CycleRAP Research and Validation

Deliverable 1: Inception report and preliminary review

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iRAP
INTERNATIONAL ROAD ASSESSMENT PROGRAMME

ABOUT IRAP

Introduction

The International Road Assessment Programme (iRAP) is a registered charity dedicated to saving lives by eliminating high risk roads throughout the world. Like many life-saving charities working in the public health arena, we use a robust, evidence-based approach to prevent unnecessary deaths and suffering.

iRAP works in partnership with governments, road authorities, mobility clubs, development banks, NGOs and research organisations to:

- inspect high-risk roads and develop Star Ratings, Risk Maps and Safer Roads Investment Plans
- provide training, technology and support that will build and sustain national, regional and local capability
- track road safety performance so that funding agencies can assess the benefits of their investments.

The programme is the umbrella organisation for EuroRAP, AusRAP, ChinaRAP, KiwiRAP, usRAP, IndiaRAP, BrazilRAP and SARAP. Road Assessment Programmes (RAP) are now active in more than 90 countries throughout Europe, Asia Pacific, North, Central and South America and Africa.

iRAP is financially supported by the FIA Foundation for the Automobile and Society. Projects receive support from the Global Road Safety Facility, mobility clubs, regional development banks and donors. Our partners, charities, the motor industry and institutions such as the European Commission also support RAPs in the developed world and encourage the transfer of research and technology to iRAP. In addition, many individuals donate their time and expertise to support iRAP.

For more information

For general enquiries, contact us at:
International Road Assessment Programme (iRAP)
Worting House, Basingstoke
Hampshire, UK, RG23 8PX
Telephone: +44 (0) 1256 345598
Email: icanhelp@irap.org

To find out more about the programme, visit www.irap.org.
You can also subscribe to 'WrapUp', the iRAP e-newsletter, by signing up on the website homepage.

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1 INTRODUCTION

ANWB and the International Road Assessment Programme (iRAP) have developed a first-generation model dedicated to assessing bicycling risk, "CycleRAP version 1.3" (hereon referred to as the "CycleRAP model").[1]

A number of pilot assessments using the CycleRAP model have been completed or are underway in the Netherlands. iRAP, via its subsidiary company, Road Assessment Services Ltd (RASL), is assisting in the quality review of these pilot projects.

In late 2018, ANWB engaged RASL to conduct further research to strengthen the evidence base that underpins CycleRAP attributes. Specifically, this includes a comprehensive review of available literature, research and data, including that from the CycleRAP pilot projects. This project further aims to establish if there is a relationship between CycleRAP crash types and attributes, risk scores (from pilot results) and, where possible, actual crash rates.

Provision of these services is being led by Monica Olyslagers (Project Manager) and James Bradford (Global Products Director). RASL will engage consultants to undertake key components of the project.

1.1 Project background

In 2014, SWOV published a number of studies on the development of quantitative method for assessing bicycling safety.[2] In 2015, ANWB formed a cooperation agreement with the City of Amsterdam and SWOV to develop a Network Safety Index (NSI) to map the road safety situation, with particular focus in urban areas, with the goal of helping municipalities to increase proactive measures to promote road safety. A second goal of the collaboration was the development of the CycleRAP instrument as part of the iRAP/EuroRAP methodology.

[1] The development of enhanced bicycle star ratings (referred to as "Cyclerap") is subject to the *iRAP Innovation Framework*
Memorandum of Understanding (MOU) between the International Road Assessment Programme (iRAP) and ANWB.

[2] Wijlhuizen, G.J. & Aarts, L. (2014). *Monitoring fietsveiligheid. Safety Performance Indicators (SPIs) en een eerste opzet voor een gestructureerd decentraal meetnet (Monitoring bicycle safety. Safety Performance Indicators (SPIs) and a first set-up for a structured decentralized monitoring network). H-2014-1*. SWOV, Den Haag.
Wijlhuizen, G.J., Dijkstra, A. & Petegem , J.W.M. van (2014). *Safe Cycling Network: Ontwikkeling van een systeem ter beoordeling van de veiligheid van fietsinfrastructuur (Safe Cycling Network: Development of a system for assessing the safety of cycling infrastructure). R-2014-14*. SWOV, Den Haag.
Wijlhuizen, G.J. & Schermers, G. (2014). *Safety Performance Indicators voor wegen; Op zoek naar een kwantitatieve beoordelingsmethode van verkeersveiligheid (Safety Performance Indicators for roads; Looking for a quantitative road safety assessment method). R-2014-39*. SWOV, Den Haag.
Dijkstra, A., Wijlhuizen G.J. & Aarts L. (2015). *Monitoring van de veiligheidskwaliteit van weginfrastructuur en fietsinfrastructuur: Proefmetingen in een aantal regio's (Monitoring the safety quality of road infrastructure and cycling infrastructure: Trial measurements in a number of regions. R-2015-5.* SWOV, Den Haag.

In 2015-16, iRAP's Global Products Director, James Bradford, developed the CycleRAP model with input from ANWB and SWOV. In 2016-17, with the support of ANWB, the CycleRAP model v1.0 (consisting of 32 attributes coded at 25m intervals) was first piloted on approximately 170km of roads/bike paths in three provinces in the Netherlands, for which iRAP provided quality assurance support and training on the model.

In 2018, a second phase of pilots using CycleRAP v1.3 (63 attributes at 25m intervals) commenced in Waterschap Rivierenland (188km), Province Flevoland (40km) and Gorredijk – Beetsterzwaag – Drachten (13km). iRAP has again provided quality-assurance support. This phase requires the calculation and reporting of safety index scores, to be completed by iRAP.

1.2 Project objectives

This Research and Validation project aims to:

- Strengthen the evidence-base that underpins CycleRAP attributes. Specifically, this would be a comprehensive review of available literature, research and data, including that from the CycleRAP pilot projects; and
- To establish if there is a relationship between CycleRAP crash types and attributes, risk scores (from pilot results) and, where possible, actual crash rates.

1.3 Project activities and deliverables

This Research and Validation project includes the following five elements:

i. A literature study of bicycle infrastructure and risk factors to identify evidence supporting CycleRAP crash types, attributes and their risk factors; and identify areas for further research to establish or strengthen the evidence base for CycleRAP attributes. The literature review should cover the available Dutch research as well as international research as can be reasonably sourced from iRAP Centres of Excellence and other partners.

ii. A review and analysis of CycleRAP pilot study results, including (where possible) validation to ensure results accurately reflect risk.

iii. An investigation of possible sources for, and quality of, bicycling crash data available in the Netherlands, in particular, and if comparable data is available for locations of CycleRAP pilot studies.

iv. Based on the above, a revision of the existing CycleRAP methodology factsheet and provision of recommendations for further research and the future development of the CycleRAP model. Presentation of the study outcomes to the iRAP Global Technical Committee (GTC).

v. If practicable*, a survey aimed at collecting data on the role of bicycle lane and path conditions on single bicycle, bicycle to bicycle and vehicle to bicycle crashes. This survey should target participants from a number of international locations where there are extensive bicycling networks. *As determined by cost and likelihood of contributing value to the project.

1.3.1 Deliverables

Deliverables will be delivered (in English) as per the following schedule:

Deliverables	*Estimated completion date*
Review of Dutch literature	31 January 2019
Analysis report of CycleRAP pilot project results	28 February 2019

Survey results*	31 March 2019
Review of international literature	30 April 2019
Revised CycleRAP factsheet	30 April 2019
Recommendations report	31 May 2019

**Subject to available budget*

1.3.2 Inception meeting

On 24 January, 2019, Monica Olyslagers (Project Manager) and Roxy Tacq (ANWB) had a teleconference meeting to discuss the details on the delivery of the project.

At this meeting, it was agreed that:

By end January:

- Initial review of Dutch literature provided by ANWB will be completed.
- The review of the CycleRAP v1.3 and associated documentation will be complete and a summary report provided to ANWB. This will be used to guide the international literature review.
- Potential international research partners will be identified.
- A contract will be signed to engage SWOV (to conduct further review of Dutch literature and to provide an overall review and quality assurance of international literature.)

By end February:

- Analysis of all results from CycleRAP pilot studies will be completed and include a summary of attributes recorded, their frequency etc.
- An initial review of potential crash data sources and their quality will be completed. (Monica to further consult with Hendrick (Friesland) and Govert (SWOV) on potential crash data sources. If available, crash data will be included in the analysis of pilot study results subject to available budget.)

By end April:

- International literature reviews completed in early March and sent to SWOV for review.
- SWOV will have completed the review of international research and have provided recommendations.
- The CycleRAP factsheet will be reviewed and amended accordingly.

By end May:

- A recommendations report will bring together the above outcomes and advise on next steps in preparation for presentation to the GTC meeting in June.

Roxy Tacq also requested iRAP follow up a potential pilot study in Sweden, as well as the potential value (if any) of a survey on bicycling crashes and provide an update in the week of 29 January 2019.

2 LITERATURE REVIEW

2.1.1 Summary and progress report

The aim of the literature review is to identify evidence supporting CycleRAP crash types, attributes and their risk factors. It also aims to identify areas for further research to establish or strengthen the evidence base for CycleRAP attributes. The literature review should cover the available international research as can be reasonably sourced from published material, iRAP Centres of Excellence and other partners.

The literature review involves three main components:

i. An initial review of literature provided by ANWB.

The existing research provided by ANWB has been summarised in section 2.1.2 below. It has been provided to SWOV to be taken into account during its detailed review of available literature.

ii. Engaging research consultants to review international literature.

Three to five research consultants will be engaged in the early weeks of February 2019 to review available international literature. The terms of reference and information sheet have been drafted to guide this research. SWOV has been engaged as one of the research consultants. Additional researchers may be sought to access research available in other languages.

iii. Collation and peer reviewing international literature.

SWOV has been engaged to collate and provide quality assurance for up to five literature reviews by the international consultants. SWOV will provide an overall written summary of the available research reviewed describing the scope of the research reviewed. The summary will be based on the information sheets and per theme/primary topic will provide the primary impact or at least the direction of the impact over all the studies (if more than one per theme). Themes or topics that do not provide sufficient evidence will be listed and recommendations developed regarding potential future research.

2.1.2 Existing research used in the CycleRAP model

In 2017, ANWB commissioned a review of existing literature to inform the development of risk factors in the current CycleRAP model. In total, 36 publications related to CycleRAP attributes were documented. Only 20 of the 50 attributes (40% – excluding location and observed flow attributes) presently have related research available. Table 1 below shows which attributes, grouped by category, have contributing research and which do not.

