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Transportation Research Procedia 14 (2016) 1772 – 1781

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

Development of a transnational accident prediction model

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Abstract

The PRACT Project (Predicting Road ACcidents – a Transferable methodology across Europe) is an ongoing project aimed at developing a European accident prediction model structure 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) model with a unique set of Crash Modification Factors (CMFs) can actually be developed, valid for all Europe and for all the different type of networks;
- the development of a specific APM model 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 PRACT project addresses these issues by developing a practical guideline and a user friendly tool that will allow for an easier implementation of APMs and CMFs in different countries and on different road networks.

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doi:10.1016/j.trpro.2016.05.143

Keywords: road infrastructure; safety measures assessment; Accident Prediction Model (APM); Crash Modification Factors (CMF)

1. Introduction

To improve Road Infrastructures Safety Management road authorities and road designers need prediction tools allowing them to analyze the potential safety issues, identify safety improvements and estimate the potential effect of these improvements in terms of crash reduction.

An inquiry conducted over 20 different countries has shown that, despite recent advances in the field of accident prediction modelling, most National Road Administrations (NRAs) and other organisations do not systematically use accident prediction methods during decision making for the implementation of road safety treatments. Furthermore, the use of APMs in decision making is more common in countries that have approved guidelines or manuals, which are normally related to a more advanced road safety culture.

Within this framework, the project PRACT (Predicting Road ACcidents – a Transferable methodology across Europe) was funded by the National Road Authorities of Germany, Ireland, UK and Netherlands within the Conference of European Directors of Roads (CEDR) 2013 Transnational Research Programme – Safety. The research partners of the PRACT project are Università degli Studi di Firenze (Project Leader), National Technical University of Athens, Technische Universität Berlin, and Imperial College London. The project aims at developing a European accident prediction model (APM) structure that could be applied to different European road networks with proper calibration.

The core principles behind the PRACT project structure are that:

- it is unrealistic to think that one unique Accident Prediction Model (APM) model with a unique set of Crash Modification Factors (CMFs) can actually be developed, valid for all Europe and for all the different type of networks of motorways and higher ranked rural roads;
- the development of a specific APM model 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 on which the PRACT project is therefore built 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 condition based on historical crash data.

The PRACT project is 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 analysed.

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.

2. Background

To improve Road Infrastructure Safety Management the road authorities and the road designers need prediction tools allowing them to analyze the potential safety issues, to identify safety improvements and to estimate the potential effect of these improvements in terms of crash reduction. For this aim in 2010 the AASHTO Highway Safety Manual (HSM) was released including a very comprehensive set of models for predicting road crashes for two-lane rural highways, multilane rural highways, and urban and suburban arterials (AASHTO (2010)).

A first study addressing the issue of the transferability of the rural two-lane two-way roads model to the European networks has been conducted by Martinelli et al. (2009) with reference to the Italian road network of provincial roads.

Crash Prediction Models (usually called also Accident Prediction Models) for freeways were developed by Hadi et al. (1995) adopting a negative binomial regression analysis to develop a set of prediction models categorized by crash severity, area type (i.e., urban, rural), and number of through lanes and using data from Florida roadways; Persaud and Dzbik (1993) developed two prediction models using data from urban freeways in Ontario, Canada: one for the total number of crashes and one for severe (fatal plus injury) crashes only. These models, together with that proposed by Wang et al. (1998), developed for rural divided highways, with characteristics similar to those of rural freeways and few or no access points, were reviewed and modified by Bonneson et al. (2005) to estimate the predicted numbers of severe crashes per year (i.e. fatal and injury crashes). Recently, Park et al. (2010) have found that the number of predicted crashes is significantly related to average daily traffic, on-ramp density, degree of road curvature, median width and inside shoulder, number of lanes (for urban freeways), and whether the freeway is in an urban or rural area while off-ramp density was not a statistically significant variable. In 2014, a supplement to the 2010 edition of the HSM has been issued with specific models for freeways and interchanges (AASHTO (2014)). The newly developed HSM Freeway model has been applied in Italy by La Torre et al. (2014).

