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Review Research

REVIEW OF MODIFYING THE INDICATORS OF ROAD SAFETY SYSTEM

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Abstract: The new vision of road safety issues is based on a systematic approach called a 'safe system'. This approach has been applied recently in some developed countries and resulted in a significant reduction in road fatalities. On the other hand, it is necessary to develop an index to use not only in assessing the size of the road safety problem but also to monitor the intermediate outcome of its operational performance. This paper aims to review the modified indicators of the operational performance of road safety systems based on the fundamentals of the 'safe system' vision. A methodology is presented to choose comprehensive, measurable, and independent indicators which are relevant to the new vision and can be used to predict the conditions of the problem and enable actions to be taken to prevent road crashes from happening. In this methodology, the main indicators of road safety are classified into thematic indicators and individual indicators. These indicators are subjected to evaluation according to measurability, comprehensiveness, and availability of data. The final set of indicators is grouped into three thematic groups; safer road mobility, safer road user behavior, and safer vehicle. Based on the evaluation of the suggested indicators, it is concluded that the iRAP star rating is the most comprehensive, measurable, and dependent indicator to reflect the safer mobility indicator. Speeding, using a protective system, consuming psychoactive substances, and using a mobile phone while driving are chosen as safer road user behavior indicators. The EuroNCAP is chosen as the safer vehicle indicator.

Keywords: *Road infrastructure; road user behavior; safer speed; vehicle safety.*

1. Introduction

Road safety has become an important global issue. It is recognized by the World Health Organization (WHO) and the United Nations (UN) as a leading cause of a high rate of death. Road fatalities have reached an average of 3000 deaths per day which exceeds the average rate [1-5]. This issue has an impact on health, economic, and social issues. Therefore, global actions have been taken based on best practices in Sweden and The Netherlands, where a significant reduction in road fatalities and injuries has been achieved [6-8]. A new vision called the 'safe system' has been produced recently. The safe system concept is that road safety is a multi-dimensional system, in which all dimensions including the vehicle and road design share responsibility for affecting the number of road deaths, while still accommodating the needs and mistakes of road users. While the traditional vision of road safety focused on road users' behavior, as it was considered the main cause of road fatalities and injuries [9-11]. Recently, actions to improve the level of road safety have been based on the

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recent vision to include developing safer vehicle design and road infrastructure, and have produced successful results.

The need for global action on road safety has been raised by the WHO [1]. Global plans to be declared, such as the UN General Assembly's Decade of Actions on Road Safety (2011- 2020) (DARS 2011-2020) and (DARS 2021-2030) with a target of reducing road fatalities by 50 million [12-14]. In addition, the UN published the 2030 Agenda of sustainable development goals (SDG), in which road safety was included in two target groups [5]. Despite this, the global rate of road killers is at a constant amount, and the results of assessments show that the majority of road fatalities are in countries with low and middle-income levels [3, 4]. This leads to a focus on assessing road strategies at national and regional scales to measure the extent to which the new vision has contributed to the change.

2. Road Safety Performance

The performance of road safety systems can be assessed by various metrics. It is essential to assess the size of the issue, to screen the improvement of the system, and to give early warnings when the system indicates early failure. It is also important to rank countries and strategies and to identify the most successful practices [3, 15-17].

Indicators are tools for expressing scientific knowledge in understandable and applicable ways [18]. The ETSC [16] defined a safety performance indicator as "*any measurement that is related to accidents and casualties, indicate the safety performance or the process that leads to accidents*". The most important characteristics of system indicators are the ability to measure the dimensions, and risk factors of unsafe systems, and the size of the factors' contribution [19]. The traditional term, and the most popular, of road safety indicators is the 'final outcome' indicator. It can be in form of crash frequency or crash rate [20-24] which can reflect the overall situation [15]. However, these indicators may be subjected to frequent inconsistence variance. In addition, an objective representation of road safety outcomes requires real crash data. Data collection problems lead to unreported and unreliable recorded data, which in turn results in an incorrect assessment of changes in the road safety situation [17]. Furthermore, outcomes could not be used to monitor the process and diagnose factors causing crashes, which mean predictions of a crash happening and the predicted severity level, will be in error. It also cannot be used to suggest a suitable treatment [25]. Moreover, the use of a single indicator is not effective in measuring performance in a multi-dimensional system since each dimension must have a different indicator [16, 26]. Therefore, it is necessary to identify more indicators to help assess the size of the problem in a better way. Recently, other types of the indicator have been used [27]. These indicators reflect the performance after treatments in different terms, such as the length of roads furnished with proper types of median [21, 22, 24, 28]. These indicators reflect the intermediate outcome of the operational performance. This type of indicator helps to predict the conditions of the problem and enables actions to be taken to prevent road crashes from happening [17, 27, 29, 30]. Studies have been conducted to identify road safety indicators. They were reviewed in this research to evaluate them according to their relevance to the safe system and according to other criteria such as comprehensiveness and measurable. This research will be focused on identifying indicators reflecting the intermediate outcome.

3. The Aim and Objectives of the Research

The main aim of this research is to review indicators of the operational performance of road safety systems and identify those based on the principles of the safe system vision. The objectives are identified as follows:

1. To identify the thematic groups of the road safety operational performance
2. To identify the individual indicators of each of the identified thematic groups.

4. Methodology

Five steps have been followed:

1. Reviewing the literature regarding the safe system to define the suggested main (thematic) group of indicators.
2. Reviewing the literature regarding indicators used in previous attempts of defining road safety indicators and the sources of data used to identify and measure the selected indicators. This step will produce the suggested set of individual indicators.
3. Reviewing the literature regarding the best indicator measurement criteria to use in this research in evaluating the potential set of indicators.
4. Evaluating the suggested set of indicators against the chosen measurement criteria.
5. Deciding the final set of thematic and individual indicators.

6. Review of the Safe System Components

Identifying the thematic indicators is based on two criteria which are the purpose and the theory. In this research, the purpose is the operational performance assessment when the theory is the "safe system" approach [31, 32].

The concept of the safe system is that it should accommodate the vulnerabilities of the human body [1, 2, 12, 17, 33]. The mistakes of road users also should be corrected. These have been achieved in the recent treatment programs by improving the roads and vehicles' design and technologies, and by managing speed limits. Road user behavior should also be improved to avoid deliberate mistakes that lead to severe crashes [4, 9, 11, 13, 17, 33, 34]. Based on that, the components of the safe system can be classified into four groups: road infrastructure, speed, vehicle, and road user behavior.

5.1. Safer Road Infrastructure

The prevention of road deaths is considered during the design stage during the construction of roads through road safety audits and inspections [17, 35, 36].

The safe system standards aim for so-called 'safe-explaining' and 'forgiving' roads [37] which results in a reduction in road fatalities of about 30% in Europe [38]. The term 'self-explaining' is used when the requirements of all road users are taken into account through good signage and interaction. The different classes of roads should be classified according to the layout with adequate markings and signs, speed limit, and traffic mass [37, 39]. The needs of cyclists and pedestrians should also be considered [40]. The forgiving roads take driver errors into account through design. For example, the error of lane departures can be controlled by lane separation devices [37, 41].

5.2. Safer Speed

Setting a speed limit is a cost-effective short-term solution [33] that can achieve a reduction

in fatal crashes by 30% by managing the interactions between vehicles and other vulnerable road users [6, 9, 10, 34, 42, 43]. It is also more The ETSC [16] demonstrated that 1.0 km/h reduction in speed may save 5% of road fatalities. Research shows that vehicle speeds of 60 km/h lead to more collisions involving serious injuries or fatalities within the pedestrian group [11, 44-46]. In Australia, a speed of 30 km/h is the safe speed limit for pedestrians and cyclists [46], and 50 km/h on motorways and intersections [9, 33]. Examples of techniques used to manage speed include using vehicle engineering enforcement (intelligent speed adaptation [47], excessive speed alerts (especially in hazardous locations)), and road engineering enforcement (speed humps) [34].

