CycleRAP Research and Review

Evaluation and Literature Review Report

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ABOUT IRAP

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.

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EXECUTIVE SUMMARY

Road safety is a critical issue which needs to be addressed to ensure sustainable modes of transport, such as cycling, can continue to fulfill its role in supporting new and greener mobility choices. Monitoring, managing and addressing safety on facilities used by bicyclists and light mobility vehicles is a challenge, even for those with the most advanced cycling networks.

Thanks to emerging studies on underreporting of bicycling crashes, there is an increasing awareness of the high rates of bicycle and other light mobility vehicle crashes which do not involving motor vehicles. This awareness of the problem—and what to do about it—underpins the need (and existing demand) for a cycling-specific risk model.

The International Road Assessment Programme (iRAP) and the Royal Dutch Touring Club (known as ANWB) have developed a crash risk model dedicated to assessing bicycling[1] risk called CycleRAP.

The CycleRAP model is based on the infrastructure characteristics of road and other bicycling facilities, and how they influence the likelihood and severity of crashes. The concept and model design drew on the existing Star Rating bicyclist model, but included more infrastructure features, expanded the range of crash types to include a range of single bicycle and bicycle-bicycle crash types, and took into account a wider range of light mobility vehicles. With the support of ANWB, CycleRAP was piloted in a number of provinces in the Netherlands between 2016-19.

This report is the summation of a detailed evaluation of the CycleRAP model and literature review, with the aim of strengthening the link between the model and available evidence.

The study involved three phases, which is reflected in the structure of this report:

1. A preliminary review of the CycleRAP model and any existing supporting evidence, by way of published studies, documented to understand the model and any challenges
2. A literature review to capture available research into bicycling crashes, their causes and their outcomes to strengthen the evidence base for the CycleRAP model, and
3. A review of the results of the pilot trials in the Netherlands and the lessons learned. This was based on consultations with the suppliers and provinces involved in pilot projects.

Phase 1: Preliminary review

The preliminary review involved a review of all existing model documentation and published studies which had been used in its development. The review found that over 30 published studies were referenced in the model development, but these had not been directly referenced in the existing model documentation. Many of the CycleRAP infrastructure attributes did not have related studies identified.

The results of this phase were used to inform the focus of the subsequent literature review (phase 2). This included recommendations to:

- Find, where available, research relating to CycleRAP attributes which had no related research identified to date
- Identify research, where available, on the likelihood and severity of bicycling crash types, with a particular focus on single bicycle, bicycle-bicycle, bicycle-light mobility vehicles (LMV)[2] and bicycle-pedestrian crashes (for which there is currently a lack of evidence)

[1] Note the term ‘bicycling’ also encompasses crashes involving users on other types of light mobility vehicles, such as powered two wheelers.

[2] LMV include electric bicycles, motorcycles, mopeds, motorised three-wheelers, scooters etc. which share the bicycle facility or road space.

- 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.

As a result of the model documentation review and conversations with both ANWB and iRAP, a number of more general issues identified as warranting further investigation in the subsequent phases of this project were:

- How to make the model more user-friendly, efficient and less resource intensive to use
- How to ensure the model is evidence-based, accessible and universally applicable, and
- How the current CycleRAP model is positioned within current iRAP tools, particularly iRAP's Star Rating bicyclist model, and other planned innovations projects (such as light Star Ratings).

Phase 2: Literature review

The literature review identified over 60 additional studies as being relevant to the CycleRAP model. This substantially increased the range of CycleRAP infrastructure attributes with relevant studies identified. The majority of studies identified were from western Europe, with a smattering from the UK, North America, Australia and New Zealand.

The quality of the published studies was varied. On the whole, robust research of infrastructure-related factors in bicycling crashes—particularly so for crash types not involving motor vehicles—is scarce. The stronger research relates to vehicle-bicycle crashes. For other crash types not involving motor vehicles, the studies included in this literature review *suggest* there may be a relationship between CycleRAP-specific attributes and bicycle crashes. However, more robust research would be required to provide the conclusive evidence necessary to substantiate the risk factors in the CycleRAP model.

Phase 3: Pilot trial evaluation

The pilot trial evaluation involved a review of the results of the pilot trials in the Netherlands and the lessons learned, based on consultations with the suppliers and provinces involved in pilot projects.

The consultation revealed a number of practical issues which affected the application of the model, and thus should be considered for any future iterations of the model and its design. Briefly these were:

- The time and cost required for the data collection and processing due to the high number of attributes, challenges with data collection and recording, as well as procedural issues in the pilot trial design.
- The effectiveness of index scoring system in communicating the results clearly (i.e. what is 'safe' or 'unsafe') or underlying factors which are needed to help address safety issues.

For future developments functionality to provide the top 3-5 safety interventions was recommended. In the opinion of those who participated in the workshop, there remains a strong demand for a cycling-specific risk model in The Netherlands and abroad.

Discussion and next steps

Overall, the study successfully achieved its aims. As a result, ANWB and iRAP now have a deeper appreciation for:

- What worked well and limitations of the CycleRAP pilot projects. This knowledge can be used in the next phase of CycleRAP development.
- There is a better appreciation for how to optimise the model for implementation, including the need for improved product support, communications and training.

- Where possible, evidence supporting the current CycleRAP attributes (version 1.3) was located and documented (in the literature review).

Upon completion of this study, iRAP has established CycleRAP Advisory Group which consists of a range organisations to help inform the future development of the CycleRAP model, including academics, mobility clubs, cycling advocates, and companies.

Subsequent discussions on the future of CycleRAP drew on the outcomes of this study and have led to planning for a second generation of the model. A CycleRAP position paper has since been completed which:

- Defines what CycleRAP is and what it is aiming to do (and what problem it seeks to address)
- Who the target users and beneficiaries are
- How the model will be used
- Where CycleRAP is now
- The development plan and required resourcing.

The recommendations for the model development (based on the findings of this study) are:

- Ensure the model is underpinned by solid research and evidence
- Improve the model's ability to capture the risk of non-collision crashes more accurately
- Reduce the data inputs required so the model is more cost effective and efficient to use
- Improve user support (manuals and training)
- Modify the model's risk scoring mechanisms, and
- Create additional functionality so the model can recommend safety treatments.

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1. INTRODUCTION

Bicycle crashes are a large—but mostly 'invisible'—road safety issue. Even for those who use the most developed crash data reporting systems, the quality of bicycling crash data remains very poor.

This is particularly so for bicycle crashes which do not involve vehicles. It is due to the simple fact that—even in the case of severe injuries—only the ambulance service is called to attend to crash victims and no report or analysis of the crash cause is completed by traffic police.

Hospital data studies from a number of countries show that between 60-90% of bicycle crashes requiring hospitalisation and approximately 17% of fatal bicycle crashes are the result of single bicycle crashes (i.e. they do not involve a motor vehicle).[3] In the United Kingdom, a study of 35,000 hospital records found that over two-thirds of hospitalisations due to bicycling crashes did not involve another vehicle.[4]

Furthermore, rapid changes in technologies (such as electric powered vehicles), service providers (such as food delivery) and the sharing economy are resulting in steep increases in the use of bicycles and a range of other light mobility vehicles in cities across the world. In the United States, for example, the increase in shared micro mobility alone more than doubled in a single year, from 35 million trips in 2017 to 84 million trips in 2018.[5]

In many places, FSI crashes for bicyclists are increasing—often while the trend of overall FSI crashes decreases. For example, serious injuries in Sweden resulting from bicycling crashes has increased by approximately 35% over the past 10 years, while serious injuries for all other crash types fell.[6]

Road safety is a critical issue which needs to be addressed to ensure these modes of transport can continue to fulfill their role in supporting new and greener mobility choices. Monitoring, managing and addressing safety on facilities used by bicyclists and light mobility vehicles is a challenge, even for those with the most advanced cycling networks.

CycleRAP is a crash risk model dedicated to assessing risk to bicyclists and light mobility vehicle users, such as powered two-wheelers, on roads and other facilities.

Cycle crash types not involving motor vehicles are central to the CycleRAP model and underpin the need (and existing demand) for a cycling-specific risk model. The reason for this is that the Netherlands and many other countries are increasingly aware that:

i. Underreporting rates for crashes which do not involve motor vehicles is very high. This is because, even if seriously injured, victims are often taken directly to hospital without the crash being reported to police. Crashes may also not be located on the road network, but may be located on cycling paths which are not routinely assessed as part of road safety assessments and audits.

ii. These crash types account for a very high proportion of serious injuries and fatalities for this road user group. For example, a study of England's Hospital Episode Statistics (HES) database shows that of the 37,504 pedal cyclists injured in traffic collisions in England between 1999 and 2005, 67% were involved in a non-collision accident.

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[3] Based on data from 12 countries. Schepers P, Agerholm N, Amoros E, et al An international review of the frequency of single-bicycle crashes (SBCs) and their relation to bicycle modal share. Injury Prevention 2015; 21:e138-e143.

[4] Knowles, J., Adams, S., Cuerden, R., Savill, T., Reid, S., and M. Tight. (2009). Collisions Involving Cyclists on Britain's Roads: Establishing the Causes. TRL (PPR 445).

[5] NACTO. (2018). Shared Micromobility in the U.S.: 2018. URL: https://nacto.org/shared-micromobility-2018/

[6] STRADA. (2018). Nationellt cykelbokslut 2018. URL: https://trafikverket.ineko.se/Files/sv-SE/62911/Ineko.Product.RelatedFiles/2019_104_nationellt_cykelbokslut_2018.pdf

The development of CycleRAP originated in 2014. The Dutch Institute for Road Safety Research, SWOV, published a number of studies on the development of quantitative method for assessing bicycling safety[7], and in the following year, ANWB formed a cooperation agreement with the City of Amsterdam and SWOV to develop a Network Safety Index (NSI).

The NSI would map the road safety situation, with particular focus on roads and cycling infrastructure 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, that is, an 'enhanced module' to objectively and comprehensively measure infrastructure risk for bicyclists which could be used globally and in concert with iRAP's core Star Rating models.

In 2015-16, iRAP developed an initial CycleRAP model[8] in collaboration with ANWB, SWOV and the Province of Friesland. ANWB first piloted the model on approximately 170km of roads and bike paths across three provinces in the Netherlands in 2016-17.

In 2018, ANWB undertook a second phase of pilots using an expanded version of the CycleRAP model[9] in Waterschap Rivierenland (188km), Province Flevoland (40km) and Gorredijk – Beetsterzwaag – Drachten (13km). The latter pilot trials also involved the calculation and reporting of safety index scores.

In 2018, ANWB engaged iRAP to undertake an evaluation of the CycleRAP pilot trials and to complete a comprehensive literature review to strengthen the link between the model and available evidence.

This report presents the findings of this project. The project was undertaken in three phases:

1. A preliminary review of the CycleRAP model and any existing evidence (i.e. related studies) documented to understand the model and any challenges
2. A literature review to capture available research into bicycling crashes, their causes and their outcomes to strengthen the evidence base for the CycleRAP model, and
3. A review of the results of the pilot trials in the Netherlands and the lessons learned. This was based on consultations with the suppliers and provinces involved in pilot projects.

The methodology, findings and recommendations for each phase are summarised in sections 2, 3 and 4 below.

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[7] 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.

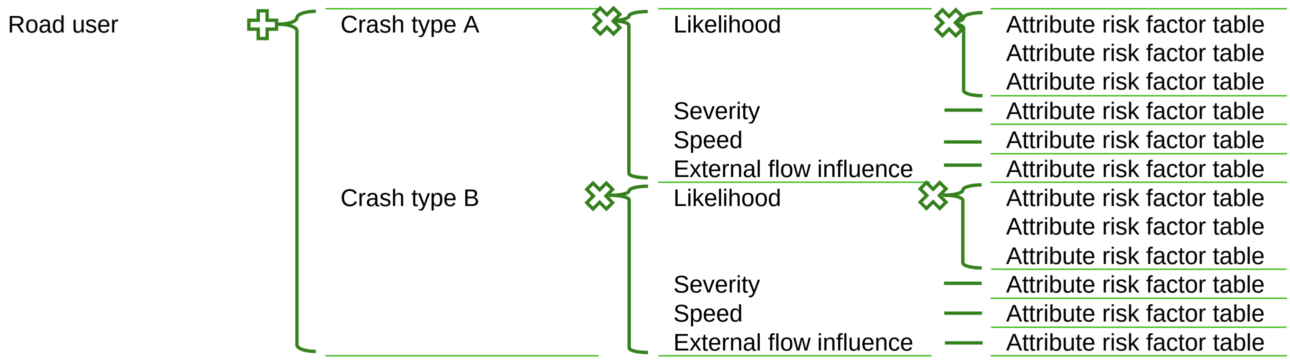
[8] The initial version of the CycleRAP model which measured 34 road characteristics at 25m intervals. Results were calculated based on the presence (or absence) of the attributes, rather than using risk scores.

[9] The subsequent version of the model was structured similar to the iRAP Star Rating models. The number of attributes were increased substantially and assigned risk factors. It is described in more detail in section 1.1 below.

1.1. About the CycleRAP model

The CycleRAP model used the same structure and approach as the iRAP v3 Star Rating models. That is, it is a multiplicative model with a tiered structure.

Figure 1: CycleRAP model structure



Attribute risk factor tables use a single or pair of road attributes to select a risk factor.

Figure 2: Attribute risk factor table

			Road attribute - secondary	
		Code	1	1
	Code	**Category name**	Category A	Category A
Road attribute - primary	1	Category A	Risk factor	Risk factor
	2	Category B	Risk factor	Risk factor
	3	Category C	Risk factor	Risk factor
	4	Category D	Risk factor	Risk factor

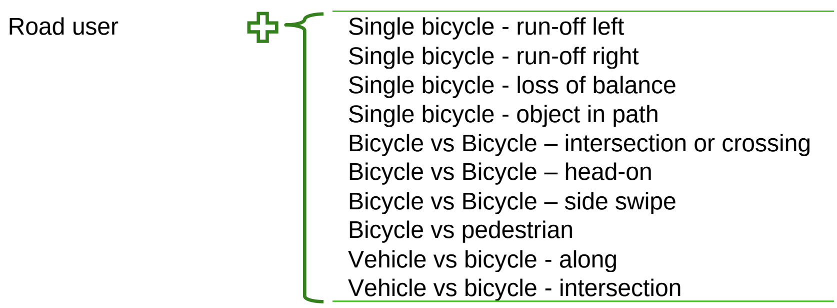
Road attributes can either be coded or combined attributes, with coded attributes coming from the road coding and combined attributes combinations of coded attributes or other combined attributes.

Attributes are collected for every 25m interval (a coding segment).[10]

1.1.1. Crash types

There are ten crash types in the CycleRAP model.

Figure 3: List of CycleRAP crash types



[10] This is different to the length of a coding segments for the Star Rating models, which are 100m intervals.

1.1.2. CycleRAP model attributes

The CycleRAP model has a total of 79 attributes (and over 450 sub-attributes). These are divided into several categories as per the table below. The full list is provided in Appendix A.

Table 1: Summary of CycleRAP attributes

CycleRAP attributes	Number
Location attributes (e.g., road names, GPS locations, etc.)	16
Observed flow* and speed attributes (e.g., number of bicyclists, speed limit, etc.)	7
Bicycle and pedestrian attributes (e.g., facility type, crossings, user mix, etc.)	5
Surface attributes (e.g., facility width, road condition etc.)	10
Side attributes (e.g., side object and distance, land use, etc.)	14
Mid-block attributes (e.g., curvature, grade, obstacles, etc.)	10
Intersection attributes (e.g., intersection type, intersection quality, etc.)	7
Post-coding attributes (e.g., AADT and user flows, operating speed, etc.)	10
Total	**79**

** Note: Observed flow attributes were not collected for pilot trials.*

1.1.3. CycleRAP attributes by crash type

The CycleRAP attributes which influence the likelihood and/or severity for each crash type are shown in the table below. Those highlighted in grey correspond to attributes used in the equivalent crash types in the iRAP Star Rating bicyclist model. For more information on the iRAP Star Rating bicyclist model, and how it compares to the iRAP model, see section 1.1.4.

Table 2: CycleRAP road attribute risk factors per crash type

	Single bicycle			Bicycle-Bicycle			Bicycle-Ped	Vehicle-bicycle	
Road attribute / **Crash type**	Run-off right / left	Loss of balance	Object in path	Intersection or crossing	Head-on	Side swipe	Along	Along	Intersection
Bicycle facility type					●	●	●	●	●
Bicycle facility crossing and quality	●	●	●	●	●	●			●
Pedestrian crossing – inspected road	●	●	●			●	●		●
Pedestrian crossing – intersecting (side) road									●
Bicycle facility surface / grip	●	●	●		●	●	●		
Bicycle facility width	●	●	●	●	●	●	●	●	
Bicycle facility width restriction	●	●	●	●	●	●	●		
Bicycle facility centre line	●	●	●	●	●		●	●	●

Road attribute \ Crash type	Single bicycle			Bicycle-Bicycle			Bicycle-Ped	Vehicle-bicycle	
	Run-off right / left	Loss of balance	Object in path	Intersection or crossing	Head-on	Side swipe	Along	Along	Intersection
Road surface / grip	●	●	●		●	●	●	●	●
Road lane width	●	●	●	●	●	●	●	●	●
Road number of lanes				●			●	●	●
Road condition	●	●	●		●	●	●	●	●
Road delineation	●	●	●		●	●		●	
Road shoulder rumble strips		●						●	
Bicycle facility edge delineation	●				●	●		●	
Bicycle facility edge transition	●				●	●			
Side surface quality	●				●	●	●		
Side object & side object distance	●				●	●	●	●	
Paved shoulder (width)								●	●
Bicycle facility one way / two way	●	●	●	●	●		●		●
Curvature and curve quality	●	●	●	●	●	●	●	●	●
Grade	●	●	●	●	●	●	●	●	●
Obstacle in path & obstacle quality	●	●	●			●	●	●	
Tram rails	●	●			●	●	●	●	
Sight distance	●		●	●	●	●	●	●	●
Street lighting	●		●	●	●	●	●	●	●
Vehicle parking – road edge				●			●	●	●
Intersection type and quality		●	●	●		●	●		●
Intersecting road volume							●		●
Intersection prioritisation							●		●
Property access and quality	●	●	●	●		●	●		●
Operating speed motorised vehicles (85th percentile)								●	●
Speed management	●	●						●	●
Operating speed bicycles	●	●	●	●	●	●	●		

Crash type / Road attribute	Single bicycle			Bicycle-Bicycle			Bicycle-Ped	Vehicle-bicycle	
	Run-off right / left	Loss of balance	Object in path	Intersection or crossing	Head-on	Side swipe	Along	Along	Intersection
Bicycle peak hour flow	●	●	●	●	●	●	●		
Pedestrian peak hour flow across	●	●			●	●			
Pedestrian peak hour flow along	●	●			●	●			
Light power two-wheel flow	●	●	●	●	●	●	●		●
Vehicle AADT	●	●						●	●
Motorcycle %	●	●						●	●
Heavy good vehicles %	●	●						●	●

1.1.4. How does the CycleRAP model compare to the iRAP Star Rating bicyclist model?

The iRAP Star Rating models measure over 50 different road attributes to provide a simple and objective measure of the level of safety which is 'built-in' to the road for each road user type: vehicle occupants, motorcyclists, bicyclists and pedestrians. Five-star roads are the safest while one-star roads are the least safe. The results are used to identify high risk locations and prioritise road safety treatments (via a Safer Road Investment Plan).