Most of the new Accident Prediction Models have identified the following form as the most suitable for allowing the widest transferability:

$$N_p = N_{spf} \cdot (CMF_1 \cdot ...... \cdot CMF_m) \cdot C \tag{1}$$

where:

N_p = predicted average crash frequency for a specific site;

N_{spf} = predicted average crash frequency determined for the base conditions of the Safety Performance Function (SPF). This typically is only a function of traffic volumes and segment length;

CMF_1…. CMF_m = crash modification factors (that could be also derived from crash modification functions) accounting for specific site conditions (geometric design, traffic control features etc);

C = calibration factor to adjust the SPF for local conditions related to the network where the model is to be applied. This accounts for all the factors that lead to safety differences and that are not considered by the safety prediction methodology itself (differences in climate; differences in animal populations that lead to higher frequencies of collision with animals; differences in driver populations and trip purposes; complexity of the geometric layout; driver attitude and behaviour (e.g. rate of compliance with road code rules); vehicle fleet characteristics; crash reporting practices; differences in road standards).

The studies conducted on the Italian network have shown that a single calibration coefficient for the whole prediction model might be insufficient to adapt the HSM models to local conditions that differ considerably from those where the model have been developed.

Crash modification factors and crash modification functions – the indicators that quantify the crash reductions that result from interventions – are the basis for evidence based safety policies. Specifically, CMFs are fundamental to identifying the most effective road safety countermeasures. Furthermore, they are a useful tool for achieving optimal use of resources as they allow for calculating safety benefits in economic analyses of safety policies. Through a crash modification function (CMF) it is possible to combine different evaluation results and consequently better comprehend and implement effective safety measures (OECD (2012)). A CMF could allow more rapid adoption and dissemination of new safety measures. The narrower the CMF distribution, the larger is the probability that policy decisions are correct. The US Federal Highway Administration has developed a very comprehensive CMF clearinghouse (www.cmfclearinghouse.org) where CMFs developed worldwide are classified and assessed with a “star rating” approach, but there are several CMFs still missing.

For the prediction of expected crashes in tunnels most APMs available worldwide are not applicable. The most used model is the one developed by Salvisberg et al. (2004) that was developed analysing Swiss roads. The applicability of the Swiss model to the Italian motorway tunnels has been studied and presented in Domenichini et al. (2012). The results show that the Swiss model fits quite well also the Italian existing tunnels even though it is not structured to consider different safety treatments, as those that equip the new tunnels. A uniform European approach to accident prediction modelling has been recently developed within the SAVeRS Project (Selection of Appropriate

Vehicle Restraint Systems) but is limited only to Run Off Road Crashes (La Torre et al. (2015) and La Torre et al. (2016)). Furthermore, the SAVeRS procedure accounts for the calibration of the base Safety Performance Functions and of the overall predicted number of crashes to local condition, but the CMFs are assumed to be transferrable from one country to another.

3. Structure of the PRACT project

The PRACT project is structured in 5 Work Packages, as shown in Figure 1, aimed at:

- collecting and analysing the APMs currently used by different national road administrations (NRAs) in Europe and worldwide, as well as the currently used data sources for the development and application of APMs (WP1). The different APMs will be reviewed and assessed in terms of theoretical approaches, characteristics of models in use, implementation conditions, data requirements and available results, with focus on motorways and higher ranked rural roads;
- proposing the functional structure of the APM to be implemented in the Guideline (WP1);
- reviewing recent and salient literature related to the CMF, including the background and development of the CMF, various methods for developing CMFs, and key issues in the application of the CMF (WP2);
- organizing the collected APMs and CMFs in a systematic web-repository to support the analysis within the project and for further public use after the project will be completed (WP4);
- identifying key CMFs which have not been fully studied or omitted in the literature and, if possible, developing new CMFs (WP2);
- creation of a Guideline for the implementation of selected accident prediction models for rural freeways and two lane rural highways and for the evaluation of the transferability of these models to a given road network (WP3). The Guideline will include a section on the models description as well as numerical examples and a section with guidance for the development of CMFs not already included in the Guideline itself;
- producing a user-friendly software tool for calibrating the APM to local conditions and for selecting the CMFs applicable to the specific network (WP3);
- dissemination of the results to the potential stakeholders at a national and international level (WP5).