Some attributes have a large amount of related research in a variety of locations thus strengthening the reliability of the risk factors. For example, ‘bicycle facility type’, ‘bicycle peak hour flow’ and ‘operating speed 85th percentile’ all have ten or more related publications. However many others only have one or two limited studies and 60% have none at all.

A number of the research publications relate to multiple attributes, some up to ten or more. All publications, and which attributes they relate to are shown in Appendix A (Table 2). Abstracts for each publication are also included in Appendix A.

Table 1: Attributes for which related research has been found and those without

Attribute category	Attributes with research	Number of related studies	Attributes without research
Location attributes	• Area Type	1 study	Remaining location attributes do not require research as they are not variables in the model.
Observed flow and speed attributes	• Speed Limit • Speed Management	2 studies 3 studies	Remaining observed flow attributes do not require research as they are not variables in the model.
Bicycle and pedestrian attributes	• Bicycle facility type • Bicycle crossing • Pedestrian crossing – inspected road	10 studies 3 studies 5 studies	• Bicycle facility user mix • Bicycle crossing quality
Surface attributes	• Bicycle facility surface / grip • Road number of lanes	2 studies 1 study	• Bicycle facility width • Bicycle facility width restriction • Bicycle facility centre line • Road surface / grip • Road lane width • Road condition • Road delineation • Road shoulder rumble strips
Side attributes	• Land use – left/right	1 study	• Bicycle facility edge delineation – left/right • Bicycle facility edge transition – left/right • Side surface quality – left/right • Side object – left/right • Side distance – left/right • Paved shoulder – left/right
Mid-block attributes	• Bicycle facility one way / two way	6 studies	• Curvature • Curve quality • Grade • Obstacle in path • Obstacle in path quality • Tram rails • Sight distance • Street lighting
Intersection attributes	• Intersection type • Intersecting road volume • Intersection prioritisation • Property access	3 studies 1 study 1 study 1 study	• Intersection quality • Intersection channelization • Property access quality

Attribute category	Attributes with research	Number of related studies	Attributes without research
Post-coding attributes	• Bicycle peak hour flow • Pedestrian peak hour flow across • Pedestrian peak hour flow along – left • Pedestrian peak hour flow along – right • Vehicle AADT • Operating Speed (85th percentile) (motorized vehicles) • Operating Speed – bicycles	13 studies 7 studies 7 studies 7 studies 1 study 15 studies 3 studies	• Light power two wheel flow (mopeds & light mopeds) • Motorcycle % • Heavy good vehicle %

2.1.3 Considerations for literature review and other activities under this project

Based on this summarisation of existing literature, it is recommended this project concentrate on the following:

- Finding literature or other available research and evidence for those attributes and attribute categories that currently have no or only few relevant publications documented here;
- Finding literature or other available evidence on bicycling crash types, including likelihood and severity measures. Particular focus should be given to single bicycle, bicycle-bicycle, bicycle-light vehicle*, and bicycle-pedestrian crashes, due to the current lack of research for these crash types. (*Light vehicles includes other small vehicles which share the bicycling facility, for example, electric bicycles, motorcycles, mopeds, motorised three-wheelers, scooters etc).
- Identifying other bicycling infrastructure risk-related research which may be of relevance, even if it does not directly correspond with an existing attribute; and
- Identifying where there are gaps in research for future consideration.

2.2 CycleRAP v1.3 preliminary review

In late 2018, the existing CycleRAP model v.1.3 and related documents were reviewed. This included:

- CycleRAP Factsheet, Version June 2018 (prepared by ANWB)
- CycleRAP Model Generation v1.3 (prepared by James Bradford)
- CycleRAP Coding Manual, February 2017 (prepared by James Bradford)
- CycleRAP pilot study assessment results analysis (prepared by Greg Smith)

As a result of this review, a number of considerations are recommended as part of this project as follows:

1. How to make the model more user-friendly, efficient and less resource-intensive.

CycleRAP needs to be as practical and affordable as possible to use. Reducing the number of attributes will reduce the labour intensive exercise of coding. Currently there are 55 CycleRAP attributes, plus 14 location attributes that should be collected for each 25m coding segment. To reduce the assessment burden, CycleRAP attributes could be consolidated and simplified as much as possible. There are a number of cases where there is unnecessary duplication (such as tram rails being separate from bicycle facility surface quality) or where, based on current assessment data, attributes appear of limited value.

2. To ensure the model is evidence-based, accessible and universally-applicable.

The literature review exercise as part of this project aims to improve the evidence which underpins the risk factors of the CycleRAP attributes. However, the CycleRAP crash types may also make the model very complex and difficult to garner the evidence necessary to support these specific crash types. Currently there are nine CycleRAP crash types. They are single bicycle (run-off, loss-of-balance, object in path), bicycle-bicycle (intersection, head-on, side swipe), 1 bicycle-pedestrian (along), and 2 vehicle-bicycle (along, intersection). There is a need for better understanding of likelihood and severity differences between crash types. Once this is known, consideration could be given to reducing the number of crash types by removing sub-types so that there are only (i.e. single bicycle, bicycle-bicycle, bicycle-pedestrian, vehicle-bicycle).

3. How the current CycleRAP model is positioned within current iRAP tools (namely the Bicyclist Core Model) and planned complimentary models (such as a network/'light' model and an intersection model); and

Consideration should be given to if and how the CycleRAP model aligns with the current Bicyclist Model and future risk models ('light' network models, intersection models etc). Opportunities to use common attribute sets across different models would have an advantage, in that it would create a more efficient suite of models that can be integrated and make conducting parallel assessments (for example, intersections and CycleRAP) easier, and have a consistent set of risk factors. However, the impact of differing factors (such as 25m versus 100m coding intervals) must be considered, particularly where the coding intervals affect risk factors.

4. The purpose and scope of application of the current CycleRAP model (i.e. exclusively for assessing risk of bicycling facilities or a general bicyclist 'heavy' model').

iRAP's core bicycle model is able to give a risk assessment for bicycles (where present) across a road network, as well as map bicycling facilities effectively to a 100m level. The purpose of CycleRAP could therefore focus exclusively on bicycling infrastructure risk. This would avoid 'double-up' with the core model but also to keep the purpose of the model focussed and more efficient in its application.

5. The calculation and type of risk scores/index for CycleRAP and how it relates to iRAP Star Ratings.

Producing a separate CycleRAP Star Rating or other risk score could, if not managed carefully, create confusion and potential conflict with the core model. As a result of this project and the pilot projects, recommendations on how to calculate and index to avoid conflict and confusion will be provided.

6. Where evidence is found to strengthen core model attributes and crash types, recommend amending the core model.

The iRAP core bicyclist model requires more evidence to refine and substantiate it. This research is only now becoming available. Recommendations to the Global Technical Committee may include adjustments to the core model's attributes and risk factors where compelling evidence is available, and corresponding additions to existing bicyclist core model factsheets.

3 APPENDICES

A number of the research publications relate to multiple attributes, some up to ten or more. All publications, and which attributes they relate to are shown in Table 2. Abstracts for each publication are also provided below.

Table 2: List of publications and corresponding attributes

		Area type	Speed limit	Speed management	Bicycle facility type	Bicycle crossing	Pedestrian crossing	Bicycle facility surface / grip	Road number of lanes	Land use	Bicycle facility one /two way	Vehicle parking - road side	Intersection type	Intersecting road volume	Intersection prioritization	Property access	Bicycle peak hour flow	Pedestrian peak flow across	Pedestrian peak flow along	Vehicle AADT	Operating Speed (85th %ile)	Operating Speed - bicycles
1	Study Title: Assessing Critical Factors Associated with Bicycle Collisions at Urban Signalized Intersections Authors: Oh et al. Publication Date: JAN, 2008	X		X		X	X		X	X			X	X		X	X			X		
2	Study Title: Handbook of Road Safety Measures Authors: Elvik, R. and Vaa, T. Publication Date: 2004		X	X		X	X						X				X	X	X			
3	Study Title: Evaluating the Safety Effects of Bicycle Lanes in New York City Authors: Chen et al. Publication Date: JUN, 2012		X		X						X						X					
4	Study Title: Speed and Road Accidents An Evaluation of the Power Model Authors: Elvik et al. Publication Date: 2004			X																		
5	Study Title: Cyclist Safety on Bicycle Boulevards and Parallel Arterial Routes in Berkeley, California Authors: Minikel, E. Publication Date: JAN, 2011				X						X						X					
6	Study Title: Bicycle Tracks and Lanes: a Before-After Study Authors: Jensen Publication Date: JAN, 2008				X							X					X					
7	Study Title: Puffin Pedestrian Crossing Accident Study Authors: Maxwell et al.																	X	X			

		Area type	Speed limit	Speed management	Bicycle facility type	Bicycle crossing	Pedestrian crossing	Bicycle facility surface / grip	Road number of lanes	Land use	Bicycle facility one /two way	Vehicle parking - road side	Intersection type	Intersecting road volume	Intersection prioritization	Property access	Bicycle peak hour flow	Pedestrian peak flow across	Pedestrian peak flow along	Vehicle AADT	Operating Speed (85th %ile)	Operating Speed - bicycles
	Publication Date: 2011																					
8	Study Title: Road Factors and Bicycle-Motor Vehicle Crashes at Unsignalized Priority Intersections Authors: Schepers et al. Publication Date: MAY, 2011				X	X					X		X		X		X					X
9	Study Title: WRRSP: Wyoming Rural Road Safety Program Authors: Ksaibati et al. Publication Date: MAY, 2009							X													X	
10	Study Title: Validation and Application of Highway Safety Manual (Part D) in Florida Authors: Abdel-Aty et al. Publication Date: MAY, 2014				X						X						X					
11	Study Title: The Effect of Cycle Lanes on Cycling Numbers and Safety Authors: Koorey and Parsons Publication Date: 2016				X												X					X
12	Study Title: Cycle-tracks, bicycle lanes & on-street cycling in Montreal: a preliminary comparison of the cyclist injury risk Authors: Nosal and Miranda-Moreno Publication Date: JAN, 2012				X						X						X					X
13	Study Title: Separated Bike Lane Crash Analysis Authors: Rothenberg et al. Publication Date: 2016				X												X					
14	Study Title: Safety Performance Functions for Bicycle Crashes in New Zealand and Australia Authors: Turner et al. Publication Date: JAN, 2011				X						X						X					
15	Study Title: Signalized Intersections: Informational Guide Authors: Rodegerdts et al. Publication Date: 2004				X												X					
16	Study Title: The Relative Effectiveness of Pedestrian Safety Countermeasures at Urban Intersections - Lessons from a New York City Experience Authors: Li Chen, Cynthia Chen, and Reid Ewing Publication Date: JAN, 2012						X											X	X			
17	Study Title: Developing Crash Modification Functions for Pedestrian Signal Improvement Authors: Sacchi et al. Publication Date: JUL, 2015						X											X	X			
18	Study Title: Safety Effects of Marked Versus Unmarked Crosswalks at						X											X	X			

