DEVELOPMENT OF A CRASH MODIFICATION FACTORS MODEL IN EUROPE

Niovi Karathodorou
Imperial College London
Skempton Building, Imperial College London,
South Kensington Campus, London SW7 2AZ, UK
Phone: +44 (0)20 7594 5924 E-mail: n.karathodorou@imperial.ac.uk

Co-authors(s); Daniel J. Graham, Imperial College of London; Thomas Richter, Technische Universität Berlin; Stephan Ruhl, Technische Universität Berlin; Francesca La Torre, University of Florence; Lorenzo Domenichini, University of Florence; George Yannis, National Technical University of Athens; Anastasios Dragomanovits, National Technical University of Athens; Alexandra Laiou, National Technical University of Athens.

ABSTRACT

The PRACT Project (Predicting Road ACcidents - a Transferable methodology across Europe) aims to develop a European accident prediction model structure that could be applied to different European road networks with proper calibration. An important part of the PRACT project involves the review of the recent and salient literature on Crash Modification Factors (CMFs) with the aim of understanding CMF availability and identifying CMF needs in Europe. In addition, a survey of 23 National Road Authorities (NRAs) from 20 countries was completed to understand CMF use and CMF needs within NRAs. The survey identified a number of CMFs that are useful to NRAs but not readily available. Based on both the literature review and the NRA survey, the PRACT project developed some key CMFs that are currently missing or underrepresented in the literature. CMFs were developed for motorways and 2-way rural roads using data from Italy, England and Germany. A number of CMFs were developed, including for work zones, speed enforcement, high friction wearing course, traffic composition, horizontal curvature and vertical gradient. This paper presents a synthesis of CMF availability and needs based on the survey of NRAs and an extensive review of the literature, and outlines the development process for CMFs within the PRACT Project.

1. INTRODUCTION

The PRACT Project (Predicting Road ACcidents - a Transferable methodology across Europe) aims at developing a European accident prediction model structure that could be applied to different European road networks with proper calibration. PRACT is 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 (Italy) - Project Leader,
- National Technical University of Athens (Greece),
- Technische Universität Berlin (Germany), and
- Imperial College London (UK).

The key aim of the project is to develop a procedure that will enable Accident Prediction Models (APMs) and Crash Modification Factors (CMFs) to be transferred to conditions different to the conditions for which they were developed. This will be implemented into a practical guideline and a user friendly tool that will allow the different road administrations to identify suitable APMs and CMFs and adapt them for use in local conditions. The project focuses in particular on motorways and two-way two-lane rural roads.

Within the PRACT project, a detailed review of existing literature on CMFs was performed, gaps in knowledge were identified and new CMFs were developed for those missing. Selection of the CMFs to develop took into account results from a survey of 23 National Road Authorities (NRAs) and other relevant institutions[1] from Europe, US and Australia that was conducted as part of the first work package of the Project. The analysis of the survey results and CMF literature review resulted in the identification of 92 key countermeasures/road features for motorways and two-way two-lane rural roads. The CMFs developed as part of the project aimed to fill some of the gaps identified during the literature review process within the limits imposed by data availability issues. In general, the estimated CMFs were identified by road agencies as valuable but not so readily available. This paper presents a synthesis of CMF availability and needs based both on the survey of NRAs and an extensive review of the literature, and outlines the development process for CMFs within the PRACT Project. Table 1 summarises the CMFs developed as part of the Project. CMF estimation used data from Italy, England and Germany.

[1] Survey participants included mostly National Road Authorities, but also Road Managing Companies, Academia/Research Institutes and Highway Consultants.

Table 1: CMFs Developed in the PRACT Project

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

The next section discusses in more detail CMF availability with a focus on CMF estimates based on European data. Section 3 outlines the approach used in the PRACT Project to develop new CMFs for Europe. Section 4 summarises key results from the project before some concluding remarks in section 5.