At the time of writing this paper WP1, WP2 and WP4 have been completed and the results will be summarized in the following paragraphs while WP3 is ongoing and will be completed by March 2016.

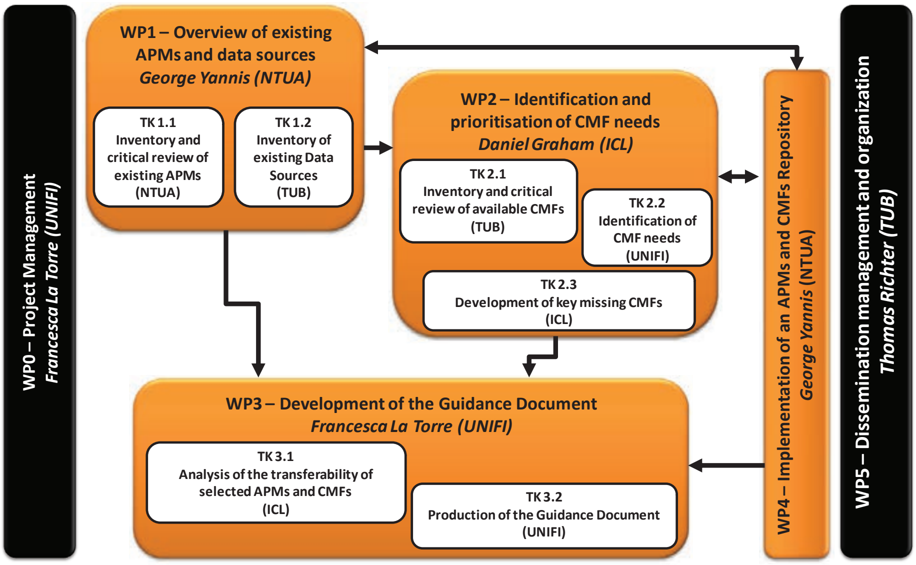


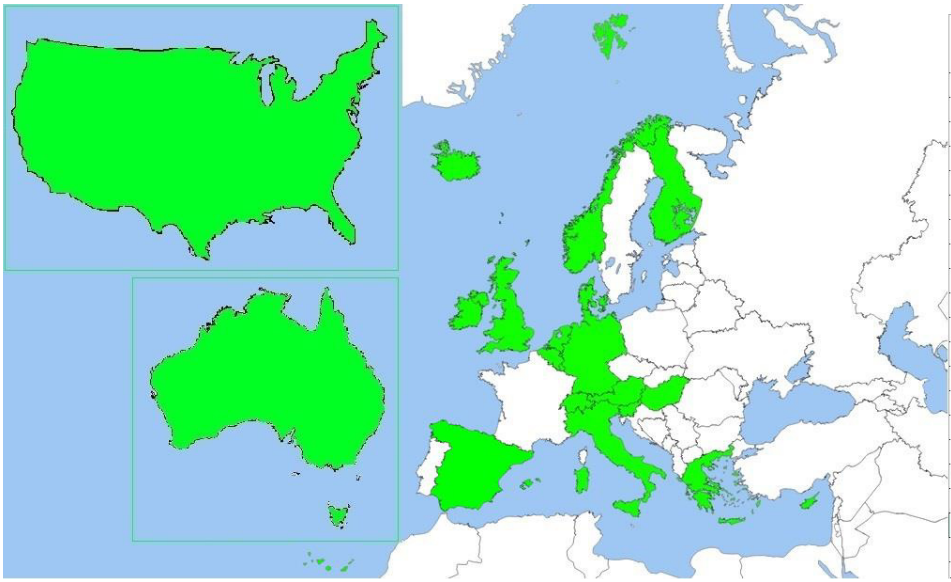
Fig. 1. PRACT project flow chart of activities.

