Comparative assessment and ranking of infrastructure related crash risk factors

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Abstract

The objective of this study is the comparative assessment and review of infrastructure related risk factors with the explicit purpose of ranking them based on how detrimental they are towards road safety (i.e. crash risk, frequency and severity). This analysis was carried out within the SafetyCube project, which aims to identify and quantify the effects of risk factors and measures related to behaviour, infrastructure or vehicle factors, and integrate the results in an innovative road safety Decision Support System (DSS). This evaluation was conducted by examining studies from the existing literature. These were selected and analysed using a specifically designed common methodology. All risk factors to be analysed were structured in a taxonomy. The infrastructure risk factors covered 10 areas with several risk factors in each area (59 risk factors in total), examples include: alignment features (e.g. horizontal-vertical alignment deficiencies), cross-section characteristics (e.g. superelevation, lane, median and shoulder deficiencies), road surface deficiencies, workzones, junction deficiencies (interchange and at-grade) etc. Consultation with infrastructure stakeholders (international organisations, road authorities, etc.) took place in dedicated workshops to identify user needs for the DSS, as well as topics of particular importance. The following analysis methodology was applied to each infrastructure risk factor:i) A search for relevant international literature, ii)Selection of studies on the basis of rigorous criteria, iii) Analysis of studies in terms of design, methods and limitations, iv) Synthesis of findings - and meta-analysis, when feasible. More than 270 high quality studies were selected and analysed. In total, 6 original meta-analyses were carried out, as well as 31 other syntheses. This allowed the ranking of infrastructure related risk factors into three groups: risky (8 risk factors), probably risky (21 risk factors), and unclear (7 risk factors).

Keywords

road infrastructure; risk factors; ranking.

1. Introduction

The European Union (EU) has made substantial progress in improving road safety and reducing traffic fatalities. In the decade up to 2010, the number of fatalities reduced by 45% and the total number injured reduced by 30% (EuroStat, 2012). To further reduce the road toll it is necessary to understand the risks involved. Safety CaUsation, Benefits and Efficiency (SafetyCube) is a European Commission supported Horizon 2020 project with the objective of developing an innovative road safety Decision Support System (DSS) that will enable policy-makers and stakeholders to select and implement the most appropriate strategies, measures and cost-effective approaches to reduce casualties of all road user types and all severities. It is the first DSS worldwide that will provide information not only on measures, but also on risk factors that induce road safety problems.

One of the most critical factors affecting road safety outcomes is road infrastructure and environment (e.g. road type, geometrical design, traffic control, lighting and weather conditions, etc.) (Elvik et al., 2009). The European Commission and the European Road Safety Observatory (ERSO) release annual reports based on macroscopic data from CARE/ CADaS, which include crash trends and developments related to road infrastructure such as road type (ERSO, 2016a; 2016b; 2016c' 2016d).

The available macroscopic data indicates that there are patterns of persistent road safety problems related to the road infrastructure and environment in the European countries, particularly as regards rural roads (including motorways), urban areas and junctions areas. This raises the need for further insight into the identification of specific critical infrastructure risk factors and their impact on road safety outcome indicators. This is not possible through the analysis of the available macroscopic data alone.

The SafetyCube project aims to identify, analyse in-depth and rank the specific road network management, design, traffic control and environmental factors that affect road safety outcomes. This analysis may shed light on the impacts of specific infrastructure risk factors on road accidents.

The objective of this study is to provide a comparative assessment and critical review of a variety of infrastructure related risk factors with the explicit purpose of ranking them based on how detrimental they are towards road safety outcomes (i.e. crash risk, frequency and severity). This evaluation was conducted by examining studies from the existing literature, selected and analysed on the basis of a dedicated common methodology.

2. Methodology

Within the SafetyCube project 'risk factor' refers to any factor that contributes to the occurrence or the consequence of road accidents. Risk factors can have a direct influence on the risk of an accident occurring, on the consequences of the accident (severity), or more indirectly by influencing a Safety Performance Indicator (SPI). All elements of the road system are potential crash risk factors.