		Area type	Speed limit	Speed management	Bicycle facility type	Bicycle crossing	Pedestrian crossing	Bicycle facility surface / grip	Road number of lanes	Land use	Bicycle facility one /two way	Vehicle parking - road side	Intersection type	Intersecting road volume	Intersection prioritization	Property access	Bicycle peak hour flow	Pedestrian peak flow across	Pedestrian peak flow along	Vehicle AADT	Operating Speed (85th %ile)	Operating Speed - bicycles
	Uncontrolled Locations: Executive Summary and Recommended Guidelines Authors: Zegeer et al. Publication Date: 2002																					
19	Study Title: Estimation of the Safety Effect of Pavement Condition on Rural Two-Lane Highways Authors: Zeng et al. Publication Date: JAN, 2014							X														
20	Study Title: Injury crashes with bicyclists at roundabouts: influence of some location characteristics and the design of cycle facilities Authors: Daniels et al. Publication Date: APR, 2009																X					
21	Study Title: Safety Effectiveness of the HAWK Pedestrian Crossing Treatment Authors: Fitzpatrick, K., and Park, E.S. Publication Date: JUL, 2010																	X	X			
22	Study Title: Pedestrian and Bicyclist Safety Effects of the California Safe Routes to School Program Authors: Guiterrez et al. Publication Date: JAN, 2008																	X	X			
23	Study Title: Safety Performance Functions for Low-Volume Roads Authors: Acqua and Russo Publication Date: NOV, 2010																				X	
24	Study Title: Safety Analysis of Driveway Characteristics along Major Urban Arterial Corridors in South Carolina Authors: Stokes et al. Publication Date: 2016																				X	
25	Study Title: A fully Bayesian multivariate approach to before-after safety evaluation Authors: Park et al. (2010) Publication Date: JUL, 2010																				X	
26	Study Title: Safety Effect of Arterial Signal Coordination Authors: Wei and Tarko Publication Date: JAN, 2011																				X	
27	Study Title: Safety Evaluation of Truck-Related Crashes at Freeway Diverge Areas Authors: Zhenyu Wang, Bin Cao, Weiping Deng, Jian John Lu, and Zhao Zhang Publication Date: JAN, 2011																				X	
28	Study Title: Applying Bayesian Hierarchical Models to Examine Motorcycle Crashes at Signalized Intersections																				X	

		Area type	Speed limit	Speed management	Bicycle facility type	Bicycle crossing	Pedestrian crossing	Bicycle facility surface / grip	Road number of lanes	Land use	Bicycle facility one /two way	Vehicle parking - road side	Intersection type	Intersecting road volume	Intersection prioritization	Property access	Bicycle peak hour flow	Pedestrian peak flow across	Pedestrian peak flow along	Vehicle AADT	Operating Speed (85th %ile)	Operating Speed - bicycles
	Authors: Haque et al. Publication Date: JAN, 2010																					
29	Study Title: Evaluation of the Impacts of Differential Speed Limits on Interstate Highways in Idaho Authors: Dixon et al. Publication Date: OCT, 2012																				X	
30	Study Title: Evaluation of Variable Speed Limits on I-270/I-255 in St. Louis Authors: Bham et al. Publication Date: OCT, 2010																				X	
31	Study Title: To brake or to accelerate? Safety effects of combined speed and red light cameras Authors: De Pauw et al. Publication Date: APR, 2014																				X	
32	Study Title: Safety effects of fixed speed cameras - An empirical Bayes evaluation Authors: Hoye Publication Date: SEP, 2015																				X	
33	Study Title: Effectiveness of speed enforcement through fixed speed cameras: a time series study Authors: Novoa et al. Publication Date: JUN, 2009																				X	
34	Study Title: A Study of the Safety Impact of Speed Limit Reduction on Abu Dhabi Freeways Authors: Abdelany et al. Publication Date: 2014																				X	
35	Study Title: Making minor rural road networks safer: The effects of 60 km/h-zones Authors: Jaarsma et al. Publication Date: JUL, 2011																				X	
36	Study Title: Full Bayesian evaluation of the safety effects of reducing the posted speed limit in urban residential areas Authors: Islam and El-Basyouny Publication Date: JUL, 2015																				X	

3.1 Abstracts

1. **Study Title: Assessing Critical Factors Associated with Bicycle Collisions at Urban Signalized Intersections**
   Authors: Oh et al.
   Publication Date: JAN, 2008
   Abstract: Understanding which factors strongly influence bicycle collisions at urban signalized intersections is an important process in improving the safety of bicyclists and in guiding the safe design of urban signalized intersections. This study recognizes this and has accordingly developed prediction models, using numerous potential variables, concerning bicycle crash occurrences at signalized intersections by conducting field surveys at 151 intersections at the Incheon Metropolitan Area in Korea. This study made a careful application and assessment of relevant statistical models for bicycle-related crashes. Consequently, it was revealed that the Poisson regression model would be suitable for estimating the probability of bicycle crashes at intersections. Based on the analysis of the parameters estimated in both primary and alternative models, significant explanatory factors (and their direction of association) were selected as follows: average daily traffic volume (+), presence of bus stops (-), sidewalk widths (-), number of driveways (+), presence of speed restrict devices (-), presence of crosswalks (+), and industrial land use (+). With respect to the suggestions made for future bicycle safety research, there is a need to include additional factors of the characteristics of the driver, geometric road design, and operational features for data in the analysis. Educational approaches or improvement of roadway designs should also be performed in order to encourage people to use bicycles as an alternative and safe mode of travel. Furthermore, the authors of this study believe that the levels of safety of bicycle travel at existing or future intersections may be estimated through the use of bicycle crash prediction models. Finally, the study suggests that efficient countermeasures may be implemented in order to decrease crash rates and reduce socio-economic loss.
   Study Citation: J., J. Jun, E. Kim, and M. Kim "Assessing Critical Factors Associated with Bicycle Collisions at Urban Signalized Intersections." TRB 87th Annual Meeting Compendium of Papers CD-ROM. Washington, D.C., (2008). http://www.cmfclearinghouse.org/study_detail.cfm?stid=126

2. **Study Title: Handbook of Road Safety Measures**
   Authors: Elvik, R. and Vaa, T.
   Publication Date: 2004
   Abstract: The second edition of the “Handbook of Road Safety Measures” (previously published in 2004) gives state-of-the-art summaries of current knowledge regarding the effects of 128 road safety measures. It covers all areas of road safety including: traffic control; vehicle inspection; driver training; publicity campaigns; police enforcement; and, general policy instruments.
   Study Citation: Elvik, R. and Vaa, T., "Handbook of Road Safety Measures." Oxford, United Kingdom, Elsevier, (2004) http://www.cmfclearinghouse.org/study_detail.cfm?stid=14

3. **Study Title: Evaluating the Safety Effects of Bicycle Lanes in New York City**
   Authors: Chen et al.
   Publication Date: JUN, 2012
   Abstract: Objectives: We evaluated the effects of on-street bicycle lanes installed prior to 2007 on different categories of crashes (total crashes, bicyclist crashes, pedestrian crashes, multiple-vehicle crashes, and injurious or fatal crashes) occurring on roadway segments and at intersections in New York City. Methods: We used generalized estimating equation methodology to compare changes in police-reported crashes in a treatment group and a comparison group before and after installation of bicycle lanes. Our study approach allowed us to control confounding factors, such as built environment characteristics, that cannot typically be controlled when a comparison group is used. Results: Installation of bicycle lanes did not lead to an increase in crashes, despite the probable increase in the number of

bicyclists. The most likely explanations for the lack of increase in crashes are reduced vehicular speeds and fewer conflicts between vehicles and bicyclists after installation of these lanes. Conclusions: Our results indicate that characteristics of the built environment have a direct impact on crashes and that they should thus be controlled in studies evaluating traffic countermeasures such as bicycle lanes. To prevent crashes at intersections, we recommend installation of "bike boxes" and markings that indicate the path of bicycle lanes across intersections.
Study Citation: Chen, L., Chen, C., Srinivasan, R., McKnight, C. E., Ewing, R., and Roe, M., "Evaluating the Safety Effects of Bicycle Lanes in New York City," American Journal of Public Health, Vol. 102, No. 6, (2012). http://www.cmfclearinghouse.org/study_detail.cfm?stid=298

4. **Study Title: Speed and Road Accidents An Evaluation of the Power Model**
   Authors: Elvik et al.
   Publication Date: 2004
   Abstract: The relationship between speed and road safety is a controversial topic. In this report, the relationship between speed and road safety has been evaluated by means of a meta-analysis of studies that provide estimates of how changes in speed affect the number of road accidents and the number and severity of injuries to road users.
   Study Citation: Elvik, R., Christensen, P., and Amundsen, A., "Speed and Road Accidents An Evaluation of the Power Model." Oslo, Norway, Transportokonomisk Institutt, (2004) http://www.cmfclearinghouse.org/study_detail.cfm?stid=15