4. Overview of existing APMs and data sources

Within the context of the PRACT Research Project (Predicting Road ACcidents – a Transferable methodology across Europe), an extensive review of currently used Accident Prediction Models (APMs) by different National Road Administrations (NRAs) in Europe and worldwide, as well as the currently used data sources for the development and application of APMs, has been performed and is described in details in Yannis et al. (2015a) and Yannis et al. (2016).

A questionnaire survey was dispatched to several NRAs in Europe and worldwide, in order to collect detailed information on APMs developed and used by them, as well as information on microscopic data used for the development and implementation of APMs (crash data, traffic data, road design data and other related data).

Furthermore, a review of relevant international literature was carried out, with focus in particular in identifying those modelling approaches and specific models that may be applicable or transferable in the European context. On the basis of the 23 responses to the questionnaire (Fig. 2) and of the literature review results, a synthesis of current practices regarding APMs was developed. Also based on the questionnaire responses, complemented with additional information from the literature, a description and discussion of available data sources for the development of APMs has been included.



Country	Sent questionnaires	Received
Austria	1	1
Belgium	2	1
Cyprus	1	1
Denmark	1	1
Finland	1	1
Germany	1	1
Greece	1	1
Hungary	1	1
Iceland	1	1
Ireland	1	1
Italy	3	2
Luxembourg	1	1
Netherlands	1	1
Norway	1	1
Slovenia	1	1
Spain	1	1
Switzerland	1	1
UK	5	3
USA	2	1
Australia	1	1
Total	28	23

Fig. 2. Geographical distribution of the questionnaire responses.

As far as current APM practices are concerned, an interesting observation resulting from the questionnaire survey is that, despite recent advances in the field of accident prediction modelling, most National Road Administrations (NRAs) and other organisations do not systematically use accident prediction methods during decision making for the implementation of road safety treatments. Furthermore, 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.

5. Identification of CMF needs

A specific section of the questionnaire discussed earlier was devoted to collecting information on the CMF needs, availability and transferability.

For each road safety measure (CMF type), included in the following table, based on your experience, please fill in the appropriate boxes (high / low) regarding the:

- **Need** to implement the road safety measure in your country's road network;
- **Availability** of assessment of measure / CMF;
- **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 your country?).

Table 1 shows, as an example, the first 15 CMF types in terms of combined HIGH NEED and LOW AVAILABILITY for motorways and divided freeways (without at grade intersections). The full results of the inquiry can be found in Yannis et al. (2015a).

Table 1. The first 15 CMFs in terms of combined HIGH NEED and LOW AVAILABILITY for motorways and divided freeways.