5.3 Safer vehicles

The active and passive vehicle safety standards are highly recommended to be taken into account in road safety studies [33, 34, 41, 42, 48, 49]. Active safety (i.e., crash avoidance by vehicle design) measures include stability control, anti-brake system (ABS), and speed limiters. Passive safety technologies (i.e., crash protection) include air cushion technology padded dashboards, and seatbelts.

5.4 Safer Road User Behavior

The deliberate errors of drivers are the reason for about 30% of road crashes in some European countries [17, 41]. The WHO [15] shows that regulating laws of road safety is essential to improve road user behavior. It has been proved that enforcement is effective in improving road user behavior [5, 26, 49]. Seven factors are essential for road safety laws legislation [46], speeding, drunk–driving, helmets, seatbelts, child restraints, using a mobile phone, and driving under the influence of drugs [4].

5.4.1 Speeding

It is the major reason for the high rate of road fatalities [50]. Innovative technologies such as speed cameras have been reduced as an enforcement tool to control speeding; it leads to reduce offenses by 70% and road fatalities by 32% in developed countries [26].

5.4.2 Psychoactive substances

Consuming alcohol and illegal drugs is another important factor in road crashes [16, 21]. Drinking alcohol reduces the ability to operate a motor vehicle [51]. Blood alcohol content (BAC) is used as a variable of alcohol drinking [26]. Studies demonstrated that each increase in BAC level by 0.02% may lead to a raise in the risk crashes [1, 53]. The allowed maximum BAC is determined by some safety policies, 0.05 g/dl is general drivers and 0.02 g/dl for novice and commercial drivers [26, 48, 46]. Breath testing is a suitably systematic check of the BAC of drivers [16, 48, 52, 53]. Chemical test tubes were also used for the detection of breath alcohol in some countries but were replaced with electronic screeners [26]. The effect of drug intake is considered recently in road safety laws, but drug testing is still more complicated. The influence of drugs is properly considered in road safety legislation and education programs [26].

5.4.3 Using protecting systems

It is reported that the wearing of a seat belt saves the life of 40–65% of the car occupants in crashes [16, 43, 46]. This is achieved by legislation and enforcement of safety rules [46]. The recent innovation that enhance the safety of car passengers such as seat belt reminder and seat belt ignition interlock [34] are essential to encourage using protective system. While seats belts are mandatory for adult occupants, child restraints have been developed for children under 9, or 12, years' old depending on the

country [53, 54]. This system reduced severe crashes among infants to 25% and among children under age 5 to half [1, 16, 43, 46]. The use of helmets is also included in road safety laws for all motorcyclists. Wearing helmets has been shown to prevent 20–45% of serious crashes and 60–80% of cyclists [1, 15, 52]. It has also been demonstrated that wearing helmets by motorcyclists may reduce the risk of head injury by 70% [16, 43, 46, 55], and wearing helmets by cyclists reduces the risk of head injuries by 63–88% [28, 56].

5.4.4 Using a mobile phone during driving

Distracted driving resulting from using mobile phones leads to significant speed variations and longer response times [4, 50, 57, 58]. Rahman et al. [58] referred to studies (Strayer et al., 2001; Schreiner et al., 2004; Caird and Scialfa, 2005) which showed that the response time of drivers to a sudden event was longer by more than a half second when using a mobile phone. Rahman et al. [58], referring to Brace et al. (2007), demonstrated that both hand-held and hands-free mobile phones affect driver behavior negatively. However, a hand-held phone is more dangerous because it affects both physical and cognitive performance.

6. Review of Road Safety Indicators on the Previous Studies

The literature identifying road safety indicators has been reviewed according to the criteria that the authors used to select indicators and according to what indicators are chosen in these studies. Table 1 shows a summary of the reviewed studies. It is noticed that the indicators of road infrastructure are different between one study and another with each considering different factors related to road infrastructure. The ETSC [16] considered the first real attempt at defining road safety indicators. Safety standards for road infrastructure are compiled in the SafetyNet study [43, 52, 59, 60] through choosing the EuroRAP score (European road assessment program) [61] which provides a comprehensive list of indicators of protecting factors. The EuroRAP was the first version of iRAP. The iRAP has been developed recently to include road design elements and technologies for protecting the road user and preventing crashes from occurring [61]. The road infrastructure classification is indicated by some studies as the motorway length [21, 28]. It is also noticed that road infrastructure indicators are not taken into account in the studies conducted by Wegman et al. [6], Wegman and Oppe [22], Bax [53], and Gitelman et al. [62]. This may relate to the unavailability of data or the challenges of finding a comprehensive indicator. Regarding vehicle indicators, most indicators are related to vehicle age, to the composition of vehicle fleet, and to the EuroNCAP rating [63] which has been developed to assess the vehicle safety requirements.

Table 1. The reviewed literature in terms of the criteria of variable selections and the selected indicators

The author	The criteria for variables selection	The selected indicators		
		Road mobility (infrastructure and speed limit) indicators	**Vehicles indicators**	**Road user behavior indicators**
• ETSC [16]	• Relevancy to the most effective practice in European countries • Data availability	• % roads meeting design standards • % roads fitting in the road network hierarchy	EuroNCAP 4 score	• Speeding • BAC • wearing seat belts • using child restraints
• Al Haji [15]	• data Availability • reliability quality • measurability • simplicity	% paved roads	%vehicles	• wearing seat belt • wearing helmet
• Vis [59] • Hakkert et al., [52] • Vis and Van Gent [60]	• Experiences • Availability of data	EuroRAP scores	EuroNCAP score	• % fatalities due to alcohol and drug consuming • Speeding • wearing seat-belts • wearing helmets
• Hermans [21]	•Relevancy •Sensitivity •Measurability •data availability •Interpretability •Comparability •Reliability	Infrastructure network density	• Vehicle age	• Speeding • BAC • wearing seat belts
• Gitelman et al.[62]	Available data-specific sources		• Crash worthiness • Vehicle fleet composition	• wearing seat belts • alcohol-impaired driving
• Wegman and Oppe [22]	• Quality aspects • Sensitivity in time • Relevancy to Policy		• EuroNCAP score • Vehicle fleet composition • Vehicle age	• % fatalities resulted from drinking alcohol • wearing seatbelts
• Bax et al. [53]	Data availability		• pedestrian protection • The average renewal rate of cars	• BAC • wearing seat belts
• Shen [28]	Data availability	• Motorway density • % motorways	• % vehicle > 6 years • % vehicles > 10 years • % heavy vehicle • % two wheels vehicles • % cars awarded 5stars	• BAC • speed limit • wearing seat belt • using child restraints
• Chen [63]	Availability and quality of data	• % paved roads, • Enforcement scores on road safety audits	• % vehicle, not motorcycles • Enforcement score	• % fatalities involving alcohol, • % seat belt use by front seated • % helmets users

Table 1. The reviewed literature in terms of the criteria of variable selections and the selected indicators

The author	The criteria for variables selection	The selected indicators		
		Road mobility (infrastructure and speed limit) indicators	Vehicles indicators	Road user behavior indicators
• Tešić et al [64]		• Motorway density	• Vehicle age	• BAC • speed limit • seat belt wearing
WHO [4]	Relevancy to safe system Policy	• protection of vulnerable road users • Promotion public transport • Promotion cycling and walking • Road audit and inspection	% vehicle provided with protection system	• % road deaths involving alcohol • wearing seat belts • wearing helmets • using child restraints • Enforcement score on using a protection system
Jameel and Evdorides [65]				• Speeding • Consuming alcohol and illegal drugs • Using protection system
Jameel [66]	• Relevancy to safe system • Availability and quality of data Policy	• iRAP score	• NCAP score	• Speeding • Consuming psychoactive substances • Using Protective system • Distracting during driving
Jameel and Evdorides [67]	Availability and quality of data	• %of roads with RAP star rating greater than 3 star	• Providing safety technologies	• Effective score of speeding enforcement, drinking-driver enforcement, wearing seat belt, child restraints, using helmets
Jameel and Evdorides [68]	• Relevancy to safe system • Availability and quality of data Policy			• The likelihood indicators include speeding, drunk drivers, drug drivers and using mobile phones during driving. • The severity indicators include using a protection system.