A bicyclist Star Rating is based on an evaluation of three bicyclist crash types[11]:

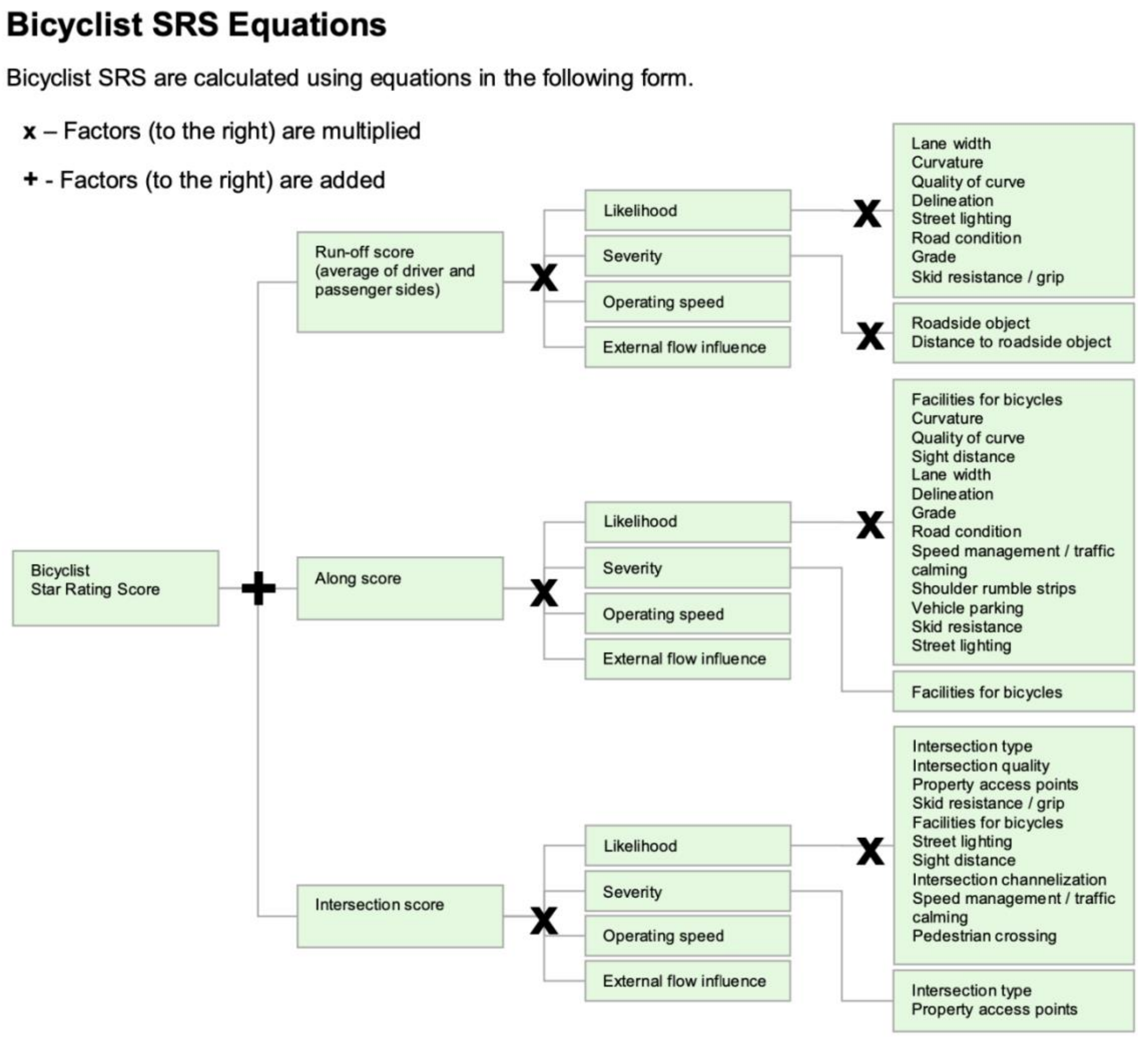
- Run-off road: The risk of a bicyclist departing the road or facility and crashing (single bicycle crash).
- Along: The risk of a bicyclist being struck by a vehicle while travelling along the road (vehicle-bicycle crash).
- Intersection: The risk of a bicyclist being struck by a turning vehicle at an intersection (vehicle-bicycle crash).

The bicyclist Star Rating Score Equations are shown in Figure 4 below.

All three of these crash types are included in the CycleRAP model, however the CycleRAP model typically uses more variables to provide a more comprehensive analysis of the risk. The bicyclist Star Rating does not account for bicycle-bicycle, bicycle-pedestrian or some kinds of single bicycle crash risk. Refer to Table 2 above for details.

[11] See *iRAP Methodology Factsheet 4: Crash types* for more information.

Figure 4: iRAP v3.2 bicyclist model Star Rating Score equations with crash types and attributes



Star Rating equations and attributes (as shown in the figure above) can be found in *iRAP Methodology Factsheet 6: Star Rating Score equations*. For a description of evidence and risk factors associated with each attribute, see the relevant iRAP road attribute risk factors factsheet at www.irap.org/methodology.

2. PHASE 1: PRELIMINARY REVIEW

The preliminary review of the CycleRAP model and any existing evidence (i.e. related studies) aimed to achieve a number of things:

1. Understand the model and the evidence (by way of published research) which had been used to inform its development
2. Assess the status and standard of the model documentation
3. Identify gaps in the evidence to help focus the second phase of this project, the literature review, and
4. Identify any other issues which should be addressed during the course of this project.

2.1. Methodology

The preliminary review was undertaken as a desktop study and involved two areas:

a) The CycleRAP model documentation, including the *CycleRAP Factsheet* (prepared by ANWB in June 2018), the *CycleRAP Model Generation v1.3* (prepared by James Bradford) and the *CycleRAP Coding Manual* (prepared by James Bradford in February 2017).

b) Existing published studies used in the model development (provided by ANWB).

2.2. Findings

2.2.1. CycleRAP model documentation

The CycleRAP model is currently only available in macros test bed (the *CycleRAP Model Generation v1.3)*. As such, it is not integrated with iRAP's ViDA system which provides the analysis and reporting for Star Rating assessments.

A *CycleRAP Coding Manual* and *Upload File* were both prepared in early 2017 for the purposes of the CycleRAP pilot trials. The *CycleRAP Factsheet* which documents the model's structure, such as crash types and likelihood and severity factors, was developed to a 'concept' stage. The intention of this project was to undertake a comprehensive literature review with the aim of documenting evidence which supports the model's risk factors.

2.2.2. Existing research used in the CycleRAP model

The list of research studies used in the CycleRAP model development was also reviewed to understand the gaps in the evidence base and understand how best to focus the literature review to be undertaken as part of this project.

The CycleRAP model shares a number of attributes with the Star Rating bicyclist model.[12] It is therefore assumed that there is evidence available to substantiate risk factors associated with these attributes (albeit limited to the crash types of the Star Rating bicyclist model and not for the expanded list of crash types in the CycleRAP model).

[12] Note that the crash types of the Star Rating bicyclist model are not the same as the CycleRAP model. How these attributes relate to the crash types of each is shown in Table 2 above.

The common attributes are:

- Pedestrian crossing – inspected road and intersecting (side) road
- Road surface/grip
- Road lane width
- Number of road lanes
- Road condition
- Road delineation
- Road shoulder rumble strips
- Side object & side object distance
- Paved shoulder (width)
- Curvature and curve quality
- Grade
- Sight distance
- Street lighting
- Vehicle parking
- Intersection type and quality
- Intersecting road volume
- Property access and quality
- Operating speed motorised vehicles (85th percentile)
- Speed management
- Bicycle peak hour flow
- Pedestrian peak hour flow across and along
- Vehicle AADT
- Motorcycle flow (% of total AADT)

In 2017, ANWB commissioned a review of existing literature to inform the development of risk factors in the current CycleRAP model. Thirty six publications were listed. Many of the studies related to multiple attributes (see Table 3 below).[13]

Table 3: Subset of CycleRAP attributes with related research (existing)

Attribute	No. of relevant publications
Area type	1
Speed limit	2
Speed management	3
Bicycle facility type	10
Bicycle crossing	3
Pedestrian crossing	5
Bicycle facility surface / grip	2

[13] This list does not reflect the strength of the conclusions relating to the attribute or what crash type the study might relate to.

Attribute	No. of relevant publications
Road number of lanes	1
Land use	1
Bicycle facility one /two way	6
Vehicle parking - road side	1
Intersection type	3
Intersecting road volume	1
Intersection prioritization	1
Property access	1
Bicycle peak hour flow	13
Pedestrian peak flow across	7
Pedestrian peak flow along	7
Vehicle AADT	1
Operating Speed (85th %ile)	15
Operating Speed - bicycles	3

Many of the model's attributes that relate to crash risk, particularly to single bicycle and bicycle-bicycle crash types, did not have related research documented. These were:

- Bicycle facility user mix
- Bicycle crossing quality
- Bicycle facility width
- Bicycle facility width restriction
- Bicycle facility centre line
- Bicycle facility edge delineation
- Bicycle facility edge transition
- Side surface quality
- Obstacle in path
- Obstacle in path quality
- Tram rails
- Light powered two wheel flow (mopeds & light mopeds)
- Heavy good vehicle %

Even where relevant studies are identified, very few relate to bicycle crash types not involving motor vehicles, particularly for single bicycle crashes, which is a central premise of the model. Appendix B provides a list of the publications, which attributes they relate to, and abstracts for each.

2.3. Recommendations

In addition to the review of the model documentation and identified literature, a number of informal discussions were had with the iRAP team, ANWB, SWOV and some of the pilot project suppliers were had on their impressions of the model and any challenges they perceived in its application or otherwise. General concerns were raised were around how 'practical' the model was to use relating to its size and complexity, (and therefore the time and cost required to undertake projects).

Additional concerns were raised internally by iRAP about how the model 'fit' with the Star Rating model and the lack of clarity around when and where the model would be used. Examples included (i) what types of roads/facilities it should/could be used for, (ii) whether it should be used in conjunction with or independently of Star Rating assessments, (iii) how not to create confusion between CycleRAP risk scoring and Star Ratings.

As a result of this preliminary review and these discussions, a number of aspects were identified as needing further investigation in the subsequent phases of this project:

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

   CycleRAP needs to be as practical and affordable as possible to use. The high number of attributes required to be collected at 25m intervals means the data collection is labour-intensive. Consideration should be given to how to reduce the assessment task through the consolidation and simplification of CycleRAP attributes as much as possible. There are a number of cases where duplication could be reduced or where, based on current assessment data, attributes appear of limited value.

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

   The literature review (Phase 2 of this project) aims to improve the evidence which underpins the risk factors of the CycleRAP model. However, the large number of crash types make the model complex and given the relative scarcity of bicycle crash research, it will likely be difficult to link the available studies with these specific crash types. There is a need for better understanding of the 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.

   Based on this summarisation of existing literature, it was recommended the subsequent literature review (phase 2) concentrate on the following:

   - Find, where available, research relating to CycleRAP attributes which had no related research identified to date
   - Identify research, where available, on the likelihood and severity of bicycling crash types, with a particular focus on single bicycle, bicycle-bicycle, bicycle-light mobility vehicles (LMV)[14] and bicycle-pedestrian crashes (for which there is currently a lack of evidence)
   - 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.

3. How the current CycleRAP model is positioned within current iRAP tools, particularly iRAP's Star Rating bicyclist model, and other planned innovations projects (such as light Star Ratings), and includes:

   a. The purpose and scope of application of the current CycleRAP model.

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

   This is relevant to both the technical aspects of model design (such as common attributes with the Star Rating model and coding intervals) as well as product positioning so end users understand when and how to use CycleRAP (particularly in conjunction with or independently of a Star Rating assessment).

[14] LMV include electric bicycles, motorcycles, mopeds, motorised three-wheelers, scooters etc. which share the bicycle facility or road space.

iRAP's core bicycle model is able to give a basic-level risk assessment for bicyclists (where present) across a road network based on the presence of bicycling facilities, vehicle speed and traffic volumes to a 100m level. When, where and for what purpose a CycleRAP assessment should be undertaken needs to be better defined and understood based on market needs and opportunities.

Producing a separate CycleRAP risk score could, if not managed carefully, create confusion and potential conflict with the core model's Star Rating. Consideration should be given to how manage this risk.

3. PHASE 2: LITERATURE REVIEW

The aim of the literature review was to build upon the existing evidence base underpinning the CycleRAP model with specific focus on cycle crash types not involving motor vehicles.

As an iRAP product, it is also important that CycleRAP is globally applicable, and as such, the research which underpins the model must be representative of a variety of cycling contexts. The existing research was primarily from western Europe and the US, with some from Australia and other OECD countries. Therefore, the secondary aim of the literature review was to expand the geographic scope to include a range of locations and cycling contexts.

3.1. Methodology

In order to capture as much available research as possible across diverse geographic regions, in addition to the literature review of English language publications, researchers were engaged to assist reviewing relevant literature published in Dutch, Portuguese, Spanish, Danish. China was also identified as a possible source of studies due to the recent rise in cycling and infrastructure. However, a suitable provider with access to relevant research (if any) could not be found within the timeframe available.

iRAP and three suppliers, SWOV (for the review of Dutch studies[15]), WRI Brazil (for the review of Spanish and Portuguese studies) and Viatrafik (for the review of Danish studies), each 'scanned' for relevant published research for their respective language group.

Each identified publication was described by its:

- Full reference
- Research location
- List of relevant road/ facility/ intersection attribute
- Crash type
- Summary of key points
- The stated impact on bicycling crashes.

In the course of their review, Viatrafik highlighted Norway's "Trafiksikkerhetshåndboken" (Road Safety Handbook), which provides an overview of current knowledge on the effects of 142 road safety measures.[16] The chapter, 'Infrastructure measures for cyclists', most recently updated in 2017, provides a comprehensive overview of the latest studies, practices and experiences regarding bicycle facilities and road safety from all over the world.[17] The content of this publication, including the references and conclusions on cycling risk factors, was subsequently analysed by iRAP and a summary of the relevant findings provided (see Norwegian Road Safety Handbook review).

SWOV also suggested an examination of SafetyCube, the European Commission's Road Safety Decision Support System (DSS). SafetyCube started in 2015 with the primary objective to develop an innovative road safety decision support system and offers a resource for road safety risks or reviews safety countermeasures.

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[15] SWOV also peer-reviewed the findings of WRI and Viatrafik.

[16] Høye, A. (2017) "Infrastrukturtiltak for syklister" in Elvik, R., Høye, A., Sørensen, M. W. J., Vaa, T. (2009). Handbook of Road Safety Measures. Transportøkonomisk institutt.

[17] A more comprehensive version of this chapter was published separately under the title "Road Safety for Cyclists" by Hoye (2017) (in Norwegian with an English summary). However, only the chapter of the handbook has been included here as it specifically focussed on infrastructure whereas the other publication contained more details not relevant to CycleRAP.

Not all references provided in the Danish and Spanish/Portuguese reviews had a direct relationship to CycleRAP attributes or crash types. This may be due to the researchers' unfamiliarity with the CycleRAP model or risk models more generally. However, these were retained as a context for the research and future applicability of a cycling risk model in those regions.

The methodologies used by each of the researchers, their key findings, and literature summaries are provided in full in Appendix C.

3.2. Findings

The literature review identified over 60 additional studies as being relevant to the CycleRAP model. As a result, nearly all infrastructure attributes used in the CycleRAP model had one or more related studies identified.

Effort was made to find research from a wide variety of cycling contexts around the world. This was achieved to a degree; however, it remains that most research is from western Europe, with a smattering from the UK, North America, Australia and New Zealand. Good quality and focussed studies of infrastructure-related bicycling risk factors elsewhere remains rare despite some places having very high rates of cycling.

Table 4: Summary of studies reviewed

Language	Countries/ regions	No. of sources identified	No. of sources reviewed	No with relevant relationships
Dutch review (SWOV)	The Netherlands	8	8	8
Spanish/ Portuguese review (WRI)	Spain, Brazil, Costa Rica and Colombia	38	13	8
Danish review (Viatrafik)	Denmark	9	9	9
English language review (iRAP)	UK, US, Australia, New Zealand, Switzerland, China	8	8	8

The literature review paid particular attention to sourcing studies relevant to single bicycle and bicycle-bicycle crash types. Even so, only a small proportion of the studies identified relate to crash types not involving motorised vehicles. Of these, very few meet the requisite standard of quality and robustness to establish a causal relationship between an attribute and the risk of a particular crash type.

In examining the literature, questions arose about the definition of used terms, the validity of the conclusions and their level of generalizability which made it difficult to compare results. It is particularly the case for:

- Variability in the names and descriptors of cycling infrastructure elements from place to place
- The lack of information regarding motorized vehicle and cyclist volumes and indicators of volumes (e.g. AADT, 24 hour or peak hour)
- Poorly defined and described crash types. For example, it is often not readily apparent if 'bicycle crashes' refers to all crashes involving a bicyclist or a subset of this (e.g. vehicle-bicycle crashes).
- Differences in the definitions of injury levels between regions/countries and reporting rates which are generally not described in the literature.

The meta-analysis provided by Hoye (2017) in the Norwegian *Road Safety Handbook* was valuable in its review of existing research, particularly for the attributes unique to the CycleRAP model and crash types not involving motor vehicles.

Other resources, such as the European Road Safety Decision Support System, *SafetyCube*[18], and the CMF Clearinghouse[19] were found to be useful for the evaluating the strength of the existing body of evidence (or in the case of the CMF clearing house, the strength of individual studies) to support the relationship between infrastructure attributes and crash risk.

Those infrastructure attributes and crash types strengthened) supported by a body of evidence are those which are already included in the Star Rating bicyclist model (labelled with a '†' in the table below), that is, the infrastructure and speed factors as they relate to vehicle-bicycle crashes.

The issue remains that robust research of infrastructure-related bicycling crashes—particularly so for crash types not involving motor vehicles—is scarce. For these, the studies included in this literature review *suggest* there may be a relationship between CycleRAP-specific attributes and bicycle crashes. However, more robust research is required to provide the conclusive evidence necessary to substantiate the risk factors in the CycleRAP model.

Table 5: Subset of CycleRAP attributes with related research (post literature review)

Attribute	**No. of relevant publications**
Area type†	3
Speed limit†	3
Bicycle facility type†	30
Facility width/ width restriction	5
Bicycle crossing	5
Bicycle crossing quality	3
Pedestrian crossing†	2
Bicycle facility surface / grip	7
Road surface / grip†	7
Road condition†	7
Road number of lanes†	7
Facility one /two way	9
Vehicle parking - road side†	4
Side object – left/right†	3
Side surface quality	1
Edge transition – left/right	4
Tram rails	4
Bicycle facility centre line	1
Obstacle in path	5
Intersection type†	21
Intersecting road volume†	1
Intersection prioritization	3
Street lighting†	4
Operating Speed (85th %ile) †	10
Bicycle facility user mix	1

[18] https://www.roadsafety-dss.eu

[19] http://www.cmfclearinghouse.org

Research publications included in this literature review, and attributes they relate to, are shown in Summary of research publications by attribute.

3.3. Recommendations

As a result of this literature review, most attributes included in the CycleRAP v1.3 model have some relevant research although the quality of this research and the reliability of the results are varied. On the one hand, the evidence underpinning attributes as they relate to vehicle-bicycle crash types (i.e., those common to both the CycleRAP and Star Rating bicyclist models) is strengthened as a result of this review. On the other hand, only a small proportion of the research relates to those crash types not involving vehicles. Where there are studies, the research typically lacks the necessary quality and robustness to establish a causal relationship between an attribute and the risk of that crash type.

Even if research in this field were to substantially increase, with over 45 infrastructure attributes and nine different crash types, coupled with the challenges of researching single bicycle and bicycle-bicycle crashes, it is highly unlikely enough evidence would become available to adequately substantiate every crash type—let alone the interactions between the 46 variables and crashes—in the CycleRAP v1.3 model in the foreseeable future.

Simplifying the CycleRAP model's crash types, attributes, and risk factors to align them more closely with what research is available could help resolve this issue. For that which relates to crash types not involving vehicles, informed assumptions will be required based on the limited research currently available until more research in this field is completed.

4. PHASE 3: PILOT PROJECT EVALUATION

The third phase of the project was to conduct in review of the pilot trials with ANWB and the suppliers which had been engaged to undertake the pilot projects.

4.1. Methodology

In February 2020, a one-day, in-person workshop was held with the suppliers of CycleRAP pilot projects. Representatives from the provinces where the trials were completed were also invited to join. The meeting was organised and hosted by ANWB in The Hague.

Representatives from ANWB, iRAP, Mobycon, RHDHV, and IV-Infra attended the meeting. Province of Friesland joined the meeting via conference call. AMSS provided written input prior to the meeting. Representatives from ESC and the provinces of Drenthe and Groningen were unable to attend the meeting.

The iRAP representative provided an overview of the CycleRAP literature study and review completed in 2019 and a short overview of iRAP/EuroRAP. Each supplier/province provided a short presentation of their project followed by discussion. A summary of key discussion points is provided in Appendix D.

4.1.1. Size of the pilot trials

The networks selected and assessed during the CycleRAP pilot trials were mostly small and discreet. The review included the round of pilot trials which used the current version of the model.