5. **Study Title: Cyclist Safety on Bicycle Boulevards and Parallel Arterial Routes in Berkeley, California**
   Authors: Minikel, E.
   Publication Date: JAN, 2011
   Abstract: This study compares the safety of bicyclists riding on bicycle boulevards to those riding on parallel arterial routes in Berkeley, California. Literature on the impact of motor vehicle traffic characteristics on cyclist safety shows that high motor vehicle speeds and volumes and the presence of heavy vehicles are all detrimental to cyclist safety. This suggests that cyclists may be safer on side streets than on busy arterials. Bicycle boulevards-traffic-calmed side streets signed and improved for cyclist use-purport to offer cyclists a safer alternative to riding on arterials. Police-reported bicycle collision data and manually collected cyclist count data from bicycle boulevards and parallel arterial routes in Berkeley, California since 2003 are used to test the hypothesis that bicycle boulevards have lower cyclist collision rates and a lower proportion of bicycle collisions resulting in severe injury. While no significant difference is found in the proportion of collisions that are severe, results show that collision rates on bicycle boulevards are two to eight times lower than those on parallel, adjacent arterial routes. The difference in collision rate is highly statistically significant, unlikely to be caused by any bias in the collision and count data, and cannot be easily explained away by self-selection or safety in numbers. This is strong evidence that bicycle boulevards, if properly implemented, can provide cyclists with a safer alternative to riding on arterials."
   Study Citation: Minikel, E., "Cyclist Safety on Bicycle Boulevards and Parallel Arterial Routes in Berkeley, California." Presented at the 90th Meeting of the Transportation Research Board, Washington, D.C., (2011). http://www.cmfclearinghouse.org/study_detail.cfm?stid=221"

6. **Study Title: Bicycle Tracks and Lanes: a Before-After Study**
   Authors: Jensen
   Publication Date: JAN, 2008
   Abstract: This paper presents a before-after crash, injury and traffic study of constructing bicycle tracks and marking bicycle lanes in Copenhagen, Denmark. Corrections factors for changes in traffic volumes and crash / injury trends are included using a general comparison group in this non-experimental observational study. Analysis of long-term crash trends points towards no significant abnormal crash counts in the before period. The safety effects of bicycle tracks in urban areas are an increase of about

10 percent in both crashes and injuries. The safety effects of bicycle lanes in urban areas are an increase of 5 percent in crashes and 15 percent in injuries. Bicyclists' safety has worsened on roads, where bicycle facilities have been implemented. Design of bicycle facilities and parking conditions for motor vehicles clearly seems to have safety implications, especially at intersections. The study has revealed a few points in relation to this. Construction of bicycle tracks resulted in a 20 percent increase in bicycle / moped traffic mileage and a decrease of 10 percent in motor vehicle traffic mileage, whereas marking of bicycle lanes resulted in a 5 percent increase in bicycle / moped traffic mileage and a decrease of 1 percent in motor vehicle traffic mileage. The changes in traffic do result in health benefits due to more physical activity, less air pollution and less traffic noise. The positive benefits may well be much higher than the negative consequences caused by new safety problems.
Study Citation: Jensen, S.U. "Bicycle Tracks and Lanes: a Before-After Study." TRB 87th Annual Meeting Compendium of Papers CD-ROM. Washington, D.C., (2008).
http://www.cmfclearinghouse.org/study_detail.cfm?stid=124

7. **Study Title: Puffin Pedestrian Crossing Accident Study**
   Authors: Maxwell et al.
   Publication Date: 2011
   Abstract: Puffin facilities were developed to replace Pelican crossings at mid-block sites and farside pedestrian signals at junctions. Research has shown that compared to existing pedestrian signal facilities, Puffin facilities can reduce both driver and pedestrian delay at junctions, and improve pedestrian comfort (particularly for older pedestrians and those with impaired mobility). Previous research has also indicated safety benefits. The aim of this study was to quantify the safety benefit. Accident data was analysed from 50 sites (40 mid-block crossings and ten junctions) that had been converted to Puffin facilities from Pelican crossings and farside pedestrian signals at junctions. The sites had no other significant changes in layout or operation, and were in general conformance with current DfT Puffin guidance. The results of the on-street inspection are reported. Statistical analysis was undertaken by using a generalised linear model which included time trends and seasonal factors. “Before” and “after” conversion accident data was paired together for each site, negating any biases for particular site factors. Mid-block Puffin crossings were shown to be safer than Pelican crossings with a mean reduction in personal injury accident frequency of 17%, statistically significant at the 5% level. The accident frequency reduction for the combined sample including junctions was 19%, statistically significant at the 5% level.
   Study Citation: Maxwell, A., Kennedy, J., Routledge, I., Knight, P., and Wood, K. “Puffin Pedestrian Crossing Accident Study.” Transport Research Laboratory, Berkshire, United Kingdom, (2011).http://www.cmfclearinghouse.org/study_detail.cfm?stid=239"

8. **Study Title: Road Factors and Bicycle-Motor Vehicle Crashes at Unsignalized Priority Intersections**
   Authors: Schepers et al.
   Publication Date: MAY, 2011
   Abstract: In this study, the safety of cyclists at unsignalized priority intersections within built-up areas is investigated. The study focuses on the link between the characteristics of priority intersection design and bicycle-motor vehicle (BMV) crashes. Across 540 intersections that are involved in the study, the police recorded 339 failure-to-yield crashes with cyclists in four years. These BMV crashes are classifed into two types based on the movements of the involved motorists and cyclists: -type I: through bicycle related collisions where the cyclist has right of way (i.e. bicycle on the priority road); -type II: through motor vehicle related collisions where the motorist has right of way (i.e. motorist on the priority road). The probability of each crash type was related to its relative flows and to independent variables using negative binomial regression. The results show that more type I crashes occur at intersections with two-way bicycle tracks, well marked, and reddish coloured bicycle crossings. Type I crashes are negatively related to the presence of raised bicycle crossings (e.g. on a speed hump) and other speed reducing measures. The accident probability is also decreased at intersections where the cycle track approaches

are deflected between 2 and 5 m away from the main carriageway. No significant relationships are found between type II crashes and road factors such as the presence of a raised median.
Study Citation: J.P. Schepers, J.P., Kroeze, P.A., Sweers, W., and Wust, J.C., "Road Factors and Bicycle-Motor Vehicle Crashes at Unsignalized Priority Intersections." Accident Analysis and Prevention, Vol. 43, Issue 3, Elsevier Ltd., (2011) pp. 853-861.
http://www.cmfclearinghouse.org/study_detail.cfm?stid=259"

9. **Study Title: WRRSP: Wyoming Rural Road Safety Program**
Authors: Ksaibati et al.
Publication Date: MAY, 2009
Abstract: SAFETEA-LU contains language indicating that State Department of Transportations (DOTs) will be required to address safety on local and rural roads. The Wyoming Local Technical Assistant Program (LTAP) coordinated an effort in cooperation with the Wyoming Department of Transportation (WYDOT) as well as Wyoming counties and cities to identify low cost safety improvements on high risk rural roads in Wyoming. In this project, safety techniques and methodologies were developed to identify and then rank high risk locations on these rural roads. This project is unique because of the high percentages of gravel roads at the local level in Wyoming. The evaluation procedure developed is based on historical crash records and field evaluations. Three Wyoming counties were included in the pilot study. The statewide implementation has begun in 2009. This report describes the findings and recommendations of this research study which is not only beneficial to Wyoming but also to those states interested in implementing a High Risk Rural Road (HRRR) Program.
Study Citation: Ksaibati, K., Zhong, C., Evans, B. "WRRSP: Wyoming Rural Road Safety Program." Report No. FHWA-WY-09/06F, Cheyenne, Wy., Wyoming Department of Transportation, (2009).http://www.cmfclearinghouse.org/study_detail.cfm?stid=183"

10. **Study Title: Validation and Application of Highway Safety Manual (Part D) in Florida**
Authors: Abdel-Aty et al.
Publication Date: MAY, 2014
Abstract: The Highway Safety Manual (HSM) Part D provides a comprehensive list of the effects of safety treatments (countermeasures). These effects are quantified by crash modification factors (CMF), which are based on compilation from past studies of the effects of various safety treatments. The HSM Part D provides CMFs for treatments applied to roadway segments (e.g., roadside elements, alignment, signs, rumble strips, etc.), intersections (e.g., control), interchanges, special facilities (e.g., highway-rail crossings), and road networks. Thus, an assessment of the applicability of the HSM in Florida is essential. The objectives of this study are (1) to develop CMFs for various treatments in Florida for the same setting (rural/urban), road type, crash type, and severity level, (2) to evaluate the difference between these Florida-specific CMFs and the CMFs in the HSM, and (3) to recommend whether the CMFs in the HSM can be applied to Florida or new Florida-specific CMFs are needed. Different methods of observational study - before-after (B-A) and cross-sectional (C-S) - were used to calculate CMFs for a total of 17 treatments applied to roadway segments, intersections and special facilities. The CMFs calculated using the before-after with comparison-group (C-G) and empirical Bayesian (EB) methods, only the CMF with lower standard error was selected. The methods of calculating CMFs were determined based on the availability of the data and the methods used in the HSM, if the CMFs were provided in the HSM. It was found that Florida-specific CMFs were generally statistically significant, and safety effects represented by the CMFs were intuitive, similar to the CMFs in the HSM. It was also found that Florida-specific CMFs for the treatments not included in the HSM showed significant positive effects in reducing crash frequencies.
Study Citation: Abdel-Aty, M.A., C. Lee, J. Park, J.Wang, M. Abuzwidah, and S. Al-Arifi. "Validation and Application of Highway Safety Manual (Part D) in Florida." Florida Department of Transportation. Tallahassee, Florida. (May 2014). Related Citations: Park, J., M. Abdel-Aty, J. Lee, and C. Lee. "Developing crash modification functions to assess safety effects of adding bike lanes for urban arterials

with different roadway and socio-economic characteristics". Accident Analysis and Prevention, Vol. 74, (2015) pp. 179-191. http://www.cmfclearinghouse.org/study_detail.cfm?stid=433"

11. ***Study Title: The Effect of Cycle Lanes on Cycling Numbers and Safety***
    Authors: Koorey and Parsons
    Publication Date: 2016
    Abstract: Marked on-road cycle lanes are a relatively inexpensive means of providing for cycling; however, their use has been questioned in terms of both their safety and their effectiveness in attracting more people to take up cycling. While both questions have been previously researched, the findings were rather inconclusive. A recent research project in Christchurch, New Zealand investigated the relative effects on cycle count and crash numbers of installing a series of cycle lanes. Twelve routes installed in Christchurch during the mid-2000s were analyzed, together with some control routes that already had cycle lanes. Cycle count data from a series of route locations and dates were used to establish cycling trends before and after installation. These were also compared against cycle crash numbers along these routes during the same periods. The results generally show no consistent "step" increase in cycling numbers immediately following installation of cycle lanes, with some increasing and decreasing. Changes on cycling growth rates were more positive, although it is clear that other wider trends such as motor traffic growth are having an effect. Taking into account the control routes and relative changes in volumes, the study also found notable reductions in cycle crashes following installation, typically with a 23% average reduction in crash rates. However, this reduction was not statistically significant at the 95% level.