2. REVIEW OF CMF NEEDS

As part of the PRACT Project a systematic review of CMF needs was completed which consisted of two parts. The first part comprised a questionnaire survey that was completed by 23 international NRAs and other relevant institutions and identified CMFs that road authorities consider much needed to assess the safety effectiveness of treatments/road features for rural motorways and two-way two-lane rural roads. The survey was completed by road authorities and institutions from Austria, Belgium, Cyprus, Denmark, Finland, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Norway, Slovenia, Spain, Switzerland, UK, USA and Australia. The survey identified 20 CMFs for rural motorways and 32 CMFs for two-lane two-way rural roads that more than 50% of NRAs considered as highly desirable (Yannis et al., 2015a). The second part of the CMF needs review process comprised a detailed review of existing literature for a list of 92 CMF types. The list consisted of those CMFs identified as much needed by road agencies and CMFs included in the Highway Safety Manual models (AASHTO 2010, 2014). Detailed results of this literature review are summarised in a set of summary sheets and a searchable web-based repository (Yannis et al, 2015b).

The literature review identified several CMFs for which no estimates were available. For rural motorways these include roadside clear zone width; number of lanes; traffic composition; sight distance and sight obstructions; use of passively safe structures tested according to EN 12767 on the roadside; replacement of barrier terminals with crashworthy terminals; effect of ramp entrance/exit (distance to the analysed section); right shoulder width and the presence of a right side barrier on ramp segments. For two-way two-lane rural roads, countermeasures/road features with no available CMF estimate include the presence of a barrier on the roadside; sight distance and sight obstructions; use of passively safe structures tested according to EN 12767 on the roadside; the presence of workzones; realignment of road segments; replacement of barrier terminals with crashworthy terminals; audible road markings; roadside barrier class; advanced warning devices, signals or beacons; raised islands and pedestrian refuge islands; automated speed enforcement; segment lighting; variable message signs; dynamic feedback speed sign; and motorcycle protection devices on the roadside.

CMF estimates available in relevant literature tend to be based on US data. Moreover, the limited existing European estimates refer to a small set of countries - Portugal, Spain, Germany, Norway, UK and Italy. Table 2 shows the number of studies reviewed for each CMF disaggregated by region. The category 'other countries' includes estimates from Australia, New Zealand, India, Canada and Korea. On average, 77% of studies for each CMF type are from the US. The corresponding proportion for European countries is 17%. For non-US and non-European countries it is 6%. For 32 CMFs, only studies from the US were found in the literature.

Table 2: *Summary of CMF Review Results. Bold font indicates CMFs estimated in the PRACT Project. (continued on next page)*

CMF title	Number of studies	USA	European country	Other country
MOTORWAYS				
Motorway segment - Horizontal curve	5	3	1	1
Motorway segment - Lane width	1	1	0	0
Motorway segment - Inside shoulder width	1	1	0	0
Motorway segment - Median width	1	1	0	0
Motorway segment - High volume	1	1	0	0
Motorway segment - Lane change	1	1	0	0
Motorway segment - Outside shoulder width	1	1	0	0
Motorway segment - Shoulder rumble strip	1	1	0	0
Motorway segment - Outside clearance	1	1	0	0
Motorway segment - Skid resistance (in general)	1	1	0	0
Motorway segment - Workzones	**5**	**3**	**2**	**0**
Motorway segment - Roadside features - crash cushions	2	1	1	0
Motorway segment - Advanced warning devices/signals/beacons	2	1	1	0
Motorway segment - Variable message signs	2	1	1	0
Motorway segment - Median barrier	3	1	2	0
Motorway segment - Outside barrier	3	1	2	0
Motorway segment - Automated speed enforcement (section or average)	**4**	**1**	**3**	**0**
Motorway segment - High friction treatments (including anti-skid/slip)	2	0	2	0
Motorway segment - Horizontal curve delineation	1	0	1	0
Speed change lane - Ramp Exit (length/side of ramp)	4	3	0	0
Speed change lane - Ramp Entrance (length/side of ramp)	2	1	1	0
Ramp segment - Lane add or drop	1	1	0	0
Ramp segment - Ramp speed change lane	1	1	0	0
Ramp segment - Weaving section	1	1	0	0
Crossroad ramp terminal - Exit ramp capacity	1	1	0	0
Crossroad ramp terminal - Crossroad left-turn lane	1	1	0	0
Crossroad ramp terminal - Crossroad right-turn lane	1	1	0	0
Crossroad ramp terminal - Access point frequency	1	1	0	0
Crossroad ramp terminal - Segment length	1	1	0	0
Crossroad ramp terminal - Median width	1	1	0	0
Crossroad ramp terminal - Protected left-turn operation for signal controlled crossroads	1	1	0	0