Road user behavior is the most studied element, and indicators belonging to this group are comprehensive. However, the research into drug and mobile phone indicators are studied only recently and therefore considered by just one study [4].

The EuroRAP, the European road assessment program, and EuroNCAP, the European new car assessment program, are highly recommended by global and regional road safety organizations as tools for assessing road infrastructure and vehicles respectively [3, 4]. They are also recommended in the recent global actions of road safety such as the DARS [12-14]. EuroRAP assesses road factors based on about 60 road attributes [61], categorized by crash type, their impact on the likelihood or severity of crashes, and road user groups (including vulnerable road users and vehicle occupants). It also considers about 60 countermeasures based on a plan to invest in safer roads, developed recently to upgrade the EuroRAP release to iRAP (The International Road Assessment Program). Since road safety strategies in many countries have been developed around the concept of a safe system, the EuroRAP has been developed to consider a balance between road and vehicle design, and driver behavior [69]. The built-in indicator of EuroNCAP includes adult and child occupants, pedestrian protection and a safety assistant system. The first version considers the passive safety factors while the latest version considers both passive and active safety indicators [70].

7. Suggestions for Thematic Indicators

Based on the review of safe system components, the thematic indicators which represent the main group of indicators have been suggested. They are: road infrastructure, speed, road user behavior, and vehicles Indicators of each group are shown in Fig. 1.

8. Suggestion for Individual Indicators

The suggested thematic and individual indicators are shown in Table 2. It is important to mention here that some individual indicators are suggested based on the requirements of the global policy of road safety, DARS [12-14], and added to the list of candidate indicators. The list is as follows:

The iRAP score of 3 stars and more is used as a target by the UN, World Bank, and the WHO [4, 12-14, 61]. Therefore, this indicator is recommended.

The road separation indicator between walkers, cyclists, and cars is recommended by literatures [4] and DARS. Therefore, this indicator is included in the candidate list of individual indicators of a safer road network.

The iRAP methodology is evaluated concerning indicators of safer road network classification. It is concluded that:

- The upgraded version (iRAP), developed in 2012, considers the requirements of all road users' safety, including pedestrians and cyclists [71]. The older alternative, the EuroRAP, was the version used in the SafetyNet study that was conducted in 2005 [59]. Therefore, the iRAP is considered in this research to be the best use as an indicator of safer road infrastructure.

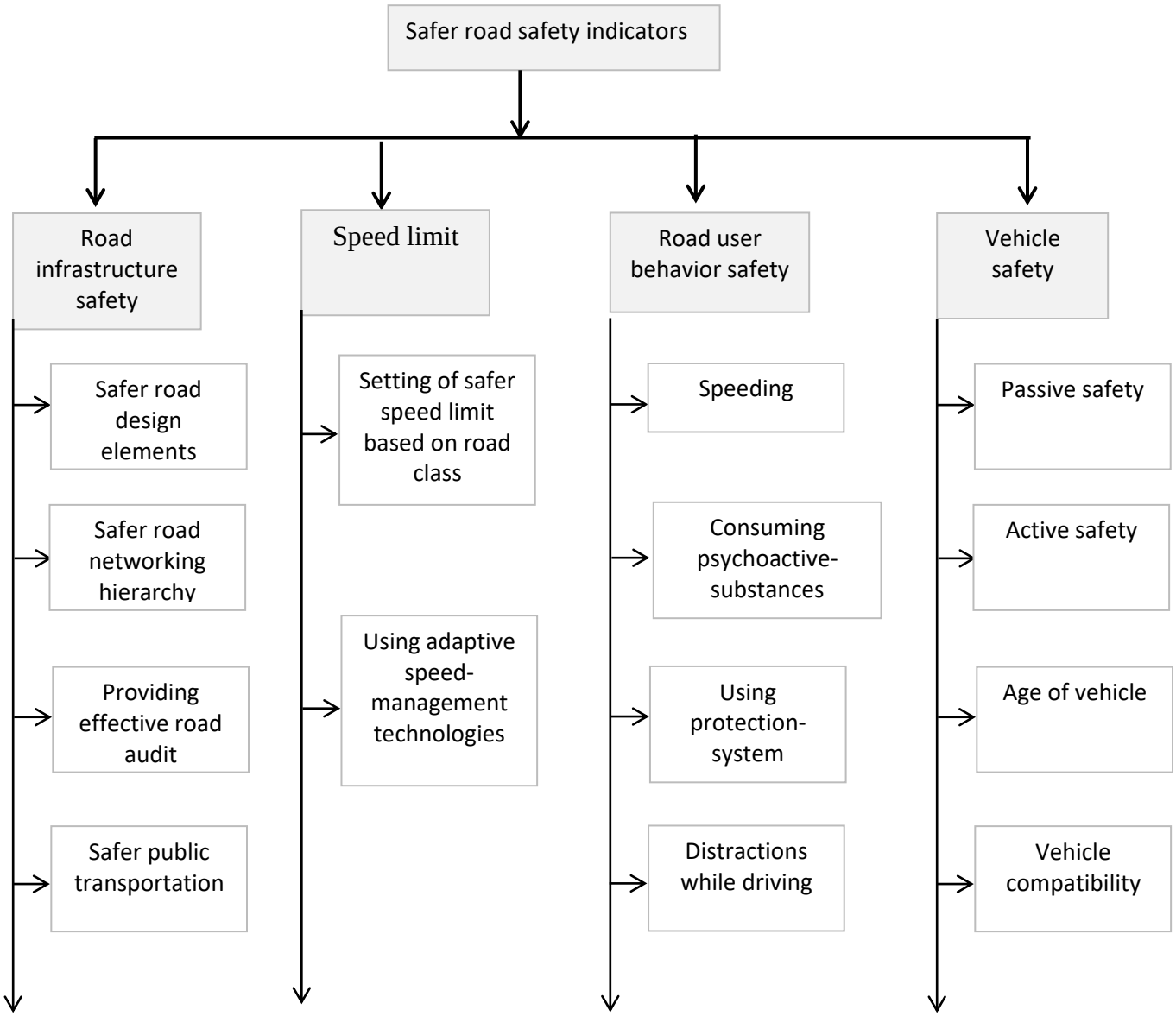

Figure 1. The suggested groups and sub-groups of the road safety performance indicators

- The ITF study [17] refers to some road features which are also considered by iRAP in the creation of a self-explaining environment such as the number of lanes and presence of curvatures [69], pavement marking, and functional design. In addition, the input indicators of the iRAP including the median type, area type, land use, and property access points [61, 69] are considered in the classification of roads by function and type [72]. Furthermore, the road network hierarchy reflects best practices in safety design such as the countermeasures for sidewalk/footpath segregation [72-75]. These may indicate the homogeneity and functionality of roads [73].
- The needs of vulnerable road users are considered by some indicators. Examples are number of lanes [76], segregation of lane and road [77, 78], intersection type, pedestrian crossing facilities [79], and pedestrian fencing [80]). The separation of walkers and cyclists is considered by the iRAP

methodology. Therefore, the iRAP is as an indicator of pedestrian safety.

