QUALITATIVE METHODOLOGY FOR ROAD SAFETY RISK RATING AND RANKING

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ABSTRACT

The aim of this article is to explain the road safety audit methodology that was developed in Manizales by the National University of Colombia - Manizales. The study was carried out with resources from the Road Safety National Agency and the interest of the town hall to reduce the city's accident rates.

The road network audit consisted in twenty-eight (28) points that were evaluated considering various parameters, such as land use, user behaviour (vehicle and pedestrian), lighting, topography, drainage and other physical aspects. This information was gathered *in situ* since no other way could provide the details needed for the analysis. After all the pertinent data was collected, digitized and organized, the risk analysis could begin as the ratings depended on the overall performance of the network and an entire overview is needed to weight the parameters. Then, these ratings are weighted to determine the prioritization order and thus conclude on the intervention importance of one point over another. The proposed methodology was created with the intention of being independent from previous accident data as it is scarce or absent in recently opened or planned roads and junctions. Lastly, we present an example of the results that are to be expected from the application of this methodological analysis.

Although the methodology has limitations of subjective considerations, it can be a helpful tool for town administrations as it rates and prioritizes the points to have a technically supported investments plan.

KEYWORDS

Road safety; Rating; Ranking; Methodology.

CONTEXT AND REASONS

The study was applied in Manizales, a city located in the centre west part of Colombia, in the department of Caldas, over the Andean mountains at an elevation of 2150 m a.s.l. approximately. The city has an urban area of 59.68 km^2 and 371,345 inhabitants in 2017 thus presenting an urban population density equal to 6,222 pop/km^2.

The city is currently ranked first in life quality in Colombia and the population satisfied with the transport means quality is above 80% (*1*). Despite being well ranked, there are factors as the vehicle fleet growth, the lack of defined and inclusive mobility policies, high impact accidents and inexistent continuity in infrastructure improvements. These issues affect the people's habits producing mobility and safety problems that will ultimately be reflected in the accident rates.

The safety in vehicular circulation has always been linked to the road history (*2*), specially due to the difference in user speeds. And although efforts have been made to reduce the frequency and severity of road accidents (*3*) (*4*), they become greater and more serious every day in some parts of the world, particularly in the Global South.

Though the research has taken different approaches over the years (*5*), one that is currently accepted because of its humane perspective, is that of the Swedish vision zero in which the priority of the mobility stops being the mobility itself and gets replaced by the safety and integrity of the user (*6*).

Inspired by these ideas and noticing how accident rates in Manizales are still too high as shown in Figure 1, the town hall, with funding from the Road Safety National Agency (Agencia Nacional de Seguridad Vial), contacted the local campus of the National University of Colombia to carry on a study on road safety over 28 points of the city's road network. These initiatives show institutional responsibility and commitment that are of great importance to solve social issues, as is the safety in public roads (*7*). This can be achieved by understanding that the road design, along with all its elements, must take into account human limitations and should foresee all the possible errors that the user could make (*8*).