Table 2: Summary of CMF Review Results. Bold font indicates CMFs estimated in the PRACT Project. (continuation from previous page)

CMF title	Number of studies	USA	European country	Other country
Crossroad ramp terminal - Channelized right turn on crossroad for signal controlled crossroads	1	1	0	0
Crossroad ramp terminal - Channelized right turn on exit ramp for signal controlled crossroads	1	1	0	0
Crossroad ramp terminal - Non-ramp public street leg for signal controlled crossroads	1	1	0	0
Crossroad ramp terminal - Skew angle for one-way stop controlled crossroads	1	1	0	0
RURAL ROADS				
Rural road segment - Superelevation	1	1	0	0
Rural road segment - Two way turning lanes	1	1	0	0
Rural road segment - Rumble strips	9	9	0	0
Rural road segment - Roadside features - embankment slope	4	4	0	0
Rural road segment - Passing Lanes	5	4	0	1
Rural road segment - Shoulder width and type	11	7	3	1
Rural road segment - Vertical curvature	**5**	**3**	**2**	**0**
Rural road segment - Driveway density (DD)	7	4	1	2
Rural road segment - Roadside hazard rating (RHR)	4	2	1	1
Rural road segment - Horizontal curvature	**8**	**4**	**3**	**1**
Rural road segment - High friction treatments (include anti-skid/slip)	4	2	1	1
Rural road segment - Effect of traffic (volume/capacity - % trucks & buses)	**2**	**1**	**0**	**1**
Rural road segment - Lane width (LW)	**13**	**6**	**5**	**2**
Rural road segment - Grade Level	5	2	2	1
Rural road intersection - Intersection Left-turn lanes	2	2	0	0
Rural road intersection - Intersection Lighting	2	2	0	0
Rural road intersection - Intersection Right-turn lanes	1	1	0	0
Rural road intersection - Intersection skew angle	2	2	0	0
Rural road intersection - Intersection sight distance	1	1	0	0
Rural road intersection - Intersection traffic control	4	3	0	1
Rural road intersection - Signal timing (including optimizing and re-timing intervals)	2	1	0	1
Rural road intersection - Roundabouts	7	2	2	3

The literature review indicated significant scope for estimating new CMFs for those missing. However, opportunities to estimate new CMFs were constrained by data availability. The CMFs that were estimated as part of the Project (see Table 1 in Section 1) are CMFs identified by road agencies as valuable but not so readily available for which suitable data for estimation were available. Table 3 below shows the percentage of NRAs participating in PRACT's questionnaire survey that identified the CMFs estimated in the Project as highly desirable and the percentage that reported a low availability of estimates.

Table 3: *Percentage of Road Agencies Reporting a High Need and Low Availability of CMF Estimates for the CMFs Developed in the PRACT Project*

	high need	**low availability**
Work zones – rural motorways	85.7%	61.5%
High friction treatments – rural motorways	71.4%	61.5%
Lane width – two-lane two-way rural roads	71.4%	66.7%
Effect of traffic (volume/capacity - % trucks & buses) - two-lane two-way rural roads	69.2%	81.8%
Horizontal curvature - two-lane two-way rural roads	69.2%	63.6%
Longitudinal grade - two-lane two-way rural roads	64.3%	72.7%
Automated speed enforcement – rural motorways	62.5%	60.0%

3. PROCEDURE FOR DEVELOPING CRASH MODIFICATION FACTORS

Two distinct approaches were used for CMF development in the Project. The choice of methodology for each CMF depended on the type of CMF to be estimated as well as data availability. Data limitations meant that for some countermeasures the choice of methodologies was limited.

