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Development of a road safety Decision Support System for road infrastructure

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Abstract

To be effective road safety policies must be informed by accurate information about accident risk factors and measures. Recent research suggests that infrastructure design guidelines may not always guarantee safety, and policy-makers and infrastructure managers need evidence-based support to identify problems and apply the right interventions. The SafetyCube - Safety Causations, Benefits and Efficiency is a research project funded by the European Commission under the Horizon 2020 research framework programme, involving 17 partners from 12 EU countries. SafetyCube aims to generate new knowledge about accident risk factors and the effectiveness of measures relevant to Europe, and to structure this information in a Decision Support System (DSS). Particular emphasis is put on road infrastructure safety, within a safe systems approach. A taxonomy of infrastructure risk factors and measures was developed alongside a methodological framework which was implemented in order to identify and quantify the relevant risk factors, and where possible to undertake a meta-analysis of existing research on infrastructure risk factors and the effects of measures (e.g. Crash Modification Factors, but also other forms of safety effects). Particular emphasis is placed on a number of "hot topics" within road infrastructure safety, namely: (i) road safety management (road safety impact assessment, road safety audits, roads star rating e.g. EuroRAP, etc.); (ii) self-explaining and forgiving roads (simpler and more readable road design standards, related traffic arrangements for VRUs, etc.); (iii) ITS applications (V2I, cooperative systems, etc.); (iv) urban road safety measures (stop-advanced-zones for motorcycles, traffic calming measures, bicycle lanes etc.). The analyses are carried out in close cooperation with road infrastructure stakeholders across Europe.

1. Introduction

1.1. The SafetyCube project

The European Union (EU) has made substantial progress in improving road safety and reducing traffic fatalities. In the decade to 2010 the number of fatalities reduced by 45% and the total injured by 30% (EuroStat, 2012). However, in 2012 the EU Member States with the highest accident rate by population had a rate nearly four times that of the best performing countries. Several countries have adopted a coherent approach to road safety management that follows the Safe System Approach (Bliss and Breen, 2009) or an equivalent. Amongst other

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factors this includes a strong reference to evidence-based policy making and a systematic evaluation of the expected impact and cost-effectiveness of measures.

Road safety policy-making is traditionally considered within the remit of governments and local or regional authorities. However, it is increasingly acknowledged that casualty reduction is a shared responsibility. All stakeholders who have an impact on road risks, including individual citizens, also have a responsibility to contribute to their reduction. The group of relevant stakeholders therefore includes publicly elected bodies but also industry groups including vehicle manufacturers, highway authorities, insurance organizations, police, public health organizations and many other groups in society. The impact on safety is to be assessed whenever there are to be substantial changes to vehicle design, road engineering, traffic management or road use rules.

However, there are several gaps in the evidence base, each one constituting a major challenge to be addressed:

- The poor availability of information relating to the causes of crashes and the estimation of the associated risks.
- The absence of a clear, consolidated set of measures evaluations relevant to European road safety
- The lack of information to fully support priority setting for road safety measures within a systems approach
- The need for further detailed safety data analysis in support of road safety “hot topics”, including new technologies and other measures that have not yet been properly evaluated.

The SafetyCube project aims to address these gaps in the evidence base. More specifically, the main objective of SafetyCube is to develop 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 and crash severity for all road users. The core of the project includes a novel and comprehensive analysis of accident causation factors combined with newly estimated data on the effectiveness and cost-effectiveness of safety measures, not just in relation to reduction of fatalities but also the number of injured. An operational framework will be established to provide future access to the DSS once the project is completed. The project has four sub-objectives:

1) To develop new analysis methods for (a) Priority setting, (b) Evaluating the effectiveness of measures (c) Monitoring serious injuries and assessing their socio-economic costs (d) Cost-benefit analysis taking account of human and material costs.

2) To apply these methods to safety data identifying the key accident causation mechanisms, risk factors and the most cost-effective measures for reducing fatally and seriously injured casualties.

3) To develop an operational framework to ensure the project facilities can be accessed and updated beyond the completion of SafetyCube.

4) To enhance the European Road Safety Observatory (ERSO, 2016) and work with road safety stakeholders to ensure the results of the project can be implemented as widely as possible.

The project outputs will be framed according to the specific policy and stakeholder areas – infrastructures, vehicles and road users – so that the measures developed in the project can be most readily applied. A systems approach will ensure effective coordination between these areas. The close involvement of road safety stakeholders of all types at national and EU levels, and wider will enable the DSS to be focused on the most appropriate policy-making procedures and ensure the project outputs have global reach.