- Road safety audit indicators. The effectiveness of road auditing is chosen by Chen [63] and suggested in this research. Since it is well known that iRAP is a comprehensive and systematic tool of road assessment [69, 81], and the validity of this tool has been proven in practical situations [82], using iRAP in assessing roads is suggested in this research as an indicator of road audit score.
- Safer public transportation. Even though this is recommended as a component of safer roads strategy by the WHO and the UN [4], there are no suitable studies regarding the indicators of safer standards of public transportation. Therefore this indicator is not included further in this research.
- Safe speed. Indicators of safe speed are represented in this research by the percentage of road length with a speed limit less than the safe speed recommended by the reviewed studies. The iRAP score is used as an alternate indicator of safe speed [83],
- The enforcement of laws covering drink-driving, drug driving, speeding, wearing seat belts, using child restraints, wearing of helmets, and using mobile phones while driving, is suggested based on best practice recommendations.
- The EuroNCAP is used to indicate the active safety of vehicles and, since its last version also considered the technologies of crashworthiness, the EuroNCAP rating can be used as a comprehensive indicator. The minimum requirement of the UN in the DARS is to provide crash avoidance and crashworthiness technologies [12-14, 84, 85]. Five stars is suggested in this research.
- Old studies adapted by Gitelman et al. [27] used vehicle age as an indicator of safer vehicles because newer vehicles are equipped with protection technologies, and managed more efficiently by the vehicle structures [86]. Since this is already included in the EuroNCAP rating, it is the EuroNCAP rating that is suggested as an alternative indicator of vehicles' age.

9. Evaluating the Suggested Indicators

In most of the reviewed literature presented in Table 1 [15, 21, 59] and in other studies from other domains in which indices have been developed [87-89], the candidate set of indicators is refined using specific criteria. Some studies [21, 64] refined the most important indicators based on the availability of data and other criteria which are:

- Relevancy to the phenomena or the assessed policy [90].
- Measurability [88]. Indicators should be represented in quantitative or qualitative measures, or in ordinal or numerical forms [90].
- Comprehensiveness [15]. Indicators that measure all or most of the factors related to the index are preferable.
- Simplicity [87-90]. Indicators should be understandable and have the tendency of changing variables.
- Comparability [87-90]. Using indicators in comparing should be considered.
- Sensitivity [87,88]. It is also preferable that indicators should be able to reflect changes over time.
- Independency. It is essential to avoid correlation between two or more indicators

[90] which means two indicators referring to the same concept.

- Achieving target. Booysen [90] refers to two kinds of objectives: means and ends. For example, the rate of road deaths involving alcohol belongs to the 'end' while the rate of enforcements per a specific length of roads belongs to the 'mean'.
- Validity [90]. That the values of indicators have a clear impact when they change.
- Data availability: This may be the most critical criteria of the most of the reviewed studies. Several sources of data are evaluated to provide the needed data such as the IRTAD, the WHO, the iRAP websites, and other local websites such as the Data.uk.gov website. The results of the evaluation are shown in Table 2.

10. Discussion of the Evaluation Results

The results of the evaluation of this set of indicators are:

- The most critical criteria in evaluating the suggested indicators are comprehensiveness, independency, and achieving set targets. The percentage of roads meeting safety standards (forgiving and self-explaining) is hardly measured because of the multitude of factors affecting the safety level of roads. However, the iRAP produces a methodology that can consider most of the factors, and it is more comprehensive than other indicators in considering the three subgroups of safer road infrastructure indicators.
- The iRAP methodology produces a rating of road section [61]. Since there is no valid methodology iRAP scores aggregation over a whole road network, it is considered to be immeasurable and it is replaced with the percentage of roads having more than three stars. This indicator is also related to the target set by the UN [4, 12-14].
- The indicators of the percentage paved road, percentage of motorway length, motorway density, and the density of the network are not comprehensive since each of them includes a factor of road infrastructure safety. In addition, some factors are already included in the iRAP, and may cause overlapping with the iRAP indicator.
- Regarding the effectiveness of road auditing, the applicability of iRAP in assessed countries is chosen because there is no other available data which reflects this indicator.
- The first stage of revision produces two indicators, the percentage of roads awarded three stars or more, and the applicability of the iRAP methodology. The data regarding these two indicators are available on the iRAP website.
- Because the iRAP indicator is already chosen to be the indicator of safer road infrastructure, and to avoid overlapping, the safer speed indicator is merged with the safer road infrastructure indicator, and given the new name of 'safer road mobility'.
- The suggested indicators of speeding factor are fit in terms of all the chosen criteria. Therefore, they are decided as the first two individual indicators of safer road user behavior.
- The effective score of drink-driving enforcement is chosen, but the effective score on the enforcement of drug consumption is excluded because of data unavailability. The data for drug-driving is limited because there is no consistent enforcement method of checking drivers for drug-driving.

Table 2. Evaluating the suggested indicators

The thematic indicators	Sub-groups of thematic indicators	The individual indicators	The criteria of selecting indicators									
			Relevant to Safe System	Measurable	Comprehensive	Simple	Comparable	Sensitive	Independent	Achieving targets	Valid	Data Available
Safer road infrastructure	**Safer Road design elements**	"% roads meeting forgiving road standards	√		√	√	√	√			√	
		% paved roads	√	√		√	√	√			√	
		EuroRAP scores	√		√	√	√	√			√	
		% roads with RAP star rating greater than 3 stars*	√	√	√	√	√	√	√	√	√	√
	Safer road network classification	% roads fitting in road network hierarchy(self-explaining criteria)	√		√	√	√	√			√	
		% motorways		√		√	√	√			√	
		infrastructure network density		√		√	√	√			√	
		Motorway density		√		√	√	√			√	
		% separated walking and cycling infrastructure*	√	√		√	√	√		√	√	
		% roads with RAP star rating of more than 3 stars*	√	√	√	√	√	√		√	√	
	Road Audit inspections	Road audit and inspection effectiveness score	√	√	√	√	√	√		√	√	
		Is RAP methodology applied?*"	√	√	√	√	√	√		√	√	√
Safer speed	**Setting max. speed limit Per road class**	"% urban roads with a max speed limit less than safer speed*	√	√		√	√	√		√	√	√
		% rural roads with a max speed limit less than safer speed*	√	√		√	√	√		√	√	√
		% motorways roads with a max speed limit less than safer speed*	√	√		√	√	√		√	√	√
	Speed management technologies	iRAP score (% of road ≤ 3 stars)*	√	√	√	√	√	√		√	√	√
		iRAP score (% of road ≤ 3 stars)*	√	√	√	√	√	√		√	√	√
		EuroNCAP score (% vehicles awarded 5 stars)"	√	√	√	√	√	√		√	√	√
Safer Road user behavior	**Speeding**	**% drivers driving above the legal limit**	√	√	√	√	√	√	√	√	√	√
		an effective score of speeding enforcement*	√	√	√	√	√	√	√	√	√	√
	Consuming psychoactive substances	% >BAC limit (0.05 for general drivers, 0.02 for novice and commercial drivers	√	√	√	√	√	√		√	√	
		% of fatalities involved alcohol and drug consumption,	√	√	√	√	√	√		√	√	√
		an effective score of drinking-driver enforcement*	√	√	√	√	√	√	√	√	√	√
		an effective score of drug enforcement	√	√	√	√	√	√	√	√	√	
	Using Protective system (seat belt, child	**% wearing seat belts,**	√	√		√	√	√	√	√	√	√
		Effective reinforcement score of wearing seat belt*	√	√		√	√	√	√	√	√	√
		% children using child restraints in front and rear seats	√	√		√	√	√	√	√	√	√

