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Development of an online Repository of Accident Prediction Models and Crash Modification Factors

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Abstract

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, analyse 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 for which they were developed. The paper aims to present an online searchable repository, developed within the research project PRACT (Predicting Road ACcidents - a Transferable methodology across Europe) funded by the Conference of European Directors of Roads (CEDR), in which a large amount of international experience on APMs and CMFs has been collected and organised. The repository includes 273 APMs and 889 CMFs that satisfy specific quality criteria, focusing on types that are considered most useful by Road Authorities. The data were either collected during an extensive review of existing literature or developed within the PRACT project and are expected to become a useful safety decision support tool for Road Authorities, designers and road safety engineers.

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, analyse potential safety issues, identify safety improvements and estimate the potential effect of these improvements in terms of crash reduction. A significant step towards this approach was the development of the Highway Safety Manual (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 Highway Safety Manual, 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 (RISMET 2011a & 2011b), 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.

Within the above context, the development of a user-friendly, comprehensive, online repository with searchable databases of existing APMs and CMFs, is expected to be a valuable assistance to transportation engineers and provide straightforward access to existing international accident prediction knowledge.

In order to develop the repository, the following methodology was applied: As a first step, a questionnaire survey focusing on CMF needs was performed with the participation of 23 international National Road Authorities (NRAs) and other relevant 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 highly desirable (Yannis et al. 2015a). In addition, a critical review of international pertinent literature on APMs and CMFs was performed, in order to examine the methods used for accident prediction modelling and to identify studies with useful related data. The review results can also be found in Yannis et al. (2015a).

Based on the results of the survey and the broad literature review, a comprehensive overview of different high need CMFactors and CMFunctions, within different road safety categories, was performed, and the gathered information was compiled in a structured CMF inventory, in order to form the basis for the CMF section of the repository. The same procedure was also applied for the development of an APM inventory, with the difference that all identified APMs were considered, and not only high-need ones, due to their limited number. Finally, a set of quality criteria were applied to the CMF inventory data and those CMFs that were considered of adequate quality, along with all the APMs, were included in the developed online repository.

This paper aims to present the development of the online APM and CMF repository. In Chapter 2, already existing online databases and road safety toolkits are presented and interesting observations that assist in defining the framework for the repository are made. Chapters 3 and 4 focus on the development of the aforementioned CMF and APM inventories respectively, and in Chapter 5 the development and operation of the repository is presented. Finally, in Chapter 6 the conclusions of the paper and directions for future research are included.

2. Review of existing online Databases and Road Safety Toolkits

In order to assist engineers in identifying the most appropriate countermeasure for their safety needs, several organisations have developed web-based databases of effective road safety measures, usually including Crash Modification Factors (CMFs). A brief description of four such databases is presented in the following paragraphs.

2.1. FHWA CMF Clearinghouse

The FHWA CMF Clearinghouse (www.cmfclearinghouse.org) offers transportation professionals a central, web-based searchable repository of Crash Modification Factors (CMFs). The FHWA Clearinghouse is directly related and provides support to the predictive methodologies included in the Highway Safety Manual (AASHTO 2010, AASHTO 2014). As far as the CMF repository is concerned, while the HSM provides only a selection of the available research-based CMFs, the CMF Clearinghouse is a comprehensive listing of all available CMFs, including the ones listed in the HSM.

For the development of the CMF Clearinghouse, a review of studies that develop CMFs was performed and a "confidence" rate in the CMF was assigned, based on the quality of the study that produced it. CMFs are rated taking into account five categories - study design, sample size, standard error, potential biases, and data source. A star rating (one through five) is assigned to each CMF, based on the cumulative performance in the five categories. This rating process differs from the one use in the HSM in that it does not attempt to adjust the standard error, but similarly to the HSM it explicitly considers criteria such as data source, which examines whether a study used data from just one locality or from multiple locations.

An important aspect of the FHWA CMF Clearinghouse is that for each CMF value included in the database, detailed background information is generally available, regarding the exact study from which the CMF was retrieved (citation, abstract and in many cases full text), the CMF development procedure (including date range of data used, geographic origin of the research, statistical methodology used, "before" sample size, "after" sample size etc.) and the aforementioned star quality rating.