1.2. Road infrastructure safety within SafetyCube

Road infrastructure safety is one of the main topics in SafetyCube. The objective within this area is the in-depth understanding of infrastructure related accident causation factors and the identification and evaluation of the most appropriate infrastructure measures to reduce the impact of crashes. A large amount of existing accident data (macroscopic and in-depth) and knowledge (e.g. existing studies) are exploited in order to achieve the following objectives:

- Identification of infrastructure related risk factors
- Identification of safety effects of infrastructure related measures
- Evaluation of key infrastructure related road safety measures
- Inventory of road infrastructure safety measures

Existing methodologies for estimating safety effects (Elvik et al. 2009; CMF Clearinghouse 2015, AASHTO Highway Safety Manual 2010) will be considered and tested with respect to their applicability to measures concerning infrastructure.

A set of “hot topics” are examined, to be given priority in the analyses (the topics were selected from the beginning of the project on the basis of the existing knowledge):

- Road safety management: Road safety impact assessment, Road safety audits, Roads star rating (e.g. EuroRAP) , etc.
- Self-explaining and forgiving roads: simpler and more readable road design standards, related traffic arrangements for VRUs, etc.
- ITS applications: Vehicle to Infrastructure communication (V2I), cooperative systems, etc.
- Urban road safety measures: interventions developed to reduce the number of VRUs casualties in urban settings, e.g. stop-advanced-zones for motorcycles, traffic calming measures, bicycle lanes etc.

Within this framework, the objective of this paper is to provide an overview of the development of a road safety Decision Support System (DSS) concerning road infrastructure. In particular, a dedicated methodology which was developed as follows:

- a taxonomy of risks and measures is created, in order to systematically classify areas and topics to be analyzed
- a methodology is developed for searching the literature and identifying the most relevant, high quality and recent studies
- tools are developed in order to analyze studies in terms of risks and safety effects of measures and systematically code them so that they can be accessible in the DSS
- a stakeholders’ consultation is carried out in order to identify user needs from the DSS and “hot topics” in the field of infrastructure safety.

The paper is structured as follows: In section 2, we present the methodology, which consists of an illustration of the taxonomy of road infrastructure risks and measures as well as the procedure to identify the effects of risk factors and measures. Section 3 illustrates the Stakeholders’ contribution (identification of user needs for a road infrastructure DSS and the “hot topics”). The last section of the present paper is dedicated to the description of the progress made and to the next steps to be taken.

2. Methodology

2.1. A taxonomy of road infrastructure risks and measures

More than 90 risk factors and 95 measures in 15 infrastructure areas have been identified by means of a thorough review of existing road infrastructure safety areas and taxonomies. General categories of infrastructure elements were firstly considered and then the specific risk factors and measures were assigned to the respective category. The main infrastructure elements that are included are exposure, road type, road surface, road environment, workzones, traffic control, alignment features and so on. Tables 1-9 illustrate the entire taxonomy of risk factors and measures utilized in SafetyCube. It is noted that not all elements include both risks and measures; for example, road safety management includes only measures.

Table 1. Taxonomy of road infrastructure risks and measures relating to exposure.

Infrastructure element	Risk factor	Specific risk factor	Measure	Specific measure
Exposure	Traffic flow	AADT, congestion	Traffic flow	flow diversion
		congestion		2+1 roads
		incident / accident		full contra flow
		traffic composition (share of pedestrians, cyclists, PTW, HGV)		one-way traffic
		distribution of flow over arms at junctions		ramp metering
				increase number of lanes
				increase lane width
				HGV traffic restrictions
				creation of HGV lanes

Table 2. Taxonomy of road infrastructure risks and measures relating to workzones.

Infrastructure element	Risk factor	Specific risk factor	Measure	Specific measure
Workzones	Workzones	small workzone length	Workzones	installation of workzone signage
		high workzone duration		improvement of workzone signage
		insufficient signage		increase of workzone length
				decrease workzone duration

Table 3. Taxonomy of road infrastructure risks and measures relating to road type, road surface and road environment.

Infrastructure element	Risk factor	Specific risk factor	Measure	Specific measure
Road type	Road functional class		Road functional class	Upgrade road class
Road surface	Road surface deficiencies (risk of ran-off road)	inadequate friction	Road surface treatments	improve friction (type of surface)
		uneven surface		road re-surfacing to improve evenness
		ice, snow		ice prevention
		oil, leaves, etc.		
Road environment	Poor visibility and lighting	poor visibility - darkness	Visibility / Lighting treatments	installation of road lighting
		poor visibility - fog		improvement of existing lightling
	Adverse weather	rain		
		snow / ice / low temperatures		
		wind		

Table 4. Taxonomy of road infrastructure measures relating to road safety management.