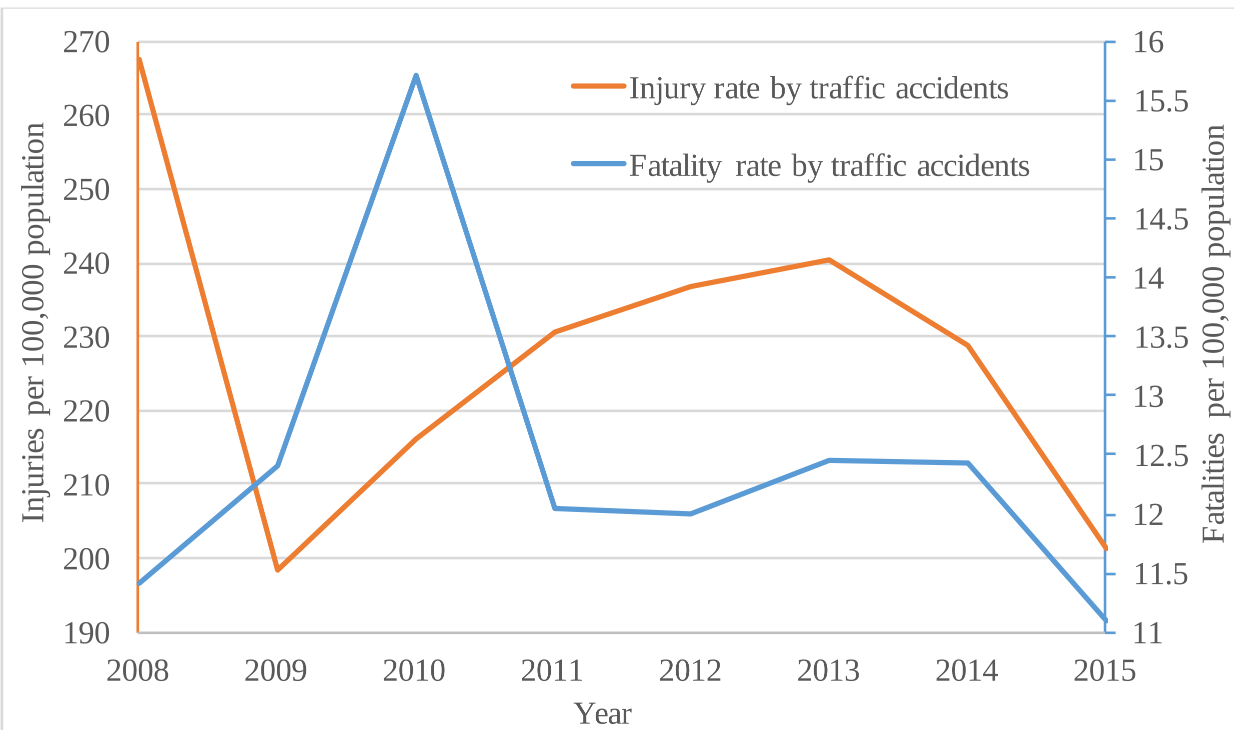

FIGURE 1 Accident rates per 100,000 population in Manizales

The university's research group reviewed past advances in the field and leaned towards methodologies that could rank the locations without the need for previous accident data. The reason is that this data is always scarce and doesn't allow for an impact observation of recently intervened locations (*9*) (*10*) (*11*) (*12*). Other perspectives such as how effective a policy implementation could be (*13*) or even how lighting affects accidents (*14*) were taken into account when designing the rating methodology.

In addition to this, the way safety is perceived by the people and how they might respond to a more conscious road design was considered important (*15*). Likewise, views on road safety as part of a sustainable way of life (*16*) (*17*) were studied to incorporate them in the current city development. One of these sustainable proposals is to increase the use of bicycles in the city to improve safety conditions for the VRU (Vulnerable Road Users) (*18*).

Understanding that road safety management is indeed linked to road safety performance (*19*), the university's sustainable mobility group developed a risk analysis and rating methodology to be applied to each point of the road network in order to improve user safety and wellbeing with proposed interventions derived from the risk analysis. Using this individual rating, a methodology for ranking the studied points is designed and proposed using simple quantitative variables.

In the next section, the methodology development is described and guidelines are given as to how it should be used.

ROAD SAFETY AUDIT METHODOLOGY

The proposed methodology is for quantitatively rate and rank various points of a road network based on their safety characteristics. This process is divided into three main stages as shown in Figure 2. The first of these stages is the information gathering from each of the sites that are going to be analysed, organizing the collected data in order to have a systematic search if needed. The second stage consists in the threat and vulnerability analysis and the risk calculation. And lastly, the third stage is the definition and weighting of the ranking variables that allow for a quantitative comparison of the road network points' safety.

Field Works

The field work is done with the objective of gathering pertinent and current information on the audit chosen points and thus begin their analysis. The order in which the next works are presented is merely a suggestion, some of them can even be developed simultaneously.

Checklists

These are the first step in the field reconnaissance as they pinpoint the prominent failures of the network point. The list is designed for each item to be a yes/no question that seeks the faults in the environment, which means that a negative answer indicates that the subject of the question satisfies the perceived safety standards. Additionally, a space is left on the paper for the auditor to write some observations if needed. Since the list is designed for all the points to be evaluated in the project, a third answer, NA (Not Applicable), is also possible.