The thematic indicators	Sub-groups of thematic indicators	The individual indicators	The criteria of selecting indicators									
			Relevant to Safe System	Measurable	Comprehensive	Simple	Comparable	Sensitive	Independent	Achieving targets	Valid	Data Available
	restraints, and helmets) Distracting during driving	**Effective reinforcement score of child restraints***	√	√		√	√	√	√	√	√	√
		rate of wearing helmets by two wheels occupants	√	√		√	√	√	√	√	√	√
		Effective reinforcement score of using helmets*	√	√		√	√	√	√	√	√	√
		% drivers using mobile phone while driving(hand-held and hand-free)	√	√	√	√	√	√	√	√	√	√
		Effective reinforcement score of using mobile phone	√	√	√	√	√	√	√	√	√	
Safer Vehicle	**Vehicle age**	% cars less than 6 years		√	√	√	√	√			√	√
		% old vehicles > 10 years		√	√	√	√	√			√	√
		Median age of the passenger car fleet		√	√	√	√	√			√	√
	Active safety requirements	% in front visibility daytime running lights	√	√		√	√	√			√	√
		Enforcement score on vehicle standard applied	√	√	√	√	√	√	√	√	√	
		EuroNCAP score (% vehicles awarded 5 stars)	√	√	√	√	√	√	√	√	√	√
		% cars awarded 5stars on car occupants	√	√		√	√	√			√	√
		% vehicle with effective electronic stability control	√	√		√	√	√		√	√	√
		% vehicle with anti-lock braking systems?	√	√		√	√	√		√	√	√
	Passive safety requirements	%Passive safety score (NCAP) (crash worthiness)	√	√	√	√	√	√		√	√	√
		score of pedestrian protection	√	√		√	√	√		√	√	√
		Enforcement score on vehicle standard	√	√	√	√	√	√		√	√	√
		% vehicle with effective seat belt	√	√		√	√	√		√	√	√
		% vehicle with anchorages	√	√		√	√	√		√	√	√
		% vehicle with child restraint systems	√	√		√	√	√		√	√	√
		% vehicle with safer frontal and side impact standards	√	√		√	√	√		√	√	√
		% cars awarded overall 5 stars”	√	√	√	√	√	√		√	√	√
	Vehicle composition	**% heavy vehicle**	√	√		√	√	√	√		√	√
		% two wheels vehicles	√	√		√	√	√			√	√
		%vehicles in the total vehicle fleet	√	√	√	√	√	√			√	√
		Vehicle fleet composition	√	√	√	√	√	√			√	√
		% vehicle not motorcycles	√	√		√	√	√			√	√

- The indicators of using a protective system are chosen together to achieve the comprehensiveness target.
- The indicator of using a mobile phone while driving is chosen, but the enforcement score is excluded because of data unavailability.
- The indicators of vehicle age are irrelevant to road safety policies based on safe system principles. These principles are based on the evolution of vehicle designs to accommodate road users' needs and mistakes. In addition, there is no target value to be set. These indicators are considered indirectly by the EuroNCAP by testing the vehicles' safety according to its year of manufacture. Therefore, this subgroup of indicators is not chosen in this research.
- The EuroNCAP is considered the most comprehensive indicator in countries where it is applied as a testing and assessment tool for vehicle safety. The EuroNCAP can also interpret the target of policies for crashworthiness and avoidance technologies. Therefore, the EuroNCAP is the chosen indicator of active and passive safety.
- Based on the results of the evaluation, the final set of indicators is selected and shown in Fig. 2.

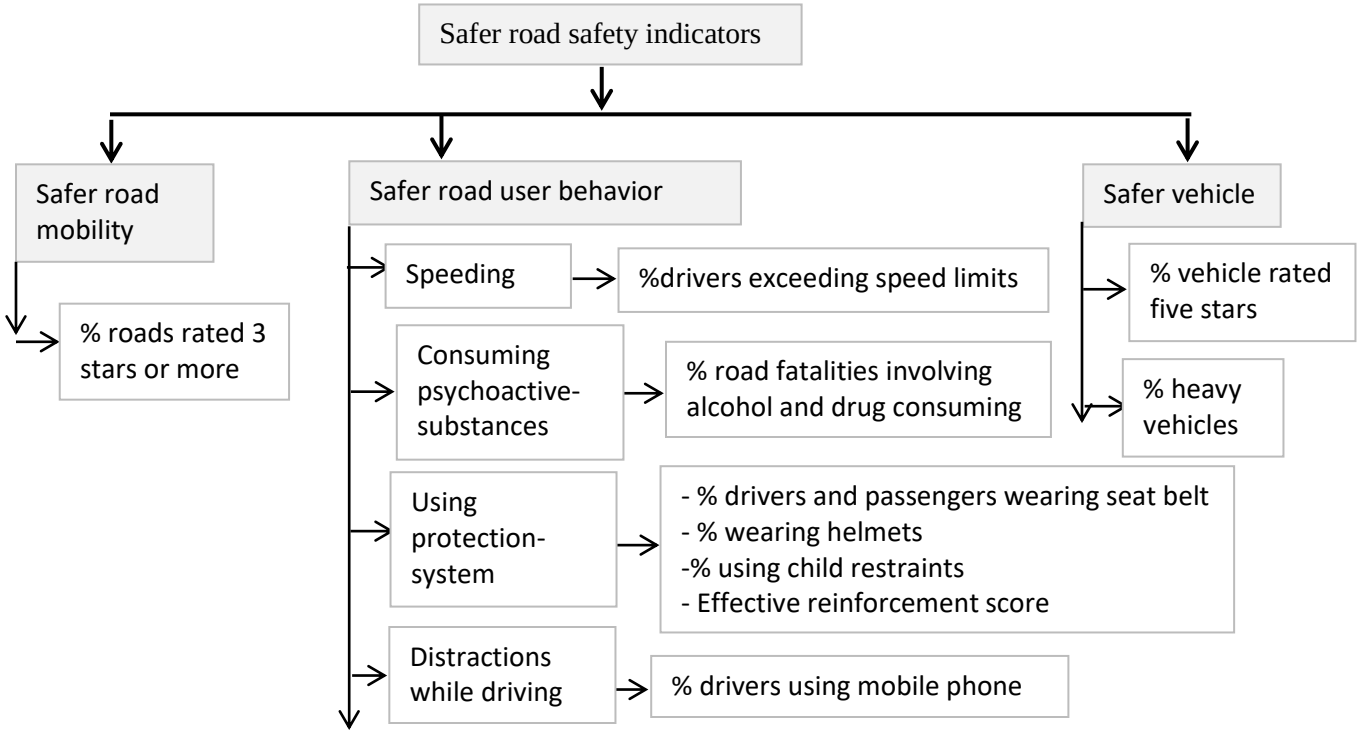

Figure 2. The final set of road safety indicators which are selected based on the determined criteria

11. Conclusions

The final set of indicators chosen in assessing the road safety system is divided into three thematic groups, these are safer road mobility, safer road user behavior, and safer vehicle. The choice of these indicators is based on several criteria such as independence, measurability, achievable targets, and comprehensiveness. Data availability is also critical to the suitability of an indicator. The first thematic group is safer road mobility indicators interpreting the 'forgiving' and 'self-explaining' concepts in road design. Based on the evaluation of the suggested indicators, it is concluded that the iRAP star rating is the most comprehensive, measurable, and dependent indicator. The percentage of roads awarded three stars and more is the individual indicator which is used. The second thematic group is safer road user behavior indicators interpreting four main risk factors. They are speeding, using a protective system, consuming psychoactive substances, and using a mobile phone while driving. The third thematic group is safer vehicle indicators interpreting the passive and active safety requirements as well as compatibility factors that reflect the vehicle composition. The EuroNCAP is chosen as the most comprehensive, measurable, and achievable target indicator. The percentage of vehicles awarded five stars is the individual indicator of the passive and active safety requirements. Regarding vehicle compatibility, most of the vehicle types are considered by the iRAP and the EuroNCAP. However, the factors related to heavy vehicles are not considered. Therefore, the percentage of heavy vehicles is added as the second indicator of safer vehicles.

12. Recommendations

The final set of indicators can be used to assess and benchmark countries according to the performance of implementing strategies incorporating the safe system vision

The indicators can be aggregated to develop a composite indicator used to benchmark countries and reflect the whole figure of the road safety situation at a national scale.