Name	Length (km)	Survey supplier	Coding supplier	Analysis and reporting supplier
Waterschap Rivierenland (The Water Board covering the provinces of Gelderland, South Holland, Utrecht and North Brabant)	188	Cyclomedia	ESC	RHDHV
Province Flevoland	40	ESC	ESC	Mobycon
Province Drenthe*	80	AMSS-CMV	AMSS-CMV	AMSS-CMV
Gorredijk – Beetsterzwaag – Drachten (Province Friesland)	13	IV-Infra	IV-Infra	IV-Infra/ Province of Friesland

* Note: The Province Drenthe pilot trial was using the initial version of the CycleRAP model which measured 34 road characteristics at 25m intervals. The full assessment report is available (in English) at https://www.anwb.nl/binaries/content/assets/anwb/pdf/belangenbehartiging/cyclerap/cyclerap-drenthe-report-juni-2018.pdf.

4.2. Findings and conclusions

There was general consensus amongst the workshop participants on a number of issues. These included:

1. Application of the model (i.e. the data collection and coding, results analysis and reporting) was found to be costly, time-consuming and prone to errors.

   This was thought to be due to the high number of attributes, challenges with data collection[20] and recording, as well as procedural issues in the pilot trial design. The model is not financially viable to use. All suppliers provided the services at a loss. Main reasons cited were:

   a. Time required collecting and coding data.
   b. Errors in data that required correction, often picked up by another supplier which made it difficult to manage.
   c. The process was too iterative. QA and index score calculation by iRAP also created additional delays.

   Overall, there was consensus among the participants that the model had too many attributes and simplification would substantially improve its viability and effectiveness. The application of the model would also benefit from improved guidance materials to support the assessment process (e.g. survey and coding and analysis and reporting manuals). There should be more consistency and standardisation for reports.

   The ability to automatically collect data from existing data sources is also critical to this tool being viable for widespread implementation. Future model versions/iterations must reflect this.

2. The index scoring system did not provide a sense of what was safe or unsafe, or easily identify the key factors underlying the score (i.e. the characteristics of the facility that made it 'safe' or 'unsafe') which are needed to help address safety issues.
3. The functionality to provide the top 3-5 safety interventions would be essential to meeting the needs of end users for this tool to provide value.
4. There remains a strong demand for a cycling-specific risk model in The Netherlands and abroad.

   There is a lack of tools available to road authorities to assist with safety monitoring indicators required. CycleRAP and EuroRAP should be promoted as tools to be used for safety assessment and benchmarking in Europe. Needs to be supported with industry expertise and clear communication. Having a viable CycleRAP tool as quickly as possible is a high priority for the Dutch context.

   A tool capable of much more extensive, faster assessments is needed. It was noted that the Dutch Cycling Federation have developed a simple assessment method which has been used for entire cycling networks in some locations. However, this model is not evidence based and data is collected by volunteers. It is subjective and lacks necessary quality controls.

The top three priorities going forward were agreed to be:

a) Address the issues with the index score so that it better communicates results in relation to an acceptable level of risk. Ideally it should align with Star Ratings.
b) Make it possible to identify the top 3-5 treatments which guide local authorities on how to improve safety.

[20] This related to the number of attributes and not the frequency of the collection. The suppliers did not see any issues in relation to data collection at 25m intervals.

c) Significantly reduce the number of attributes required for the model and ensure the model balances risk of different crash types (i.e. vehicle-bicycle vs others).

4.2.1. Crash correlation analysis by Province of Friesland

Analysis of the results and known locations of bicyclist crashes was completed by the Province of Friesland, which reported that on the limited pilot project results (13km) there was a correlation with the crash data.

4.2.2. Index score analysis by RHDHV

To gain a better understanding of which attributes had the greatest influence over the index score, RHDHV analysis found a clear correlation between the index score and:

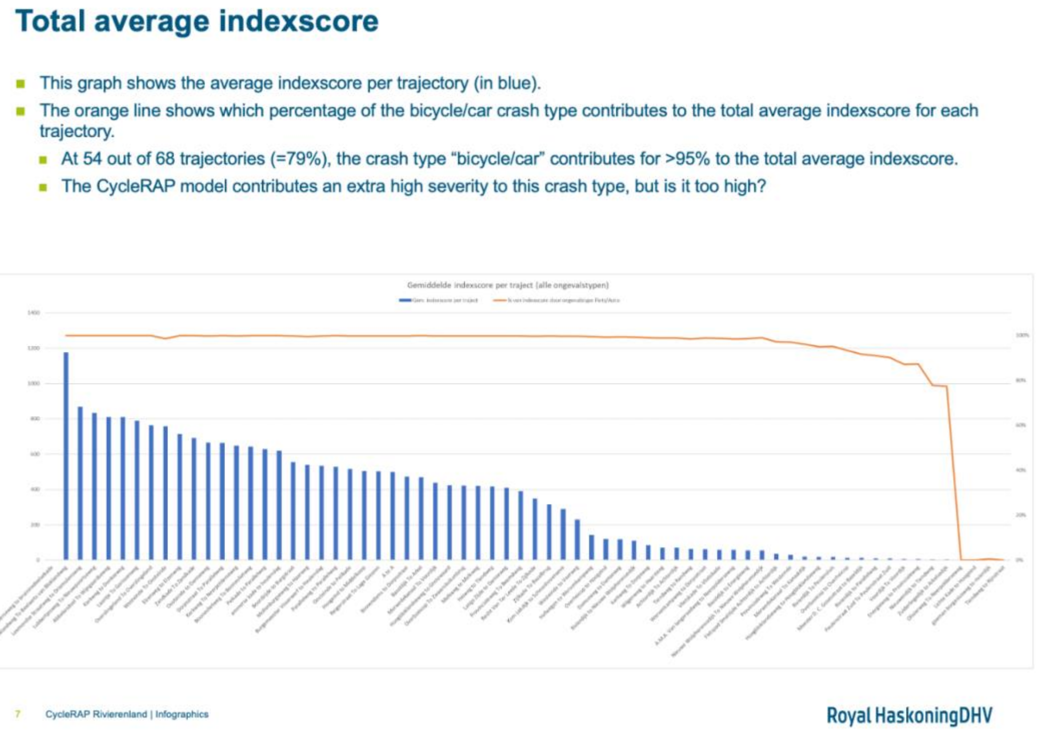
- Facility type: The higher the proportion of separated cycle facilities, the lower the index score.
- Area type: Index scores are lower in rural areas
- Intersections and access roads: Higher presence of both had high index scores.

Vehicle-bicycle crash types were found to account for 95% of the weighting in index scores, compared to other crash types (bicycle-bicycle, single bicycle and bicycle-pedestrian), as per figure below. They conclude that vehicle-bicycle interactions are weighted too heavily in the model, and that other (non-vehicle) crash types have such a minimal impact on the index score that they become ‘noise’.

If the vehicle-bicycle crash type is removed from analysis, a strong correlation can be seen between single bicycle crash types and facility type similar to the aggregated results (i.e. the risk decreases as the proportion of separated facilities increase).

Figure 5: Proportion of the vehicle-bicycle crash type in calculation of CycleRAP index scores

Image used with permission of RHDHV.



5. DISCUSSION AND NEXT STEPS

Road safety is a critical issue facing every country, everywhere—regardless of wealth, transport infrastructure, travel patterns, mobility choices, cultural or demographic differences. In recent years, a number of countries that had previously had steadily decreasing road crashes have seen a plateau or uptick in road crashes, others have struggled to decrease high rates of serious crashes, and rapidly developing countries have seen sharp increases in crash rates as motorisation increases.

During this study, the emergence of the COVID-19 global pandemic resulted in massive disruption to travel patterns and mode choice. Lock downs, remote working, challenges with social distancing on mass transit, the safety of transit operators, have all had very real (and possibly long term) impacts on how, where, when and why people choose to move about.

The pandemic has made it unequivocally clear that the insistent burden of preventable road crashes on health systems, families and communities, society and economies is unacceptable. In February 2020, the Third Global Ministerial Conference on Road Safety in Stockholm culminated in the “Stockholm Declaration”, which called for a new confirmed the extension of the global Sustainable Development Goal target to reduce road traffic deaths and injuries by 50% by 2030. This global target was then formally adopted in September 2020 by the United Nations General Assembly and 2021–2030 proclaimed as the Second Decade of Action for Road Safety.

The pandemic also resulted in an uptake of cycling in many places around the world as people took advantage of empty streets and looked for alternatives to mass transit. Many cities responded with rapid implementation of temporary ‘pop-up’ bicycling facilities to meet demand. NACTO’s COVID Response Centre tracking recorded over 180 cities worldwide which undertook one or more bicycling or micro-mobility initiatives in the first seven months of the pandemic (between February and August 2020).

For many, the benefits of lower motorised traffic (namely decreased noise and air pollution and traffic congestion) reinforced the need and motivation to pursue increased sustainable mobility policies, planning and investment. Tools to help inform decision-making for bicycling and micro-mobility—particularly those with a safety focus—are needed now more than ever.

CycleRAP is a crash risk model dedicated to assessing risk to bicyclists and light mobility vehicle users, such as powered two-wheelers, on roads and other facilities. It was essentially created with the aim of addressing bicycling crash types which are not currently included in the Star Rating bicyclist model (particularly single bicycle crashes). It was also aimed that it could be applied on bicycling networks which were separate to road networks.

CycleRAP was first developed by iRAP in 2015-16, in collaboration with ANWB, SWOV and the Province of Friesland and was subsequently piloted on over 400km of roads and paths throughout the Netherlands.

The purpose of this project was to evaluate CycleRAP pilot trials and to complete a comprehensive literature review with the aim of strengthening the link between the CycleRAP model and available evidence. To do this, the project was broken up into three phases:

1. A preliminary review of the CycleRAP model and any existing evidence (i.e. related studies) documented to understand the model and any challenges
2. A literature review to capture available research into bicycling crashes, their causes and their outcomes to strengthen the evidence base for the CycleRAP model, and
3. A review of the results of the pilot trials in the Netherlands and the lessons learned. This was based on consultations with the suppliers and provinces involved in pilot projects.

Detailed findings and/or recommendations for each phase are provided in sections 2.3 (phase 1), 3.2 and 3.3 (phase 2) and 4.2 (phase 3) above.

Overall, the study successfully achieved its aims. As a result, ANWB and iRAP now have a deeper appreciation for:

- What worked well and limitations of the CycleRAP pilot projects. This knowledge can be used in the next phase of CycleRAP development.
- There is a better appreciation for how to optimise the model for implementation, including the need for improved product support, communications and training.
- Where possible, evidence supporting the current CycleRAP attributes (version 1.3) was located and documented (in the literature review).

Next steps

iRAP has a suite of evidence-based and globally-applicable protocols and tools including Crash Risk Mapping, Star Ratings and Fatality and Serious Injury Estimations. CycleRAP, as a potential part of iRAP's suite of tools, is more than just a risk model. It must be:

- A tool of comparable quality that is both globally applicable and evidence based
- Be commercially viable to use, in that it is cost effective, efficient, user friendly and produces something of value to the end user, and
- Does not create confusion and/or conflict with existing tools (such as the Star Rating bicyclist model).

Developing a model that meets this criteria is no small task. It requires balancing (and managing the trade-offs) between the model design (and its 'intelligence') and factors such as the cost and time required to collect the input data required and the design of user interfaces to both use the model and analyse its results.

A lot of effort was invested in the development of the CycleRAP model and the pilot trials. Although the findings of this evaluation did identify some limitations, the work which has been done to this point is a strong basis on which further CycleRAP development can occur.

The biggest challenge facing CycleRAP is the weakness of the evidence available for crash types not involving motor vehicles. Further development of the model would benefit from simplification which would bring it closer to the level of available evidence.

Data collection is another major consideration in for operationalising any model. Capability and technology that enables fast and efficient (and increasingly cost-effective) data collection and processing has eclipsed manual data collection techniques. To maximise the potential application and uptake of the model, the CycleRAP model should be optimised to facilitate automated data collection and processing.

Upon completion of this study, iRAP has established CycleRAP Advisory Group which consists of a range organisations to help inform the future development of the CycleRAP model, including academics, mobility clubs, cycling advocates, and companies.

Subsequent discussions on the future of CycleRAP drew on the outcomes of this study and have led to planning for a second generation of the model. A CycleRAP position paper has since been completed which:

- Defines what CycleRAP is and what it is aiming to do (and what problem it seeks to address)
- Who the target users and beneficiaries are
- How the model will be used
- Where CycleRAP is now
- The development plan and required resourcing.

The recommendations for the model development (based on the findings of this study) are:

- Ensure the model is underpinned by solid research and evidence
- Improve the model's ability to capture the risk of non-collision crashes more accurately
- Reduce the data inputs required so the model is more cost effective and efficient to use
- Improve user support (manuals and training)
- Modify the model's risk scoring mechanisms, and
- Create additional functionality so the model can recommend safety treatments.

APPENDIX A: CYCLERAP VERSION 1.3 ATTRIBUTES

Note: Starred attributes (*) were not collected in pilot trials.

Column ID	Column letter	Group	Attribute name	Type	Cat ID	Category
1	A	Location attributes	Coder name	Text	NA	NA
2	B	Location attributes	Coding date	Text	NA	NA
3	C	Location attributes	Road survey date	Text	NA	NA
4	D	Location attributes	Image reference	Text	NA	NA
5	E	Location attributes	Road name	Text	NA	NA
6	F	Location attributes	Section	Text	NA	NA
7	G	Location attributes	Distance	Text	NA	NA
8	H	Location attributes	Length	Text	NA	NA
9	I	Location attributes	Latitude - start	Text	NA	NA
10	J	Location attributes	Longitude - start	Text	NA	NA
11	K	Location attributes	Latitude - end	Text	NA	NA
12	L	Location attributes	Longitude - end	Text	NA	NA
13	M	Location attributes	Landmark	Text	NA	NA
14	N	Location attributes	Comments	Text	NA	NA
15	O	Location attributes	Carriageway	Category	1	Carriageway A of a divided road
					2	Carriageway B of a divided road
					3	Undivided road
					6	Bicycle facility A
					7	Bicycle facility B
16	P	Location attributes	Area type	Category	1	Rural
					2	Urban
17	Q	Observed flow and speed attributes	Bicycle observed flow*	Category	1	None
					2	1 bicycle
					3	2 to 3 bicycles
					4	4 to 5 bicycles
					5	6 to 7 bicycles
					6	8+ bicycles
18	R	Observed flow and speed attributes	Pedestrian observed flow across the road*	Category	1	None
					2	1 pedestrian across the road
					3	2 to 3 pedestrians across the road
					4	4 to 5 pedestrians across the road
					5	6 to 7 pedestrians across the road
					6	8+ pedestrians across the road

Column ID	Column letter	Group	Attribute name	Type	Cat ID	Category
19	S	Observed flow and speed attributes	Pedestrian observed flow along – left*	Category	1	None
					2	1 pedestrian along driver-side
					3	2 to 3 pedestrians along driver-side
					4	4 to 5 pedestrians along driver-side
					5	6 to 7 pedestrians along driver-side
					6	8+ pedestrians along driver-side
20	T	Observed flow and speed attributes	Pedestrian observed flow along – right*	Category	1	None
					2	1 pedestrian along passenger-side
					3	2 to 3 pedestrians along passenger-side
					4	4 to 5 pedestrians along passenger-side
					5	6 to 7 pedestrians along passenger-side
					6	8+ pedestrians along passenger-side side
21	U	Observed flow and speed attributes	Powered two wheeler observed flow*	Category	1	None
					2	1 motorcycle
					3	2 to 3 motorcycles
					4	4 to 5 motorcycles
					5	6 to 7 motorcycles
					6	8+ motorcycles
22	V	Observed flow and speed attributes	Speed limit	Category	1	30km/h
					3	40km/h
					5	50km/h
					7	60km/h
					9	70km/h
					11	80km/h
					13	90km/h
					15	100km/h
					17	110km/h
					19	120km/h
					21	130km/h
					23	140km/h
					25	>=150km/h
					26	15km/h
					27	20km/h
					28	25km/h
					31	<20mph
					33	30mph
					35	40mph
					37	50mph
					39	60mph
					41	70mph
					43	80mph
					44	85mph
					45	>=90mph
23	W	Observed flow and	Speed management	Category	1	Not present

Column ID	Column letter	Group	Attribute name	Type	Cat ID	Category
		speed attributes				
					2	Present
24	X	Bicycle and Pedestrian	Bicycle facility type	Category	1	Segregated path with barrier
					2	Segregated path >1m
					3	On-road lane
					4	None
					6	Signed shared roadway
					8	Segregated path <1m
					9	Shared space
					10	Cars are guests
25	X	Bicycle and Pedestrian	Bicycle facility user mix	Category	1	Bicycle only
					2	Bicycle and pedestrian
					3	Bicycle and light moped (<= 25km/h)
					4	Bicycle and moped (<=45km/h)
26	Y	Bicycle and Pedestrian	Bicycle crossing	Category	1	Not applicable/not crossing road
					2	unsignalised
					3	signalised
					4	unsignalised raised
					5	signalised raised
					6	cycle path
					7	cycle roundabout
					8	unsignalised crossing with refuge island
					9	signalised crossing with refuge island
					10	Crossing without facility
27	Z	Bicycle and Pedestrian	Bicycle crossing quality	Category	1	Adequate
					2	Poor
					3	Not applicable
28	AA	Bicycle and Pedestrian	Pedestrian crossing - inspected road	Category	1	Grade separated facility
					2	Signalised with refuge
					3	Signalised without refuge
					4	Unsignalised marked crossing with refuge
					5	Unsignalised marked crossing without a refuge
					6	Refuge only
					7	No facility
					14	Unsignalised raised marked crossing with refuge
					15	Unsignalised raised marked crossing without refuge
					16	Raised unmarked crossing with refuge
					17	Raised unmarked crossing without refuge
29	AB	Surface attributes	Bicycle facility surface / grip	Category	1	Sealed - adequate
					2	Sealed - medium
					3	Sealed - poor
					4	Unsealed - adequate
					5	Unsealed - poor
					6	Not applicable
30	AC	Surface attributes	Bicycle facility width	Category	1	0 to 1.0m
					2	1.0 to 1.5m
					3	1.5 to 2.0m

Column ID	Column letter	Group	Attribute name	Type	Cat ID	Category
					4	2.0 to 2.5m
					5	2.5 to 3.0m
					6	3.0 to 3.5m
					7	3.5 to 4.0m
					8	>4.0m
					9	Not applicable
31	AD	Surface attributes	Bicycle facility width restriction	Category	1	Not present
					2	Present
32	AE	Surface attributes	Bicycle facility centre line	Category	1	Not present
					2	Present
33	AF	Surface attributes	Road surface / grip	Category	1	Sealed - adequate
					2	Sealed - medium
					3	Sealed - poor
					4	Unsealed - adequate
					5	Unsealed - poor
					6	Not applicable
34	AG	Surface attributes	Road lane width	Category	1	Wide (≥ 3.25m to < 4.25m)
					2	Medium (≥ 2.75m to < 3.25m)
					3	Narrow (≥ 1.75m to < 2.75m)
					4	Very wide (≥ 4.25m)
					5	Very narrow (≥ 0m to < 1.75m)
35	AH	Surface attributes	Road number of lanes	Category	1	One
					2	Two
					3	Three
					4	Four or more
					5	Two and one
					6	Three and two
36	AJ	Surface attributes	Road condition	Category	1	Good
					2	Medium
					3	Poor
37	AK	Surface attributes	Road delineation	Category	1	Adequate
					2	Poor
38	AL	Surface attributes	Road shoulder rumble strips	Category	1	Not present
					2	Present
39	AM	Side attributes	Bicycle facility edge delineation - left	Category	1	Adequate
					2	Poor
40	AN	Side attributes	Bicycle facility edge transition – left	Category	1	Adequate
					2	Moderate
					3	Poor
41	AO	Side attributes	Side surface quality – left	Category	1	Smooth
					2	Uneven
					3	Rough
42	AP	Side attributes	Side object – left	Category	1	Safety barrier - metal
					2	Safety barrier - concrete
					3	Safety barrier - motorcycle friendly
					4	Safety barrier - wire rope