A drawback of the FHWA CMF Clearinghouse is that the search function of the database is generally limited to keyword search (on the treatment's name, study's abstract, study's citation or CMF ID). More advanced search capabilities are available only by performing a two-stage search, i.e. searching with a blank field on the treatment's name and subsequently filtering the results according to crash type, crash severity, road type, intervention category etc. This procedure can be more complicated and time consuming and furthermore, some useful search functions existing in Austroads or iRAP toolkits (e.g. searching for measures addressing a specific road safety issue, or affecting specific road user groups), are not available.

2.2. SPF Clearinghouse

The SPF Clearinghouse (http://spfclearinghouse.org/) became available at the beginning of 2016 and is owned and operated by Tatum Group LLC. The website aims to incorporate information on already developed Safety Performance Functions. Data are gathered primarily on a voluntarily basis from users. For each SPF, the website provides the mathematical equation, a graphical representation of the equations outcome, a list of keywords that describe its applicability range (e.g. for segments or intersections, the type of intersection, for rural or urban areas etc.), and an additional window with more details, where available. A search function navigates the user around the information included in the website.

The graphical representation of the SPFs results is a valuable addition to the already existing repositories. However, background information (e.g. sample size, study methodology etc.) on the development of the presented SPFs is not readily available; thus the user is not able to assess the reliability and transferability of the presented SPFs to the specific circumstances at hand.

2.3. Austroads Road Safety Engineering Toolkit

The Austroads Road Safety Engineering Toolkit (www.engtoolkit.com.au) brings together existing road safety engineering knowledge for easy access by practitioners, based on research into the effectiveness of road safety countermeasures, retrieved from relevant studies in Australia and New Zealand. In addition to the originally included data, road safety practitioners are allowed to submit case studies which will be evaluated and possibly included in the knowledge framework of the Toolkit.

A total of 67 treatments, all concerning road infrastructure, are included in the Toolkit, which incorporates more user-friendly search functions as compared to the FHWA Clearinghouse. For each treatment the Toolkit includes a description, the associated key benefits, a presentation of issues concerning implementation, the related crash reduction effectiveness, a qualitative cost rating (using a 5 scale system) and treatment life estimation (using a 4 scale system), along with reference to technical papers, studies and guides concerning the treatment.

Quantitative values for the expected crash reduction effectiveness of each measure are included in the Toolkit. However, detailed information regarding the development of each expected crash reduction percentage is not available (such as the exact reference for each CMF, the statistical method that was used, the geographic area, conditions that the value refers to, the data that were used, etc.).

2.4. iRAP Road Safety Toolkit

The iRAP Road Safety Toolkit is very similar in design and operation with the Austroads Road Safety Engineering Toolkit, incorporating, however, less information and capabilities. A total of 58 treatments are included in the Toolkit: 42 related to road infrastructure, 5 related to vehicles and 11 related to users. Search within the web-based toolkit can be performed according to the specific treatment name, the dominant crash types or the road user groups, while the search according to the road safety deficiency to be addressed (as in the Austroads Toolkit) is not possible. For each treatment, the iRAP Toolkit includes a description of the problem and the treatment, the associated key benefits, a presentation of issues concerning implementation, a qualitative effectiveness rating, cost rating and treatment life estimation, reference to technical papers, studies and guides concerning the treatment and reference to related case studies (if available).

It should be noted that specific CMF values are not included in the iRAP Toolkit, only an assessment of each treatment's effectiveness using a four scale system (0-10%, 10-25%, 25-40%, 60% or more). Therefore, the iRAP toolkit has limited applicability in the process of quantitatively estimating the effectiveness of road safety measures.

2.5. Discussion

Based on the review of the existing online accident prediction databases, the following important observations can be made:

- Most databases focus on the crash reduction effectiveness of specific measures by providing information on the specific CMFs. Only the SPF Clearinghouse presents broader Safety Performance Functions that serve as a basis for accident prediction, but the background information that will assist road safety practitioners in deciding if the SPF is suitable for the case they examine, is not readily available. Furthermore, no existing database includes stand-alone, multivariate regression models that have been developed for accident prediction.
- Almost all of the accident prediction information included in the aforementioned databases originates either from the United States (FHWA and SPF clearinghouses) or from Australia (Austroads and iRAP toolkits). European studies are generally not included in the existing databases.