For the analysis of infrastructure related risk factors, a dedicated methodology was developed as follows (Martensen et al. 2017):

- a stakeholders' consultation was carried out in order to identify user needs from the DSS and "hot topics" in the field of infrastructure safety.
- a taxonomy of risks was created, in order to systematically classify areas and topics to be analyzed
- a dedicated methodology was developed for searching the literature and identifying the most relevant, high quality and recent studies; moreover, tools were developed in order to analyze studies and systematically code them and assess their findings so that they can be accessible in the DSS.

2.1 A taxonomy of infrastructure risk factors

The aim of creating a taxonomy is to identify the relevant topics covering all aspects of infrastructure and road environment risk factors, and structure them in a meaningful way (e.g. general topics, specific topics), to serve as the back-bone of the analyses. A comprehensive list of risk factors specific to the road infrastructure was created on the basis of several key publications. Relevant information was then sought on their general description, the related risk mechanisms, and a rough assessment of the safety effects (high / low or range of values, if known). In order to do so, existing studies on infrastructure related risk factors were thoroughly reviewed (ERSO, 2016; Elvik et al. 2009; CEDR, 2008; ROSEBUD, 2006; SUPREME, 2007, OECD/ITF, 2012; PRACT, 2016; iRAP, 2016).

The entire taxonomy of risk factors utilised in the SafetyCube project is not presented here for the economy of space and the reader is referred to Filtness & Papadimitriou (2016). General categories of infrastructure elements were firstly considered and then 59 specific risk factors were assigned to the respective element and general risk factor. The 10 infrastructure elements that are included are as follows:

- Exposure.
- Road type.
- Road surface.
- Road environment.
- Presence of work zones.
- Alignment - Road segments.
- Cross-section - Road segments.
- Traffic control - Road segments.
- Alignment - Junctions.
- Traffic control - Junctions.

2.2. Identification of “hot topics” / Stakeholders’ contribution

The SafetyCube project had already identified a core group of stakeholders from government, industry, research, and consumer organizations covering the three road safety pillars: vehicle, infrastructure, road user, and several workshops and consultations took place from the beginning of the project.

Another more dedicated workshop was carried out with the participation of 12 road infrastructure stakeholders on February 22nd, 2016, in Brussels (SafetyCube, 2016). The participants represented key road infrastructure stakeholders, including EC-INEA, EC-DG-MOVE, EURORAP, ASECAP, ETSC, POLIS network, FIA, BRRC and Belgian regional authorities. The objectives of the workshop were the analysis of infrastructure stakeholders’ needs for the DSS, as well as selecting “hot topics” from the infrastructure related risk factors from the taxonomy.

On the basis of the workshop results, it was indicated that the Decision Support System (DSS) should be suitable for use by a wide range of end users. It should not be limited to EU policy makers, but also be applicable for local authorities. It is intended that the system will help policy makers make an “informed decision”. Moreover, it has to be an impartial system, which will not advocate for specific measures – the intention is “to guide, rather than to dictate”. Using this structured approach to policy making should eventually enhance public acceptance of measures by providing a solid evidence base for decisions. In addition, it was suggested that the DSS should include robust data, allowing for critical analysis and transparency, there should be access to the studies used and to all results as well.

The main expected outcomes of the DSS are the following:

- Recommended good quality studies covering the topics at each taxonomy level
- Contextual information on studies (local, environmental, etc.), limitations of studies, implementation difficulties
- A meta-analysis where possible
- A range of solutions suitable for address any particular road safety problem

A complete list of “hot topics” identified through previous consultations was examined in the dedicated infrastructure workshop, to be given priority in the analyses. More specifically, the hot-topics were rated for relative importance by stakeholders. Both the general areas and the specific topics within each area were rated.

The four main areas were prioritised in the following order of importance: 1) Urban road safety measures & Self-explaining and forgiving roads (equally rated), 2) Road safety management, 3) ITS applications.

The top rated specific risks and measures for each area are shown in Table 1. Consequently, the SafetyCube analyses will take this into account and put special emphasis on the highest priority topics.

Table 1. Prioritisation of “hot topics” by road infrastructure stakeholders.