Column ID	Column letter	Group	Attribute name	Type	Cat ID	Category
					5	Aggressive vertical face
					6	Upwards slope - roll over
					7	Upwards slope - no roll over
					8	Deep drainage ditch
					9	Downwards slope
					10	Cliff
					11	Tree >=10cm
					12	Sign/ post./pole >=10cm
					13	Rigid structure/bridge or building
					14	Semi-rigid structure or building
					15	Unprotected safety barrier end
					16	Large boulders >=20cm high
					17	No object
					18	Bushes
					19	parking
					20	deep water
					21	Sign/ post./pole <10cm
					22	Road lane
43	AQ	Side attributes	Side distance – left	Category	1	0m
					2	0 to 0.5m
					3	0.5 to 1m
					4	1m to 2m
					5	2 to 5m
					6	5 to <10m
					7	>=10m
43	AQ	Side attributes	Paved shoulder – left	Category	1	Wide (≥ 2.4m)
					2	Medium (≥ 1.0m to < 2.4m)
					3	Narrow (≥ 0m to < 1.0m)
					4	None
44	AR	Side attributes	Land use - left	Category	1	Undeveloped areas
					2	Farming and agricultural
					3	Residential
					4	Commercial
					6	Educational
					7	Industrial and manufacturing
45	AS	Side attributes	Bicycle facility edge delineation - right	Category	1	Adequate
					2	Poor
46	AT	Side attributes	Bicycle edge transition – right	Category	1	Adequate
					2	Moderate
					2	Poor
47	AU	Side attributes	Side surface quality – right	Category	1	Smooth
					2	Uneven
					3	Rough
48	AV	Side attributes	Side object – right	Category	1	Safety barrier - metal
					2	Safety barrier - concrete
					3	Safety barrier - motorcycle friendly
					4	Safety barrier - wire rope
					5	Aggressive vertical face
					6	Upwards slope - roll over

Column ID	Column letter	Group	Attribute name	Type	Cat ID	Category
					7	Upwards slope - no roll over
					8	Deep drainage ditch
					9	Downwards slope
					10	Cliff
					11	Tree >=10cm
					12	Sign/ post./pole >=10cm
					13	Rigid structure/bridge or building
					14	Semi-rigid structure or building
					15	Unprotected safety barrier end
					16	Large boulders >=20cm high
					17	No object
					18	Bushes
					19	Parking
					20	Deep water
					21	Sign/ post./pole <10cm
					22	Road lane
49	AW	Side attributes	Side distance – right	Category	1	0m
					2	0 to 0.5m
					3	0.5 to 1m
					4	1m to 2m
					5	2 to 5m
					6	5 to <10m
					7	>=10m
50	AX	Side attributes	Paved shoulder - right	Category	1	Wide (≥ 2.4m)
					2	Medium (≥ 1.0m to < 2.4m)
					3	Narrow (≥ 0m to < 1.0m)
					4	None
51	AY	Side attributes	land use - right	Category	1	Undeveloped areas
					2	Farming and agricultural
					3	Residential
					4	Commercial
					6	Educational
					7	Industrial and manufacturing
52	AZ	Mid-block attributes	Bicycle facility one way / Two way	Category	1	One way
					2	Two way
53	BA	Mid-block attributes	Curvature	Category	1	Straight or gently curving
					2	Moderate
					3	Sharp
					4	Very sharp
54	BB	Mid-block attributes	Curve quality	Category	1	Adequate
					2	Poor
					3	Not applicable
55	BC	Mid-block attributes	Grade	Category	1	≥ 0% to <7.5%
					4	≥ 7.5% to <10%
					5	≥ 10%
56	BD	Mid-block attributes	Obstacle in path	Category	1	None
					2	Pole
					3	Island

Column ID	Column letter	Group	Attribute name	Type	Cat ID	Category
57	BE	Mid-block attributes	Obstacle in path quality	Category	1	Adequate
					2	Poor
					3	Not applicable
58	BF	Mid-block attributes	Tram rails	Category	1	Perpendicular / angled
					2	Parallel
					3	not present
59	BG	Mid-block attributes	Sight distance	Category	1	Adequate
					2	Poor
60	BH	Mid-block attributes	Street lighting	Category	1	Not present
					2	Present
61	BI	Mid block attributes	Vehicle parking - road side	Category	1	None
					2	One side
					3	Two sides
62	BJ	Intersection attributes	Intersection type	Category	1	Merge lane
					2	Roundabout
					3	3-leg unsignalised with protected turn lane
					4	3-leg unsignalised with no protected turn lane
					5	3-leg signalised with protected turn lane
					6	3-leg signalised with no protected turn lane
					7	4-leg unsignalised with protected turn lane
					8	4-leg unsignalised with no protected turn lane
					9	4-leg signalised with protected turn lane
					10	4-leg signalised with no protected turn lane
					12	None
					13	Railway Crossing - passive (signs only)
					14	Railway Crossing - active (flashing lights / boom gates)
					15	Median crossing point - informal
					16	Median crossing point - formal
					17	Mini roundabout
63	BK	Intersection attributes	Intersection quality	Category	1	Adequate
					2	Poor
					3	Not applicable
64	BL	Intersection attributes	Intersection channelization	Category	1	Not present
					2	Present
					3	Not applicable
65	BM	Intersection attributes	Intersecting road volume	Category	1	≥15,000 vehicles
					2	10,000 to 15,000 vehicles
					3	5,000 to 10,000 vehicles
					4	1,000 to 5,000 vehicles
					5	100 to 1,000 vehicles
					6	1 to 100 vehicles
					7	Not applicable
67	BO	Intersection attributes	Intersection prioritization	Category	1	Not present
					2	Present
					3	Not applicable
68	BP	Intersection attributes	Property access	Category	1	Commercial Access ≥1
					2	Residential Access ≥3
					3	Residential Access <3

Column ID	Column letter	Group	Attribute name	Type	Cat ID	Category
					4	None
69	BQ	Intersection attributes	Property access quality	Category	1	Adequate
					2	Poor
					3	Not applicable
70	BR	Post-coding attributes	Bicycle peak hour flow	Category	1	none
					2	1 to 5
					3	6 to 25
					4	26 to 50
					5	51 to 100
					6	101 to 200
					7	201 to 300
					8	301 to 400
					9	401 to 500
					10	501 to 900
					11	900+
71	BS	Post-coding attributes	Pedestrian peak hour flow across	Category	1	none
					2	1 to 5
					3	6 to 25
					4	26 to 50
					5	51 to 100
					6	101 to 200
					7	201 to 300
					8	301 to 400
					9	401 to 500
					10	501 to 900
					11	900+
72	BT	Post-coding attributes	Pedestrian peak hour flow along - left	Category	1	none
					2	1 to 5
					3	6 to 25
					4	26 to 50
					5	51 to 100
					6	101 to 200
					7	201 to 300
					8	301 to 400
					9	401 to 500
					10	501 to 900
					11	900+
73	BU	Post-coding attributes	Pedestrian peak hour flow along - right	Category	1	none
					2	1 to 5
					3	6 to 25
					4	26 to 50
					5	51 to 100
					6	101 to 200
					7	201 to 300
					8	301 to 400
					9	401 to 500
					10	501 to 900
					11	900+
74	BV	Post-coding attributes	Light power two wheel flow	Category	1	none
					2	1 to 5
					3	6 to 25
					4	26 to 50
					5	51 to 100

Column ID	Column letter	Group	Attribute name	Type	Cat ID	Category
					6	101 to 200
					7	201 to 300
					8	301 to 400
					9	401 to 500
					10	501 to 900
					11	900+
75	BW	Post-coding attributes	Motorcycle %	Category	2	0%
					3	1% - 5%
					4	6% - 10%
					5	11% - 20%
					6	21% - 40%
					7	41% - 60%
					8	61% - 80%
					9	81% - 99%
					10	100%
76	BX	Post-coding attributes	Heavy good vehicle %	Category	2	0%
					3	1% - 5%
					4	6% - 10%
					5	11% - 20%
					6	21% - 40%
					7	41% - 60%
					8	61% - 80%
					9	81% - 99%
					10	100%
77	BY	Post-coding attributes	Vehicle AADT	Text	NA	NA
78	BZ	Post-coding attributes	Operating Speed (85th percentile)	Category	1	<30km/h
					2	35km/h
					3	40km/h
					4	45km/h
					5	50km/h
					6	55km/h
					7	60km/h
					8	65km/h
					9	70km/h
					10	75km/h
					11	80km/h
					12	85km/h
					13	90km/h
					14	95km/h
					15	100km/h
					16	105km/h
					17	110km/h
					18	115km/h
					19	120km/h
					20	125km/h
					21	130km/h
					22	135km/h
					23	140km/h
					24	145km/h
					25	>=150km/h
					26	15km/h
					27	20km/h
					28	25km/h
					31	<20mph

Column ID	Column letter	Group	Attribute name	Type	Cat ID	Category
					32	25mph
					33	30mph
					34	35mph
					35	40mph
					36	45mph
					37	50mph
					38	55mph
					39	60mph
					40	65mph
					41	70mph
					42	75mph
					43	80mph
					44	85mph
					45	>=90mph
79	BY	Post-coding attributes	Operating Speed - bicycles	Category	1	0 to 5km/h
					2	5 to 10km/h
					3	10 to 15km/h
					4	15 to 20km/h
					5	20 to 25km/h
					6	25 to 30km/h
					7	30 to 35km/h
					8	35 to 40km/h
					9	>40km/h
					10	0 to 5mph
					11	5 to 10mph
					12	10 to 15mph
					13	15 to 20 mph
					14	20 to 25mph
					15	>25mph

APPENDIX B: STUDIES REFERENCED IN THE CYCLERAP MODEL

		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. Publication Date: 2011																	X	X			
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				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
	Florida Authors: Abdel-Aty et al. Publication Date: MAY, 2014																					
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 Uncontrolled Locations: Executive Summary and Recommended Guidelines Authors: Zegeer et al. Publication Date: 2002						X											X	X			
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														

		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
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 Authors: Haque et al. Publication Date: JAN, 2010																				X	
29	Study Title: Evaluation of the Impacts of Differential Speed Limits on Interstate Highways in Idaho Authors: Dixon et al.																				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: OCT, 2012																					
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	
	Total	*1*	*2*	*3*	*10*	*3*	*5*	*2*	*1*	*1*	*6*	*1*	*3*	*1*	*1*	*1*	*13*	*7*	*7*	*1*	*15*	*3*

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*](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

APPENDIX C: LITERATURE REVIEWS – DETAILED METHODOLOGY AND FINDINGS

SWOV – Dutch literature summary

Methodology and findings

SWOV reviewed literature specific to the effect of infrastructural factors on cycle crash types not involving motor vehicles.

In order to identify relevant literature, scientific research applications such as Web of Knowledge, SCOPUS, Google Scholar and Science Direct were consulted and searched using search terms (stated in the Dutch language) such as “single sided cycling crashes AND infrastructure”, “cycl* AND (crash* OR accident*) AND infrastructure”, ”Cycl* AND accident*”, “Cycl* AND infrastructure”. These did not reveal any relevant Dutch literature particularly on single sided cycling crashes. In addition, Google and www.swov.nl was used to find relevant literature or reports in the Dutch language.

In total, eight Dutch-language reports on cycling crashes were found. These reports were published by SWOV (3), TNO (2) and The Directorate-General for Public Works and Water Management (3). Of these reports, three investigated cyclist’s behaviour using video observation (Hair-Buijssen & van der Horst; de Goede, Obdeijn & van der Horst, 2012; Janssen, 2017). Two reports were based on questionnaires sent out to victims of one-sided cycling crashes who were admitted to a hospital (Ormel, Klein Wolt & den Hertog, 2009; Schoon & Blokpoel, 2000), and another visited the crash locations of these victims who were approached with a survey (Schepers, 2008).

Davidse et al. (2014) reported an in-depth study of crash locations of cyclists aged 50 and Wijlhuizen et al. (2016) annotated cyclist infrastructure to determine their influence on cyclist crashes.

The results mostly show concurrent results. Bicyclists crashes (all crash types) seem to be related to:

- The width of a cycling path
- The quality of the road surface
- The presence of hazardous objects and features (e.g. tram rails)
- Cyclist- and motor vehicle volumes
- Roundabout density
- Intersection density

Multiple studies reported that the width of the cycling path, the quality of the road surface and the presence of hazardous objects and features are factors that influenced cycling crashes. Of the reported studies, only Wijlhuizen *et al.* (2016) investigated cyclist and motor vehicle volumes, intersection density and roundabout density and found these to be relevant factors.

Three studies sent out questionnaires to victims (survey studies) of traffic accidents who were hospitalised. Two of these were based purely on the questionnaire results (Ormel, Klein Wolt & den Hertog, 2009; Schoon & Blokpoel, 2000), whereas the third (Schepers, 2008) visited 80 crash sites in addition to the questionnaire in order to identify infrastructure characteristics.

Surface quality and obstacles

All three of the above mentioned survey studies reported that the type and quality of the road is a prevalent cause in one-sided bicycle crashes. Cycling paths and tracks might contain potholes or have underlying tree roots that cause bumps. Additionally, obstacles in or on the cycling path such as tram tracks, poles, trees, animals or parked cars are a further cause of cycling crashes. Also, cyclists might have to evade such obstacles causing them to fall or impede other cyclists. They swerve onto the adjacent verge or bank and/or they collide with something or someone else while evading (Ormel et al. 2000; Schepers, 2008).

Cycle path width and sidewalk encroachment

Hair-Buijssen & van der Horst (2012) used video cameras on locations in urban and recreational areas. They found that the width of the cycling path influenced the number of conflicts between cyclists per 1000 cyclists. On the wider cycling path (a T-junction in the Dutch city of Eindhoven) with approach cycle lane widths of between 4.95 and 5.46m, there were less serious conflicts (1.6/h) than on a 3.7m wide cycling path in Amsterdam (3.0/h); both were two-way cycling paths. Furthermore, cyclists in Amsterdam were 5 times more likely to have a conflict with a cyclist coming from the opposite direction (Hair-Buijssen & van der Horst).

The follow-up of this study found the same results on one way cycling paths in the Dutch cities of Utrecht and The Hague (de Goede, Obdeijn & van der Horst, 2012). More cycling conflicts (e.g. overtaking conflicts) happened on a narrow cycling path (1.75m) compared to wider paths (both 2.25m). They also found that narrow cycling paths are host to relatively many overtaking crashes because there is limited room to overtake or evade. Furthermore, wider cycling paths showed more bicyclists cycling on the wrong side of the cycle path.

Video observation was also used by Janssen (2017) to examine whether vertical, mountable or diagonal kerbs affected the extent that cyclists encroach on sidewalks. Not surprisingly, mountable kerbs lead to higher encroachment.

Interestingly, the width of cycling paths was found to be one of the reasons cyclists encroach onto the sidewalk. It was found that the wider cycling paths allowed for more room to overtake, manoeuvre, evade and being overtaken, while narrower paths allowed for less room to do so. This was also found by Davidse et.al (2014) in their in-depth study crashes among of senior cyclists (50+). Some crash victims reported that the cycling path was too narrow. There was not enough room to evade, overtake or to prevent a collision with objects next to the cycle path . Elderly cyclists also tended to cycle into objects when they were hazardously placed or when they were unexpected (without appropriate warning).

Traffic volume, unsafe road/path features and density of intersections and roundabouts

Wijlhuizen *et al.* (2014) used 360° images of streets in Amsterdam to index road characteristics. This was done on all 50 km/h roads with and without cycling paths or lanes. Annotators inspected 25m road segments and noted down predefined infrastructure features. The authors used cyclist's crash density (no. of crashes/1000m) as a dependant variable and crash data were obtained from the registry kept by the ambulance services in the Netherlands. They found that:

- Higher cyclist and higher motor vehicle volumes related to a higher number of cyclist crashes.
- The number of unsafe aspects of the vertical and horizontal alignment of cyclist infrastructure, (unclear signage and diminished visibility of other road users, concurrent use by other vehicles/persons, lighting, sudden narrowing, sharp curves) were related to a higher number of cyclist crashes.
- Finally, a higher density of roundabouts as well as a higher intersection density (both large and small intersections) was correlated to higher cycling crash rates.

Wijlhuizen *et al.* (2014) investigated injury severity by dividing the victims into two groups: (1) the cyclists that were taken to a hospital after the incident and (2) cyclists that were not. There appeared to be no correlation between cycling crash severity and infrastructural features; the same results were found for both groups (which were similar to the results found on the whole group). In contrast with other studies, no influence was found of objects or the quality of the infrastructure. This is because there were very few objects (like poles) present on the cycling paths so the relationship could not be found. However, the authors did find an indicative relationship that bad road quality leads to more crashes, but the relationship was not significant.

Most studies in The Netherlands reported results based on cycling paths in major cities. It is uncertain what the effects are on different cycling path types, on less busy locations or in rural areas. Some studies used retrospective surveys which might suffer from recall errors and questionnaire return bias. Caution is advised when generalizing the presented results to other cycling infrastructure.

Table 6: Relevant Dutch studies identified

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes (*Additional remarks by SWOV)
Hair-Buijssen, de, S.H.H.M & Horst, van der, A.R.A. 2012. Conflicten op fietspaden – fase 1. TNO Rapport R10084.	Amsterdam and Eindhoven, Netherlands	Amsterdam: Two-way bicycle path. Eindhoven: T-junction of two way bicycle lanes	Cycling path (cyclist-cyclist, cyclist-pedestrian). .	Cyclist behaviour was recorded using video imaging. This was done on two cycling paths in Amsterdam (two-way cycling path, width 3.7m) and Eindhoven (T-junction; through: two-way cycling path width between 5.15m and 5.46m. Joining: 4.94m). The videos showed that the narrower bicycle path in Amsterdam hosts more serious conflicts (3.02/hour) compared to the wider bicycle path in Eindhoven (1.625/hour). When relating this to the traffic intensities, bicyclists are twice as likely to be involved in a serious traffic conflict on the Amsterdam cycle path compared to Eindhoven. When specifically looking at a conflict between a cyclist and a pedestrian, the Amsterdam cycle path showed that 23 out of 40 serious traffic incidents were of this type, while Eindhoven showed none. When looking at a conflict between two cyclists going in the opposite direction, Amsterdam cyclists were 5 times as likely to have a conflict of this type compared to Eindhoven.	The most important difference (aside from the layout) between the two locations is the width of the cycle paths. The cyclists in Eindhoven have more room to cycle, leading to fewer incidents between cyclists because there is room to evade. * This is an explorative feasibility study to test the method of data collection. Cyclist risk was not measured, only chance of conflict.
Goede, de, M., Obdeijn, C., Horst, van der, A.R.A. 2012. Conflicten op fietspaden – fase 2. TNO Rapport R10084.	Utrecht, The Hague and Westland Municipality, Netherlands.	Two one-way cycling paths in Utrecht and one in The Hague. Additionally, two two-way recreational cycling paths in the municipality of Westland.	Cyclist-cyclist, cyclist-pedestrian.	A study of cycling paths in three municipalities (Utrecht, the Hague and Westland) in the Netherlands used video observations to examine cyclist behaviour. The video analysis showed that: • More conflicts happen on the narrow cycling path (1.75m wide). • Relatively many overtaking conflicts happen due to high cyclist volumes, narrowness of the cycling path and the limited room for evading. • Crossing trajectories are the cause of many conflicts relatively speaking.	Overall, wider cycling paths show less (serious) conflicts compared to narrow cycling paths while at the same time higher speeds and more cycling on the wrong side of the road are observed. However, more flanking conflict arises because of the higher prevalence of mopeds on these wider paths. * Cyclist volumes were determined by counting cyclists