From the above it becomes evident that there is a need for a comprehensive online repository of both CMFs and APMs (SPF based as well as regression equation models) that will also include all available data from existing European studies. The repository should include all the information required by transportation engineers in order to judge the suitability and transferability of the models and the CMFs for the situation under consideration, and should provide a user-friendly way to search the available data.

3. Inventory of existing CMFs

Prior to the repository development, a comprehensive inventory of CMFs that can be found in international literature was developed, focusing on rural freeways and rural two-way two-lane rural roads and including both road segments and intersections. Thus, the following six roadway element categories of CMFs were identified: freeway segments, freeway speed change lanes, freeway ramp segments, crossroad ramp terminals, rural road segments (two-way two-lane), and rural road intersections.

Within these six roadway elements, it was decided to include in the inventory review all the CMF types that have been evaluated and included in the Highway Safety Manual (AASHTO 2010 & 2014), with the addition of those CMF types which are considered as the most needed ones by the responsible road administrations and by road safety practitioners or specialists, according to the results of the respective questionnaire survey (Yannis et al. 2015a). By applying this process, a total of 92 CMF types to be reviewed were selected; 54 CMFs types originated from the Highway Safety Manual, 49 CMFs types from the questionnaire survey and one more CMF type (CMF type 26: Horizontal Curve Delineation on Freeway Segments) was considered important and was added in the review list. 12 CMF types originated from both the Highway Safety Manual and the results of the questionnaire survey.

The review of literature for the development of the CMF inventory was conducted following a two-phased approach: in the first phase, a screening within the known literature was realised to identify those literature sources, which possibly can provide information about the several mentioned CMF types. Therefore a matrix was created involving the literature source on the one side and the 92 CMF types on the other side. Here it was discernible that there were CMF types with a lot of literature sources and others with very limited sources. The second phase of the CMF review involved a critical examination of CMFs within all 92 CMF types. The review results were compiled in a comprehensive CMF template that includes the following main aspects:

- Basic CMF information: value or function, variables - in case of function, CMF type, applicability.
- CMF development information: study design, potential standard errors, sample sizes (number of sites/ years/ accidents, further explanatory variables in the accident prediction model (if applicable), the general model form of multivariate cross-sectional models and potential sources of bias.
- Basic information about the reviewed study.
- Information of considered road elements: geographic origin of data, observed road network length, types of road elements, number of lanes per direction, minimum and maximum traffic volume, types of intersections and of intersection traffic control (if applicable).
- Information of considered accidents: accident severity, different accident types, number of involved vehicles, types of road users etc.
- Information about the countermeasure: related safety deficiency, corresponding countermeasure as well as categories, lifespan, acceptance and cost of the countermeasure.

The complete CMF inventory data can be found in Yannis et al. (2015b). The inventory has been developed after further elaboration of the aforementioned list of 1,577 CMFs, which included homogenisation of similar answers, removal of a few not statistically significant cases as well as a few base-case scenarios with CMFs equal to 1. A total of 1,526 CMFs (Factors and Functions) are included in the CMF inventory. Some points of interest deriving from the CMF review results are as follows:

The range of available CMF values lies from 0.016 to 1.000 for safety gains due to safety improvements and from 1.000 to 3.144 for CMFs indicating an increase in accident rates. Regarding the study design, the most commonly used methods for CMF development are multivariate cross-sectional regression models followed by Empirical Bayes studies and Before-After studies with comparison groups. These methods generally enable statistical significance estimations. For naive before-after comparisons as well as simple cross-sectional comparisons, the tests for significance are often missing. Regarding sample sizes, the number of sites ranges from a single site up to 30,577 sites for large cross-sectional studies; the overall range of involved years of accident data ranges from 1 to 18 years, starting from 1978 up to 2013. The range of involved accidents in the studies starts with 5 accidents on a limited number of samples combined with very limited accident conditions (special chosen accident types and accident severity levels) and ceases with 45,901 accidents for large scale safety analysis in road networks with no limitations on accidents selection. The range of considered road network length is also widespread, from 16Km to 29,500Km). Finally, annual average daily traffic ranges from 50 vehicles per direction and day for two-lane two-way rural road segments up to more than 100,000 vehicles per direction and day for heavily trafficked freeways.