1.Urban road safety (detailed ranking was not possible)	2. Self-explaining and forgiving roads	3. Road safety management	4. ITS applications
Pedestrians / cyclists	1.Removing obstacles	1.Quality of measures implementation	1.ISA
Upgrade of Crossings	2.Introduce shoulder	2.Appropriate speed limits	2. Dynamic speed warning
New crossings	3.Alignment (horizontal / vertical)	3.Enforcement	3.ADAS and active safety with V2I
Junctions / roundabouts treatments for VRU	4.Sight distance	4.Availability of cost-effectiveness data	4.Implementation of VMS
Visibility	5.Traffic signs	5.Workzones	
	6.Raised crossings / intersections		

2.3. Dedicated Methodology for the assessment of risk factors

The aim of the development of a common methodology was to collect information for each risk factor in a uniform way to allow for the ranking of risk factors in a standardised manner. This included developing a literature search strategy, a ‘Coding template’ to record key data and metadata from individual studies, and Guidelines for summarising the findings per risk factor.

Collating information from a variety of studies each of which may use different underlying theories, designs and methods represented a big challenge. Therefore the approach and ‘coding template’ developed was designed to be flexible enough to capture important information but also facilitate the comparison between studies. These documents and the associated instructions and guidelines can be found in Martensen et al (2017).

2.3.1. Literature search and Study Selection

For each of the identified risk factor topics a standardised literature search was conducted in order to identify relevant studies to include in the Decision Support System (DSS) and to form a basis for a concluding summary (synopsis) and further analyses. A standardised procedure was developed and applied for each examined risk factor; however, in some cases insufficient literature was identified and some risk factors could not be evaluated. The literature searches were carried out between May and September 2016. The literature search, study coding and synopses creation for a particular risk factor was completed within the same SafetyCube partner organisation. The process was documented in a standard format to make the gradual reduction of relevant studies transparent.

The main databases used to search for infrastructure risk factors were the following: Scopus, TRID, Google Scholar, Science Direct. Taylor & Francis Online, Springer Link.

The aim was to find studies that provided an estimate of the risk of being in a crash due to the presence of the risk factor. Therefore, studies considering crash data were designated the most important. However, while the actual occurrence of crashes can be seen as the ultimate outcome measure for road safety, SPIs have in recent years been taken into consideration to quantify the road safety level (Gitelman et al., 2014). SPIs include driving behaviour, like speed choice and lane positioning. These metrics give an indication of safe (or unsafe) driving behaviour. The SPI variables included for analysis are those for which there is some scientific evidence of an association with increased crash risk. For some risk factors, studies considering SPIs are included in addition to those focusing directly on crashes. However, where possible, the selected studies for coding all contained crash data.

Since the study design and the outcome variables are just basic criteria, for some risk factors the literature search had the potential to yield an excessive number of related studies and therefore additional selection criteria were adopted. Furthermore, on major and well-studied infrastructure risk factors, meta-analyses were available and the results of these were identified and incorporated. While the aim was to include as many studies as possible for as many risk factors as possible, it was simply not feasible, given the scope and resources of the project, to examine all available studies for all risk factors and their variants. The general criteria for prioritising studies to be selected for further analysis and eventual inclusion in the DSS were based on the following guideline:

- Key meta-analyses (studies already included in the key meta-analysis were not coded again)
- Most recent studies
- High quality of studies
- Country origin: Europe before North America/Australasia before other countries
- Importance: number of citations
- Language: English
- Peer reviewed journals

According to the level of detail of the topic and the history of research in the field, the exact approach to prioritisation and number of studies that were eligible for 'coding' varied.

A challenge within the task of identifying studies to be included in the repository of risk factor studies was to distinguish between risk factors and countermeasures. For example, studies dealing with the absence of a safety barrier may be designed to record e.g. crashes before and after the installation of a safety barrier. Although dealing with a risk factor, these studies describe effects resulting from the treatment of a risk factor/application of a remedial measure. Such studies will be coded and considered within the subsequent measures analysis of SafetyCube activities.