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes (*Additional remarks by SWOV)
				When the cycling paths gets wider (2.25m), mopeds are the main cause of flanking conflict and these conflicts are more serious. This is mainly because of their increased prevalence on these paths and their ability to reach higher speeds more easily and quickly on a wider cycling path. Considering the recreational cycling paths, whenever a centre line is missing, more cyclists are observed cycling on the wrong side of the road. Cyclists cycle at the same relative distance from the pavement edge. Meaning that cyclist cycle closer to the sidewalk on narrow paths when compared to the wider paths. On narrow recreational cycling paths serious conflicts arise when race cyclists overtake and recreational cyclists meet in opposite direction.	for 15 minutes. It is unclear at which time of day this was done. Furthermore, a cap of 32 was set on the number of followed cyclists each half hour.
Ormel, W., Klein Wolt, K., den Hertog, P. 2009. Enkelvoudige fietsongevallen. Een LIS-vervolgonderzoek. Consument Veiligheid.	The Netherlands. Hospitalised cyclists (n=723) that had a one-sided accident where approached for a survey two months after their accidents.	Cycling path and roads. The specific type is unknown.	Single bicycle crashes	A survey on the causes of one-sided cycling accidents revealed that infrastructural factors are: Road quality. In some cases there is not a lot that can be done (e.g. a wet road surface). In other cases however, cyclists fall because of holes in the road, tram tracks or tree roots that grow underneath the path, creating “bumps”. Evasive manoeuvres leading to a fall when cyclists encounter an object. Additional information on the characteristics of one-sided accidents. Risk was calculated by using mobility numbers: • Children up to 11 years old and seniors above 65 are at a higher risk of being involved in a one-sided cycling accident. • Men aged 55 and lower have a higher risk of being involved in a one-sided cycling accident	The biggest infrastructural factors that cause one sided accidents are the road quality and evasive manoeuvres. * This is retrospective research which is heavily dependent on the (correct) recollection of the victims. Additionally, the risks found for children and seniors were likely to be cause due to deteriorating or underdeveloped cycling skills. The increased risks at night and during the weekends might be heavily influenced by alcohol use.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes (*Additional remarks by SWOV)
				compared to women. At the age of 55 and above, women are at a higher risk than men. The risk of having a one-sided cycling accident is higher during the night and during the weekend, with the highest risk being found during weekend nights.	
Schepers, P. 2008. De rol van infrastructuur bij enkelvoudige fietsongevallen. Directoraat-Generaal Rijkswaterstaat, Dienst Verkeer en Scheepvaart DVS, Delft.	Netherlands. A continuation of Ormel, Klein Wolt & Den Hartog; accident locations were visited and documented (n=80).	Cyclings path and roads.	Single and cyclist-cyclist crashes on cycling paths and lanes.	One-sided cycling accidents happen most often on streets and bicycle paths or lanes (80%). The resulting 20% happens on footpaths, parking spaces and unpaved roads. One-sided cycling accidents happen because of a combination of one or more infrastructural components. Analysis of one-sided crash locations on cycling paths revealed that accidents most often happen on/while: • Entering the bank or hitting the kerb. • Colliding with poles • Slippery road surface Specifically on cycling lanes: • Entering the bank or hitting the kerb • Collisions on road narrows • Accidents with road slits • Accidents with bumps, pits and items on the road surface. • Collisions with parked cars and open car doors.	Accidents happen because of: Reduced recognisability of obstacles and the road course in bends. A combination of narrow cycling paths and behavioural aspects leading to deviations of trajectory and a lessened perception The lack of a physical barrier between the cyclist and tramlines. The lack of a parking strip. Cycling path is not always a straight line due to parked cars. Slipping due to slippery surfaces, narrow tires on racing bikes and edges of sidewalks, concrete slabs etc. * The results are based on absolute numbers, without correction of exposure. While some factors show more accidents, this does not mean a higher risk.
Schoon, CC., & Blokpoel, A. 2000. Frequentie en oorzaken van enkelvoudige	Netherlands	Cycling path	One-sided cycling crash	A survey gathered from 1600 hospitalized cyclists revealed that 47% had a one-sided accident. These one-sided accidents could be accounted to:	The sample used was stratified and leaned towards more serious accidents.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes (*Additional remarks by SWOV)
fietsongevallen. SWOV R-2000-20				• Stunting with the bike (27%) • Foot between the spokes (18%) • Defect of the bike (13%) • Bad road surface (8%) • Falling while cornering (7%) • Baggage (6%) Slipperiness of the cycling path were often also the cause of one-sided accidents. Furthermore, 12% collided with objects, animals or parked cars: • -36% collided with the sidewalk • -18% collided with cycling path poles • -11% collided with parked cars • -10% collided with trees/wooden poles • -9% collided with animals • 16% collided with other obstacles/items Finally, 40% collided with other traffic.	
Janssen, B. (2017) Verkeersveiligheid van trottoirbanden. Rijkswaterstaat Water Verkeer en Leefomgeving.	Netherlands	Cycling paths with or without kerbs.	One-sided cyclist, cyclists-cyclist, cyclist-pedestrian	Cyclist behaviour was recorded using video observation. These revealed that cyclists tend to encroach onto the sidewalks most often when there is no kerb. They are less likely to do so when the kerb is mountable and the least likely with vertical kerbs. The most common reason for cyclist to ride on the sidewalk is to overtake or when they are being overtaken. Furthermore, cyclists tend to cycle closer to the sidewalk when they are cycling next to one another. Cyclists tend to cycle closer to the edge when they cycle on a one-way cycle path compared to a two-way cycle path. The authors conclude that the width of a cycling path is essential, allowing for more room to	While a horizontal sidewalk edge is the most crossed over, cyclist tend to adapt their speed and behaviour when the situation changes. Therefore, it was concluded that there is no additional risk in having horizontal or diagonal edges, compared to the vertical edge. The width of cycling paths however showed to be a determining factor of kerb encroachment.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes (*Additional remarks by SWOV)
				cycle, overtake and being overtaken without having to get onto the sidewalk.	* No accidents were observed or analysed and only 45 cyclists were used in the analysis. Cyclist intensities were not measured.
Davidse, R., Boele, M., Duivenvoorden, K & Louwerse, Fietsongevallen van 50-plussers in Zeeland. Hoe ontstaan ze en wat kunnen we eraan doen? R-2014-16A, SWOV, Den Haag	Netherlands	Cycling path/street	One-sided cyclists, cyclist-cyclist.	A qualitative in-depth study into 35 accidents of cyclists aged 50 and over revealed that in 23% of the crashes the cycling path/street was narrow. Cyclists did not have enough space to evade, overtake or prevent a collision with an object. Furthermore, it was observed that the width of a cycling path plays a role especially in collisions with objects and being touched by other cyclists. Additionally, in 11% of the accidents an obstacle was placed hazardously or not announced (such as a pole), causing the cyclist to miss the object and crash into it.	The results are based on a small amount of cyclists. It is therefore difficult to generalize and to determine risks.

WRI – Spanish/Portuguese literature summary

Methodology and findings

WRI sourced literature using three approaches:

1. Road safety journals were reviewed (e.g. Accidents Analysis and Prevention and Transportation Research Part F) for cycling road safety articles using the key word *cycl** and screening for abstracts related to crashes and accidents from authors of Spanish- or Portuguese-speaking countries. Very few were found.
2. Scientific research applications such as Google Scholar, CAPES (Brazilian platform) and SCOPUS were searched using different key words combinations. These key word combinations were searched in Portuguese and Spanish. They always involved one key word related to cycling or cycling infrastructure (*Cicl*, Bici**) and one word related to road safety and/or infrastructure such as 'bicycle', 'traffic accident', 'road safety', 'crashes', 'cycle track/path/lane/route', 'cyclist', 'bike', 'intersection', 'junction', 'bike box', 'injuries', 'fatalities', 'active mobility', and 'non-motorized vehicles'.
3. Websites containing relevant city reports and other organizations' studies were searched. These non-academic documents provided interesting information about data collected by the municipalities (e.g. Instituto Cordial, 2018; Unidad de Seguridad Vial y Transportes, 2015).

In total, 38 publications were found; 26 directly related to cycling road safety and 12 others with relevant information about cycling in Latin America. 13 of the 26 publications directly related to cycling road safety presented conclusions about cycling infrastructure. These 13 publications, which were subsequently summarised, included and discussed the following topics:

- Risk factors for bicycle crashes (da Silva 2018; Ruiz, 2015; Espinoza-Bolaños, 2017),
- Mapping the density of cyclist accidents (Leite, 2015)
- Road safety in cycle paths (Riccardi, 2010; da Silva, 2016)
- Cycle lanes (Junior, 2016; Riccardi, 2010)
- Cycle routes (Muñoz, 2015)
- Shared streets (Junior, 2017; Instituto Cordial, 2018)
- Intersections and mid-blocks (Roldán, 2012)
- Temporary street intervention for cyclists' safety (Bacchieri, 2010)

The publications make a number of conclusions about, and connections between, road/cycling facilities and bicycle crashes, including[21]:

- Cycle lanes are often implemented instead of cycle paths considering financial costs, but some studies show that cycle lanes in streets with bus corridors or many bus stops have higher number of crashes with cyclists (Instituto Cordial, 2018).
- Bus stops and street vendors (obstacles) are related to an increase in bicycle crashes (Muñoz, 2015).
- Disconnected networks increase crash risk. In heat maps of bicycle crashes many are located at, or close to the end/beginning of cycle paths/lanes. (Leite, 2015).

[21] Most of the conclusions were found in more than one of the articles. The reference provided was the publication which contained the most analysis.

- Intersections with pedestrian crossings have a higher concentration of bicycle-pedestrian crashes (Ruiz, 2015).
- Bike boxes near traffic light junctions reduce bicycle-vehicle crashes in intersections (Junior, 2016).
- Crashes in intersections have higher chances of resulting in fatalities (da Silva, 2018).
- Analyzing bicycle crashes in urban areas in Spain, there was not a signficiant difference in the number of intersection crashes vs. non-intersection (mid-block) crashes (Roldán, 2012).

Summaries for each paper and the references are provided in Table 7 below.

Peer review observations (performed by SWOV)

A number of the studies included do not directly relate to the CycleRAP attributes or crash types. Specifically, some of the papers' findings are too generalised for the purposes of this review, are not specific to infrastructure-related factors, and/or assertions are not supported by adequate evidence of associated risk. Summaries of these papers have been retained and labelled accordingly in Table 7.

Table 7: Relevant Portuguese/Spanish studies identified

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
Ruiz; V. et al "Factores asociados al riesgo de provocar uma colisión entre un ciclista y un peatón en España, 1993-2011 / *Risk factors for provoking collision between cyclists and pedestrians in Spain, 1993-2011*" Gac Sanit, 2015:29(S1):10-15. Madrid, Spain (2015).	Madrid, Spain	Intersections, Pedestrian Crossings,	Bike-pedestrians	Objective: To identify and quantify the factors depending on pedestrians, cyclists and the environment associated with the risk of causing a collision between a cyclist and a pedestrian in Spain from 1993 to 2001. Methods: Study design: retrospective case series. Population: 1228 pedestrian-cyclist pairs involved in the same number of collisions in an urban area, only one of whom committed an infraction. Source: Register of Traffic Accidents with Victims, supported by the Spanish Traffic General Directorate. Variables: committing an infraction (yes/no), age, sex, helmet use (cyclist), hour, type of day, year, existence of sidewalk, place of accident and priority regulated. Analysis: logistic regression model to estimate the strength of the association between the pedestrian's responsibility and independent variables. The association with the cyclists' responsibility was assessed by reversing the value of the odds ratios obtained. Results: In both groups of users, the risk of causing a collision was higher in extreme ages. Female cyclists had a slightly higher risk than male cyclists, while the use of helmet had a protective effect. The risk of the pedestrian causing an accident was higher in the absence of sidewalks. Cyclists more frequently provoked accidents in crosswalks. Conclusion: We recommend the implementation of safety campaigns aimed at pedestrian and cyclists, with special attention paid to the youngest and older	Accidents between cyclists and pedestrians, that are provoked by cyclists, happen more often in pedestrian crossings.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
				people. Interventions for correct road use would also be advisable.	
Leite, M.; Neto, N.; Rosa, B."Mapeamento da densidade de acidentes com ciclistas na cidade de Montes Claros/MG / *Mapping the density of accidents with cyclists in the city of Montes Claros/MG*" ACTA Geográfica, Boa Vista, v.9, n.21, pp 82-94. Boa Vista, Brazil (2015)	Montes Claros, MG, Brazil.	Cycle path end, cycle path, roundabout, street with no bike infrastructure	No information	The Non-Motorized Transport (NMT), in which the bicycle is the most prominent, is used in cities of rich countries as a means of transportation, thus, there were improvements in the transport system for these urban spaces. However, this is not the reality of Brazilian cities, where cyclists have several difficulties to use the bicycle as a means of safe transportation. The incentive for this type of transport structuring actions permeates the city to provide safe routes for users of this type of transport, given that the bike is more vulnerable to accidents, besides the fragility of life that puts the cyclist at risk. The mining town of Montes Claros has poor road system for the size of its car fleet, thus encouraging alternative means, such as NMT would be a measure to improve the quality of urban traffic. The lack of appropriate conditions for the use of bicycles, besides the poor condition of roads and congestion makes daily accidents with cyclists in this city usual. In this context, this study aimed to analyze the concentration of accidents with cyclists in the city of Montes Claros. In this context, this study aimed to analyze the concentration of accidents involving cyclists in Montes Claros. Therefore, we applied the method of kernel density through Geographic Information System (GIS). The identification of the major points of accidents involving cyclists in urban roads showed the difficulty in reconciling data from different government agencies, while pointing out the concentration of accidents on major roads in the city.	The city has disconnected cycle paths and where the cycle paths starts or ends many accidents are registered.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
				The results point to the need to create specific transport infrastructure for cyclists vying for the space in traffic with cars and motorcycles, consequently, end up being victims of accidents.	
Muñoz, O. et al "Seguridad vial em las ciclo rutas de Bogotá em el tramo Autopista Norte calle 192 - Avenida Boyacá Calle 170 / Road safety in cycle routes of Bogotá at Autopista Norte calle 192 - Avenida Boyacá Calle 170" Universidad Católica da Colombia. Bogotá, Colombia (2015).	Bogotá, Colômbia	Cycle routes	No information	The document aims to identify and establish the magnitude of factors that influence road safety in the district system of cycle routes as possible accident factors. The study was made in a part of the network with 5km extension.	The study found that bus stops and street vendors were two great external risk factors. Parts of the cycle route lacked vertical and horizontal signage creating confusion. *Review note: Not included in attribute table. No direct/specific link to CycleRAP attributes.*
Junior, R. S.; Nodari, C. "Gestão de Atributos de Segurança Cicloviária: Avaliação das ciclofaixas de Porto Alegre/ Management of cycling safety atributes: evaluation of cycle lanes in Porto Alegre" Universidade Federal do Rio Grande do Sul. Porto Alegre, Brazil (2016)	Porto Alegre, Brazil	Cycle lanes, Bike boxes	Vehicle-bicycle, Dooring	This study has as main objective compare the perceptions of influence on the safety of cyclists with the perception of importance attributed by the managing agency to the road safety factors in the provision of cycle lanes in the city of Porto Alegre. This study proposes: (i) identify in the international literature the State of the Art in relation to road safety discussions for cyclists; (ii) identify between the traffic system actors in Porto Alegre which are main road safety factors for cyclists; (iii) analyze the influence of cycling safety factors in cycle lanes based on the perception of cyclists using cycle lanes;	Focusing on cycle lanes, it analyses which measures are considered more important for the cyclists and compare it with the perception of decision makers. It recommends the use of bike boxes in traffic light junctions. Width, signage for cyclists, reduced speeds and good quality pavement can improves safety being related to cycling crashes.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
				(iv) analyze the importance attributed by managing agency to the cycling safety factors in the provision of cycle lanes; (v) (v) identify gaps between the perception of influence on cycling safety performance (view of cyclists) with the importance given by managing agency in the provision of cycle lanes (view of managing agency). Based on the survey of factors related to cycling safety context for cycle lanes, a survey was conducted with cyclists and managers requesting the hierarchization of cycling safety attributes. From these perceptions was possible to create a chart that relates the influence on safety performance with the importance attributed to safety attributes that identifies more clearly the discrepancies and the alignments between perceptions. The results indicate improvement opportunities in cycling security attributes management in cycle lanes, and suggest that the managing agency may be prioritizing attributes that do not influence the safety performance in view of cyclists.	
Espinoza-Bolaños, J. L.; Hernández-Veja, H.; Jiménez-Romero, D. "Caracterización de la movilidad ciclista en el cantón Puntaneras, Costa Rica: resultados de los distritos com mayor cantidad de ciclistas involucrados en colisiones / *Characterization*	Cantón de Puntaneras, Costa Rica	Highways with no dedicated infrastructure, cycle paths disconnected	Vehicle-bicycle	The paper presents a study about the cycling mobility in districts of Cantón de Puntaneras, Costa Rica, with highest number of cyclists injured in bike-vehicle crashes. The cyclists were characterized within the study area considering social aspects and mobility. For example: • 75% are men, most of the trips are for shopping or commuting,	The parts of the highway with more accidents involving cyclists were also the ones with greatest cyclist flow and no dedicated infrastructure.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
***of cycle mobility at cantón Puntaneras, Costa Rica: results from districts with highest number of injuried cyclist in accidents*" Universidad de Costa Rica.** San José, Costa Rica (2017).				• 25% of the cyclists suffered traffic accidents and half of them in the last two years. In general, the trips are shorter than 4km and take less than 30 minutes. Safety items used by cyclists are very rare. This information can be used for the elaboration of a cycling master plan including interventions that improve safety and mobility.	
Junior, R. S. "Fatores que influenciam a segurança cicloviária em vias compartilhadas: uma abordagem qualitativa / *Factors that influence cycling safety in shared streets: a qualitative approach*" XXXI Congresso Nacional de Pesquisa em Transporte da ANPET. Recife, Brazil (2017)	Porto Alegre, Brazil	Streets with no dedicated infrastructure, bike boxes near traffic light junctions	Vehicle-bicycle	This paper presents a qualitative research with the objective of identifying factors that influence cycling safety from the point of view of cyclists and drivers. To carry out this research were conducted semi-structured interviews that allowed to collect opinions and perceptions of different profiles of respondents who were selected by 3 stratification variables: type of driver, gender and age group. In the interviews 18 factors were identified that influence cycling safety in shared roads, these factors were grouped in 3 dimensions: infrastructure, behaviour and bicycle + IPEs. The results of the research suggest that behavioural aspects deserve greater attention in cycling safety studies.	Behavioral aspects deserve greater attention in streets with no dedicated infrastructure both from drivers and from cyclists. Bike boxes, width, signage for cyclists, reduced speeds and good quality pavement can help. *Review note: Not included in attribute table. No direct/specific link to CycleRAP attributes*
Riccardi, J. C. "Ciclovias e ciclofaixas: critérios para localização e implantação / *Cycle paths and cycle lanes: criteria for location and implementation*" Universidade Federal do Rio Grande do Sul. Porto Alegre, Brazil (2010)	Porto Alegre, Brazil	Cycle paths and Cycle lanes, Slope, Lane width	No information	The current study analyses e discusses the criteria used to justify the location of cycle paths or cycle lanes in the urban area. It is necessary to understand which spaces the bike can share and where it needs an exclusive space, how the road characteristics, as well as the level of service of each one. Considering road characteristics, traffic, advantages and disadvantages of cycle paths and	It presents Brazilian legislation and international information about how you choose between different cycling infrastructure considering road hierarchy, speed, etc. *Review note: Not included in attribute table. No direct/specific link to CycleRAP attributes*