4. Inventory of existing APMs

The APM inventory was developed following a similar approach to the CMF inventory. The same six roadway element categories were assumed and the reviewed APMs were grouped into two major categories:

- 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).
- SPF and CMF APMs (such as the Highway Safety Manual 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.

During the APM inventory review, a total of 146 different Accident Prediction Models were examined (APMs for speed change lanes and ramp segments not included); 85 Regression Equation models and 61 SPF & CMF models. These models were compiled in the APM inventory as 273 entries (several models have been 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 complete APM inventory data can be found in Yannis et al. (2015b).

5. Development of the APMs & CMFs Repository

The basic core of the repository is an online searchable database with the most important Accident Prediction Models (APMs) and Crash Modification Factors (CMFs), compiled on the basis of the aforementioned APM and CMF inventories respectively. In the following paragraphs, important information on the APM and CMF repository are presented, regarding both the structure and operation of the web repository and the databases underneath the website. Specifically, in section 5.1 the applied quality criteria for CMF data inclusion are presented, and in section 5.2 the structure and main features of the online repository are analysed, along with the search capabilities of the databases and the presentation of results. The repository can be found in http://www.pract-repository.eu/.

5.1. Criteria for CMF data inclusion

The purpose of the repository is to provide NRAs and road safety practitioners with the ability to select amongst a set of high quality CMFs the ones that are most suitable for application in a specific case. It is therefore considered very important that all CMFs (factors or functions) included in the repository are of high quality and meet certain minimum quality criteria, as far as (a) statistical design, (b) testing for statistical significance, and (c) sample size are concerned.

It is generally accepted that CMFs included in the Highway Safety Manual - Part C, have been thoroughly examined through a systematic review procedure regarding their reliability and quality. It was therefore decided that CMFs originating from the Highway Safety Manual will be 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.

5.1.1 Statistical design

An important criterion for the quality of a CMF is the statistical design of the analysis. 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 modelling. 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 modelling: 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.

5.1.2 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.

5.1.3 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 over all 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.

5.2. Main features of the repository

The online repository (http://www.pract-repository.eu/) comprises of 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 most important parts of the website are obviously the "SEARCH FOR APMs" and "SEARCH FOR CMFs" sections that provide access to the respective searchable databases. The APM search page allows the user to search the database for APMs by providing any of the following characteristics:

- 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.

If one or more of the above search criteria are left blank (or the blank field is selected at the drop-down list), the criterion is ignored. Thus, a search with all fields blank will return all the 273 entries of the APM database.

Execution of the search provides the user with a results page (see Fig. 1) 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 (Fig.2).