2.3.2. Study Coding and Quality Control

Within the aim of creating a data-base of crash risk estimates related to road infrastructure design and layout, a template was developed to capture relevant information from each study in a manner that this information could be uniformly reported and shared across topics within the overall SafetyCube project. Guidelines were also made available for the task of coding with detailed instructions on how to use the template. The coding template was designed to accommodate the variety and complexity of different study designs. At the same time its complexity required partners to learn how to use it. For each study the following information was coded and will ultimately be presented in the DSS:

- Road system element (Road User, Infrastructure, Vehicle) and level of taxonomy so that users of the DSS will be able to find information on topics they are interested in.
- Basic information of the study (title, author, year, source, origin, abstract)
- Road user group examined
- Study design
- Measures of exposure to the risk factor
- Measures of outcome (e.g. number of injury crashes)
- Type of effects (within SafetyCube this refers to the numerical and statistical details of a given study in a manner to quantify a particular association between exposure (either to a risk factor or a countermeasure) and a road safety outcome)
- Effects (including corresponding measures e.g. confidence intervals)
- Limitations
- Summary of the information relevant to SafetyCube (this may be different from the original study abstract).

For the full list of information provided per study see Martensen et al (2017). Completed coding files (one per study) were uploaded to a relational database which serves as the back-end of the DSS.

Even though the instructions for coding were detailed, these still allowed room for interpretation e.g. which design describes the study the best (if not mentioned by author), which estimates to include or exclude, what are essentially the weak points of the study etc. Therefore, a quality control procedure was established in which all risk factors were allocated to the primary and secondary coding partner. The primary coding partner undertook the literature search, selected the papers for coding and coded these studies. The initial coded studies for each partner where shared between primary and secondary coding partners to confirm coding decisions. Once there was agreement on the coding of the initial studies, the rest of the studies were coded without sharing between the primary and secondary coding partners unless the studies were complicated or caused problems for the coders. These complicated studies which proved were discussed between the primary and secondary coding partner so as to reach consensus. Coders had the opportunity to have more than one study checked if they were uncertain.

2.3.3. Synopses and ranking of risk factors

The syntheses of studies for each topic were made available in the form of a 'synopsis' indicating the main findings for a particular risk factor derived from meta-analyses or another type of comprehensive synthesis of the results (e.g. vote-count analysis), according to the guidelines and templates available in Martensen et al. (2016).

Synopses were created on different levels of the risk factor taxonomy, dependent on the availability of studies for a certain topic. The synopses contain context information for each risk factor from literature that could not be coded (e.g. literature reviews or qualitative studies). However, not all the coded studies that will populate the DSS are included in the analysis of the synopsis. For some risk factors where it was possible to code only a few studies, these coded studies will be included in the DSS. However, there was not enough information to write a full synopsis.

The synopses aim to facilitate different end users: decision-makers looking for global estimates vs. scientific users interested in result and methodological details. Therefore, they contain sections for different end user groups that can be read independently. The structure of each risk factor synopsis, including the corresponding sub items (uniform for human, vehicle, and infrastructure related risk factors), is as follows (note. Slight differences occur between synopses due to the variability in information from the literature):

- Summary: Abstract, Overview of effects, Analysis methods
- Scientific overview: Short synthesis of the literature, Overview of the available studies, Description of the analysis methods, Analysis of the effects (meta-analysis, other type of comprehensive synthesis like vote-count table or review-type analysis)
- Supporting documents: Details of literature search, Comparison of available studies in detail (optional)

The final step was the ranking of risk factors and for that purpose a colour code scale was created, as follows. The colour code indicates how important this risk factor is in terms of the amount of evidence demonstrating its impact on road safety as regards increasing crash risk, frequency or severity:

- Red: Risky. Consistent results showing an increased risk of crashes or injuries when exposed to this risk factor.
- Yellow: Probably risky. Some evidence that there is increased risk when exposed to this risk factor, but results are not consistent. This could be because while the majority of studies demonstrate a risk, there may be some studies with inconsistent results. Or, studies indicate a risk but are few in number or have methodological weakness.
- Grey: Unclear. Studies report opposite effects. There are few studies with inconsistent results, few studies with weak indication or risk.
- Green. Probably not risky. Studies consistently demonstrate that this risk factor is not associated with increased crash risk, frequency or severity.