Infrastructure element	Measure	Specific measure
Road safety management	Formal tools to address road network deficiencies	implementation of road safety audits
		implementation of road safety inspections
		identification of high risk sites
		improvement of land use regulations
	Speed management	reduction of speed limit
		weather-variant speed limits
		installation of individual dynamic speed warning
		installation of speed cameras
		installation of section control
		installation of speed humps
		implementation of woonerfs / narrowings
		implementation of 30-zones
		implementation of traffic calming scheme

Table 5. Taxonomy of road infrastructure risks and measures relating to alignment-road segments.

Infrastructure element	Risk factor	Specific risk factor	Measure	Specific measure
Alignment - Road segments	Horizontal/vertical alignment deficiencies	low curve radius	Horizontal & vertical alignment treatments	creation of weaving area
		absence of transition curves		increase horizontal curve radius (curve re-alignment)
		frequent curves		implement transition curves (curve re-alignment)
		densely spaced junctions		reduce number of curves (re-alignment)
		poor sight distance - horizontal curves		creation of by-pass road
		high grade		creation of weaving area
		vertical curve radius		reduce tangent length

		tunnel		address limited sight distance
		poor sight distance - vertical curves		reduce gradient (re-alignment)
				increase vertical curve radius (curve re-alignment)
				address limited sight distance

Table 6. Taxonomy of road infrastructure risks and measures relating to cross-section (road segments).

Infrastructure element	Risk factor	Specific risk factor	Measure	Specific measure
Cross-section - Road segments	Superelevation / cross-slopes (risk of ran-off road)	superelevetion at curve	Superelevation / cross-slopes treatment	improve superelevation
		cross-slope		improve cross-slope
	Lanes / ramps deficiencies	number of lanes	Lanes / ramps treatments	increase number of lanes
		narrow lane		create speed change lane
				increase lane width
	Median / barrier deficiencies (risk of crash with oncoming traffic)	undivided road	Median / barrier treatments	installation of median
		narrow median		increase median width
				change median type
				implementation of rumble strips at centerline
	Shoulder and roadside deficiencies (risk of ran-off road or crash with obstacle)	absence of shoulder	Shoulder & roadside treatments	implement shoulder (shoulder type)
		narrow shoulder		increase shoulder width
		absence of guardrails or crash cushions		change shoulder type
		absence of clear-zone		installation of guardrails or crash cushions
		roadside obstacles (per type of obstacle e.g. trees)		change type of guardrails
		sight obstructions		create clear-zone / remove obstacles
				increase width of clear-zone
				removal of sight obstructions
				installation of chevron signs at curves
				implementation of edgeline rumble strips
			Sidewalks treatments	installation of sidewalk
				increase of sidewalk width
			Cycle lanes	installation of cycle lane (type of cycle path)
				increase of cycle lane width

Table 7. Taxonomy of road infrastructure risks and measures relating to traffic control-road segments.

Infrastructure element	Risk factor	Specific risk factor	Measure	Specific measure
Traffic control - Road segments	Poor road readability	absence of traffic signs	Traffic signs treatments	installation of traffic sign
		misleading or unreadable traffic signs		replacement of traffic sign
		absence of road markings	Delineation and road markings	implementation of road markings
		absence of rumble strips		installation of chevron signs at curves
				implementation of edgeline rumble strips

				implementation of marked crosswalk
			Driver information and alert	installation of variable message signs: incident / accident warning
				installation of variable message signs: congestion / queue warning
				installation of dynamic speed warning
				implementation of V2I scheme

Table 8. Taxonomy of road infrastructure risks and measures relating to alignment-junctions.

Infrastructure element	Risk factor	Specific risk factor	Measure	Specific measure
Alignment-junctions	Interchange deficiencies	inadequate ramp capacity	Interchanges treatments	convert at-grade junction to interchange
		insufficient ramp length		increasing ramp width
		insufficient acceleration / deceleration lane length		increasing ramp curve radius (ramp re-alignment)
		absence of channelisation		increasing acceleration / deceleration lane length
		absence of access control		increasing lane width
		poor sight distance		
	At-grade junctions deficiencies	high number of conflict points	At-grade junctions treatments	channelisation
		type of junction		address limited sight distance
		skewness / junction angle		implementation of access control
		poor sight distance		convert junction to roundabout
		gradient		convert to 4-leg junction to staggered junctions
				channelisation
				provision of left-turn lanes
				provision of right turn lanes
				improve skewness / junction angle

Table 9. Taxonomy of road infrastructure risks and measures relating to traffic control-junctions.