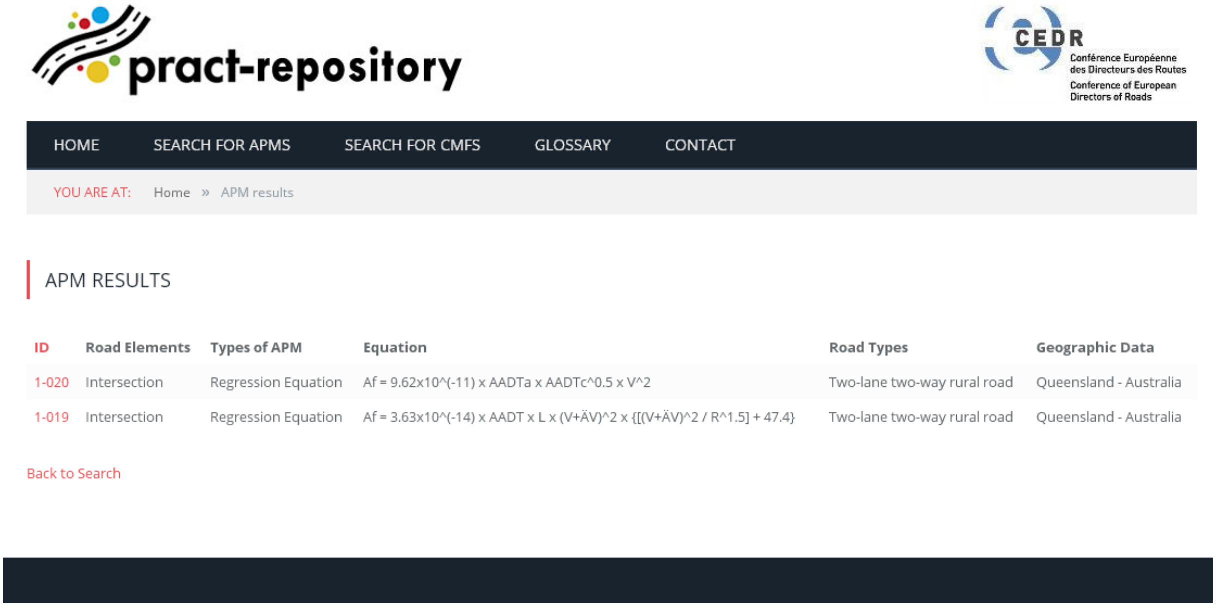

Fig. 1. Indicative results of a search for APMs in the repository, with the following criteria: Road Element = "Intersection" & Geographic Data Origin = "Australia".

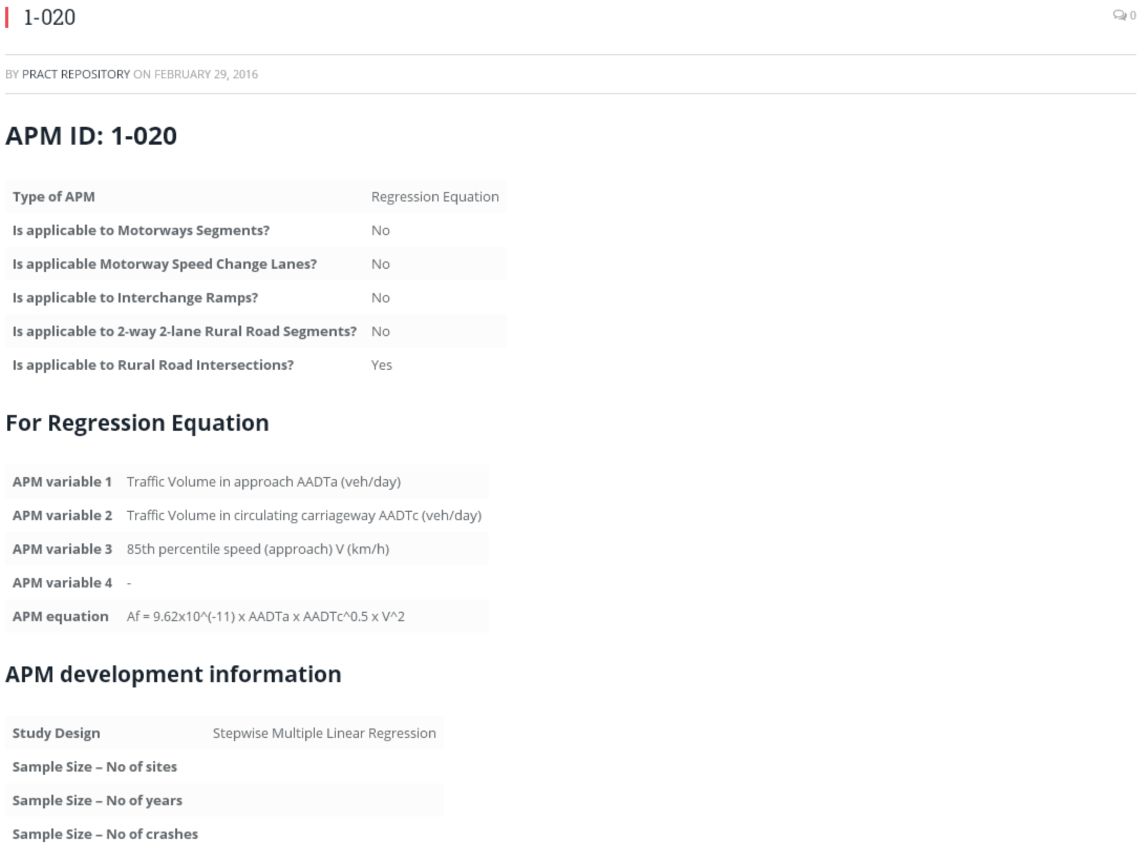

Fig. 2. Part of the detailed results page for APM with ID number 1-020.