12. **Study Title: Cycle-tracks, bicycle lanes & on-street cycling in Montreal: a preliminary comparison of the cyclist injury risk**
    Authors: Nosal and Miranda-Moreno
    Publication Date: JAN, 2012
    Abstract: This paper estimates the relative cyclist injury risk of bicycle facilities with respect to streets without bicycle provisions, and explores the differences in cyclist injury risk between different types of facilities, namely, cycle-tracks and bicycle lanes. The cyclist injury rates for a set of four cycle tracks (totaling 11.75 km) and four bicycle lanes (totaling 3.76 km) in the City of Montreal are compared to injury rates for corresponding control streets using relative risk ratios. Nine control streets are used. Overall, it was found that most bicycle facilities in the analysis do indeed exhibit lower cyclist injury rates than the corresponding control streets. Furthermore, factors that may affect the injury risk of a particular bicycle facility include whether or not it is bidirectional, visibility, physical separation, presence and location of parking, vehicular traffic, and the direction of vehicular traffic. However, further research is required to determine the exact effect of these factors, and to address several limitations in data.
    Study Citation: Nosal, T. and L.F. Miranda-Moreno. "Cycle-tracks, bicycle lanes & on-street cycling in Montreal: a preliminary comparison of the cyclist injury risk." Presented at the 91st Annual Meeting of the Transportation Research Board, January 22-26, Washington, DC, 2012.
    http://www.cmfclearinghouse.org/study_detail.cfm?stid=274

13. **Study Title: Separated Bike Lane Crash Analysis**
    Authors: Rothenberg et al.
    Publication Date: 2016
    Abstract: This paper highlights the methodology and results of a safety data analysis undertaken as part of the study process for the Federal Highway Administration's (FHWA) Separated Bike Lane Planning and Design Guide. It outlines challenges and recommends a data collection framework that will lead to a better understanding of the full volume and safety picture for separated bike lanes. This study evaluated 18 sites before and after the installation of separated bike lanes. Of the 18 sites, 14 locations had data on both total crashes and bicycle crashes. Eight of these locations saw a decrease in total crashes and five sites saw a decrease in bicycle crashes. This translates to nine of 14 sites demonstrating a decrease in crashes of some sort. Four of the 14 sites saw decreases in both bicycle and total crashes. Similar

trends are seen when considering bicycle exposure at sites with at least four average annual bicycle crashes. Five of the 10 sites saw decreases in average annual bicycle crashes per average hourly bicycle volume. It appears that the introduction of separated bike lanes may result in increased challenges at intersections. All six of the sites where the analysis included consideration of intersection vs. midblock crashes saw an increase in the percentage of crashes that occurred at an intersection. This was true for bicycle crashes as well as those not involving a bicycle. However, these comparisons did not control for changes in bicycle volumes between the before and after periods. There are significant data limitations to this study. In particular, challenges associated with obtaining bicycle volume data (both before and after) make it difficult to understand the true impacts on safety of separated bike lanes. Also, the small number of bicycle crashes occurring at these locations yield analysis results with very large percentage changes (increases or decreases) since a change of one or two crashes can effectively double or triple the crash count for that site. It is critical that this data is collected so that future studies may evaluate the safety of separated bike lanes under different conditions and designs in greater detail. For this reason, a recommended minimum data collection approach is presented in this paper to, over time, improve the quantity and quality of data on separated bike lanes.
Study Citation: Rothenberg, H., D. Goodman, and C. Sundstrom, "Separated Bike Lane Crash Analysis." Presented at the 95th Annual Meeting of the Transportation Research Board, Washington, D.C., (2016). http://www.cmfclearinghouse.org/study_detail.cfm?stid=460"

14. **Study Title: Safety Performance Functions for Bicycle Crashes in New Zealand and Australia**
Authors: Turner et al.
Publication Date: JAN, 2011
Abstract: After decades of decline, recreational and commuter cycling is becoming more popular in many Australasian cities. While this is encouraging from a sustainable transport and public health perspective, a major concern to national, state and local governments is the higher crash risk faced by cyclists compared with drivers or passengers in motor-vehicles, particularly when cycling on roads. It is important that transport professionals understand the level of risk faced by cyclists within various parts of the road network and the measures they can employ to mitigate that risk. This paper presents research findings from three main safety studies undertaken in New Zealand using data from New Zealand cities and Adelaide in Australia. Research has been undertaken using both generalized linear modelling and before-after control-impact methods. Over the various studies, crash, traffic and cycle volumes and layout data has been collected for urban road links, traffic signals and roundabouts. Flow-only models have demonstrated a "safety in numbers" effect; with crash risk per cyclist shown to be lower as cycle volumes increase. By adding other variables to the models, it is been possible to gain a level of understanding of the impact that road section length, motor-vehicle speed, visibility, presence and type of cycle facilities and lane and road width have on various crash types. Before and after analysis has been employed to help understand whether there is any bias in the sites that have received cycle facilities The research findings concerning the effect of cycle facilities in improving safety are mixed. Well designed facilities, including those of adequate width and painted with colour appear to perform the best.
Study Citation: Turner, S. A., Wood, G., Hughes, T., and Singh, R., "Safety Performance Functions for Bicycle Crashes in New Zealand and Australia." Presented at the 90th Annual Meeting of the Transportation Research Board, Paper #11-3156, Washington, D.C., (2011). http://www.cmfclearinghouse.org/study_detail.cfm?stid=230"

15. **Study Title: Signalized Intersections: Informational Guide**
Authors: Rodegerdts et al.
Publication Date: 2004
Abstract: This guide provides a single, comprehensive document with methods for evaluating the safety and operations of signalized intersections and tools to remedy deficiencies. The treatments in this guide range from low-cost measures such as improvements to signal timing and signage, to high-cost measures such as intersection reconstruction or grade separation. Topics covered include fundamental principles of user needs, geometric design, and traffic design and operation; safety and operational

analysis techniques; and a wide variety of treatments to address existing or projected problems, including individual movements and approaches, pedestrian and bicycle treatments, and corridor techniques. It also covers alternative intersection forms that improve intersection performance through the use of indirect left turns and other treatments. Each treatment includes a discussion of safety, operational performance, multimodal issues, and physical and economic factors that the practitioner should consider. Although the guide focuses primarily on high-volume signalized intersections, many treatments are applicable for lower volume intersections as well. The information contained in this guide is based on the latest research available on treatments and best practices in use by jurisdictions across the United States. Additional resources and references are highlighted for the student, practitioner, researcher, or decisionmaker who wishes to learn more about a particular subject.
Study Citation: Rodegerdts, L. A., Nevers, B., and Robinson, B., "Signalized Intersections: Informational Guide." FHWA-HRT-04-091, (2004) http://www.cmfclearinghouse.org/study_detail.cfm?stid=82"

16. **Study Title: The Relative Effectiveness of Pedestrian Safety Countermeasures at Urban Intersections - Lessons from a New York City Experience**
Authors: Li Chen, Cynthia Chen, and Reid Ewing
Publication Date: JAN, 2012
Abstract: Walking has many benefits for pedestrians and the society. Yet, pedestrians are a vulnerable group and safety concerns are a significant barrier in one's decision to walk. Multiple countermeasures have been proposed to promote pedestrian safety, however, their relative effectiveness is unknown and those effective in reducing pedestrian crashes may be at odds with motorist safety. In this study, we seek to evaluate the relative effectiveness of five countermeasures in New York City - increasing the total cycle length, Barnes Dance, split phase timing, signal installation, and high visibility crosswalk - and examine potential trade-offs in their effectiveness in reducing pedestrian crashes and multiple vehicle crashes. We adopted a rigorous two-stage design that first identifies a comparison group, corresponding to each treatment group, and then estimates a negative binomial model with the Generalized Estimating Equation (GEE) method to further control confounding factors and within-subject correlation. Built environment characteristics are also accounted for. Set in a large urban area, this study suggests that the four signal-related countermeasures are more effective in reducing crashes than high visibility crosswalks. The findings indicate that the types of conflicts and balance the time for different groups of road users at the intersections should be considered so that the improvement of the safety of one group does not compromise that of other groups.
Study Citation: Chen, L., C. Chen, and R. Ewing. "The Relative Effectiveness of Pedestrian Safety Countermeasures at Urban Intersections - Lessons from a New York City Experience." Presented at the 91st Annual Meeting of the Transportation Research Board, January 22-26, Washington, DC, 2012. http://www.cmfclearinghouse.org/study_detail.cfm?stid=280"

17. ***Study Title: Developing Crash Modification Functions for Pedestrian Signal Improvement***
Authors: Sacchi et al.
Publication Date: JUL, 2015
Abstract: Pedestrian signals are viable traffic control devices that help pedestrians to cross safely at intersections. Although the literature is extensive when dealing with pedestrian signals design and operations, few studies have focused on the potential safety benefits of installing pedestrian signals at intersections. Most of these studies employed simple before-after (BA) safety evaluation techniques which suffer from methodological and statistical issues. Recent advances in safety evaluation research advocate the use of crash modification functions (CMFunctions) to represent the safety effectiveness of treatments. Unlike crash modification factors (CMFs) that are represented as single values, CMFunctions account for variable treatment location characteristics (heterogeneity). Therefore, the main objective of this study was to quantify the safety impact of installing pedestrian signals at signalized intersections by developing CMFunctions within an observational BA study. The use of observational BA framework to develop the CMFunctions avoids the cross-sectional approach where the functions are derived based on a single time period and no actual treatment intervention. Treatment sites

heterogeneity was incorporated into CMFunctions using fixed-effects and random-effects regression models. In addition to heterogeneity, the paper also advocates the use of CMFunctions with a time variable to acknowledge that the safety treatment (intervention) effects do not occur instantaneously but are spread over future time. This is achieved using non-linear intervention (Koyck) models, developed within a hierarchical full Bayes context. The results demonstrated the importance of considering treatment sites heterogeneity (i.e., different circulating volumes and area type among treated locations) and time trends when developing CMFunctions for pedestrian signal improvement.
Study Citation: Sacchi, Emaunuele, T. Sayed, and A. Osama. "Developing crash modification functions for pedestrian signal improvement". Accident Analysis and Prevention, Vol. 83, (2015) pp. 47-56.http://www.cmfclearinghouse.org/study_detail.cfm?stid=469"