The selected indicators can be categorized according to their impact on the likelihood or severity of road crashes.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Author Abeer K. Jameel proposed the research problem, developed the methodology, performed the review and evaluation of the proposed indicators, and developed the final set of indicators.

Author Harry T. Evdorides: supervised the findings of this work.

Both authors discussed the results and contributed to the final manuscript.

13. References

1. Peden, M., Scurfield, R., Sleet, D., Mohan, D., Hyder, A. A., Jarawan, E. and Mathers, C., (2004). *"World Report on Road Traffic Injury Prevention*" Geneva, Switzerland: World Health Organization. https://www.who.int/publications-detail-redirect/world-report-on-road-traffic-injury-prevention.

2. World Health Organization (2009). *"Global status report on road safety: time for action*". Geneva. www.who.int/violence_injury_prevention/road_safety_status/2009/en/index.html.
3. World Health Organization, (2013). *"Global status report on road safety: Supporting a decade of Action*". [online]. http://www.who.int/violence_injury_prevention/road_safety_status/2013.
4. World Health Organization, (2015), *"Global status report on road safety"*, http://apps.who.int/iris/bitstream/10665/44122/1/9789241563840_eng.pdf.
5. Van Vliet, P. and Schermers, G., (2000). *"Sustainable Safety: A new approach for road safety in the Netherlands"*. Traffic Research Centre, Ministry of Transport, Rotterdam. https://swov.nl/nl/publicatie/sustainable-safety-new-approach-road-safety-netherlands.
6. Wegman, F., Aarts, L. and Bax, C., (2008). *"Advancing sustainable safety: National road safety outlook for The Netherlands for 2005–2020*".SafetyScience, 46(2), pp.323-343. https://doi.org/10.1016/j.ssci.2007.06.013.
7. Matts-ÅkeBelin, Per, Tillgren & Evert Vedung, (2012). *"Vision Zero – a road safety policy innovation",* International Journal of Injury Control and Safety Promotion, 19:2,171-179. https://doi.org/10.1080/17457300.2011.635213
8. Johansson, R., (2009).*"Vision zero–implementing a policy for traffic safety*". Safety Science, 47, pp.826-831. https://doi.org/10.1016/j.ssci.2008.10.023.
9. Turner, B., (2013). *"Implementing the safe system approach to road safety: Some examples of infrastructure related approaches"*. In 16th International Conference Road Safety on Four Continents. Beijing, China (RS4C 2013). 15-17 May 2013. http://vti.diva-portal.org/smash/get/diva2:760022/FULLTEXT01.pdf
10. Larsson, P. and Tingvall, C., (2013). *"The Safe System Approach–A Road Safety Strategy Based on Human Factors Principles"*. In International Conference on Engineering Psychology and Cognitive Ergonomics (1928). July, Springer, Berlin, Heidelberg. https://link.springer.com/content/pdf/10.1007/978-3-642-39354-9_3.pdf.
11. Turner, B. and Jurewicz, C., (2016). *"Development and use of the Austroads Safe System Assessment Framework*". In Australasian Road Safety Conference, September 2016, Canberra, ACT, Australia. https://acrs.org.au/files/papers/arsc/2016/Turner%2000035%20PR.pdf.
12. World Health Organization System, (2011), *"Global Plan for the Decade of Action for Road Safety, 2011-2020"*, http://www.who.int/roadsafety/decade_of_action/plan/plan_english.pdf?ua=1
13. United Nations Road Safety Collaboration, (2011). *"Global plan for the decade of action for road safety 2011-2020"*. Geneva: World Health Organization. https://www.who.int/publications/m/item/global-plan-for-the-decade-of-action-for-road-safety-2011-2020.
14. World Health Organization System, (2021), *"Global Plan for the Decade of Action for Road Safety, 2021-2030"*, https://www.who.int/teams/social-determinants-of-health/safety-and-mobility/decade-of-action-for-road-safety-2021-2030.

15. Al-Haji, G., (2007). "*Road Safety Development Index (RSDI*). Theory, Philosophy and Practice". Linkoeping Studies in Science and Technology, Dissertation No. 1100, Norrkoeping, Sweden. http://www.diva-portal.org/smash/get/diva2%3A23510/FULLTEXT01.pdf
16. ETSC: European Transport Safety Council, (2001). *"Transport Safety Performance Indicators. European Transport Safety Council*", Brussels. ISBN: 90-76024-11-1. https://etsc.eu/transport-safety-performance-indicators.
17. International Transport Forum, (2016). "*Zero Road Deaths and Serious Injuries: Leading a Paradigm Shift to a Safe System"*, OECD Publishing, Paris. https://www.oecd.org/publications/zero-road-deaths-and-serious-injuries-9789282108055-en.htm
18. Singh, R.K., Murty, H.R., Gupta, S.K. and Dikshit, A.K.,(2012)."*An overview of sustainability assessment methodologies*". Ecological indicators, 9(2), pp.189-212. https://doi.org/10.1016/j.ecolind.2011.01.007.
19. Elvik, R., (2008). "*Road safety management by objectives: a critical analysis of the Norwegian approach*" Accident Analysis and Prevention, 40, pp. 1115-1122. https://doi.org/10.1016/j.aap.2007.12.002.
20. OECD and JRC: European Commission-Joint Research Centre-, (2008). *"Handbook on constructing composite indicators: Methodology and user guide"*. OECD publishing. https://www.oecd.org/sdd/42495745.pdf
21. Hermans E., (2009). *"A Methodology for Developing a Composite Road Safety Performance Index for Cross-country Comparison"*, Ph.D. Thesis, Hasselt University, Hasselt, Belgium. http://hdl.handle.net/1942/10232.
22. Wegman F. Oppe S. (2010). "*Benchmarking road safety performances of countries*" Safety Science, 48 (9). 12031211. https://doi.org/10.1016/j.ssci.2010.02.003
23. Oluwole, A. M., Abdul Rani, M. R. and Rohani, J. M., (2013). *"Integrating road safety indicators into performance Road safety index"*. ARPN Journal of Engineering and Applied Sciences. 8, 9, (Sep.2013). http://eprints.utm.my/id/eprint/49873/1/AroworoloMatthewOluwole2013_Integratingroadsafetyindicators.pdf.
24. Aarts, L.T., and Houwing, S., (2015). *"Benchmarking road safety performance by grouping local territories: A study in the Netherlands"*. Transportation research part A: policy and practice, 74, pp.174-185. Accident Analysis and Prevention, 42 (2) (2010), pp. 595-603. https://doi.org/10.1016/j.tra.2015.02.008.
25. Hermans, E., Brijs, T., Wets, G. and Vanhoof, K., (2009). *"Benchmarking road safety: lessons to learn from a data envelopment analysis"*. Accident Analysis & Prevention, 41(1), pp.174-182. https://doi.org/10.1016/j.aap.2008.10.010.
26. Wegman, F., Aarts, L., Bax C., (2008). *"Advancing sustainable safety National road safety outlook for the Netherlands 2005–2020*" Safety Science, 46, pp.323-343. https://doi.org/10.1016/j.ssci.2007.06.013.
27. Gitelman, V. and Vis, M.A., (2007). *"Road safety performance indicators: Theory*". Deliverable D3, 6, p.164. https://dspace.lboro.ac.uk/2134/4952.
28. Shen, Y., (2012). *"International Benchmarking of Road Safety Performance and Development using Indicators and Indexes: Data Envelopment Analysis based*

Approaches" (Doctoral dissertation). Hasselt University. http://dx.doi.org/10.1016/j.trc.2014.07.006.