Infrastructure element	Risk factor	Specific risk factor	Measure	Specific measure
Traffic control - junctions	Rail-road crossings (risk of collision with train)	uncontrolled rail-road crossing	Rail-road crossings	installation of rail-road crossing traffic sign
				installation of automatic barriers
	Poor junction readability	uncontrolled junction	Traffic signs treatments	installation of STOP / YIELD signs
		misleading or unreadable traffic sign		replacement of STOP / YIELD signs
		absence of road markings	Road markings	implementation of road markings
		absence of marked crosswalks		implementation of marked crosswalk
			Traffic signals treatments	installation of traffic signals
				improve traffic signals timing
				implementation of pedestrian signal phase

2.2. Methodology for identifying risk factors and measures effects

The first step of the methodology includes a detailed and recorded literature research so that studies are identified (at each detailed level of the taxonomy, i.e. for each specific risk factor or measure). There are different types of studies dealing with the safety effects of infrastructure risks and measures. Study designs in road safety are closely related to those in epidemiology. Each study design is characterized by a number of principles (addressing exposure to risk/measure; experimental vs. observational; presence of control group; time dimension) and their principal application is mentioned. After the study design is appropriately categorized, the next step is to identify and record the estimators of effects, which may also very (e.g. Crash Modification Factor (CMF), Absolute difference, Regression coefficient / slope, Odds ratios and so on).

Within SafetyCube, a framework was created in order to systematically characterize a range of identified studies for each specific risk factor or measure of the taxonomy (Elvik et al., 2015). Overall, studies can be classified in two categories, namely, experimental and observational. Observational studies are further classified into analytical and descriptive studies which can then be divided to cohort studies, case control, case cross-over and cross-sectional. Similarly, the experimental studies can be classified in randomized or non-randomized control trials, quasi-experimental studies, between group, before and after studies and cross over.

A core characteristic of the approach is to identify the outcomes and the exposure for each study, and their relationship to each other within the study design. Outcomes typically concern accidents or injuries and in particular, their (absolute/relative) numbers, their types and severities. Exposure, in the context of road safety, either refers to exposure to risk factors or exposure to countermeasures. For a full description and details, the reader is referred to Elvik et al., (2015). Figure 1 gives an overview of the categorization of studies.

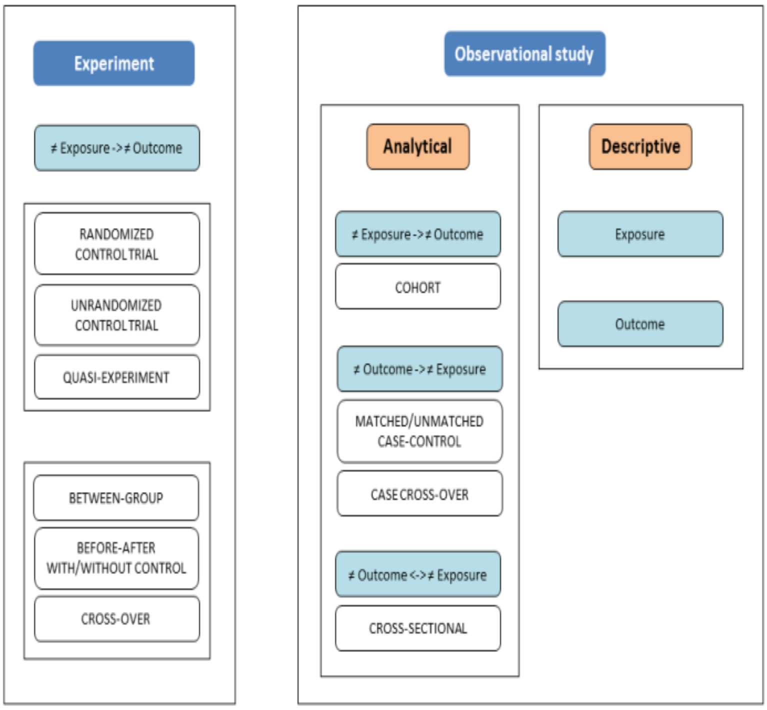

Fig. 1. Study design in risk analysis and evaluation of countermeasures (source: Elvik et al. 2015).