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
				cycle lanes you can find a solution that attends to the needs of motorized traffic and cyclists.	
Unidad de Seguridad Vial y Transporte "Inspección de Seguridad Vial enfocada a ciclistas y peatones en la Ruta Nacional 4. Tramo Bajos de Chilamate - Intersección Ruta 32 / *Road Safety Inspection focused on cyclists and pedestrians at Ruta Nacional 4. Tramo Bajos de Chilamate - Intersection Ruta 32*". Universidad de Costa Rica. San José, Costa Rica (2015).	Chilamate, Costa Rica	Highway with presence of cyclists and pedestrians. No dedicated infrastructure.	No information	It is presented the results of the road safety audit focusing on cyclists and pedestrians in Ruta Nacional 4 in the part of Tramo Chilamate - Intersection Ruta 32. The report includes recommendations for immediate implementation such as building sidewalks , signage warning about cyclists and pedestrians, pedestrian crossings, horizontal signage painting, educational campaigns for cyclists and basic road safety measures for cyclists.	This highway lacks basic infrastructure for cyclists and pedestrians. The report classified different parts of the analysed kilometres according to the risk of accidents. Some parts near *poblados* were critical. *Review note: Not included in attribute table. No direct/specific link to between attributes and crash types*
Bacchieri, G. et al "Intervenção comunitária para prevenção de acidentes do trânsito entre trabalhadores ciclistas / *A community intervention to prevent traffic accidents among bicycle commuters*" Revista Saúde Pública 44(5):867-76. São Paulo, Brazil (2010)	Pelotas, RS, Brazil	No information	No information	The study looked for to evaluate an educational intervention designed to prevent traffic accidents among workers that use the bicycle for commuting. A longitudinal intervention study with a stepped wedge implementation was carried out between January 2006 and May 2007. Five neighbourhoods with distinct geographic characteristics were selected in the city of Pelotas, Brazil, and 42 census tracts were randomly selected from these neighbourhoods. The outcomes analysed were “traffic accidents” and “near accidents”. The cyclists were interviewed monthly by phone to record traffic accidents and “near accidents”. Every 15 days, from the second month of study, a group of about 60 cyclists was invited to attend the intervention meeting that included an educational component (a	Nearly 45% of the cyclists did not attend the intervention. During the study period, 9% of the study individuals reported a traffic accident and 88% reported a “near accident”. The intervention tested was not capable of reducing traffic accidents among bicycle commuters. Lack of interest in safety by commuters and external factors, such as road design and motorist behaviour, may have together influenced this result.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
				talk and a video presentation), distribution of a safety kit (reflective belt & sash, reflective tape and an educational booklet) and a bicycle breaks check-up (maintenance performed if necessary). Poisson regression adjusted for time effect was used to assess the intervention effect.	*Review note: Not included in attribute table. No direct/specific link to between attributes and crash types*
da Silva, A. L. "Prevalência de fatores associados à ocorrência e severidade de acidentes com bicicleta em Porto Alegre / *Prevalence of factors associated with the occurrence and severity of bicycle accidents in Porto Alegre*" Universidade Federal do Rio Grande do Sul. Porto Alegre, Brazil (2018).	Porto Alegre, Brazil	Intersections (more accidents specially in arterial roads), bus stops, cycle path, taxi stop, traffic sign, slope	Vehicle-bicycle, Motorcycle-bicycle, Heavy Vehicle-Bicycle	This thesis aims to verify the relationship between built environment, socio-economic factors and other risk sources and frequency and severity of traffic crashes involving cyclists in Porto Alegre. By using GIS software, the collected data were consolidated according to the defined analysis units. Accident's frequencies were modelled, and the coefficients were estimated by using Negative Binomial Regression Model and the severity of accidents was modelled as a Multinomial Logit Model. The accident frequency model counted with two significant variables. Then, a new accident frequency model was estimated from the elimination of possible sources of data discrepancy. Results have shown that the second model fit better on the studied scenario. The accident severity model resulted in 18 significant variables. Finally, the elements that showed highest prevalence on cyclists' safety were car interaction, presence of arterial roads, proximity to intersection areas and vulnerable cyclists' users (young and old ones cycling) involvement on accidents.	Frequency model: highlights the impact of arterial roads on crashes with cyclists. Arterial roads have a negative impact on road safety of cyclists. Also, actions focused on vulnerable bike users (children and elderly) can have positive results on road safety (suggests actions involving education). Severity model: intersections raise up to 83% a crash involving bicycle to result in a fatal victim. Signalized intersections have a positive impact on road safety for cyclists.
da Silva, C. "Perfil de acidentes envolvendo bicicleta na cidade do Rio de Janeiro / *Pattern of*	Rio de Janeiro, Brazil.	Bike path, urban streets without bicycle	Single bike accidents, vehicle-	To try to advance the understanding of the circumstances that lead to the accidents involving bicycles in the city of Rio de Janeiro and to shed	The bicycle paths appeared as the use of site of the marked bicycle with 77.8%. The lack of

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
accidents involving bikes in the city of Rio de Janeiro" Fundação Oswaldo Cruz. Rio de Janeiro, Brazil (2016).		infrastructure, inefficiency of infrastructure for cyclists	bike accidents	light on the profile of the Rio de Janeiro's cyclist, the present work, with the objective of characterizing the population of cyclists, used a questionnaire published on the Internet and disseminated by social media which can be divided into three parts. The exploratory work was concerned with hypotheses that could be tested in future studies. The first one wanted to draw a profile of the research participant, with identification of socioeconomic characteristics. The second raised information about the uses and habits of these cyclists. Finally, the third part made a survey of aspects related to traffic accidents that occurred. In this way, it was possible to determine socioeconomic and demographic characteristics, to identify the profile of the bicycle user in the city and the profile of this use, and to point out characteristics of these accidents among the cyclists who participated in the present research	safety in traffic (76.3%) and the inefficiency of infrastructure for cyclists (68.6%) were the main reasons to ride less. Accidents involving bicycles in the city of Rio de Janeiro were reported by 40.7% of survey participants. Most of them (68.4%) occurred in the urban streets. The second most commonly identified was the bike path (32.9%). And at the time of the accident the most common use was the bicycle as a means of transport (50.6%), followed by leisure (44.3%). The survey showed that 97 accidents hotspots, and the fall was the most reason given (46.8%), followed by collisions with cars (32.9%). Accidents occur more with men (59%) than women (41%), involving people who rides in any day of the week (78.5%).
Instituto Cordial "Análises Territorias para o Plano de Segurança Viária de São Paulo / Territorial analyzis for the Road Safety Plan for Sao Paulo" São Paulo, Brazil (2019).	São Paulo, Brazil.	Cycle path, cycleway, intersections, mid-blocks, etc	Vehicle-bicycle, Motorcycle-bicycle, Heavy Vehicle-Bicycle,	The main goal of the study was to identify and analyse the relation between traffic accidents - patterns of the accidents, number and characteristics of fatal and non-fatal victims, Severity Standard Unity (UPS) - and infrastructures characteristics of the city, looking for correlations that help to comprehend better the street design .	More accidents per kilometre happen in cycle lanes than in cycle paths. Were cycle paths were installed the number of accidents reduced in 78%.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
			Bicycle-pedestrians		In Avenues with cycle lanes and bus corridors the number of accidents is higher.
Roldán, O. M. G. et al. "Cycling mobility accidentability in Spain" Securitas Vialis, 4:97-104 (2012)	Spain	Cycle paths, cycle lanes, intersections, mid blocks, etc	No information	The bicycle use as a means of transport is basic to improve the sustainable mobility in cities. Despite their contrasting advantages, the risk in this type of travel creates a barrier to their use. This article studies the cycling crashes in Spain, analysing different variables as the number of accidents, the number of victims, types of accidents or location among others.	Between 2000 and 2011, the number of accidents in intersections was similar to the number of accidents in midblock in urban areas and has been increasing every year. In intersections 50% of the accidents happened in X-type intersections, while 12% happened in roundabouts and 33% in Y or T-type intersections.

Viatrafik – Danish literature summary

Methodology and findings

Viatrafik focussed on published Danish literature on risk factors associated with cycling facilities and bicycle crash types. To limit the number of documents and include the latest and most relevant research, the list is limited to only consist of research that goes back five years.

Generally the publications investigate the impact of a very specific and detailed issues relating to cycling infrastructure in Denmark – for instance a before and after analysis of how staggered stop lines affect the number of right-turning crashes between right-turning motor vehicles and straight-ahead riding cyclists in signalised junctions, or how bicycle boxes are used and affect the risk factors.

A total of nine publications were summarised, which related to:

- Vehicle-bicycle crashes and characteristics of:
    - Rural roads, roundabouts, signalised junctions, unsignalised junctions, bicycle paths/lanes (Jensen, 2017)
    - Roundabouts, signalised junctions, unsignalised junctions, bicycle paths/lanes (Jensen, 2017a)
    - Signalised junctions and bicycle paths/lanes (Buch & Jensen, 2017)
    - Roads, roundabouts, signalised junctions, unsignalised junctions, bicycle paths/lanes (Road Directorate, 2015)
    - Signalised junctions, bicycle boxes, bicycle paths/lanes (Lahrmann et al., 2017)
    - Related to characteristics of signalised junctions and bicycle paths/lanes (specifically conflicts between right-turning motor vehicles and straight- ahead bicycles and mopeds) (Buch, 2015)
    - Bi-directional bicycle paths, crossings between roads and bi-directional bicycle paths (Buch & Jensen, 2013).
- Bicycle-bicycle crashes and characteristics of:
    - Signalised junctions, bicycle boxes, bicycle paths/lanes (Lahrmann et al., 2017)
    - Signalised junctions, T-junctions, bicycle paths/lanes (including moped-bicycle crashes) (Jensen et al. 2014).

The publication 'Bicycle accidents 2005-2014' from 2015 by the Danish Accident Investigation Board provides a more general approach to the risk factors associated with cycling facilities. The publication gives an overall statistical overview of all the bicycle crashes in Denmark during the period from 2005 through 2014, defined as police-registered traffic accidents involving a killed or injured person, and where a cyclist was involved in the accident. It summarizes many general figures and trends regarding road safety for cyclists in Denmark. It also highlights that under-reporting of single bicycle crashes are very high. Only approximately 10% of single bicycle crashes are reported to police compared to emergency room admissions.

Viatrafik noted that Denmark uses crash prediction models for bicycling infrastructure. The publication 'Accident prediction models, accident modification factors and tools for rural road network – junctions and segments in rural areas' from 2017 describes estimated safety prediction functions for signalised junctions, roundabouts, give-way junctions and segments. The functions can be used to calculate the expected numbers of injury and property-damage-only accidents and numbers of fatalities, severe and slight injuries for specified variants of the four types of junctions and segments. The publication

‘Trafiksikkerhedsberegninger og ulykkesbekæmpelse’ (Traffic safety calculations and accident prevention) from the Danish Road Directorate in 2015 includes similar estimated risk factors.

In the course of their review, Viatrafik discuss Norway’s “Trafiksikkerhetshåndboken” (Road Safety Handbook), which provides an overview of current knowledge on the effects of 142 road safety measures. The content of this publication, including the references and conclusions on cycling risk factors, was subsequently analysed by iRAP (see Norwegian Road Safety Handbook).

Table 8: Relevant Danish studies identified

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
Jensen, S.U. "Accident prediction models, accident modification factors and tools for rural road network – junctions and segments in rural areas", Trafitec, The Road Directorate, 2017	Several locations, Denmark	Rural roads, roundabouts, signalised junctions, unsignalized junctions, bicycle paths, bicycle lanes	Vehicle-bicycle	The report describes accident prediction models for the rural road network. Estimated safety prediction functions for signalised junctions, roundabouts, give-way junctions and segments can be used to calculate numbers of injury and property-damage-only accidents and numbers of fatalities, severe and slight injuries for specified variants of the four types of junctions and segments.	Signalised or unsignalised intersections: - The average effect of establishing cycle lanes in a signalised or unsignalised intersection is an estimated increase in the number of accidents of 6% - compared to junctions without cycle facilities. - The average effect of establishing single and bi- directional bicycle paths are respectively a 4% decrease in the number of accidents and an increase of 24%. Roundabouts: - Compared to roundabouts without any cycle facilities and cycling allowed, the effect of implementing cycle lanes increase the number of accidents by 40%, while construction of a bicycle path where cars should give way for cyclists at the gateways only increase the number of accidents by 5 %. - A ban on cycling in the roundabout results in a decrease in number of accidents by 13 % and constructing of a bicycle path where cyclists must give way for cars at the gateways reduce the number of accidents by 29 %.
Lahrmann, H., Tønning, C., Christensen, P. M., Madsen, T. "Evaluation of large-scale experiments with bicycle boxes". Trafik-forskningsgruppen, Institut for Byggeri og Anlæg,	Hjørring, Aalborg, Kolding, Odense, Frederiksberg and Copenhagen, Denmark	Signalised junctions, bicycle boxes, bicycle paths, bicycle lanes	Vehicles-bicycle, bicycle-bicycle	Bicycle boxes are one of several initiatives, which The Road Directorate assesses can prevent accidents in signalised intersections between right-turning vehicles/trucks and straight-ahead riding cyclists. Since cycling boxes aren't widely used in Denmark,	The analysis shows that it is not possible to say whether bicycle boxes, have any effect on the risk of right- or left-turning accidents between turning vehicles and straight-ahead riding cyclists in signalised junctions. Very few cyclists tend to use the bicycle boxes. This could be related to the fact, that the first cyclists arriving at the stop line in the

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
Aalborg University, The Road Directorate, June 2017				The Road Directorate decided to carry out a large-scale experiment to evaluate the impact on road safety in 2016. The evaluation was carried out in 7 signalised intersections and based on a before-after study of more than 3.600 hours of video, and a total of 644 conflicts have been recorded.	intersection, don't have any reason for pulling out into the bicycle box. If the first cyclists don't choose to use the bicycle box, then they will block for the possibility for other cyclists to do so. *Review note: Not included in attribute table. No direct/specific link to CycleRAP attributes.*
Jensen, S.U. "Safe roundabouts for cyclists" Accident Analysis & Prevention **Volume 105, August 2017, Pages 30-37**	Several locations, Denmark	Roundabouts, signalised junctions, unsignalised junctions, bicycle paths, bicycle lanes	Vehicles-bicycle	A before-after safety study of conversions of intersections to 255 single-lane roundabouts in Denmark.	High central islands above 2 metres are safer to cyclists than lower at single-lane roundabouts. Central island diameters of 20–40 m seem safest for cyclists. Separate cycle paths are safer to cyclists than cycle lanes at roundabouts.
Buch, T. S., Jensen S.U. "Incidents between Straight-ahead Cyclists and Right-turning Motor Vehicles at Signalised Junctions", Accident Analysis & Prevention **Volume 105, August 2017, Pages 44-51**	Several locations, Denmark	Signalised junctions, bicycle paths, bicycle lanes	Vehicles-bicycle	A before-after safety evaluation of applying staggered stop lines in 189 arms at 123 signalised junctions is presented. The evaluation accounts for long-term accident trends and changes in motor vehicle traffic volumes. Applying staggered stop lines gives no decline in accidents between right-turning motor vehicles and straight-ahead cyclists. However, there is a statistical tendency to a decline of these right-turn accidents involving heavy vehicles.	Staggered stop lines do not seem to reduce the number of right-turn accidents. Staggered stop lines may reduce the number of right-turn accidents involving lorries. Most right-turn conflicts occur in the middle and the end of the green phase. Fast cyclists have a high relative risk of being involved in right-turn conflicts. The visibility of cyclists affects their relative risk of being involved in conflicts.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
"Bicycle accidents 2005-2014", Accident Investigation Board, 2015	Denmark	All	All	The report contains a statistical overview of all the bicycle accidents in Denmark during the period from 2005 through 2014, where bicycle accidents are defined as a police-registered traffic accident involving a killed or injured cyclist as one of the elements. The number of bicycle accidents in Denmark decreased by 36 % from 2005 through 2014 – although the development stagnated from 2010 to 2014. Bicycle accidents represent 23 % of all accidents from 2005 through 2014.	Studies from Odense University Hospital shows the dark figure for number of bicycle accidents are very high. The police only get to know about 10 % of the cyclists who are admitted to the emergency room. 85 % of the bicycle accidents are registered in urban areas against 15 % in land zones. Compared to all accidents, bicycle accidents are more often registered in intersections and, to a lesser extent, on straight roads and in curves. In relation to other accidents types, a minor proportion of single bicycle accidents are recorded. The 5 most common accident situations with cyclists are all accidents in intersections. There is a variation in the bicycle accidents over the year. Most people cycle during the summer; however, it is during the winter months that most bicycle accidents are recorded in proportion to the bicycle transport. The proportion of bicycle accidents is less during the weekend compared to other modes. Especially a smaller number of bicycle accidents is recorded during the night hours. The bicycle accidents do not differ significantly from other accidents with other modes regarding weather, road conditions and visibility. However, the proportion of bicycle accidents in poor lighting conditions is lower than with other transport modes. The bicycle accidents are most often recorded on roads with a speed limit of 50 km/h or more. Only 4% of the bicycle accidents are registered at roads with a speed limit lower than 50 km/h.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
					14 % of the bicycle accidents are right-turning accidents between right- turning vehicles/trucks and straight-ahead riding cyclists. Most of the accidents happen with vehicles as a counterpart, while trucks account for the most serious right- turning accidents - including 88 % of the killed cyclists in the right-turning accidents.
Buch, T. S. "Right-turn conflicts in signalised Junctions", Trafitec, Ministry of Transport, May 2015	Several locations in Copenhagen and on Zealand, Denmark	Signalised junctions, bicycle paths, bicycle lanes	Vehicle-bicycle (conflicts between right-turning motor vehicles and straight-ahead bicycles and mopeds)	Analysis of conflicting behaviour between right-turning motor vehicles and straight- ahead bicycles/mopeds. The report contains an analysis of situations with conflicting behaviour collected at 10 arms at signalized junctions, which differs regarding design and traffic composition. The analysis focus on factors leading to the conflicting behaviour to investigate why the situations arise. The goal is to produce new knowledge to prevent accidents between right-turning motor vehicles and straight-ahead bicycles and mopeds.	Very few conflicts arise where both the car driver and the bicyclist stand still before driving forward for green light. There is a higher relative risk of a conflict if both the car and the bicycle is in motion arriving at the green light in the intersection. Most of the conflicts arise in the middle or at the end of the cyclists' green phase. The fastest cyclists have a significantly higher risk of being involved in a conflict than other cyclists. For the individual cyclist it is safer to pass the intersection at the same time as other cyclists (safety in numbers).
"Trafiksikkerhedsberegninger og ulykkesbekæmpelse", The Road Derectorate, August 2015	Several locations, Denmark	Roads, roundabouts, signalised junctions, unsignalized junctions, bicycle	Vehicle-bicycle	This guide gives a comprehensive presentation of methods in accident prevention and its presumptions.	The guide introduces useful examples, methods and tools to systematic accident prevention. It also introduces a list of possible solutions for different kinds of accidents with cyclists involved.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points	The stated impact on bicycling crashes
		paths, bicycle lanes			*Review note: Not included in attribute table. Not enough detail provided.*
Jensen, S.U., Lund B. C., Andersson P. K. "Vulnerable road users outside signals in intersections – Accident analysis and behavioural analysis", Trafitec, The Road Directorate, April 2014	Several locations, Denmark	Signalised junctions, T-junctions, bicycle paths, bicycle lanes	Bicycle-bicycle, moped-bicycle	Trafitec has on the behalf of the Road Directorate, investigated the effect on traffic safety in signalized junctions with right-turning shunts or sub-signs indicating that cyclists can turn right despite what the signal shows.	The analysis shows that it is not possible to say whether signalised junctions where bicyclists and mopeds can turn right using a shunt, have any difference in numbers of accidents and conflicts between vulnerable road users compared to other signalised junctions. The same goes with junctions with signs showing that bicyclists can turn right despite what the signal shows and T- crosses with or without allowed straight-ahead riding for red signal for cyclists.
Buch, T. S., Jensen, S. U. "Traffic safety in junctions with bi-directional cycle paths", Trafitec, September 2013.	Several locations, Denmark	Bi-directional bicycle paths, Crossings between roads and bi- directional bicycle paths	Vehicle-bicycle	The report clarifies by means of accident rates and accident densities the connection between the design and the risk of accidents in intersections, where a two-way bicycle path runs along the road.	It is safest to make road crossings in two levels. Crossing in one level is safest when the vulnerable road users on the bi- directional bicycle path must give way and when there are at least 6 meters between the bi-directional bicycle path and the nearest traffic lane for straight-ahead traffic on the primary road.

iRAP – English/other language literature summary

Methodology and findings

iRAP undertook a ‘scan’ for literature relevant to the CycleRAP model, with a specific focus on those which looked at infrastructure characteristics and their relationship to bicycle crash types not involving motor vehicles. The searches mainly focussed on the Anglosphere countries (e.g. Australia, United States, Britian, Canada etc.), however, specific effort was made to identify recent studies which were of highest relevance and any which related to low and middle income countries.

Studies were identified via Google searches (using search terms such as ‘single bicycle crash’) which yielded results from a number of academic journals and articles. Similar searches were conducted on ResearchGate, specific journal databases, such as *Injury Prevention* and *Accident Analysis and Prevention*.

The search yielding eight relevant articles from the United Kingdom (2), Australia (2), Switzerland (1), United States (1), New Zealand (1) and China (1).

Despite a concerted effort to identify literature relevant to single bicycle crashes, studies into risk factors and crash types for cycle crashes not involving motor vehicles remain rare—particularly for single bicycle crashes. In recent years, the growing awareness of underreporting of these crash types and increasing e-bike use are triggering more research in this area.

For example, a study by Boufous and Olivier (2015) of cycling fatalities in Australia between 1991 and 2013 found that while cyclist deaths following multi-vehicle crashes decreased at a rate of 2.9% per year, deaths from single bicycle crashes increased by 5.8% per year and suggest that road conditions, particularly irregular and slippery surfaces as well as collisions with road furniture may be a contributing factor.

A recent study by Hertach et al. (2018) into characteristics of 638 single e-bike crashes in Switzerland found that the top four reasons for serious injuries in crashes were reported as being:

(i) Skidding/slipping on the road surface (e.g. water, leaves, ice, gravel) (31%)

(ii) Crossing a threshold (e.g. pavement, kerbstone, bump, change of surface) (18%)

(iii) Getting stuck in or skidding on a tram/railway track (13%)

(iv) Evasive actions (e.g. other road users, pothole, object on the lane) (12%)

(v) Collision with an object on the lane (e.g. object or pothole) (6%) and collision with a roadside obstacle (3%) were also listed.

