the proper consideration of local data (if available) by the tool significantly improves the reliability of the estimates.

6. Conclusions

The paper presented on overview of the research project PRACT, aiming to assist road safety practitioners in the use of the most relevant and suitable Accident Prediction Models for specific road safety problems. The project's results included:

- a comprehensive online repository of APMs and CMFs, based on an extensive review of pertinent international literature, focusing on high quality studies. Emphasis was placed on providing the end user with all the available background information on the APM or CMF development, in order to assist in the assessment of the quality and suitability of the provided data.
- a set of Accident Prediction Models for Europe, based on the HSM structure, but developed and calibrated using data from several European countries. Along with the models, a transferability evaluation procedure was developed.
- a practical tool to assist practitioners in the accident prediction process.

Within the project it was identified that accident prediction research is significantly based on US Data. Moreover, the limited existing European estimates refer to a small set of countries, namely Portugal, Spain, Germany, Norway, UK and Italy, and estimates from other countries, also limited in number, include Australia, New Zealand, India, Canada and Korea. Therefore, European research should focus on CMF and APM development for European roads, using methodologies (such as Empirical Bayes method) that allow for results of sufficient quality. Finally, a further challenge for the future is to maintain the operation of the online repository and further enhance its practical use by continuously updating its content and adding new references and data.

Acknowledgements

This research was carried out within the project PRACT - Predicting Road Accidents - a Transferable methodology across Europe funded by the National Road Authorities of Germany, Ireland, UK and the Netherlands within the Conference of European Directors of Roads (CEDR) 2013 Transnational Research Programme - Safety.

7. References-Bibliography

AASHTO (2010). *Highway Safety Manual, First Edition*. American Association of State and Highway Transportation Officials, Washington, D.C.

AASHTO (2014). *Highway Safety Manual (supplement), First Edition*. American Association of State and Highway Transportation Officials, Washington, D.C.

AustRoads, (2016). Road Safety Engineering Toolkit. [online] Available at: http://www.engtoolkit.com.au/

Azeredo Lopes S., Cardoso J. L. (2011). Accident Prediction Models for Rural Junctions on Four European Countries. RISMET Consortium, Deliverable Nr 6.1.

Cafiso S., Di Graziano A., Di Silvestro G., La Cava G., Persaud B. (2010). Development of comprehensive accident models for two-lane rural highways using exposure, geometry, consistency and context variables. *Accident Analysis and Prevention*, Vol.42, pp.1072-1079.

Caliendo C., Guida M., Paris A. (2007). A crash-prediction model for multilane roads. *Accident Analysis and Prevention*, Vol.39, pp.657–670.

Dietze M., Weller G. (2011). Applying speed prediction model models to define road sections and todevelop accident prediction models: A German case study and a Portuguese exploratory study. RISMET Consortium, Deliverable 6.2.

FHWA, (2016). CMF Clearinghouse [online] Available at: http://www.cmfclearinghouse.org

Harkey, D.L., Srinivasan, R., Baek, J., Council, F., Eccles, K., Lefler, N., Gross, F., Persaud, B., Lyon, C., Hauer, E., Bonneson, J., 2008. Accident Modification Factors for Traffic Engineering and ITS Improvements. NCHRP Report 617, NCHRP, Transportation Research Board, Washington, DC.

Hauer, E. 1997. Observational Before-After studies in road safety. Pergamon Press, Elsevier Science Ltd., Oxford, England.

iRAP, (2016). iRAP Road Safety Toolkit [online] Available at: http://toolkit.irap.org/

Karathodorou N., Graham D., Hu J., Richter T., Ruhl S., Yannis G., Dragomanovits A., Laiou A., La Torre F., Domenichini L., 2015. Development of new Crash Modification Factors/Functions per key safety treatments. PRACT Project Deliverable D2. Available at http://www.practproject.eu.

Karathodorou, N., Graham, D., Richter, T., Ruhl, S., La Torre, F., Domenichini, L., Yannis, G., Dragomanovits, A., Laiou, A. (2016). Development of A Crash Modification Factors Model in Europe. Proceedings of Road Safety on Five Continents (RS5C) Conference, May 17-19, 2016, Rio de Janeiro, Brazil.

Khan M., Abdel-Rahim A., Williams C.J., 2015. Potential crash reduction benefits of shoulder rumble strips in two-lane rural highways. *Accident Analysis and Prevention* 75, pp. 35–42.

La Torre, F., Tanzi, N., Karathodorou, N., Graham, D., Richter, T., Ruhl, S., Yannis, G., Dragomanovits, A. (2016). Final Guidelines. PRACT Project Deliverable D3. Available at http://www.practproject.eu.

Lyon C., Persaud B., 2008. Safety Effects of Targeted Program to Improve Skid Resistance. *Transportation Research Record* 2068, p. 135-140, Transportation Research Board of the National Academies, Washington, D.C.

Montella A., Colantuoni L., Lamberti R. (2008). Crash Prediction Models for Rural Motorways.Transportation Research Board ISSN: 0361-1981.

Park B.J., Fitzpatrick K., Brewer M., 2012. Safety Effectiveness of Super 2 Highways in Texas. *Transportation Research Record* 2280, pp. 38-50.

Persaud B., Lyon C., Bagdade J., Ceifetz A.H., 2012. Evaluation of Safety Performance of Passing Relief Lanes. *Transportation Research Record* 2348, pp. 58-63.

Tatum Group LLC (2016). SPF Clearinghouse [online] Available at: http://spfclearinghouse.org/

Turner S., Singh R., Nates G. (2012). The next generation of rural road crash prediction models: final report. NZ Transport Agency research report 509.

Yannis G., Dragomanovits A., Laiou A., Richter T., Ruhl S., Calabretta F., Graham D., Karathodorou N., La Torre F., Domenichini L. and Fanfani F. (2016). Inventory and Critical Review of existing APMs and CMFs and related Data Sources. PRACT Project Deliverable D4. Available at http://www.practproject.eu.

Yannis G., Dragomanovits A., Laiou A., Richter T., Ruhl S., La Torre F., Domenichini L., Fanfani F., Graham D., Karathodorou N. and Li H., (2014). Overview of existing Accident Prediction Models and Data Sources. PRACT Project Deliverable D1. Available at http://www.practproject.eu.

Yannis, G., Papadimitriou, E., Evgenikos, P. & Dragomanovits, A. (2015). Good practices on cost – effective road infrastructure safety investments. *International Journal of Injury Control and Safety Promotion*, DOI: 10.1080/17457300.2015.1047864.