MOTORWAYS & DIVIDED FREEWAYS (without at grade intersection)	NEED		AVAILABILITY		TRANSFERABILITY	
Countermeasure – CMF	HIGH	LOW	HIGH	LOW	HIGH	LOW
Work zones	86.7%	13.3%	35.7%	64.3%	50.0%	50.0%
Roadside features – clear zone width	75.0%	25.0%	26.7%	73.3%	50.0%	50.0%
Effect of traffic (volume/capacity – % trucks & buses)	68.8%	31.3%	21.4%	78.6%	40.0%	60.0%
Sight distance and sight obstruction	61.1%	38.9%	21.4%	78.6%	63.6%	36.4%
Advanced warning devices/signals/beacons	62.5%	37.5%	26.7%	73.3%	72.7%	27.3%
Roadside features – use of passively safe structures (tested according to EN 12767)	58.8%	41.2%	35.0%	75.0%	58.3%	41.7%
Superelevation (cross slope)	46.7%	53.3%	8.3%	91.7%	70.0%	30.0%
Roadside features – motorcycle protection devices	53.3%	46.7%	21.4%	78.6%	54.5%	45.5%
High friction treatments (including anti-skid/slip)	73.3%	26.7%	42.9%	57.1%	63.6%	36.4%
Effect of ramp entrance/exit (distance to the analysed section)	53.3%	46.7%	23.1%	76.9%	45.5%	54.5%
Roadside features – replacement of barriers terminals with crashworthy terminals	56.3%	43.8%	28.6%	71.4%	66.7%	33.3%
Median Width	57.1%	42.9%	30.8%	69.2%	60.0%	40.0%
Skid resistance (in general)	64.7%	35.3%	40.0%	60.0%	63.6%	36.4%
Curvature	66.7%	33.3%	42.9%	57.1%	63.6%	36.4%
Rumble strips	58.8%	41.2%	37.5%	62.5%	75.0%	25.0%
Automated speed enforcement (section or average)	64.7%	35.5%	43.8%	56.3%	66.7%	33.3%

Based on the outcome of the questionnaire and considering the CMFs implemented in the Highway Safety Manual a list of 92 treatments (CMF types) to be investigated in further detail has been identified covering the following areas:

- Freeway segments
- Speed change lanes
- Ramp segments
- Crossroad ramp terminals
- Rural road segments (2-way 2-lane)
- Rural road intersections

For each CMF type a detailed review of all the relevant studies has been performed and a total of 1,577 specific CMFs (values or functions) have been identified. The results are presented in summary sheets included in Yannis et al. (2015b).

6. Development of new CMFs based on European crash data

6.1. Procedures adopted for the development of new CMFs

Two distinct approaches are used for CMF development in the project. The choice of methodology for each CMF depends on the type of CMF to be estimated as well as data availability. Data limitations mean that for some countermeasures the choice of methodologies is limited.

When a countermeasure had been implemented, the treatment year/date is known, and data on accident rates and traffic volumes are available both for the period before and after application of the countermeasure, CMFs are 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 C, Persaud B. (2008), Park et al. (2012); Patel et al. (2007); Persaud et al. (2004); Persaud et al. (2012)). In the PRACT project it is 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 Italian data.

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 accident black spots, the countermeasure variable will be endogenous in the model (i.e. correlated with the error term) leading to biased estimates; more advanced modelling 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 analysed 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.

For this project, negative binomial models are estimated using data from England and German to obtain CMFs 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. A specification as detailed as possible given the data available was applied to avoid the issue of omitted variable bias.

6.2. New CMFs developed as part of the PRACT project

Considering the CMF needs and lack of availability identified in the questionnaire and the availability of data suitable for developing new quality CMFs, a set of 13 new CMFs has been produced as shown in Table 2. CMFs for motorways have been developed based on data from Italy, while data from Germany and UK have been used to develop CMFs for rural two-way two-lane roads. CMFs for sight distance have not been included in this study (even though there is an ongoing activity on this based on the Italian Motorway data) as within the same CEDR safety Call a specific project has been funded (EU Sight Project, ongoing). Full details on the CMFs developed in the PRACT Project can be found in Karathodorou et al, 2015 and Karathodorou et al. (2016).

Table 2. 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

(*) The base conditions Safety Performance Function (SPF) for two-way two-lane rural roads is defined with only the length as a variable and AADT is considered as a CMF but this CMF can be included in the SPF to be consistent with the HSM, if required.

7. Transferability of CMFs

This task of the PRACT Project explores how CMFs developed in past research and within the PRACT project can be applied to decisions about future actions to be implemented under different circumstances. Since CMFs are based on random variables and are not universal constants that apply everywhere, it is necessary to assess the transferability of such estimates.