3. Results and discussion

In total, more than 270 studies on infrastructure related risk factors have been coded. Ultimately 37 synopses on road infrastructure risks have been developed for inclusion in the DSS, namely by merging some of the 50 specific topics for which there were not enough studies. This work has been completed by 9 different SafetyCube partner organisations.

Table 2 presents the risk factors separated by colour code. In total 8 risk factors were given the colour Red, indicating that there is consistent evidence that this risk factor has a negative effect on road safety in terms of increasing crash risk, frequency or severity. The specific risk factors in the red category are distributed across a range of infrastructure elements, demonstrating that the greatest risk is spread across several aspects of the taxonomy. This is a particularly important finding for the following risky factors, as these were also identified as hot topics: Presence of work zones-Workzone length, Alignment deficiencies-Low curve radius, Shoulder and roadside deficiencies -Absence of paved shoulders, Shoulder and roadside deficiencies -Narrow shoulders.

It is interesting to note that some risk factors allocated a Red colour code were not identified by stakeholders as being hot topics. This suggests that there is a degree of discordance between stakeholder perception or opinion of which infrastructure factors pose most risk and the scientific evidence. This may be due to the fact that different stakeholders may have different specific areas of interest, and therefore not all risk factors are of equal importance to all stakeholders. Alternatively, stakeholders may be aware of the risk but feel it is already controlled for in their specific area of activity, or not possible to control for.

A further 20 risk factors were considered to be Yellow demonstrating some evidence of impact to road safety, however, problems of weak findings, inconsistency between studies or few studies means that the evidence for risk was not considered sufficient to be coded Red. More risk factors were coded Yellow than any other rating. This likely reflects the growing field of road safety research. It is very likely that these are risky but at the moment not enough research of high quality has been conducted to confirm this. Several risk factors allocated a Yellow colour code are hot topics.

Seven risk factors were considered to be Grey indicating that there was not enough evidence to draw a clear conclusion about their impact on road safety. This represents a gap in road safety scientific literature. It would be beneficial for future research to consider addressing each of these factors. This is a particular problem because some of the Grey colour coded risk factors are hot topics. This demonstrates that the scientific literature is not currently meeting all the needs of road safety stakeholders for evidence-base.

Table 2. Infrastructure related risk factor ranking by colour code

Red (Risky)	Yellow (Probably risky)	Grey (Unclear)
! Effect of Traffic Volume on safety	! Occurrence of Secondary crashes	? Congestion as a risk factor
! Risks associated with Traffic Composition	! Absence of Transition curves	? Risks associated with the distribution of traffic flow over arms at junctions
! Road Surface - Inadequate Friction	! Risk of Different Road Types	? Adverse weather - Frost and snow
! Workzone length	! Adverse weather - Rain	? Workzone duration
! Low Curve Radius	! Poor Visibility - Darkness	? Frequent curves
! Number of Lanes	! Superelevation	? Densely spaced
! Absence of paved shoulders	! High grade	
! Narrow Shoulders	! Presence of Tunnels	
	! Narrow lanes	
	! Undivided road	
	! Narrow median	

	! Risks associated with Safety Barriers and Obstacles ! Sight Obstructions (Landscape, Obstacles and Vegetation) ! Ramp Length ! At-grade junctions - Number of conflict points ! Risk of different junction types ! Skewness / Junction angle ! At-grade junctions - Poor sight distance ! At-grade junctions - Gradient ! Uncontrolled rail-road crossing ! Poor junction readability - Absence of road markings and crosswalks ! Poor junction readability - Uncontrolled junction	junctions ? Acceleration / deceleration lane length

A detailed assessment of infrastructure related road safety problems is presented in Table 3. Results are separated for each of the infrastructure elements, with the specific risk factors within each element ranked by colour code and indication on the type of road safety outcomes affected, as well as whether or not this is a hot topic. The infrastructure elements Exposure and Cross-Section Road Segments have the greatest number of specific risk factors with a Red colour code.