18. **Study Title: Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines**
Authors: Zegeer et al.
Publication Date: 2002
Abstract: Pedestrians are legitimate users of the transportation system, and they should, therefore, be able to use this system safely. Pedestrian needs in crossing streets should be identified, and appropriate solutions should be selected to improve pedestrian safety and access. Deciding where to mark crosswalks is only one consideration in meeting that objective. The purpose of this study was to determine whether marked crosswalks at uncontrolled locations are safer than unmarked crosswalks under various traffic and roadway conditions. Another objective was to provide recommendations on how to provide safer crossings for pedestrians. This study involved an analysis of 5 years of pedestrian crashes at 1,000 marked crosswalks and 1,000 matched unmarked comparison sites. All sites in this study had no traffic signal or stop sign on the approaches. Detailed data were collected on traffic volume, pedestrian exposure, number of lanes, median type, speed limit, and other site variables. Poisson and negative binomial regressive models were used. The study results revealed that on two-lane roads, the presence of a marked crosswalk alone at an uncontrolled location was associated with no difference in pedestrian crash rate, compared to an unmarked crosswalk. Further, on multilane roads with traffic volumes above about 12,000 vehicles per day, having a marked crosswalk alone (without other substantial improvements) was associated with a higher pedestrian crash rate (after controlling for other site factors) compared to an unmarked crosswalk. Raised medians provided significantly lower pedestrian crash rates on multilane roads, compared to roads with no raised median. Older pedestrians had crash rates that were high relative to their crossing exposure. More substantial improvements were recommended to provide for safer pedestrian crossings on certain roads, such as adding traffic signals with pedestrian signals when warranted, providing raised medians, speed-reducing measures, and others.
Study Citation: Zegeer, C. V., Stewart, R., Huang, H., and Lagerwey, P., "Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines." FHWA-RD-01-075, McLean, Va., Federal Highway Administration, (2002)http://www.cmfclearinghouse.org/study_detail.cfm?stid=61

19. **Study Title: Estimation of the Safety Effect of Pavement Condition on Rural Two-Lane Highways**
Authors: Zeng et al.
Publication Date: JAN, 2014
Abstract: The condition of the pavement surface can have an important effect on highway safety. For example, skidding crashes are often related to pavement rutting, polishing, bleeding, and dirty pavements. When transportation agencies develop paving schedules for their roadways, they often make decisions based on asset management condition targets but do not explicitly account for the role of pavement condition in roadway safety. The Virginia Department of Transportation (VDOT) began automated pavement condition data collection using digital images and an automated crack detection methodology in 2007. This development enabled the DOT to track historical pavement condition information, and thus facilitates research regarding pavement condition impacts on safety. Information

on how pavement condition influences safety could be used to inform paving decisions and better set priorities for maintenance. The objective of this study is to quantitatively evaluate the safety effectiveness of good pavement conditions versus deficient pavement conditions on rural two-lane undivided highways in Virginia. Using the Empirical Bayes method, it was found that good pavements are able to reduce fatal and injury (FI) crashes by 26 percent over deficient pavements, but do not have a statistically significant impact on overall crash frequency. Further analysis indicated that the safety benefit of pavement condition improvement on FI crashes does not statistically significantly change as the lane or shoulder width increases. In conclusion, improving pavement condition from deficient to good can offer a significant safety benefit in terms of reducing crash severity.
Study Citation: Zeng, H., M.D.Fontaine.,and B.L.Smith.,Estimation of the Safety Effect of Pavement Condition on Rural Two-Lane Highways.Presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, D.C., (2014). http://www.cmfclearinghouse.org/study_detail.cfm?stid=366

20. ***Study Title: Injury crashes with bicyclists at roundabouts: influence of some location characteristics and the design of cycle facilities***
Authors: Daniels et al.
Publication Date: APR, 2009
Abstract: Problem Previous research indicated that conversions of intersections into roundabouts appear to increase the number of injury crashes with bicyclists. However, it was assumed that the effectiveness of roundabouts could vary according to some differences in design types of cycle, facilities and other geometrical factors. Method Regression analyses on effectiveness-indices resulting from a before-and-after study of injury crashes with bicyclists at 90 roundabouts in Flanders, Belgium. Results Regarding all injury crashes with bicyclists, roundabouts with cycle lanes appear to perform significantly worse compared to three other design types (mixed traffic, separate cycle paths, and grade-separated cycle paths). Nevertheless, an increase of the severest crashes was noticed, regardless of the design type of the cycle facilities. Roundabouts that are replacing signal-controlled intersections seem to have had a worse evolution compared to roundabouts on other types of intersections. Impact on industry The results might affect design guidelines for roundabouts, particularly for the accommodation of bicyclists.
Study Citation: Daniels, S., Brijs, T., Nuyts, E., Wets, G. "Injury crashes with bicyclists at roundabouts: influence of some location characteristics and the design of cycle facilities." Journal of Safety Research. Vol. 40, Issue 2, pp. 141-148. (2009)http://www.cmfclearinghouse.org/study_detail.cfm?stid=199"

21. **Study Title: Safety Effectiveness of the HAWK Pedestrian Crossing Treatment**
Authors: Fitzpatrick, K., and Park, E.S.
Publication Date: JUL, 2010
Abstract: The High intensity Activated crossWalK (HAWK) is a pedestrian-activated beacon located on the roadside and on mast arms over major approaches to an intersection. It was created in Tucson, AZ, and at the time of this study, it was used at more than 60 locations throughout the city. The HAWK head consists of two red lenses over a single yellow lens. It displays a red indication to drivers when activated, which creates a gap for pedestrians to use to cross a major roadway. A before-after study of the safety performance of the HAWK was conducted. The evaluations used an empirical Bayes (EB) method to compare the crash prediction for the after period if the treatment had not been applied to the observed crash frequency for the after period with the treatment installed. To develop the datasets used in this evaluation, crashes were counted if they occurred within the study period, typically 3 years before the HAWK installation and 3 years after the HAWK installation or up to the limit of the available crash data for the after period. Two crash datasets were created. The first dataset included intersecting street name (ISN) crashes, which were all crashes with the same intersecting street names that matched the intersections used in the study. The second dataset included intersection-related (IR) crashes, which were only those ISN crashes that had "yes" for the intersection-related code. The crash types that were examined included total, severe, and pedestrian crashes. From the evaluation that considered data for 21 HAWK sites (treatment sites) and 102 unsignalized intersections (reference group), the following changes in crashes were found after the HAWK was installed: a 29 percent reduction in total crashes

(statistically significant), a 15 percent reduction in severe crashes (not statistically significant), and a 69 percent reduction in pedestrian crashes (statistically significant).
Study Citation: Fitzpatrick, K. and Park, E.S. Safety Effectiveness of the HAWK Pedestrian Crossing Treatment, FHWA-HRT-10-042, Federal Highway Administration, Washington, DC. (2010). Also published in: Fitzpatrick, K., E.S.Park, and S. Turner. "Effectiveness of the HAWK Pedestrian Crossing Treatment". ITE Journal, Vol. 82, No. 4, Washington, D.C., (2012).http://www.cmfclearinghouse.org/study_detail.cfm?stid=196"

22. **Study Title: Pedestrian and Bicyclist Safety Effects of the California Safe Routes to School Program**
Authors: Guiterrez et al.
Publication Date: JAN, 2008
Abstract: In the last decade, there has been an increased focus in California on encouraging children to walk and bicycle to school safely. In 1999, the California Legislature created the Safe Routes to School (SR2S) program, authorizing issuance of a competitive grant process for roadway construction projects. There has been an overall decline in the numbers of child pedestrian/bicyclist collisions in California as a whole. When compared with the control areas, the SR2S project areas did not show a greater decline in numbers of collisions. However, it is likely that the number of children walking/bicycling in the SR2S project areas increased over the relevant time frame. When changes in mobility in the program areas are taken into account, the SR2S program appears to be associated with a net safety benefit for affected school age students.
Study Citation: Guiterrez, N., Orenstein, M., Cooper, J., Rice, T., Ragland, D.R. "Pedestrian and Bicyclist Safety Effects of the California Safe Routes to School Program." TRB 87th Annual Meeting Compendium of Papers CD-ROM. Washington, D.C., 2008.
http://www.cmfclearinghouse.org/study_detail.cfm?stid=128

23. **Study Title: Safety Performance Functions for Low-Volume Roads**
Authors: Acqua and Russo
Publication Date: NOV, 2010
Abstract: This paper analyzes roadway safety conditions using the network approach for a number of Italian roadways within the Province of Salerno. These roadways are characterized by low-volume conditions with a traffic flow of under 1,000 vehicles per day and they are situated partly on flat/rolling terrain covering 231.98 kilometers and partly on mountainous terrain for 751.60 kilometers. Since 2003, the Department of Transportation Engineering at the University of Naples has been conducting a large-scale research program based on crash data collected in Southern Italy. The research-study presented here has been used to calibrate crash prediction models (CPMs) per kilometer per year. The coefficients of the CPMs are estimated using a non-linear multi-variable regression analysis utilizing the least-square method. In conclusion, two injurious crash prediction models were performed for two-lane rural roads located on flat/rolling area with a vertical grade of less than 6 percent and on mountainous terrain with a vertical grade of more than 6 percent. A residuals analysis was subsequently developed to assess the adjusted coefficient of determination and p-value for each assessible coefficient of the prediction model. CPMs are a useful tool for estimating the expected number of crashes occurring within the roads' geometric components (intersections and road sections) as a function of infrastructural, environmental, and roadway features. Several procedures exist in the scientific literature to predict the number of crashes per kilometer per year. CPMs can also be used as a tool for safety improvement project prioritization.
Study Citation: Acqua, G. D. and F. Russo., "Safety Performance Functions for Low-Volume Roads." Presented at the 90th Annual Meeting of the Transportation Research Board, Washington, D.C., (2011).http://www.cmfclearinghouse.org/study_detail.cfm?stid=207"