The "SEARCH FOR CMFs" function operates in a similar way to the aforementioned APM search, and it provides access to the searchable CMF database. The search page allows the user to search for CMFs by providing any of the following characteristics:

- 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.

If one or more of the above search criteria are left blank (or the blank field is selected at the drop-down list), the criterion is ignored. Thus, a search with all fields blank will return all the 889 entries of the CMF database. Execution of the search provides the user with a results page (see Fig. 3) 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 Crash Modification Factor or Function, in a similar way to the APM search function.

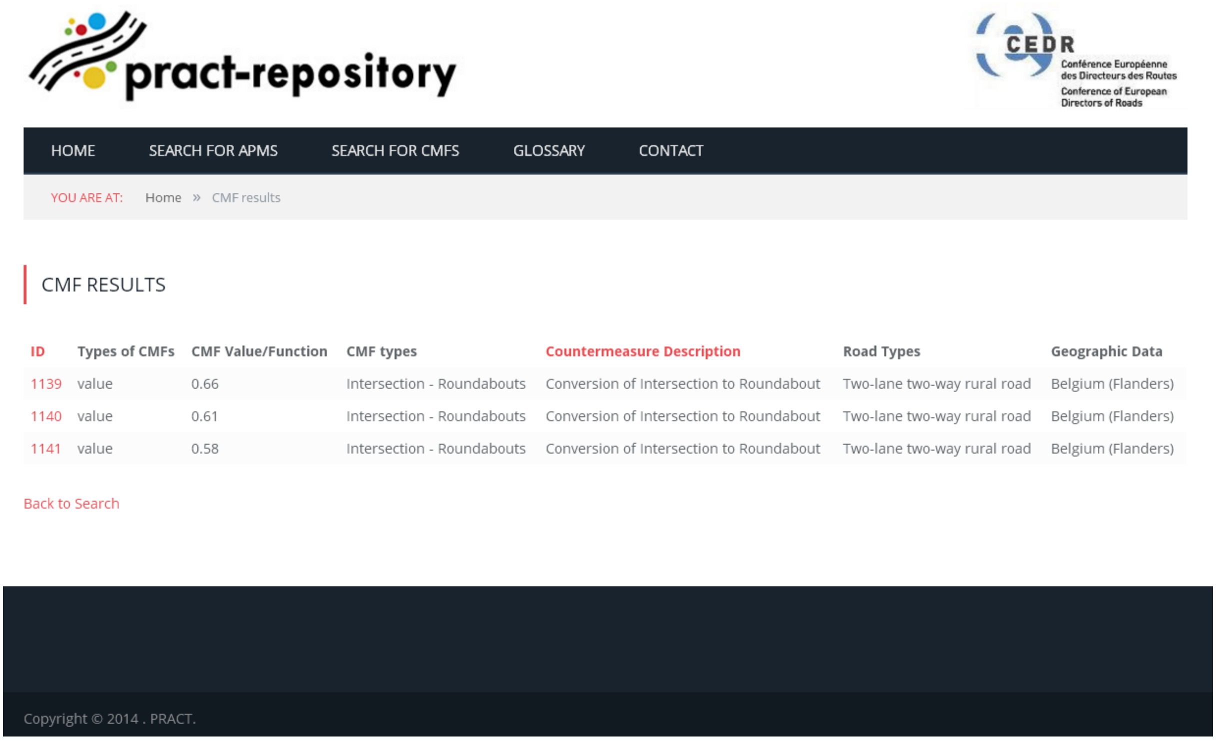

Fig. 3. Indicative results of a search for CMFs in the repository, with the following criteria: "Roundabouts" in Countermeasure Description & Geographic Data Origin = "Europe".

6. Conclusions

The paper presented the development of a comprehensive online repository of Accident Prediction Models (APMs) and Crash Modification Factors (CMFs) that provides valuable assistance to national road authorities and road safety practitioners in identifying suitable the models and data that are most relevant and suitable for specific road safety problems.

The repository was based on an extensive review of pertinent international literature, focusing on high quality studies, and 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. Furthermore, as far as CMFs are concerned, a set of inclusion criteria were applied to ensure that specific minimum quality standards are fulfilled.

The literature review, as well as the repository content itself, indicate 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.

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