When data on the year/date that a countermeasure was implemented as well data on accident rates and traffic volumes were available both for the period before and after application of the countermeasure, CMFs were developed using an Empirical Bayes Before-After (EB) approach (Hauer, 1997). The advantage of this approach is that it controls for the effects of regression to the mean. Countermeasures tend to be implemented at sites where high accident rates have been recorded (e.g. accident black spots). 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 random rather than due to the implemented countermeasure. To deal with RTM, EB estimates the expected number of accidents at sites where a countermeasure is implemented before implementation as a weighted sum of the observed number of accidents and the number of accidents predicted by safety performance functions developed for reference sites similar to the treated sites that have not received the treatment. 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 et al 2008; Park et al 2012; Patel et al 2007; Persaud et al 2004; Persaud et al 2012).

In the PRACT Project, the EB method 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 in Italy. For high friction wearing course, the project focused on run-off-road accidents occuring on wet pavement, while for speed enforcement separate CMFs were estimated for various crash types (single-vehicle versus multi-vehicle), injury types (fatal and injury versus property damage only) and traffic flow levels. The project also estimated separate CMFs for different work zone layouts. CMFS were estimated using data from a motorway network of approximately 2100km that were provided by Autostrade per l'Italia (ASPI).

When no suitable data is available to employ the Empirical Bayes approach, multivariate regression models can also be used to estimate CMFs. This 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 blackspots, 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 traffic composition that do not depend on accidents. 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 also correlated with the error term can 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.

Within the PRACT Project, two separate negative binomial models were estimated for the number of fatal or injury crashes on two-way two-lane rural roads in England and Germany. The English model was estimated using accident and traffic flow data from 120 road segments for the period 2010-2013. Traffic flow (annual average daily traffic), horizontal curvature, vertical gradient, the % of heavy goods vehicles and the % of two-wheel motor vehicles were included as explanatory variables. The German model was estimated using accident and traffic flow data from 949 road sections for the year 2014. Traffic flow (annual average daily traffic), horizontal curvature, vertical gradient, lane width and the % of heavy goods vehicles were included as explanatory variables.

The models were used to obtain CMFs for traffic volume, traffic composition, lane width, horizontal curvature and vertical gradient. Such features are unlikely to depend on accident rates and hence the methodology should provide unbiased estimates of their effect on accident rates provided that a comprehensive set of explanatory variables is included in the model to avoid omitted variable bias. To avoid omitted variable bias, a specification as detailed as possible was used given the data available.

Table 4 summarizes the CMFs developed in the PRACT project using each approach.

Table 4: *Methodologies Employed in CMF Estimation*

Methodology	Country/ Road Type	CMF
Empirical Bayes Before-After	Italy / rural motorways	Work zones Average speed enforcement (section control) High friction wearing course
Negative Binomial Model	England / two-way two-lane rural roads	Traffic composition Horizontal curvature Vertical gradient
	Germany / two-way two-lane rural roads	Traffic composition Lane width Horizontal curvature Vertical gradient

4. SUMMARY OF KEY RESULTS

Key results from the study are summarised in Table 5. More detailed results can be found in Karathodorou et al (2015). Some key conclusions are discussed below:

- The effect of speed enforcement (section control) varies for different injury and crash types. For certain injury and crash types, such as single vehicle fatal and injury crashes, speed enforcement appears not to have a statistically significant effect on accident numbers, even though an average crash reduction is observed for higher traffic volumes.
- In general, the presence of a work zone appears to increase accidents by 33%. However, this figure varies depending on the work zone layout. For instance, results suggest that the accident rate in a partial diversion of the flow in a 2 lanes carriageway, with a single lane for the traffic flow not diverted, is more than three times higher compared to when no works are taking place on the carriageway. On the other hand, closure of the emergency or the slow lane in a 3 lane carriageway does not appear to have a significant impact on accident rates.
- CMFs appear to depend on the local conditions for which they were estimated as illustrated by the distinct conclusions reached for traffic composition and horizontal and vertical gradient in the English and German accident prediction models.