The study design and the corresponding estimator of effects of interest are then entered in a template constructed for coding research studies and existing results. The template includes information on: core elements of the study (study design, road users profile, severities, potential sources of biases etc.), flexible elements (e.g. additional information that characterizes the study design), exposures, outcomes, reported results (measure of effects, estimates, p-values, confidence intervals, etc.) and also a brief summary (critical synopsis of the study).

The objective of SafetyCube is to analyse and code a large number of studies for each specific risk factor or measure, and then draw the findings together into a neat "synopsis" for each topic. The SafetyCube approach is the resulted summaries represent a complete synthesis of knowledge on the topic, and (where possible) including a meta-analysis of existing studies on the topic.

3. Stakeholders' contribution

3.1. User needs for a road infrastructure DSS

Stakeholders play a crucial role in developing the DSS and in achieving excellence. 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.

A first workshop on June 17th 2015 was carried out in Brussels in order to start a dialogue between the project participants and a number of key stakeholders for road safety in Europe. The workshop both introduced the audience to the SafetyCube project and also solicited input from the stakeholders that will form the structure and priorities of a DSS. An extensive list of “hot topics” was also created on the basis of feedback from stakeholders, allowing to enhance the SafetyCube initial lists. A total of 30 delegates attended the event (Hagström et al. 2015).

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 ranking of infrastructure related “hot topics”.

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 have the following characteristics. Firstly, it should include robust data, allowing for critical analysis and transparency. There should be access to the studies used and to all results as well. It is important to provide information of the best quality studies and recommendations. A platform built in the project should be operational after the project.

The main expected outcomes of the DSS are the following:

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

A number of additional elements would be of interest to infrastructure stakeholders such as, decomposition into effects on exposure and risk, cost-benefit analysis especially for the local authorities, focus on fatality reduction and on surrogate measures as well, justification of road safety budget within public expenditure, identification of potential lack of interest on a topic or methodological difficulties.

3.2. Infrastructure “Hot topics”

The complete list of “hot topics” identified through the first consultation was examined in the dedicated infrastructure workshop, to be given priority in the analyses. More specifically, the hot-topics were ranked by stakeholders according to their relative importance. Both the four general areas (see section 1.2) and the specific topics within each area were ranked.

The four main areas are ranked as follows: 1) Urban road safety measures & Self-explaining and forgiving roads (which received equal ranks), 2) Road safety management, 3) ITS applications.

The top ranked specific risks and measures for each area are demonstrated on Table 10.

Table 10. Ranking 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 application
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		

Consequently, the SafetyCube analyses will take into account this ranking and put special emphasis on the highest priority topics.

4. Progress and next steps

A great number of risks, measures and studies related to road infrastructure have been identified, mostly based on the CMF approach. The selection criteria to assess the eligibility of studies to be coded and included in the DSS include:

- Meta-analyses
- Recent studies
- High quality studies (prestigious journals preferred)

So far, more than 400 studies have been analyzed in the area of road infrastructure risks and measures, and many more are in progress. In addition, more than 20 existing meta-analyses are updated and about 65 more are in progress. Summary reports which will provide a critical synthesis of each risk factor and measure are under development.

Next, the main challenges to be addressed are the implementation of the systems approach, the investigation of the combined effect of measures, other potential methodological issues, the transferability of Crash Modification Functions and lastly the complexity of some of the "hot topics" (e.g. self-explaining roads).

The work is in progress and a number of outcomes are expected to be produced in the coming months. First of all, an inventory of road infrastructure safety measures will be created. Moreover, information will be provided on the examined risk factors and the safety effects of related measures. Particular emphasis will be given to the quality assessment of the studies and the data used to produce the estimates of the effects. However, since specific care for the potential transferability of results is needed, special notes will be based on the conditions for transferability of the measures effects. Eventually, an efficiency assessment of the proposed measures in different countries, settings and so on will be carried out.

SafetyCube project is a highly ambitious project aiming to address several critical gaps in the knowledge for implementing evidence based policy making. The DSS will include concise, reliable and easily accessible information to enable a systematic, evidence-based application of the entire road safety policy-making cycle. Information will be organised and structured to facilitate application by both industry and government stakeholders and will be based on analyses of the causes of accidents, the associated risks and the effectiveness of measures structured within a new dedicated methodological framework. As well as this data resource the DSS will also establish a process to support road safety stakeholders in developing evidence based policies through the provision of test examples ("hot topics"), training and procedural support and by establishing an ongoing operational framework for future road safety evaluations.

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