Table 3. Overview of infrastructure related problems and associated risk to crashes

Infrastructure Element	Specific Risk Factor	Colour code	Crash risk	Crash frequency	Crash severity	Hot topic (Yes/No)
Exposure	Effect of Traffic Volume on safety	Red	↓	↑	-	N
	Risks associated with Traffic Composition	Red	↓	↑	-	N
	Occurrence of Secondary crashes	Yellow	↑	-	-	N
	Congestion as a risk factor	Grey	-	↑	-	N
	Risks associated with the distribution of traffic flow over arms at junctions	Grey	-	-	↑	N
Road Surface	Inadequate Friction	Red	↑	-	↑	N
Road Type	Risk of Different Road Types	Yellow	-	↑	↑	N
Road environment	Adverse weather - Rain	Yellow	-	↑	-	N
	Adverse weather - Frost and Snow	Grey	-	-	-	N
	Poor Visibility - Darkness	Yellow	↑	-	↑	N
Presence of workzones	Workzone Length	Red	↑	↑	-	Y
	Workzone Duration	Grey	-	-	-	Y
Alignment - Road Segments	Low Curve Radius	Red	-	↑	↑	Y

	Absence of transition curves	Yellow	↑	-	-	Y
	High Grade	Yellow	-	↑	↑	Y
	Presence of Tunnels	Yellow	-	↑	↑	Y
	Frequent curves	Grey	-	-	-	Y
	Densely spaced junctions	Grey	-	-	-	Y
Cross-Section - Road Segments	Number of lanes	Red	-	↑	↑	N
	Absence of paved shoulders	Red	-	↑	-	Y
	Narrow shoulders	Red	-	↑	-	Y
	Narrow lanes	Yellow	-	↑	-	N
	Undivided Road	Yellow	-	-	↑	N
	Narrow Median	Yellow	-	↑	↑	N
	Risks associated with safety barriers and obstacles	Yellow	-	↑	↑	Y
	sight obstructions (Landscape, Obstacles and Vegetation)	Yellow	-	-	-	Y
	Superelevation	Yellow	↑	↑	-	N
Alignment - Junctions	ramp length	Yellow	-	-	↑	N
	At-grade junctions -Number of conflict points	Yellow	-	↑	-	Y
	Risk of different junction types	Yellow	↑	-	↑	Y
	Skewness / junction angle	Yellow	↑	-	↑	Y
	Poor Sight Distance	Yellow	↑	-	-	Y
	Gradient	Yellow	↑	-	↑	N
	Acceleration/Deceleration lane length	Grey	-	-	-	N
Traffic Control - Junctions	Uncontrolled Rail-Road Crossing	Yellow	↑	-	↑	N
	Poor junction readability - absence of road markings and crosswalks	Yellow	-	-	↑	N
	Poor junction readability- Uncontrolled junctions	Yellow	-	↓	↑	N

Unfortunately it was not possible to produce a synopsis for all specific risk factors listed in the taxonomy. This was due to difficulties of finding enough relevant studies. Often this was due to the absence of an infrastructure element or with a strong association with a measure/solution to improve road safety e.g. insufficient signage in workzones. These topics will be dealt with in the next steps of SafetyCube which deal with the relationship between crashes effects resulting from treatments/measures deployed to improve road infrastructure defects or problems.

The following specific risk factors were identified as hot topics by stakeholder but not have a synopsis: Insufficient signage (Presence of workzones), Vertical curve radius (Alignment – Road segments), Poor sight distance – vertical curve (Alignment – Road segments), Poor road readability (Traffic control – road segments), Misleading or unreadable traffic signs (Traffic control – junctions).

This demonstrates that there are some emerging issues for road safety practitioners and policy makers which the scientific community has not yet adequately investigated. Although there is not enough evidence to produce a synopsis for each of these risk factors, in some cases there are a few studies. If this is the case (as with insufficient signage at workzones) the individual studies have been coded and included in the DSS. This will give DSS users access to as much information as is currently possible, even though it is not meaningful to summarise this information.

Poor road readability is an example of a risk factor which is commonly investigated by evaluating the impact of a treatment/measure to improve road readability. As such, this infrastructure element will be considered in detail as part of the measures analysis.