24. **Study Title: Safety Analysis of Driveway Characteristics along Major Urban Arterial Corridors in South Carolina**
Authors: Stokes et al.
Publication Date: 2016
Abstract: In April, 2013, SCDOT initiated research to improve driveway safety and enhance access management practices in South Carolina. The intent of the study was to determine the potential safety and operational consequences of individual driveways and their specific characteristics, so that informed decisions can be made when granting or denying a particular access point permit application. The researchers examined current and historical practices used by other transportation agencies with regard to access management. A comprehensive driveway database was developed using empirical data collected along several corridors that was used to rank driveway related crashes from highest to lowest frequency. The researchers used this database to statistically analyze and identify the correlation of access issues with crash data from 2012. Crash data were associated with driveways using complex Geographic Information System (GIS) modeling tools. A new South Carolina Collision and Ticket Tracking System (SCCATTS) has enhanced crash location data significantly, and was found to be a critical component for correctly associating crashes with driveways. The statistical analysis identified several significant independent variables that influence crash rates either positively or negatively. The results indicate that increasing the distance between driveways, increasing the number of entry lanes, and having a raised median will decrease driveway related crashes. Conversely, increasing driveway width, corridor volume and corridor speed limit will increase crashes. Similarly, a driveway with high turnover land use, a driveway with full access (as opposed to right-in right-out), and the presence of nearby signalized intersections will increase frequency of crashes. The statistical analysis was used to develop crash modification factors for different driveway characteristics.
Study Citation: Stokes, A., Sarasua, W., Huynh, N., Brown, K., Ogle, J., Mammadrahimli, A., Davis, W., and Chowdhury, M., "Safety Analysis of Driveway Characteristics along Major Urban Arterial Corridors in South Carolina." Presented at the 95th Annual Meeting of the Transportation Research Board, Washington, D.C., (2016).http://www.cmfclearinghouse.org/study_detail.cfm?stid=453"

25. **Study Title: A fully Bayesian multivariate approach to before-after safety evaluation**
Authors: Park et al. (2010)
Publication Date: JUL, 2010
Abstract: This paper presents a fully Bayesian multivariate approach to before-after safety evaluation. Although empirical Bayes (EB) methods have been widely accepted as statistically defensible safety evaluation tools in observational before-after studies for more than a decade, EB has some limitations such that it requires a development and calibration of reliable safety performance functions (SPFs) and the uncertainty in the EB safety effectiveness estimates may be underestimated when a fairly large reference group is not available. This is because uncertainty (standard errors) of the estimated regression coefficients and dispersion parameter in SPFs is not reflected in the final safety effectiveness estimate of EB. Fully Bayesian (FB) methodologies in safety evaluation are emerging as the state-of-the-art methods that have a potential to overcome the limitations of EB in that uncertainty in regression parameters in the FB approach is propagated throughout the model and carries through to the final safety effectiveness estimate. Nonetheless, there have not yet been many applications of fully Bayesian methods in before-after studies. Part of reasons is the lack of documentation for a step-by-step FB implementation procedure for practitioners as well as an increased complexity in computation. As opposed to the EB methods of which steps are well-documented in the literature for practitioners, the steps for implementing before-after FB evaluations have not yet been clearly established, especially in more general settings such as a before-after study with a comparison group/comparison groups. The objectives of this paper are two-fold: (1) to develop a fully Bayesian multivariate approach jointly modeling crash counts of different types or severity levels for a before-after evaluation with a comparison group/comparison groups and (2) to establish a step-by-step procedure for implementing the FB methods for a before-after evaluation with a comparison group/comparison groups. The fully Bayesian multivariate approach introduced in this paper has additional advantages over the corresponding

univariate approaches (whether classical or Bayesian) in that the multivariate approach can recover the underlying correlation structure of the multivariate crash counts and can also lead to a more precise safety effectiveness estimate by taking into account correlations among different crash severities or types for estimation of the expected number of crashes. The new method is illustrated with the multivariate crash count data obtained from expressways in Korea for 13 years to assess the safety effectiveness of decreasing the posted speed limit.
Study Citation: Park, E.S., Park, J., Lomax, T.J. "A fully Bayesian multivariate approach to before-after safety evaluation." Accident Analysis & Prevention, Vol.42, No. 4, pp. 639 1118-1127. (2010)http://www.cmfclearinghouse.org/study_detail.cfm?stid=197"

26. **Study Title: Safety Effect of Arterial Signal Coordination**
Authors: Wei and Tarko
Publication Date: JAN, 2011
Abstract: Traffic signals are coordinated mainly with traffic mobility in mind while the impact on safety is not well known. It is not clear how strong this impact is under specific conditions and which coordination solutions increase or reduce this impact. Engineers who set coordinated signals have at their disposal a number of tools to improve traffic mobility along urban streets but no tool to account for safety. This paper studies the impact of arterial signal coordination on the frequency and severity of rear-end and right-angle collisions - the two types of crashes that are prevalent at signalized intersections - the frequency and severity of which are likely to be affected by signal coordination. Multinomial logit models were developed to estimate crash likelihood in 15-minute intervals as well as the severity of crash outcome on arterial intersection approaches. The obtained models were used to investigate the safety impact of signal coordination and other road and traffic variables. The following was determined. (1) Signal coordination can significantly affect crash likelihood and severity. The concentration of vehicle arrivals in the second half of a green phase is associated with significantly lower crash likelihood and severity. (2) Certain components of the traffic flow are most susceptible to crashes. (3) Short distances between intersections and short cycle lengths are associated with a lower risk of crash. (4) The presence of a right-turn bay is associated with a considerable improvement in safety manifested by a lower risk of rear-end and right-angle collisions. The developed models can be used as a tool for evaluating alternative signal coordination plans from the standpoint of safety.
Study Citation: Wei, L. and Tarko, A., "Safety Effect of Arterial Signal Coordination." Presented at the 90th Meeting of the Transportation Research Board, Washington, D.C., (2011).http://www.cmfclearinghouse.org/study_detail.cfm?stid=219"

27. **Study Title: Safety Evaluation of Truck-Related Crashes at Freeway Diverge Areas**
Authors: Zhenyu Wang, Bin Cao, Weiping Deng, Jian John Lu, and Zhao Zhang
Publication Date: JAN, 2011
Abstract: The study evaluated the impacts of geometric design factors and traffic factors on the truck-related crashes at freeway diverge areas. For this purpose, 391 freeway segments with different geometric designs were selected in various locations throughout the State of Florida. Crash data and inventory data were collected from the selected freeway segments and organized into two sets: site-based and crash-based for developing two prediction models (truck-related crash frequency model and truck-related injury severity model) respectively. The truck-related crash frequency model, fitted by the Negative Binominal regression, is used to identify the significant factors contributing to truck-related crash frequency at freeway diverge areas, and quantify the impacts of the factors. And the injury severity model, developed by the Ordered Probit regression, is utilized to address the factors that contribute to the injury severity of truck-related crashes at freeway diverge areas and the factor impacts. The analysis of the two models show that exit configurations (Type I, II, III and IV) have no significant influence on the injury severity of truck-related crashes at diverge areas. Type III exit configuration has the best safety performance in terms of the lowest truck-related crash frequency at freeway diverge areas. For one-lane freeway exit ramp, replacing a Type I exit configuration with a Type II exit configuration will increase truck-related crash counts at freeway diverge area by 21%. For two-lane exit ramps, replacing a Type III

configuration with a Type IV configuration will increase crash counts at freeway diverge area by 26%. Other significant factors on truck-related crashes at freeway diverge areas include deceleration lane length, number of through lanes/surface width, median/shoulder width, curvature and grade design, speed limit, AADT on mainline/ramp, and truck percentage.
Study Citation: Wang, Z., B. Cao, W. Deng, J.J. Lu, and Z. Zhang. "Safety Evaluation of Truck-Related Crashes at Freeway Diverge Areas." TRB 90th Annual Meeting Compendium of Papers. Washington, D.C. 2011. CMFs associated with this Study:
http://www.cmfclearinghouse.org/study_detail.cfm?stid=227"

28. **Study Title: Applying Bayesian Hierarchical Models to Examine Motorcycle Crashes at Signalized Intersections**
Authors: Haque et al.
Publication Date: JAN, 2010
Abstract: Motorcycles are overrepresented in road traffic crashes and particularly vulnerable at signalized intersections. The objective of this study is to identify causal factors affecting the motorcycle crashes at both four-legged and T signalized intersections. Treating the data in time-series cross-section panels, this study explores different Hierarchical Poisson models and found that the model allowing autoregressive lag-1 dependence specification in the error term is the most suitable. Results show that the number of lanes at the four-legged signalized intersections significantly increases motorcycle crashes largely because of the higher exposure resulting from higher motorcycle accumulation at the stop line. Furthermore, the presence of a wide median and an uncontrolled left-turn lane at major roadways of four-legged intersections exacerbate this potential hazard. For T signalized intersections, the presence of exclusive right-turn lane at both major and minor roadways and an uncontrolled left-turn lane at major roadways increases motorcycle crashes. Motorcycle crashes increase on high-speed roadways because they are more vulnerable and less likely to react in time during conflicts. The presence of red light cameras reduces motorcycle crashes significantly for both four-legged and T intersections. With the red light camera, motorcycles are less exposed to conflicts because it is observed that they are more disciplined in queuing at the stop line and less likely to jump start at the start of green.
Study Citation: Haque, M. M., Chin, H. C., and Huang, H., "Applying Bayesian Hierarchical Models to Examine Motorcycle Crashes at Signalized Intersections." Accident Analysis and Prevention, Vol. 42, No. 1, Elsevier Ltd, (2010) pp. 203-212. http://www.cmfclearinghouse.org/study_detail.cfm?stid=201"

29. **Study Title: Evaluation of the Impacts of Differential Speed Limits on Interstate Highways in Idaho**
Authors: Dixon et al.
Publication Date: OCT, 2012
Abstract: In this research, an evaluation of the impacts of differential speed limits on rural interstate highways in Idaho was completed. The main purpose for this research was to determine if there have been any speed or safety effects after enacting the DSL, and also to study some of the geometric effects, like rumble-strips, on the safety of vehicles on rural Idaho interstates. Regarding the effects of DSL on speed, it was found that passenger car and truck speeds stabilized since the DSL policy implementation date. More specifically, the DSL reduced truck speeds, resulting in mean passenger vehicle and truck speeds of 74.7 and 65.6 mph, respectively. Regarding the DSL effect on speed compliance, Passenger vehicle compliance slightly worsened, while truck compliance improved. Establishment of the DSL policy also contributed to a decrease in the crash rates on Idaho's rural interstates.
Study Citation: Dixon, M., A. Abdel-Rahim, S. Elbassuoni. "Evaluation of the Impacts of Differential Speed Limits on Interstate Highways in Idaho." Report No. FHWA-ID-13-218. Idaho Transportation Department. (Oct. 2012)http://www.cmfclearinghouse.org/study_detail.cfm?stid=337