29. Hermans, E., Brijs, T., Wets, G., (2008). "*Developing a theoretical framework for road safety performance indicators and a methodology for creating a performance inde".*Steunpunt Mobiliteit & Openbare Werken. http://www.steunpuntverkeersveiligheid.be/sites/default/files/RA-MOW-2008-010.pdf.
30. Assum, T. and Sørensen, M., (2010). *"Safety Performance Indicator for alcohol in road accidents—International comparison, validity and data quality*". Accident Analysis & Prevention, 42(2), pp.595-603. https://doi.org/10.1016/j.aap.2009.10.005.
31. Sharpe, A., (2004). *"Literature review of frameworks for macro-indicators"* (No. 2004-03). Ottawa: Centre for the Study of Living Standards. http://www.csls.ca/reports/LitRevMacro-indicators.pdf.
32. Freudenberg, M., (2003). *"Composite Indicators of Country Performance: A Critical Assessment, OECD Science*", Technology and Industry Working Papers, 2003/16, OECD Publishing, Paris. http://dx.doi.org/10.1787/405566708255.
33. Woolley, J, Stokes, C, Turner, B, Jurewicz, C, (2018). *"Towards Safe System Infrastructure: A Compendium of Current Knowledge"* Austroads Ltd. Austroads Publication No. AP-R560-18. https://www.onlinepublications.austroads.com.au/items/AP-R560-18
34. OECD, (2008). *"Towards zero: ambitious road safety targets and the safe system approach"* - isbn 978-92-8210195-7 c oecd/itf,2008 http://www.oecd.org/transport/towards-zero-9789282102640-ru.htm
35. Robinson, R. and Thagesen, B., (2004). "*Road engineering for development"*. CRC Press. https://www.academia.edu/34948978/Road_Engineering_for_Development_pdf.
36. McInerney, R. and Smith, G., (2009). *"Saving lives through investment in safer roads: The iRAP partnership*". Proceedings of the 13th Road Engineering Association of Asia and Australasia, pp.23-26. http://reaaa.vms.my/images/2/24/(6-13)SAVING_LIVES_THROUGH_Rob_Mclnerney_Australia(108).pdf.
37. Bekiaris, E., and Gaitanidou, E., (2011). "Towards forgiving and self-explanatory roads. In Infrastructure and Safety in a Collaborative World" (pp. 15-22). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-18372-0_2
38. Stigson, H., Krafft, M. and Tingvall, C., (2008). *"Use of fatal real-life crashes to analyze a safe road transport system model, including the road user, the vehicle, and the road"*. Traffic Injury Prevention, 9(5), pp.463-471. https://doi.org/10.1080/15389580802335240 .
39. Zaloshnja, E. and Miller, T.R., (2009), October. "*Cost of crashes related to road conditions, United States, 2006*". In Annals of Advances in Automotive Medicine/Annual Scientific Conference (Vol. 53, p. 141). Association for the Advancement of Automotive Medicine. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3256793.
40. Mackie, H.W., Charlton, S.G., Baas, P.H. and Villasenor, P.C., (2013). *"Road user behaviour changes following a self-*

explaining roads intervention". Accident Analysis & Prevention, 50, pp.742-750. https://doi.org/10.1016/j.aap.2012.06.026.

41. Wegman, F., Dijkstra, A., Schermers, G. and van Vliet, P., (2005). *"Sustainable Safety in the Netherlands: the vision, the implementation, and the safety effects*". SWOV. www.semanticscholar.org/paper/Sustainable-Safety-in-the-Netherlands%3A-the-Vision%2C-Wegman-Dijkstra/70b8e64da3a6c548c3cf5c6413bf96777a4ec52a
42. Corben, B.F, Logan, D.B., Fanciulli, L., Farley, R., Cameron. I., (2010). *"Strengthening road safety strategy development 'Towards Zero' 2009–2020 – Western Australia's experience scientific research on road safety management"* SWOV workshop 16 and 17 November 2010. https://doi.org/10.1016/j.ssci.2009.10.005
43. Gitelman, V., Vis, M., Weijermars, W. and Hakkert, S., (2014). *"Development of road safety performance indicators for the European countries"*. Advances in Social Sciences Research Journal, 1(4), 138-158. https://doi.org/10.14738/assrj.14.302.
44. Belin, M.Å., Tillgren, P. and Vedung, E., (2012). *"Vision Zero–a road safety policy innovation"*. International journal of injury control and safety promotion, 19(2), pp.171-179. https://doi.org/10.1080/17457300.2011.635213
45. May, M., Tranter, P.J., Warn, J.R. (2008). *"Towards a holistic framework for road safety in Australia J*". Transport Geogr., 16, pp. 395-405. https://doi.org/10.1016/j.jtrangeo.2008.04.004
46. World Health Organization, (2013). *"Strengthening road safety legislation: A practice and resource manual for countries"*. http://apps.who.int/iris/bitstream/10665/85396/1/9789241505109_eng.pdf. ISBN 978 92 4 150510 9
47. Chorlton, K., Conner, M., (2012). *"Can enforced behaviour change attitudes: exploring the influence of intelligent speed adaptation"* Accid. Anal. Prev., 48, pp. 49-56. https://doi.org/10.1016/j.aap.2010.06.007.
48. Jackisch, J., Sethi, D., Mitis, F., Szymański, T. &Arra, I. (2015). *"European facts and the Global status report on road safety 2015"* The Regional Office for Europe World Health Organization. http://www.euro.who.int/en/publications.
49. Larsson, P., Dekker, S.W.A., Tingvall, C. (2010). *"The need for a systems theory approach to road safety*". Safety Science, 48 (9).1167-1174. https://doi.org/10.1016/j.ssci.2009.10.006.
50. Papadimitriou, E., Tselentis, D.I. and Yannis, G., (2018). *"Analysis of Driving Behaviour Characteristics Based on Smartphone Data"*. Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria TRA2018, Vienna, Austria, April 16-19. https://doi.org/10.1016/j.ssci.2009.10.006.
51. Martin, TL, Solbeck, PAM, Mayers DJ, Langille, RM, Buczek, Y, Pelletier, MR. (2013). *"A review of alcohol-impaired driving: The role of blood alcohol concentration and complexity of the driving task"*. J Forensic Sci58 (5): 1238–1250. https://doi.org/10.1111/1556-4029.12227.
52. Hakkert, A.S, Gitelman, V. and Vis, M.A. (Eds.) (2007). *"Road Safety Performance Indicators: Theory"*. Deliverable D3.6 of

the EU FP6 project SafetyNet. https://dspace.lboro.ac.uk/2134/4952.