4. Conclusions and next steps

The present paper describes the identification and evaluation of infrastructure related risk factors. It outlines the related results of the SafetyCube project, which aimed to identify and evaluate infrastructure related risk factors and related road safety problems by (i) presenting a taxonomy of infrastructure related risks, (ii) identifying "hot topics" of concern for relevant stakeholders and (iii) evaluating the relative importance for road safety outcomes (crash risk, crash frequency and severity etc.) within the scientific literature for each identified risk factor. To help achieve this, this research initially exploited current knowledge (e.g. existing studies) and, where possible, existing accident data (macroscopic and in-depth) in order to identify and rank risk factors related to the road infrastructure.

In order to develop a comprehensive taxonomy of road infrastructure-related risks, an overview of infrastructure safety across Europe was undertaken to identify the main types of road infrastructure-related risks, using key resources and publications. In addition to this, stakeholder consultations in the form of a series of workshops were undertaken to prioritise risk factors ('hot topics') based on the feedback from the stakeholders on which risk factors they considered to be the most important or most relevant in terms of road infrastructure safety. To evaluate the scientific literature, a SafetyCube methodology was developed and applied to road infrastructure risk factors. This uniformed approach facilitated systematic searching of the scientific literature and consistent evaluation of the evidence for each risk factor. It also allowed for a consistent and evidence-based ranking of infrastructure risk factors, on the basis of a dedicated 'colour-code' scale.

In total, eight risk factors were given a Red code (e.g. traffic volume, traffic composition, road surface deficiencies, shoulder deficiencies, workzone length, low curve radius), twenty were given a Yellow code (e.g. secondary crashes, risks associated with road type, narrow lane or median, roadside deficiencies, type of junction, design and visibility at junctions) seven were given a Grey code (e.g. congestion, frost and snow, densely spaced junctions etc.). The specific risk factors given the red code were found to be distributed across a range of infrastructure elements, demonstrating that the greatest risk is spread across several aspects of infrastructure design and traffic control. However, four 'hot topics' were rated as being risky, which were 'small work-zone length', 'low curve radius', 'absence of shoulder' and 'narrow shoulder'. Based on the sample of countries from which the reviewed studies were conducted (predominantly European, Australian, and North American), the results of the analysis may be cautiously considered generally transferable, particularly for industrialized countries. Several hot topics were also ranked as "grey", suggesting that the scientific literature is not currently meeting the needs of policy makers in all cases.

The limitations of this work should be noted. The process of allocating colour codes was related to both the magnitude of risk observed and the level of evidence for this. It is possible for a risk factor with a yellow colour code to have a greater impact on road safety (e.g. increased severity of crashes) than a risk factor coded red, if there was limited evidence of its risk. Because of this it is important to recognise that road safety benefits may be expected from implementing measures to mitigate any red or yellow coded infrastructure risks.

Findings are limited both by the implemented literature search strategy and the quality of the studies identified. The common approach using the TRID search database was adopted since this is a rich source of information for research into the relationship between infrastructure design and layout and crashes/safety. However, TRID is an American database which may have artificially increased the number of American studies reviewed. Nevertheless, the studies identified were of sufficiently high quality to inform understanding of the risk factor.

Due to resources constraints, prioritising of study coding was necessary for risk factors with many identified studies. Across all risk factors, priority was given to studies which considered crashes over changes in driving behaviour or effects of safety performance indicators such as speeds. This approach focused on studies with the highest methodological quality, however, it is possible that some detail of level of risk may have been missed by failure to consider a broad range of methodological approaches. Finally, within the considered literature, crash risk and crash frequency are much more commonly studied than crash severity. For some risk factors this makes it difficult (or impossible) to consider the implications for injury causation.

The coded studies and synopses for the infrastructure risk factors will be accessible to the users of the DSS; pilot operation is expected to start mid-2017, and full operation mid-2018 (end of the SafetyCube project). The next task of SafetyCube is identify measures that will counter the identified risk factors. Priority will be placed on investigating measures aimed to mitigate the risk factors identified as Red. The priority of risk factors in the Yellow category will depend on why they were assigned to this category and whether or not they are a hot topic. Overall, the final DSS will support evidence-based policy making. When deciding how to allocate limited resources for improving road safety, the DSS will increase awareness of the relative evidence for risk of each factor and therefore assist in decision making.

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