30. **Study Title: Evaluation of Variable Speed Limits on I-270/I-255 in St. Louis**
Authors: Bham et al.
Publication Date: OCT, 2010
Abstract: In May of 2008, MoDOT installed a “Variable Speed Limit” (VSL) system along the I-270/I-255 corridor in St. Louis. This project evaluated the VSL system and its potential impacts and benefits to the transportation users. The technical system evaluation focused on three areas - mobility, safety, and public and police perceptions. The VSL is not performing as desired in terms of improvements to overall mobility along the corridor, but is providing limited benefits to some segments. Noticeable benefits have been seen with respect to reduction in the number of crashes during the evaluation period. The driving public and law enforcement are widely dissatisfied with the VSL system based on their perceptions of benefits to congestion relief, compliance with posted speed limits, and overall visibility of the current sign configuration.
Study Citation: Bham, G. H., Long, S., Baik, H., Ryan, T., Gentry, L., Lall, K., Arezoumandi, M., Liu, D., Li, T., and Schaeffer, B., “Evaluation of Variable Speed Limits on I-270/I-255 in St. Louis.” RI08-025, Missouri University of Science and Technology, Rolla, MO., (2010). http://www.cmfclearinghouse.org/study_detail.cfm?stid=233

31. **Study Title: To brake or to accelerate? Safety effects of combined speed and red light cameras**
Authors: De Pauw et al.
Publication Date: APR, 2014
Abstract: Introduction: The present study evaluates the traffic safety effect of combined speed and red light cameras at 253 signalized intersections in Flanders, Belgium that were installed between 2002 and 2007. Method: The adopted approach is a before-and-after study with control for the trend. Results: The analyses showed a non-significant increase of 5% in the number of injury crashes. An almost significant decrease of 14% was found for the more severe crashes. The number of rear-end crashes turned out to have increased significantly (+44%), whereas a non-significant decrease (-6%) was found in the number of side crashes. The decrease for the severe crashes was mainly attributable to the effect on side crashes, for which a significant decrease of 24% was found. Practical Applications: It is concluded that combined speed and red light cameras have a favorable effect on traffic safety, in particular on severe crashes. However, future research should examine the circumstances of rear-end crashes and how this increase can be managed.
Study Citation: De Pauw, E, S. Daniels, T. Brijs, E. Hermans, and G. Wets. “To brake or to accelerate? Safety effects of combined speed and red light cameras”. Journal of Safety Research, Vol. 50, (2014) pp.59-65.http://www.cmfclearinghouse.org/study_detail.cfm?stid=401"

32. **Study Title: Safety effects of fixed speed cameras - An empirical Bayes evaluation**
Authors: Hoye
Publication Date: SEP, 2015
Abstract: The safety effects of 223 fixed speed cameras that were installed between 2000 and 2010 in Norway were investigated in a before-after empirical Bayes study with control for regression to the mean (RTM). Effects of trend, volumes, and speed limit changes are controlled for as well. On road sections between 100 m upstream and 1 km downstream of the speed cameras a statistically significant reduction of the number of injury crashes by 22% was found. For killed and severely injured (KSI) and on longer road sections none of the results are statistically significant. However, speed cameras that were installed in 2004 or later were found to reduce injury crashes and the number of KSI on road sections from 100 m upstream to both 1 km and 3 km downstream of the speed cameras. Larger effects were found for KSI than for injury crashes and the effects decrease with increasing distance from the speed cameras. At the camera sites (100 m up- and down-stream) crash reductions are smaller and non-significant, but highly uncertain and possibly underestimated.
Study Citation: Hoye, A. “Safety effects of fixed speed cameras - An empirical Bayes evaluation”. Accident Analysis and Prevention, Vol. 82, (2015) pp. 263-269.http://www.cmfclearinghouse.org/study_detail.cfm?stid=441"

33. **Study Title: Effectiveness of speed enforcement through fixed speed cameras: a time series study**
Authors: Novoa et al.
Publication Date: JUN, 2009
Abstract: Objective To assess the effectiveness of speed cameras in reducing the numbers of crashes and people injured on the arterial roads of Barcelona, and to assess their long-term effectiveness on the beltway. Methods Time series analyses were performed separately for the arterial roads and the beltway. The stretches of arterial roads encompassing 500 m before and after the location of a speed camera were considered the enforced stretches, the remaining stretches of arterial roads being considered the comparison group. The outcome measures were the numbers of crashes and of people injured. Quasi-Poisson regression models were fitted, controlling for time trend, seasonality and implementation of other road safety measures. Results Both on the enforced and non-enforced arterial road stretches, the risks of crashes and people injured were similar in the two periods. On the beltway, reductions of 30% (95% CI 38% to 20%) and 26% (95% CI 36% to 14%) were observed, respectively. Conclusions Speed cameras do not reduce the numbers of crashes or people injured on the arterial roads of Barcelona. However, they are effective in the short and in the long-term on the beltway. Speed enforcement through fixed speed cameras is thus effective in medium-high-speed roads, although effectiveness could not be generalised to roads with lower speed limits and traffic lights.
Study Citation: Novoa,A., Pérez,K., Santamariña-Rubio,E., Marí-Dell'Olmo,M., and Tobías,A. "Effectiveness of speed enforcement through fixed speed cameras: a time series study." Injury Prevention, Vol. 16, Issue 1, pp. 12-16. (2009)
http://www.cmfclearinghouse.org/study_detail.cfm?stid=193"

34. **Study Title: A Study of the Safety Impact of Speed Limit Reduction on Abu Dhabi Freeways**
Authors: Abdelany et al.
Publication Date: 2014
Abstract: This study aims at evaluating the safety impact of reducing the speed limit on two major freeways in Abu Dhabi, United Arab Emirates, from 160 km/h o 140 km/h. A third freeway with unchanged speed limit was used as a comparison. Data was made available from the Abu Dhabi Police Head Quarters that includes collision records, frequency, location, an severity, along the three freeways in this study. Five years of collision records have been studied. Four years before the treatment and one year after. Average Annual Daily Traffic, lengths of road segments, number of lanes a each segment, speed treatment, existence of trucks, an construction works along the road are all considered as covariates in the developed collision prediction models. Furthermore, these models were developed for minor, intermediate, serious injury, fatal, and total number of collisions. An Empirical Bayes before and after analysis was conducted in order to investigate the safety impact of the treatment. Using the developed models and the Empirical Bayes, it was found that reducing the speed limit does not improve safety.
Study Citation: Abdelnaby, A., Y. Albadi, K. Ismail, and Y. Hassan. A Study of the Safety Impact of Speed Limit Reduction on Abu Dhabi Freeways. Presented at the 93rd Annual Meeting of the Transportation Research Board, Paper No. 14-5667, Washington, D.C., (2014).
http://www.cmfclearinghouse.org/study_detail.cfm?stid=396"

35. **Study Title: Making minor rural road networks safer: The effects of 60 km/h-zones**
Authors: Jaarsma et al.
Publication Date: JUL, 2011
Abstract: For safety reasons a maximum speed limit of 60 km/h has been applied to minor rural roads in the Netherlands since 1998. To support this structurally, a part of these roads have also received additional physical measures in a so-called “low cost design” that is expected to reduce the number of traffic casualties by 10-20%. This measure has been implemented as much as possible in an area oriented way. To measure the design's effectivity, road safety in 20 specific rural areas was studied for 5 years before changes were implemented and, on average, 3.5 years thereafter. The study examined

851km of roads, and a control study was done on 2105km of comparable roads with a speed limit of 80 km/h. Both the study and the control roads are managed by water boards. Results show that the measures implemented on the roads in the 60 km/h-zones had statistically significant effects ($p < 0.05$) on casualty accidents (-24% overall), especially at intersections (-44%). This high reduction is probably caused by the concentration of technical interventions at intersections. Both outcomes are somewhat higher than previously expected and are comparable with the outcome of a meta-analysis of safety effects on area-wide urban traffic calming schemes. However, the cost-effectiveness ratio of the 60 km/h zones measures (D 33,000 per prevented KSI-casualty) is much more favourable than the ratio in urban 30 km/h-zones (D 86,000 per prevented KSI-casualty).
Study Citation: Jaarsma, R., Louwerse, R., Dijkstra, A, de Vries, J., and Spaas, J., "Making minor rural road networks safer: The effects of 60 km/h-zones." Accident Analysis and Prevention, Vol. 43, No. 4, Oxford, N.Y., Pergamon Press, (2011) pp. 1508-1515.http://www.cmfclearinghouse.org/study_detail.cfm?stid=244"

36. **Study Title: Full Bayesian evaluation of the safety effects of reducing the posted speed limit in urban residential areas**
Authors: Islam and El-Basyouny
Publication Date: JUL, 2015
Abstract: Full Bayesian (FB) before-after evaluation is a newer approach than the empirical Bayesian (EB) evaluation in traffic safety research. While a number of earlier studies have conducted univariate and multivariate FB before-after safety evaluations and compared the results with the EB method, often contradictory conclusions have been drawn. To this end, the objectives of the current study were to (i) perform a before-after safety evaluation using both the univariate and multivariate FB methods in order to enhance our understanding of these methodologies, (ii) perform the EB evaluation and compare the results with those of the FB methods and (iii) apply the FB and EB methods to evaluate the safety effects of reducing the urban residential posted speed limit (PSL) for policy recommendation. In addition to three years of crash data for both the before and after periods, traffic volume, road geometry and other relevant data for both the treated and reference sites were collected and used. According to the model goodness-of-fit criteria, the current study found that the multivariate FB model for crash severities outperformed the univariate FB models. Moreover, in terms of statistical significance of the safety effects, the EB and FB methods led to opposite conclusions when the safety effects were relatively small with high standard deviation. Therefore, caution should be taken in drawing conclusions from the EB method. Based on the FB method, the PSL reduction was found effective in reducing crashes of all severities and thus is recommended for improving safety on urban residential collector roads.
Study Citation: Islam, M.T., K. El-Basyouny. "Full Bayesian evaluation of the safety effects of reducing the posted speed limit in urban residential areas". Accident Analysis and Prevention, Vol. 80, (2015) pp. 18-25.http://www.cmfclearinghouse.org/study_detail.cfm?stid=448