Table 5: Summary of New CMFs Developed for the PRACT Project (F=Fatal, I=Injury, ROR=Run-Off-Road)

Countermeasure/ feature	Country	Value/ function	Injury Type	Crash Type
Presence of a work zone	Italy	0.84-3.11 depending on the work zone layout (1.33 on average)	F+I	ALL
Speed enforcement (section control)	Italy	0.52-1.55 depending on injury and crash type No significant effect on some injury and crash types	Various	Various
High friction wearing course	Italy	0.27	F+I	ROR, wet pavement
Horizontal curvature (HC)	England	no significant effect	F+I	ALL
Vertical gradient (V)	England	$CMF = e^{0.09*\Delta V}$	F+I	ALL
% HGV (HGV)	England	$CMF = e^{-7.58*\Delta HGV}$	F+I	ALL
% two wheel traffic	England	no significant effect	F+I	ALL
Road width	Germany	$CMF = e^{-0.17*\Delta RW}$	F+I	ALL
Horizontal curvature (HC)	Germany	$CMF = e^{0.003*\Delta HC}$	F+I	ALL
Vertical gradient (V)	Germany	no significant effect	F+I	ALL
% HGV (HGV)	Germany	no significant effect	F+I	ALL

5. CONCLUSION

This paper reports on the review of CMF needs and the development of new CMFs for those missing that were undertaken as part of the PRACT Project. CMF needs were identified through a questionnaire survey of worldwide National Road Agencies and a comprehensive review of existing literature on CMF developed for 92 countermeasures/road features. The Project focused on rural motorways and two-way two-lane rural roads. The review identified several countermeasures/road features for which no CMF estimates are available in the literature and highlighted that available CMF estimates are overwhelmingly based on US data.

An important finding of the Project has been that gaps that exist in the CMF literature are difficult to fill, and this is due to a lack of suitable data for CMF estimation. Data availability issues also limit methodological choices for CMF estimation. In the PRACT Project, 10 new CMFs were estimated for Italian rural motorways and English and German two-lane two-way rural roads. An Empirical Bayes approach was used to develop CMFs for the implementation of high friction treatments, the installation of speed enforcement (section control) and the presence of work zones. Negative binomial models were developed to obtain CMF estimates for several road characteristics that do not depend on accident rates. Developing further Empirical Bayes estimates for additional road safety treatments was hindered by a lack of suitable data. The Empirical Bayes approach requires accident and traffic flow data both from before and after treatment implementation. Such data can be difficult to obtain as treatment implementation dates are often not recorded in a systematic way.

Increased data availability will enable the estimation of further missing CMFs, including estimation of further CMFs based on non-US data. Increased data availability could also enable the use of more advanced statistical techniques based on causal modelling for CMF estimation. Such methods could overcome a shortcoming of the Empirical Bayes approach, which is its dependency on the existence of a reference set of roads similar to the roads that underwent the treatment under consideration and the ambiguity on how to define ‘similar’. The lack of local CMF estimates can also be dealt with by developing procedures to enable CMFs to be transferred to countries/jurisdictions/local conditions different to those for which they were estimated. The development of such a procedure, as well as a corresponding easy to use tool for practitioners, is the next step of the PRACT Project.

ACKNOWLEDGMENTS

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.

REFERENCES

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

AASHTO (2014). Highway Safety Manual, First Edition, 2014 Supplement, American Association of State and Highway Transportation Officials, Washington DC.

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

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.

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 (available at www.practproject.eu).

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.

Lyon C, Persaud B. (2008). *Safety Effects of a Targeted Skid Resistance Improvement Program - Valid for angle crashes.*

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

Patel R.B., Council F.M., Griffith M.S. (2007). *Estimating Safety Benefits of Shoulder Rumble Strips on Two-Lane Rural Highways in Minnesota: Empirical Bayes Observational Before-and-After Study.* Transportation Research Record 2019, pp. 205-211.

Persaud B., Retting R., Lyon C., (2004). *Crash reductions following installation of centre-line rumble strips.* Accident Analysis and Prevention 36, pp. 1073–1079.

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.

Yannis, G., Dragomanovits, A., Laiou, A., Richter, T., Ruhl, S., La Torre, F., Domenichini, L., Fanfani, F., Graham, D., Karathodorou, N., Li, H., (2015a). Overview of existing Accident Prediction Models and Data Sources (available at www.practproject.eu).

Yannis G., Dragomanovits A., Laiou A., Richter T., Ruhl S., Calabretta F., La Torre F., Domenichini L., Graham D., Karathodorou N., (2015b) Inventory and Critical Review of existing APMs and CMFs and related Data Sources (available at www.practproject.eu).