53. Bax, C., Wesemann, P., Gitelman, V., Shen, Y., Goldenbeld, C., Hermans, E., Doveh, E., Hakkert, ,Wegman, F., Aarts, L. (2012). "*Developing a Road Safety Index"*. Deliverable 4.9 of the EC FP7 project DaCoTA. https://www.dacota-project.eu/Deliverables/DaCoTA_D4.9_developing%20a%20RSI%20deliverable.pdf.
54. Brubacher, J.R., Desapriya, E., Erdelyi, S. and Chan, H., (2016). *"The impact of child safety restraint legislation on child injuries in police-reported motor vehicle collisions in British Columbia: An interrupted time series analysis"*. Paediatrics & child health, 21(4), pp.e27-e31. https://doi.org/10.1093/pch/21.4.e27.
55. Bambach, MR, Mitchell, RJ, Grzebieta, RH, Olivier, J, (2013). *"The effectiveness of helmets in bicycle collisions with motor vehicles: a case-control study"*. Accid Anal Prev 53: 78–88. https://doi.org/10.1016/j.aap.2013.01.005.
56. Høye, A., (2018). *"Bicycle helmets–To wear or not to wear? A meta-analyses of the effects of bicycle helmets on injuries"*. Accident Analysis & Prevention, 117, pp.85-97. https://doi.org/10.1016/j.aap.2018.03.026.
57. Gariazzo, C., Stafoggia, M., Bruzzone, S., Pelliccioni, A. and Forastiere, F., (2018). *"Association between mobile phone traffic volume and road crash fatalities: A population-based case-crossover study"*. Accident Analysis & Prevention, 115, pp.25-33. https://doi.org/10.1016/j.aap.2018.03.008.
58. Rahman, Z., Martinez, D., Martinez, N., Zhang, Z., Memarian, A., Pulipati, S., Mattingly, S.P. and Rosenberger, J.M., (2018). *"Evaluation of cell phone induced driver behavior at a type II dilemma zone"*. Cogent Engineering, 5(1), p.1436927. https://doi.org/10.1080/23311916.2018.1436927.
59. Vis, M.A., (2005). *"State of the art report on road safety performance indicators*". Deliverable D3, 1. https://www.dacota-project.eu/Links/erso/safetynet/fixed/WP3/Deliverable%20wp%203.1%20state%20of%20the%20art.pdf.
60. Vis, M.A. and Van Gent, A.L. (Eds.) (2007). *"Road Safety Performance Indicators: Country Comparisons"*. Deliverable D3.7a of the EU FP6 project SafetyNet. https://www.dacota-project.eu/Links/erso/safetynet/fixed/WP3/sn_wp3_d3p7a_spi_country_comparisons.pdf.
61. iRAP: The International Road Assessment Programme (2020), the official website, http://www.irap.org/en.
62. Gitelman, V., Doveh, E. and Hakkert, S., (2010). "*Designing a composite indicator for road safety"*. Safety Science, 48(9), pp.1212-1224. https://doi.org/10.1016/j.ssci.2010.01.011.
63. Chen, F., Wang, J., Wu, J., Chen, X. and Zegras, P.C., (2017). "*Monitoring road safety development at regional level: a case study in the ASEAN region"*. Accident Analysis & Prevention, 106, pp.437-449. https://doi.org/10.1016/j.aap.2017.07.016.
64. Tešić, M., Hermans, E., Lipovac, K. and Pešić, D., (2018). *"Identifying the most significant indicators of the total road safety performance index*". Accident Analysis & Prevention, 113, pp.263-278. https://doi.org/10.1016/j.aap.2018.02.003.
65. Jameel, A.K. and Evdorides, H., (2018). "*Assessment of safer road user behaviour"*. *WIT* Transactions on Ecology

and the Environment, 217, pp.755-767. https://doi.org/10.2495/SDP180641.

66. Jameel, A.K., (2019). "*Development of a holistic index for safer roads*". (Doctoral dissertation, University of Birmingham). https://etheses.bham.ac.uk/id/eprint/9038/1/Jameel2019PhD.pdf.
67. Jameel, A.K. and Evdorides, H., (2019). "*Assessment of Road Safety Performance for Southeast Asian Countries*". Journal of the Society of Automotive Engineers Malaysia, 3(3). https://doi.org/10.56381/jsaem.v3i3.125.
68. Jameel, A.K. and Evdorides, H., (2021). "*Developing a safer road user behaviour index"*. IATSS Research, 45(1), pp.70-78. https://doi.org/10.1016/j.iatssr.2020.06.006.
69. Lynam, D, (2012). "*Development of Risk Models for the Road Assessment Programme"*. RAP504.12 and TRL Report CPR1293, Published by iRAP and TRL. http://www.trl.co.uk and at http://www.irap.org.
70. EuroNCAP: European New Car Assessment Program, (2020). https://www.euroncap.com/en [accessed Jan 2020]
71. iRAP: International Road Assessment Programme, (2013). *"iRAP Methodology Fact Sheet #2" Development history"*. http://irap.org [accessed online 2021]
72. Weijermars, W.A.M. (ed.), (2008). *"Safety Performance indicators for Roads: Pilots*". in the Netherlands, Greece, Israel, and Portugal. Deliverable D3.10c of the EU FP6 project SafetyNet. https://www.yumpu.com/en/document/view/36630412/pilots-in-the-netherlands-greece-israel-and-portugal-erso-swov.
73. Yannis, G., Weijermars, W., Gitelman, V., Vis, M., Chaziris, A., Papadimitriou, E. and Azevedo, C.L., (2013). "*Road safety performance indicators for the interurban road network*". Accident Analysis & Prevention, 60, pp.384-395. https://doi.org/10.1016/j.aap.2012.11.012.
74. iRAP: The International Road Assessment Programme, (2013). *"iRAP Road Attribute Risk FactorsRoadside Severity–Object*". http://irap.org [accessed online 2021]
75. iRAP: International Road Assessment Programme, (2015). "*iRAP Methodology Fact Sheet #11, Countermeasures*". http://irap.org[accessed online 2021]
76. iRAP: The International Road Assessment Programme, (2013). *"Road Attribute Risk Factors, Number of Lanes"*. http://irap.org [accessed online 2021]
77. iRAP: The International Road Assessment Programme, (2013). "*iRAP Road Attribute Risk Factors Facilities for Motorcycles"*. http://irap.org [accessed online 2021]
78. iRAP: The International Road Assessment Programme, (2014). *"iRAP Road Attribute Risk Factors Facilities for Bicycles*". http://irap.org [accessed online 2021]
79. iRAP: The International Road Assessment Programme, (2013). "*iRAP Road Attribute Risk Factors Property Access Points*". .http://irap.org [accessed online 2021]
80. iRAP: The International Road Assessment Programme, (2013) "*iRAP Road Attribute Risk Factors Pedestrian Fencing*". http://irap.org [accessed online 2021]
81. Turner, B., Affum, J., Tziotis, M. and Jurewicz, C. (2009). "*Review of iRAP Risk Parameters"*. ARRB Group Contract. Report for iRAP. http://irap.org/about-irap-3/research-and-technicalpapers?download=111:review-of-irap-risk-parameters.
82. iRAP (2011). *"Crash Rate-Star Rating Comparison Paper*". http://irap.org/about-irap-3/research-and-

technicalpapers?download=40:crash-rate-star-rating-comparison-paper. http://irap.org [accessed online 2017]

83. Harwood, E. and Mclnerney, R., (2011). *"Vehicle Speeds and the iRAP Protocols. International Road Assessment Programme (iRAP)"*. London, England last accessed online on June, 26. http://irap.org.
84. Van Ratingen, M., Williams, A., Lie, A., Seeck, A., Castaing, P., Kolke, R., Adriaenssens, G. and Miller, A., (2016). "*The European new car assessment programme: a historical review"*. Chinese journal of traumatology, 19(2), pp.63-69. https://doi.org/10.1016/j.cjtee.2015.11.016.
85. Gaylor, L., delFueyo, R.S. and Junge, M., (2016). *"Crashworthiness improvements of the vehicle fleet*". In 2016 IRCOBI Conference Proceedings pp. 592-605. IRBCOBI. http://worldcat.org/issn/22353151.
86. Hermans, E., Van den Bossche, F. and Wets, G., (2009). "*Uncertainty assessment of the road safety index"*. Reliability Engineering & System Safety, 94(7), pp.1220-1228. https://doi.org/10.1016/j.ress.2008.09.004.
87. Farchi, S., Molino, N., Rossi, P.G., Borgia, P., Krzyzanowski, M., Dalbokova, D. and Kim, R., (2006). *"Defining a common set of indicators to monitor road accidents in the European Union"*. BMC Public Health, 6(1), p.183. https://doi.org/10.1186/1471-2458-6-183.
88. Ledoux, L., Mertens, R. and Wolff, P., (2005), "*EU sustainable development indicators: An overview"*. In Natural Resources Forum November (Vol. 29, No. 4, pp. 392-403). Oxford, UK: Blackwell Publishing Ltd. http://dx.doi.org/10.1111/j.1477-8947.2005.00149.x.
89. Litman, T., (2007). "*Developing indicators for comprehensive and sustainable transport planning"*. Transportation Research Record: Journal of the Transportation Research. Board, (2017), pp.10-15. https://doi.org/10.3141/2017-02.
90. Booysen, F., (2002). "*An overview and evaluation of composite indices of development"*. Social indicators research, 59(2), pp.115-151. https://doi.org/10.1023/A:1016275505152.