Beck et al. (2019) found that in Australia, tram tracks and potholes were the greatest road-related causes of single bicycle crashes. They also found that single bicycle crash victims tended to have faster injury recovery rates than vehicle-bicycle crash victims, suggesting the injuries of the former do not tend be as severe.

An older study into causes of single bicycle crashes by Munster et al (2001) found that of the road features identified as crash causes, loose gravel caused the single greatest number of crashes (34%). Surface irregularities, when considered as a group of features (e.g. corrugations, uneven surfaces, potholes, maintenance and finishing issues), accounted for the largest grouping (39%) of crashes. Together the loose gravel and surface irregularities accounted for the majority of crashes as opposed to road furniture and design.

Two studies were included on the basis of their focus on particular infrastructure characteristics. The unpublished paper by Atkins (2005) on the effectiveness of advanced stop lines in the UK in reducing crash risk was inconclusive. The second, a paper by Wall et al. (2016) examined the effectiveness of protected bicycle lanes and other features (such as sharrows and painted lanes) in New York City.

A study by Yuan and Chen (2017) from China was included for its examination of injury severity of bicyclists, e-bikers and pedestrians in relation to vehicle impact speed. While not specific to single bicycles crashes, it strengthens the evidence for vehicle-bicycle crash type severity, particularly in relation to vehicle speed.

These studies are summarised in Table 9 below.

Table 9: Relevant English language studies identified

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points/ Abstract	The stated impact on bicycling crashes
Atkins. (2005) Advanced Stop Line Variations Research Study – Research Findings. [Unpublished report].	UK	Intersection	Vehicle-bicycle (intersection)	Atkins was commissioned by Transport for London (TfL) to carry out a research study into experimental cycle facilities at a number of signal-controlled junctions on the A202 and A23. The key area of study involved experimental variations of Advanced Stop Lines for cyclists (ASLs). These variations related to the ASL reservoir feeder lane and the layout of the reservoir itself.	No conclusive relationship between ASLs and reduced number of crashes. *Review note: Not included in attribute table. No direct/specific link to CycleRAP attributes.*
Beck, B., Stevenson, M.R., Cameron,P., Oxley, J., Newstead, S., Olivier, J., Boufous, S., Gabbe, B.J. (2019) Crash characteristics of on-road single-bicycle crashes: an under-recognised problem. Inj Prev Epub 0:1–5.	Australia	Road surface quality, tram tracks	Single bicycle	Compared with crashes with motor vehicles, single-bicycle crashes are an under-recognised contributor to cycling injury and the aetiology is poorly understood. Using an in-depth crash investigation technique, this study describes the crash characteristics and patient outcomes of a sample of cyclists admitted to hospital following on-road bicycle crashes. Enrolled cyclists completed a structured interview, and injury details and patient outcomes were extracted from trauma registries. Single-bicycle crashes (n=62) accounted for 48% of on-road crashes and commonly involved experienced cyclists. Common single-bicycle crash types included loss-of-control events, interactions with tram tracks, striking potholes or objects or resulting from mechanical issues with the bicycle. To address single-bicycle crashes, targeted countermeasures are required for each of these specific crash types.	Beck et al. (2019) found that tram tracks and potholes were the greatest road-related causes of single bicycle crashes. They also found that single bicycle crash victims tended to have faster injury recovery rates than vehicle-bicycle crash victims, suggesting the injuries of the former do not tend be as severe.
Boufous, S. and J. Olivier (2015). Recent trends in cyclist fatalities in Australia. Injury Prevention 22(4).	Australia	Road surface quality, obstacles	Single bicycle	The study examines trends in bicycling fatalities reported to the Australian police between 1991 and 2013. Trends were estimated using Poisson regression modelling. Overall, cycling fatalities decreased by 1.9% annually between 1991 and 2013. However, while deaths following multivehicle crashes decreased at a rate of 2.9% per annum (95% CI -4.0% to -1.8%), deaths from single vehicle crashes increased by 5.8% per annum (95% CI 4.1%	The study by Boufous and Olivier (2015) of cycling fatalities in Australia between 1991 and 2013 found that while cyclist deaths following multi-vehicle crashes decreased at a rate of 2.9% per year, deaths from single bicycle crashes increased by

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points/ Abstract	The stated impact on bicycling crashes
				to 7.5%). Over the study period, the average age of cyclists who died in single vehicle crashes (45.3 years, 95% CI 41.5 to 49.1) was significantly higher than cyclists who died in multivehicle crashes (36.2 years, 95% CI 34.7 to 37.7). The average age of deceased cyclists increased significantly for both types of crashes. The observed increase in single vehicle crashes need to be closely monitored in Australia and internationally. In-depth studies are needed to investigate the circumstances of fatal single bicycle crashes in order to develop appropriate countermeasures.	5.8% per year and suggest that road conditions, particularly irregular and slippery surfaces as well as collisions with road furniture may be a contributing factor.
Hertach, P., Uhr, A., Niemann, S. and M. Cavegn. (2018). Characteristics of single-vehicle crashes with e-bikes in Switzerland. Accident Analysis and Prevention 117, 232-238.	Switzerland	Road surface quality, obstacles, edge transition, tram track, roadside hazard	Single bicycle/e-bike	In Switzerland, the usage and accident numbers of e-bikes have strongly increased in recent years. According to official statistics, single-vehicle accidents constitute an important crash type. Up to date, very little is known about the mechanisms and causes of these crashes. To gain more insight, a survey was conducted among 3658 e- cyclists in 2016. The crash risk and injury severity were analysed using logistic regression models. 638 (17%) e- cyclists had experienced a single-vehicle accident in road traffic since the beginning of their e-bike use. Risk factors were high riding exposure, male sex, and using the e-bike mainly for the purpose of getting to work or school. There was no effect of age on the crash risk. Skidding, falling while crossing a threshold, getting into or skidding on a tram/railway track and evasive actions were the most important accident mechanisms. The crash causes mentioned most often were a slippery road surface, riding too fast for the situation and inability to keep the balance. Women, elderly people, riders of e-bikes with a pedal support up to 45 km/h and e-cyclists who considered themselves to be less fit in comparison to people of the same age had an increased risk of injury. This study confirms the high relevance of single-vehicle crashes with e-bikes. Measures to prevent this type	Found that the top four reasons for serious injuries in e-bike crashes were reported as being: • Skidding/slipping on the road surface (e.g. water, leaves, ice, gravel) (31%) • Crossing a threshold (e.g. pavement, kerbstone, bump, change of surface) (18%) • Getting stuck in or skidding on a tram/railway track (13%) • Evasive actions (e.g. other road users, pothole, object on the lane) (12%) • Collision with an object on the lane (e.g. object or pothole) (6%) and

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points/ Abstract	The stated impact on bicycling crashes
				of accident could include the sensitisation of e-cyclists regarding the most common accident mechanisms and causes, a regular maintenance of bicycle pathways, improvements regarding tram and railway tracks and technological advancements of e-bikes.	collision with a roadside obstacle (3%) were also listed.
Knowles, J., Adams, S., Cuerden, R., Savill, T., Reid, S., and M. Tight. (2009). ***Collisions Involving Cyclists on Britain's Roads: Establishing the Causes*****. TRL (PPR 445).**	UK	Road surface, intersections	Single bicycle, vehicle-bicycle	In 2008, 115 pedal cyclists were killed and 2,450 reported as seriously injured on Britain's roads, accounting for 9% of all killed or seriously injured (KSI) road casualties. The Government is committed to reducing road casualties for all road users, including cyclists, and has a national casualty target of reducing by 40% the number of people KSI in road collisions by 2010, compared with the baseline average for 1994-98. Whilst there is no specific target relating to cyclists, in 2004 the number of KSI had fallen to 38% below the baseline average. However, the number of KSI has increased steadily since then and in 2007 and 2008 was 31% below the baseline average. The Department for Transport commissioned research to assess the causes of collisions involving cyclists. This report investigates the key causal factors relating to accidents involving cyclists. The work involved an international literature review and a detailed analysis of cyclist casualties in Great Britain, drawing on both national and in-depth databases of road collisions and cycling.	Analysis of police reporting of crashes showed that: For single bicycle crashes: • 16% of total bicyclist fatalities are the result of single bicycle crashes • Two-thirds (68%) occurred on urban roads and on-third (32%) on rural roads • Over half occurred at intersections (56%) and the majority when the bicyclist was travelling straight ahead (86%). • Loss of control* (68%), slippery road, poor or defective road surface, swerving, turning were reported in the top ten reasons for fatal and serious crashes. (*Whether loss of control events result from rider error, lack of skill or defects in the design or maintenance of

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points/ Abstract	The stated impact on bicycling crashes
					infrastructure is not clear.) The presence of heavy vehicles represents high risk for cyclists, accounting for 18% of bicyclist fatalities). Most vehicle-bicycle crashes occur on urban roads (75%) at intersections (70%) when the bicyclist is travelling straight ahead (78%). Bicyclists entering an intersection from the pavement is also considered a principal reason for vehicle-bicycle crashes.
Munster, D., Koorey, G., Walton, D. 2001. Role of road features in cycle-only crashes in New Zealand. Transit New Zealand Research Report No. 211.	NZ	Road surface	Single bicycle	A survey was carried out in 2001, to identify the causes of cycle-only crashes on our public roads, cycle ways and footpaths. Of particular interest was the role of road features in these crashes. This report presents the findings of this survey. Details including causes of cycle crashes involving a motor vehicle are reported in the Land Transport Safety Authority's (LTSA) crash analysis system. Cycle-only crashes (i.e. those not involving impact with a motor vehicle) are excluded from this system. Hospital and Accident Compensation (ACC) records distinguish cycle-only crashes from those involving a motor vehicle, and from these records cycle-only crashes appeared to be twice as frequent as cycle and motor vehicle crashes. However insufficient detail was available to determine their causes. A 1989 study of cycle crashes in Christchurch found 20% were due to road features, in particular to loose gravel and poor maintenance. These findings were to	Munster et al (2001) found that of the road features identified as crash causes, loose gravel caused the single greatest number of crashes (34%). Surface irregularities, when considered as a group of features (e.g. corrugations, uneven surfaces, potholes, maintenance and finishing issues), accounted for the largest grouping (39%) of crashes. Together the loose gravel and surface irregularities accounted for the majority of crashes as opposed to road furniture and design.

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points/ Abstract	The stated impact on bicycling crashes
				be compared with those of our national survey of cyclist accidents occurring between 1999 and 2000. The group surveyed were cyclists who had received either treatment for a cycle-only crash as public hospital inpatients, or compensation from Accident Compensation Corporation (ACC) for specialist treatment or other assistance. The survey was by questionnaire.	
Quan Yuan & Hongyun Chen (2017) Factor comparison of passenger-vehicle to vulnerable road user crashes in Beijing, China, International Journal of Crashworthiness, 22:3, 260-270.	China	Intersection, vehicle speed	Vehicle-bicycle	Vehicle to vulnerable road user (VRU) crash is a large portion of traffic crashes in China Crash data from Beijing, China from the year 2009 to 2012 are used to identify the factors associated with the likelihood of vehicle to VRU crashes. 180 passenger-vehicles to VRU crashes are collected including 60 vehicle to pedestrian, 60 vehicle to bicycle and 60 vehicle to electric-bicycle cases. Then the statistics of the crash data are carried out, and the variables of human, vehicle, road, environment are investigated. Further, a logic regression model is established to analyse the significance of main contributing factors of these crashes. This paper describes the sample data, which includes time of incident, road user's age and gender, impact speed, crash pattern and VRU's head impact position. According to the results, some characteristics of three crash types are different, such as the occurrence time, road position, impact speed and the impact position of VRU's head on the passenger-car. Moreover, chi-square test reveals that night-time travelling, crash type involving pedestrian and speeding of vehicle are significant related to non-fatal/fatal crashes. The logic regression model shows that night-time, intersection, older age of VRU and higher speed of vehicle increased the crash severity.	Intersections and higher vehicle speeds increased crash severity

Full reference	Research location	List of relevant road/ facility/ intersection attribute	Crash type	Summary of key points/ Abstract	The stated impact on bicycling crashes
Wall, S.P., Lee D.C., Frangos, S.G., Sethi, M., Heyer, J.H., Ayoung-Chee, P. and C.J DiMaggio. (2016). The Effect of Sharrows, Painted Bicycle Lanes and Physically Protected Paths on the Severity of Bicycle Injuries Caused by Motor Vehicles. *Safety (Basel)* *2*(4).	US	Bicycle facility	Vehicle-bicycle	This study conducted individual and ecologic analyses of prospectively collected data from 839 injured bicyclists who collided with motorized vehicles and presented to Bellevue Hospital, an urban Level-1 trauma center in New York City, from December 2008 to August 2014. Variables included demographics, scene information, rider behaviors, bicycle route availability, and whether the collision occurred before the road segment was converted to a bicycle route. We used negative binomial modeling to assess the risk of injury occurrence following bicycle path or lane implementation. We dichotomized U.S. National Trauma Data Bank Injury Severity Scores (ISS) into none/mild (0–8) versus moderate, severe, or critical (>8) and used adjusted multivariable logistic regression to model the association of ISS with collision proximity to sharrows (i.e., bicycle lanes designated for sharing with cars), painted bicycle lanes, or physically protected paths.	Physically protected paths were associated with 23% fewer injuries. Painted bicycle lanes reduced injury risk by nearly 90% Compared to no bicycle route, a bicycle injury nearby sharrows was nearly twice as likely to be moderate, severe, or critical.

Norwegian Road Safety Handbook review

In the course of their review, Viatrafik discuss Norway's "Trafiksikkerhetshåndboken" (Road Safety Handbook – henceforth referred to as 'The Handbook'), which provides an overview of current knowledge on the effects of 142 road safety measures.[22] The chapter, 'Infrastructure measures for cyclists', most recently updated in 2017, provides a comprehensive overview of the latest studies, practices and experiences regarding bicycle facilities and road safety from all over the world.[23] The content of this publication, including the references and conclusions on cycling risk factors, was subsequently analysed by iRAP and included in this report.

SWOV has confirmed the Handbook (English version from 2009) is widely used and cited in Europe and the US. It is based on a collection of carefully selected studies and, where possible, meta-analyses have been carried out on report effects. It is therefore a good source document, especially for reporting documented effects of vehicle-bicycle crashes and establishing the effect of providing various cycle dedicated infrastructure.

For the purposes of this literature review, the relevant bicycling-related risk factors and safety countermeasures included in the Handbook which are relevant to CycleRAP have been summarised in Table 10. The Handbook also identifies a number of "unproven" bicycling-related safety treatments which are summarised in Table 11. These either have no available studies confirming their effects on safety or are studies with small sample sizes and/or have not confirmed a safety benefit.

Due to the time constraints of this project, the original publications and their conclusions were not individually reviewed, with a few exceptions. For the purposes of clarity, some terminology was altered slightly from the translation to that which is commonly used in the context of the iRAP and CycleRAP models.

Table 10: Bicycle-related risk factors and safety treatments

No.	Attribute/category	Crash type	Publication reference & location	Risk factors/ findings
1	Area type (Urban/rural)	Vehicle-bicycle	Boufous et al. (2012, Australia)	Risk of serious injury is 28% higher in sparsely populated areas than in densely populated areas.
2	Speed limit	Vehicle-bicycle	Boufous et al. (2012, Australia)	Risk of serious injury, compared to roads with speed limit 40 or 50 km/h, is: • 13% higher at speed limit 60 km/h • 29% higher at speed limit 70-90 km/h • 51% higher on roads with speed limit 100 km/h or higher.
3	Operating speed	Vehicle-bicycle	Cripton et al. (2015, Canada)	Risk of serious injuries in bicycle crashes increases by 27% (+6; +51) for each increase in average speed of 10 km/h (>30km/h).
4	Speed limit/intersection signalisation	Vehicle-bicycle Intersection	Wang et al. (2014, USA)	Risk of serious injuries in bicycle crashes at non-signalised intersections is higher at speed limits of 64 or 80 km/h than at lower speed limits.

[22] Høye, A. (2017) "Infrastrukturtiltak for syklister" in Elvik, R., Høye, A., Sørensen, M. W. J., Vaa, T. (2009). Handbook of Road Safety Measures. Transportøkonomisk institutt.

[23] A more comprehensive version of this chapter was published separately under the title "Road Safety for Cyclists" by Hoye (2017) (in Norwegian with an English summary). However, only the chapter of the handbook has been included here as it specifically focussed on infrastructure whereas the other publication contained more details not relevant to CycleRAP.

No.	Attribute/category	Crash type	Publication reference & location	Risk factors/ findings
5	Bicycle facility/speed limit	Vehicle-bicycle	Petritsch et al. (2006, USA)	"Sidepaths" (segregated/off-road path not exclusively reserved for cyclists) have been shown to have greater crash-reducing effect on roads with higher speed limits.
6	Vehicle parking*/bicycle facility	Vehicle-bicycle (Note it is not clear what proportion of injuries are caused by dooring vs. conflict with a moving vehicle – further review required)	Teschke et al. (2014, Canada)	Main roads without street parking have 35% (statistically significant) fewer bicycle crashes involving personal injury than highways with street parking and no bicycle lane or path. On main roads with bicycle lanes the difference is smaller (-11%).
7	Tram rails	Single bicycle	Teschke et al. (2012, Canada)	Risk of personal injury crashes with bicycles is 3.04 times as high (1.80; 5.11) on roads with tram rails as on otherwise comparable roads without tram rails.
8	Street lighting	(Not stated – further review required)	Bíl et al., 2010 (Czech Republic) Romanov et al., 2012 (Canada) Wanvik, 2009 (The Netherlands)	Major reductions in both crashes and the degree of injury in crashes.
9	Street lighting	(Not stated – further review required)	Vavatsoulas et al., 2014 (Denmark)	No significant difference in the severity of cyclist injuries with vs. without lighting.
10	Bicycle facility	Vehicle-bicycle Intersection (Bicycle-bicycle not stated – further review required)	Turner et al., 2009 (New Zealand) Turner et al., 2011 (New Zealand) Teschke et al., 2012 (Canada) Hamann & Peek-Asa, 2013 (USA) Abdel-Aty, 2014 (USA) Park et al., 2015 (USA) Pulugurtha & Thakur, 2015 (USA)	Combined results of studies found that bicycle lanes reduce bicycle crashes by 53% and all crashes by 22%.*^ *With control for the number of cyclists. Studies which observe numbers of bicycle crashes before and after bicycle facilities are installed (not controlling for volume) observe an overall increase of crashes which corresponds to the increase in bicycle volumes. ^The reduction of total crashes is at intersections. (Note the difference between 'bicycle crashes' and 'all crashes' is not clear – further review required).
11	Bicycle facility	Vehicle-bicycle	Buckley & Wilke, 2000 (New Zealand) Hamann & Peek-Asa, 2013 (USA) Poulos et al., 2015 (Australia) Prato et al., 2014 (Denmark) Vavatsoulas et al., 2013 (Denmark)	Bicycle lanes have fewer and less serious crashes than mixed traffic.* *With control for the number of cyclists. Studies which observe numbers of bicycle crashes before and after bicycle facilities are installed (not controlling for volume) observe an overall increase of crashes which corresponds to the increase in bicycle volumes.