Specifically, this task will address the following issues:

- the similarities and differences among the current functions applied in different countries, and factors that reduce the transferability;
- the conditions to justify transferring a model from one to the other, such as data requirement and the characteristics of the treatment studied;
- the temporal and spatial transferability of selected CMFs.

The first issue was tackled by analysing in detail the 92 selected CMF types and producing a summary sheet for each study identifying the key variables considered in each study. All the information on the 92 CMF types (including a total of 1,577 specific CMFs) has been digitalized and included in a searchable database in the PRACT web-based Repository (Yannis (2015b)).

The core issue in the project was how to define a procedure to establish if a CMF is directly transferrable to a condition different than the one for which it has been developed. This depends on:

- availability of data on the conditions under which the CMF was developed (e.g. traffic ranges, curvature ranges, number of lanes, characteristics of the treatment etc);
- availability of local data on the specific treatment to validate the CMF based on a sample of local sections.

Currently, a set of procedures are being developed to guide the user in verifying transferability of CMFs based on either of the two approaches above.

When none of the above options are applicable (either because the detailed information on the existing CMF is not available or because local data are not available), or when the procedures above lead to a negative outcome (the specific CMF is not transferrable to local network), then one or more existing CMFs will have to be combined to have a more reliable estimate. To do so a procedure is under development accounting also for the guidance given in OECD (2012).

8. Development of the full accident prediction model

The final part of the project deals with the procedure to adapt/calibrate a European APM (based on the structure shown in eq. 1) to local condition based on locally available crash, geometric and traffic data.

As far as different countries, as well as different road authorities within a country, have different level of expertise and different data availability, the procedure will be structured allowing for different possible levels of calibration considering at least:

- a total lack of historical data (in this case the user will be proposed different sets of reference calibration parameters that will be calculated within the PRACT project based on the available datasets and indications on how to select the set of parameters that are the more suitable for the specific situation);
- the typical situation in which crash data are available and the APM model can be calibrated to be used with already developed "uncalibrated" CMFs;
- situations where detailed crash data, traffic data and geometric data are all available and the road administration could also calibrate key CMFs to local conditions.

The calibration can be done both at the N_{spf} level (fitting a new SPF to local data) at the full APM by calculating the C coefficient included in eq. 1.

This approach has been recently developed within the SAVeRS Project (Selection of Appropriate Vehicle Restraint Systems) but is limited only to Run Off Road Crashes (La Torre et al. (2015) and La Torre et al. (2016)).

One of the core issues in using models developed in other conditions and "calibrating" them to different conditions is the assessment of the reliability and potential biases associated with the crash predictions, as highlighted also in Martinelli et al (2009) and La Torre et al. (2014). This issue has not been addressed in the different studies dealing with APM calibration.

Within the PRACT Project a procedure to assess the reliability of the calibrated APMs is being developed.

9. Conclusions

The preliminary results of the PRACT project show that there is a strong need for a practical and harmonized approach to accident modelling. Based on the analysis of the 23 responses to the questionnaire dispatched worldwide, the Crash Modification Factors (CMFs) that are considered highly needed to assess the safety effectiveness of a given treatment/feature have been identified. Combining this information with the CMFs included in the Highway Safety Manual models, a list of 92 key CMFs have been produced and for each of these a detailed analysis has been conducted to identify and analyse all the different studies related to a given CMF. The results are summarized in a set of summary sheets and digitalized in a searchable database in a web-based repository.

Within the PRACT Project a set of 13 new CMFs has been produced for motorways (in Italy) and for rural two--way two-lane roads (in Germany and UK). The new CMFs cover traffic composition effects, speed management, geometric layout and pavement friction effects as well as the effect of work zones on safety.

The ongoing activities include the definition of a procedure for evaluation of the transferability of CMFs developed in one condition (country, network configuration etc) to a different condition and the definition of a procedure to calibrate the full accident prediction model and to assess the prediction capabilities on the local network where the calibrated model is applied.

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. The authors wish to thank the Project Manager (Elizabeth Mathie) for her support and advice.

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