No.	Attribute/category	Crash type	Publication reference & location	Risk factors/ findings
12	Bicycle facility one-way/two-way and intersections	Vehicle-bicycle Intersection (Not clear if these studies also discuss bicycle-bicycle crashes – further review required)	Vandenbulcke et al., 2014 (Belgium) Schepers et al., 2011 (The Netherlands)	Two-way bicycle lanes have almost twice as many bicycle crashes at intersections as one-way bicycle lanes (with control for the number of cyclists). The risk of crashes on a double-lane cycle path is greatest for cyclists who cycle on the "wrong" side of the road from the perspective of the crossing driver (Schepers & Voorham, 2010).
13	Bicycle facilities at intersections	Vehicle-bicycle Intersection	Schepers et al., 2011 (The Netherlands) Poulos et al. 2015 (Australia)	Results of studies are conflicted. Bicycle paths at intersections with particular intersection design configurations show a clear safety benefits over a bike lane (e.g. cyclist right-of-way, one-way path in direction of travel, good visibility and traffic calming such as speed humps) (Schepers et al., 2011), but the presence of a bicycle path alone may not yield a safety benefit over a bike lane. Poulos et al. 2015 found a 40% increase in bicycle crashes on bike paths compared to bike lanes. Results suggest a greater safety benefit can be achieved with a bike lane over a bike path (vs. mixed traffic) at intersections.
14	Sidewalks and shared paths	Vehicle-bicycle Bicycle-bicycle Bicycle-pedestrian Intersection	Moritz, 1998 (USA) Rome et al., 2013 (Australia) Cripton et al., 2015 (Canada) Poulos et al., 2015 (Australia) Senturia et al., 1997 (USA) Aultman-Hall & Adams, 1998 (Canada) Aultman-Hall & Hall, 1998 (Canada) Aultman-Hall & Kaltenecker, 1999 (Canada)	The studies show that the risk of bicycle crashes is about doubled on shared paths and even higher on sidewalks than in mixed traffic. In addition, bicycle crashes on shared paths are on average more serious (collisions with motor vehicles at crossings are included in the results). (All studies controlled for cyclist numbers.)
15	Bicycle streets (where a lane in a pedestrian street is reserved for bicyclists).	Bicycle-pedestrian	Bjornskau et al., (2017)	A study of a pedestrian street in Oslo by Bjornskau et al., (2017) showed that there is a very high level of conflict between pedestrians and cyclists.
16	Two-way bicycle lanes on one-way streets.	Vehicle-bicycle Bicycle-pedestrian	Vandenbulcke et al., 2014 (Belgium) Alrutz et al., 2002 (Germany) Dupriez, 2009 (Belgium) Bjørnskau et al. (2012, Norway)	Vandenbulcke et al., 2014 found the number of bicycle crashes was approximately halved in streets with cycling towards one-way (statistically significant). Other studies also indicate that the number of bicycle crashes is declining, but this cannot be quantified (Alrutz et al., 2002, Germany; Dupriez, 2009, Belgium).

No.	Attribute/category	Crash type	Publication reference & location	Risk factors/ findings
				The proportion of cyclists cycling on the sidewalk is more than halved in a German study (Alrutz et al., 2002). Bjørnskau et al. (2012, Norway) shows that almost all conflicts that occur in one-lane streets with bicycle lanes against the direction of travel occur as a result of the bicycle lanes being blocked by parked cars, containers, etc., which forced cyclists into the roadway. The study also shows that cycling against one-way driving results in a reduction in the number of cyclists on the sidewalk, fewer conflicts with pedestrians and no more conflicts with motor vehicles.
17	Roundabouts	Intersection	de Brabander Vereeck, 2007 (Belgium) Daniels et al., 2008 (Belgium) Daniels et al., 2009 (Belgium) Harris et al., 2013 (Canada) Jensen, 2013 (Denmark) Vandenbulcke et al., 2014 (Belgium)	The most common cause of crash involving a bicycle is between a bicycle on the roundabout and a motor vehicle entering the roundabout. Roundabouts by nature do not significantly increase risk for bicyclists. The Handbook lists six studies (four from Belgium, and one each from Canada and Denmark) on the bicycling safety effects of converting a standard intersection into a roundabout which show a non-significant increase in crashes (7%). However, the features and design of roundabouts can increase crash rates. These include: • Presence of bicycle lanes (see 18) • High speeds • Multiple lanes • Large size of roundabout and large curve radii of entry and exits.
18	Bicycle lanes on roundabouts	Intersection	Vandenbulcke et al., 2007	Bicycle lanes in roundabouts had more than double the number of crashes (+123%) than in bicycle lanes in light-regulated intersections. Results vary significantly between studies and urban/rural areas. It also largely depends on the specific design of the roundabout and the configuration of the crossing points between the bicycle path and entry/exit points. In general, roundabouts with mixed traffic have no significant effect on the number of bicycle crashes. Bicycle lanes increase the number of bicycle crashes by a significant 93%. The increase is even greater when there is a physical barrier between the bicycle lane and the lane in the roundabout.

No.	Attribute/category	Crash type	Publication reference & location	Risk factors/ findings
				Cyclists cycling in the "wrong" direction of travel (i.e. counterclockwise) have the greatest potential for conflict.

Unproven treatments

The handbook mentions a number of other "unproven" bicycling-related safety countermeasures (Table 11) which have either no available studies confirming their effects on safety or are studies with small sample sizes and/or have not confirmed a safety benefit.

These have been included in this review for the purposes of identifying those countermeasures which, even if generally accepted safety measures, do not have established evidence as being effective in reducing cycling crashes. With the possible exception of extended road shoulders, the countermeasures tend to be those not widely used.

Table 11: Unproven treatments

Safety measure	Crash type	Comments
Extended road shoulders (for mixed traffic)	Vehicle-bicycle	Extended road shoulders provide more space for cyclists, especially on roads without street parking or sidewalks. No studies of the impact on crashes have been found.[24]
Coloured bicycle lanes (for mid-block on-road bike lanes)	Vehicle-bicycle	The Handbook states that the effects of coloured bicycle lanes on mid-block sections are unknown, but cyclists feel safer.
Sharrows (lane markings to indicate a shared road for mixed traffic)	Vehicle-bicycle	The Handbook mentions two studies [Teschke et al. (2012, Canada) and Hamann & Peek-Asa 2013 (USA)] that showed that sharrows reduce bicycle crashes on both mid-block and at intersections. However, the studies had small sample sizes and not statistically significant.
Field-in-field (painted bike lane in the centre of a regular lane for mixed traffic)	Vehicle-bicycle	A study by Furth & Dulaski, 2010 (USA) showed that this treatment increases prevalence of bicyclists riding in the middle of a lane (17% before installation to 92% after installation). Thought to have a safety benefit by increasing the visibility of cyclists and reducing overtaking. However, the crash reduction effect is not stated.
Two-minus-one road (narrow centre lane without centreline) and extra-wide shoulders for pedestrians and cyclists)	Vehicle-bicycle	This is a concept being trialled in Sweden, Denmark and The Netherlands on local roads. A study by Erke & Sorensen, 2008 did not find this treatment reduced vehicle speeds or conflicts, and that it possibly leads to increased confusion.

The handbook discusses a number of safety treatments for intersections. These are summarised in Table 12. Again, some treatments do not have a sufficient amount of evidence to support their effect on reducing bicycling-related crashes. However, unlike the mid-block countermeasures above, these measures tend to be more widely used.

Table 12: Intersection safety treatments

Safety measure	Publication reference	Comments
Coloured bike lanes at intersections	Jensen, 2006 (Denmark) König, 2006 (Sweden)	Painted bicycle lanes across intersections, merge lanes and property access points have been widely applied in a number of locations globally.

[24] It is worth noting for the purposes of this review that extended road shoulders is included as having a safety benefit for cyclists in the core iRAP bicycling model (run-off-road crashes)

Safety measure	Publication reference	Comments
	Jensen, 2008 (Denmark) Schepers et al., 2011 (The Netherlands)	Overall, the results from the studies listed in the Handbook show that the number of bicycle crashes has been reduced by 18%. However, the results vary between studies and between different intersections. Most studies have not controlled for either bicycle traffic or regression effects, so it is not immediately possible to generalize the results. A separate study into bicycling injury severity by Wall et al., 2016 (USA) (not included in the Handbook) shows that painted lanes reduced injury risk of nearly 90%.
Other markings at intersections (e.g. harlequin patterns and bicycle symbols)	Jensen & Nielsen, 1999 Jensen, 2002 Andersen et al., (2004) Berggrein and Bach, 2007	The studies found reductions in the number of bicycle crashes between 5% and 45%. None of the results are statistically significant and it is noted that the methodological quality of the studies is relatively poor so that the results cannot be generalized.
Staggered stop lines at signalised intersections (stop line for motorised vehicles is 2-5m back from the cyclist stop line)	Not stated	Older studies from Denmark and the United Kingdom (1993-2002) found a reduction in the number of bicycle crashes by 18% (-46; +25), but due to methodological weaknesses the effect can be overestimated and may not necessarily be generalized. (This treatment is gaining more attention to prevent conflict between heavy vehicles and bicyclists and further review of available research is recommended).
Bicycle box at signalised intersections		No studies which have found a safety benefit for bicycle box have been identified, although those that look at the effects on behaviour conclude that in that respect, they are largely positive (increased visibility and awareness of cyclists, cyclists feel safer). An unpublished study by Atkins (2005) of ten intersections with bicycle boxes in London (not included in the Handbook) did not find conclusive safety benefits.
Centred bicycle lane in signal-controlled intersections/ pocket-lane (marked field to the left of the right-hand turn lane for motor vehicles)	Celis, 1999 (Denmark) Nielsen, 1995 (Denmark)	Studies show that the mid-range bicycle field reduces the number of crashes but without quantifying the results. Other studies show that the number of conflicts is also declining, and that the proportion of motorists who have complied with cyclists' duty and who used turn signals is increasing.
Filter field in signal-controlled intersections (a separate turn-right-on-red bicycle lane)	Andersen et al., 2004 (Denmark)	The main purpose is to improve the accessibility of right-turning cyclists. No clear conclusions about the impact on crashes or conflicts.
Segregated bicycle path or shared path	See 13-14 in Table 1	Results from empirical studies are likely to vary, because the effects largely depend on the specific design and visibility. Optimal design is to have the crossing at least 5m from the intersection, preferably as a raised crossing. The potential for conflict can be large, especially when the traffic rules are unclear or seem illogical and when the visibility conditions are not optimal.
Truncated bicycle path (where bicycle path ends on intersection approach and cycles join bicycle lane or mixed traffic)	Pfeifer, 1999 (Denmark) Jensen & Nielsen, 1999 (Denmark)	The purpose is that motorists and cyclists become more aware of each other and that cyclists should not experience a (false) safety through separation from motor vehicles right up to the intersection. The effects have been studied in two Danish studies, but the results are sparse, and it is not possible to draw clear conclusions on the safety benefit.

Safety measure	Publication reference	Comments
Bicycle raised crossing (cycle path is designed as a speed hump for traffic on the side road. Cyclists have right of way)	Gårder et al., 1998 (Sweden) Schepers et al., 2011 (The Netherlands)	The combined effect is a large and statistically significant reduction in the number of bicycle-motor vehicle collisions (-47%). A reduced number of crashes was also found in a Swedish study, but without the results being included in the combined result (Leden et al., 2000). The study also showed that this measure reduced speeds of both motor vehicles and cyclists.
Grade-separated facilities (overpasses and underpasses)	Daniels et al., 2009	Bicycle overpasses and underpasses found to reduce cycling injuries by 44%.
Roundabouts	Cumming, 2012	Measures to improve the safety of cyclists in roundabouts with mixed traffic include speed-reduction (traffic calming) and measures that 'force' the cyclists in the middle of the lane of the roundabout so that motorised vehicles and cyclists do not run in parallel.

Summary of research publications by attribute

Table 13: Summary of research publications identified in the literature review as they relate to road infrastructure and/or speed attributes.

		Area type	Speed limit	Bicycle facility type	Facility width/ width restriction	Bicycle crossing	Bicycle crossing quality	Pedestrian crossing	Bicycle facility surface / grip	Road surface / grip	Road condition	Road number of lanes	Facility one /two way	Vehicle parking - road side	Side object – left/right	Side surface quality	Edge transition – left/right	Tram rails	Bicycle facility centre line	Obstacle in path	Intersection type	Intersecting road volume	Intersection prioritization	Street lighting	Operating Speed (85th %ile)	Bicycle facility user mix
	DUTCH REVIEW																									
1	Hair-Buijssen, de, S.H.H.M & Horst, van der, A.R.A. 2012.				X																					
2	Goede, de, M., Obdeijn, C., Horst, van der, A.R.A. 2012.				X														X							X
3	Ormel, W., Klein Wolt, K., den Hertog, P. 2009.								X	X	X															
4	Schepers, P. 2008.			X					X	X	X			X	X		X	X		X						
5	Schoon, CC., & Blokpoel, A. 2000.								X	X	X			X	X		X			X						
6	Janssen, B. 2017.				X												X									
7	Davidse, R., Boele, M., Duivenvoorden, K & Louwerse, 2014.				X									X						X						
	SPANISH/PORTUGUESE REVIEW																									
8	Ruiz; V. et al. 2015							X																		
9	Leite, M.; Neto, N.; Rosa, B. 2015.			X																						
10	Junior, R. S.; Nodari, C. 2016.				X				X	X	X														X	
11	Espinoza-Bolaños, J. L.; Hernández-Veja, H.; Jiménez-Romero, D. 2017.			X																						
12	da Silva, A. L. 2018.											X									X	X			X	
13	da Silva, C. 2016.			X																						
14	Instituto Cordial. 2019.			X																						
15	Roldán, O. M. G. et al. 2012.																				X					
	DANISH REVIEW																									
16	Jensen, S.U. 2017a.	X											X								X					
17	Jensen, S.U. 2017b.																				X					
18	Buch, T. S., Jensen S.U. 2017.																				X					

		Area type	Speed limit	Bicycle facility type	Facility width/ width restriction	Bicycle crossing	Bicycle crossing quality	Pedestrian crossing	Bicycle facility surface / grip	Road surface / grip	Road condition	Road number of lanes	Facility one /two way	Vehicle parking - road side	Side object – left/right	Side surface quality	Edge transition – left/right	Tram rails	Bicycle facility centre line	Obstacle in path	Intersection type	Intersecting road volume	Intersection prioritization	Street lighting	Operating Speed (85th %ile)	Bicycle facility user mix
19	Accident Investigation Board, 2015.		X																		X					
20	Buch, T. S. 2015																				X					
21	Jensen, S.U., Lund B. C., Andersson P. K. 2014.																				X					
22	Buch, T. S., Jensen, S. U. 2013.					X							X													
	NORWEGIAN HANDBOOK*																									
23	Boufous, S., de Rome, L., Senserrick, T., & Ivers, R. 2012.	X	X																							
24	Cripton, P. A. et al. 2015.			X		X																			X	
25	Wang, Y., & Nihan, N. L. 2004.		X																		X					
26	Petritsch, T. A. et al. 2006.																									
	Teschke, K. et al. 2012.			X														X								
27	Teschke, K. et al. 2014.			X										X												
28	Bíl, M., Bílová, M., & Müller, I. 2010.																							X		
29	Romanow, N. T. et al. 2012.																							X		
30	Vavatsoulas, K., Kaplan, S., & Prato, C. G. 2013.			X																				X		
31	Wanvik, P. O. 2009.																							X		
32	Turner et al., 2009.			X																						
33	Turner et al., 2011.*			X																						
34	Hamann & Peek-Asa, 2013.			X																						
35	Abdel-Aty, 2014.*			X									X													
36	Park et al., 2015.			X																						
37	Pulugurtha & Thakur, 2015.			X																						
38	Buckley & Wilke, 2000.																									
39	Poulos et al., 2015			X		X	X														X		X			
40	Prato et al., 2014			X																						
41	Vandenbulcke et al., 2014					X	X						X								X		X			
42	Schepers et al., 2011*					X	X						X								X		X			
43	Moritz, 1998			X				X																		
44	Rome et al., 2013			X																						
45	Senturia et al., 1997			X																						
46	Aultman-Hall & Adams, 1998			X																						

		Area type	Speed limit	Bicycle facility type	Facility width/ width restriction	Bicycle crossing	Bicycle crossing quality	Pedestrian crossing	Bicycle facility surface / grip	Road surface / grip	Road condition	Road number of lanes	Facility one /two way	Vehicle parking - road side	Side object – left/right	Side surface quality	Edge transition – left/right	Tram rails	Bicycle facility centre line	Obstacle in path	Intersection type	Intersecting road volume	Intersection prioritization	Street lighting	Operating Speed (85th %ile)	Bicycle facility user mix
47	Aultman-Hall & Hall, 1998			X																						
48	Aultman-Hall & Kaltenecker, 1999			X																						
49	Bjornskau et al., (2017)			X																						
50	Vandenbulcke et al., 2014.			X									X													
51	Alrutz et al., 2002.			X									X													
52	Dupriez, 2009.			X									X													
53	Bjørnskau et al. 2012.			X									X													
54	de Brabander Vereeck, 2007											X									X				X	
55	Daniels et al., 2008											X									X				X	
56	Daniels et al., 2009											X									X				X	
57	Harris et al., 2013											X									X				X	
58	Jensen, 2013											X									X				X	
59	Vandenbulcke et al., 2014											X									X				X	
60	Vandenbulcke et al., 2007	X		X																	X					
	ENGLISH PUBLICATIONS																									
61	Boufous and Olivier. 2015.								X	X										X						
62	Hertach et al. 2018.								X	X					X	X	X	X		X						
63	Beck et al. 2019.										X							X								
64	Knowles et al. 2009.										X										X					
65	Munster et al. 2001.								X	X	X															
66	Quan Y. & Hongyun C. 2017.																				X				X	
67	Wall, S.P. et al.			X																						
	Total	***3***	***3***	***30***	***5***	***5***	***3***	***2***	***7***	***7***	***7***	***7***	***9***	***4***	***3***	***1***	***4***	***4***	***1***	***5***	***21***	***1***	***3***	***4***	***10***	***1***

*Three publications which were included in the Hoye (2017) chapter of the *Road Safety Handbook* were already cited in the development of the CycleRAP model.

APPENDIX D: PILOT TRIAL EVALUATION

Meeting notes

On 24 February 2020, a one-day, in-person workshop was held with the suppliers of CycleRAP pilot projects. Representatives from the provinces where the trials were completed were also invited to join. The meeting was organised and hosted by ANWB in The Hague.

Representatives from ANWB, iRAP, Mobycon, RHDHV, and IV-Infra attended the meeting. Province of Friesland joined the meeting via conference call. AMSS provided written input prior to the meeting. Representatives from ESC and the provinces of Drenthe and Groningen were unable to attend the meeting.

Key points from each of the workshop participants are summarised below.

Mobycon

- ESC completed the survey and coding and Mobycon was responsible for the analysis and reporting.
- To do the coding and analysis effectively, one needed knowledge of how the model worked. The large number of attributes made coding and analysis consuming and difficult.
- Was challenging for vehicle free roads and a number of errors were made in the data collection/coding that required correcting.
- The index scores are not categorised, which made it challenging for the municipalities to understand.
- Some single attributes were mapped to assist with analysis, but difficult to communicate what is most important. Maps and colour coding in GIS are needed.
- The model works ok in showing overall risk, but it is not possible to see what the problem is or what to do about it.

Province of Friesland/IV-Infra

- Province of Friesland was part of the development of CycleRAP in a move toward a proactive approach to assessing and addressing bicycling risk, rather than a reactive approach (i.e. responding after a crash has happened). Part of a broader approach to expand the cycling network throughout the province. For Friesland, cycling infrastructure is primarily rural. Understanding that municipalities face a much larger task in managing the safety issues across their networks and need a tool that is suitable for this purpose.
- The pilot showed the CycleRAP model to be slow and expensive to implement.
- Results were mapped in GIS and colour coded by index score. The interface allows single attributes to be displayed.
- The results aligned with 'common sense' on where higher risk sections are. For the corridors assessed, the index scores correlated with known crash locations.
- Asset data on cycling facilities tends to be poor, so CycleRAP is a way to collect this data.
- IV-Infra trialled LIDAR assessment, however this was not successful and required manual coding.

- CycleRAP index scores made it hard to compare or benchmark the results. This needs to be made easier. There needs to be a sense of what is ‘acceptable risk’ (i.e. 3-star or better equivalent), and it needs to be able to show which risk factors have the biggest weighting.
- There were challenges with coding and quality checks. More initial guidance on process and best practice in line with what is used for EuroRAP would have saved time spent working it out.

RHDHV

- Rivierenland was the most extensive networks assessed. ESC coded images from Cyclomedia.
- Issues with time, cost, quality, practicality: The process is too iterative and there are too many road characteristics/data points. It is not economically viable in its current form.
- Vehicle-bicycle interactions are weighted too heavily in the model. Other (non-vehicle) crash types have such a minimal impact on the index score that they become ‘noise’.
- Very hard to establish a clear link between the index score and the effect of measures. Need top 3-5 risk factors and interventions needed by the local authority.
- An improved coding manual and reporting guidance could streamline process issues and reduce error rates.

AMSS-CMV input (provided prior to meeting)

AMSS-CMV completed a CycleRAP pilot in province Drenthe. For that purpose, the RAP inspection system was adopted for CycleRAP inspections. A bicycle was equipped with all necessary equipment for the survey. We also adopted coding form according to the CycleRAP manual (image below). Images were collected every 5m and coded every 25m.

AMSS-CMV coding form