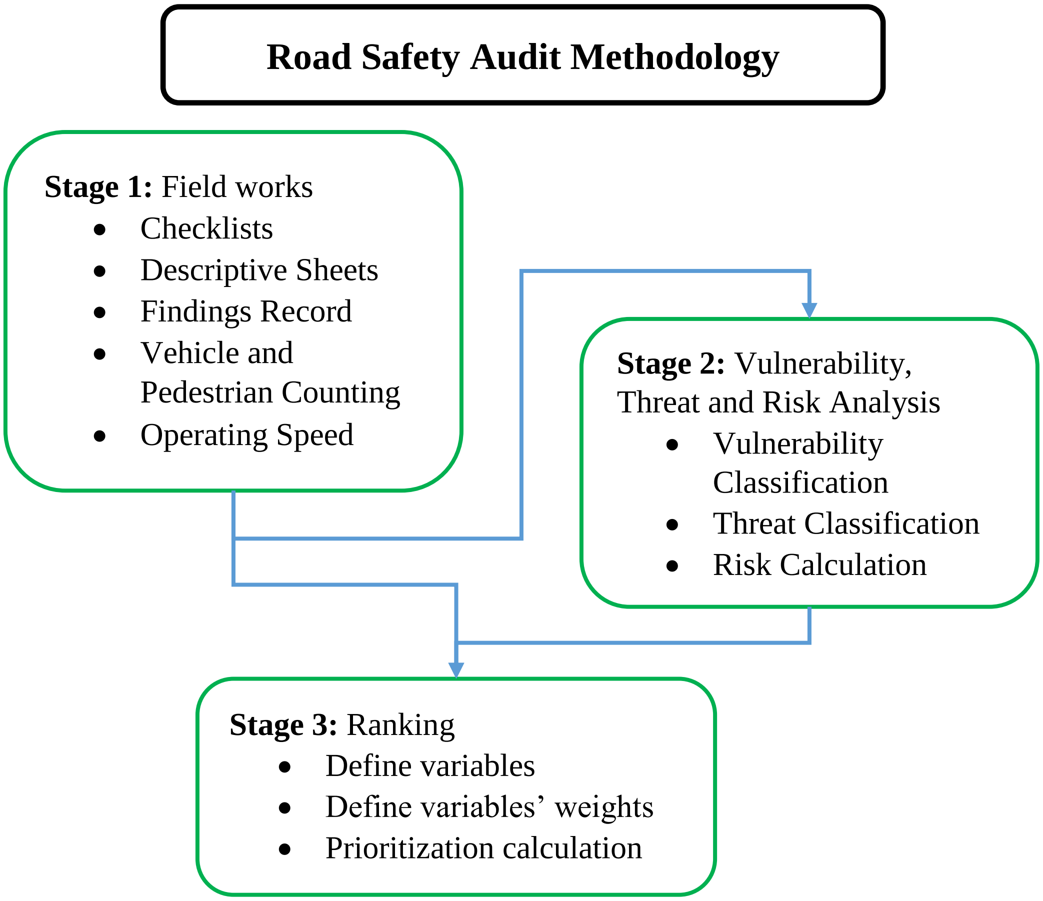

FIGURE 2 Flowchart of the road safety audit methodology

Descriptive Sheets

These are filled with general but pertinent information about the road infrastructure around the network junction or segment. The space taken into account consists of the nearby street blocks, so in a four-way intersection there would be four sheets, one for each access with information like the state of the road surface, the pertinence, existence or state of the road signs, pedestrian infrastructure, lighting, drainage, etc.

Findings Record

What we call findings are the incidents that can be noticed while doing any of the other field works. These incidents include dangerous actions performed by any road user or faults found in the nearby infrastructure. It is important to record these findings using photos and videos as they will serve as evidence or reminders on the next steps of the analysis process.

Vehicle and Pedestrian Counting

The vehicle and pedestrian flows were counted and the movement conflicts identified between vehicular transport means and pedestrians, considering for the latter the importance as VRUs and as the principal character in the sustainable mobility mindset (*20*). The vehicular composition was calculated using this data and while on site, the non-motorized user behaviour was observed and annotated. The schedule in which the counting was taken for each site was defined considering the nearby land use and the existence of educational institutions.

Operating Speed

For some sectors of the points, mostly intersections, the operating speed was measured on site, and for the rest a previous database was considered enough.

Vulnerability, Threat and Risk Analysis

Vulnerability Classification

The vulnerability considers the possible loss in a hypothetical accident. In other words, the vulnerability is the affected subject, which can be a road or surrounding environment user (pedestrians, cyclists, drivers, neighbours, shoppers in a commercial zone, etc.) or physical infrastructure that can be damaged, either public or private. The proposed rating scale goes from 1 to 3, where 1 represents a low-cost loss and 3 one with a greater value.

Threat Classification

The threat is understood as the factors that cause the accidents, either passive or actively. These threats are classified into functional and behavioural. The functional ones are related to the physical characteristics of the road and the behavioural depend on the particular performance of some users. In this case, the proposed rating scale also goes from 1 to 3, where 1 represents a low threat and 3 a greater one.

Because the rating of each factor is defined by an audit team, it is recommended that enough time is dedicated to socializing the criteria to be used in order to homogenize it among the team members for the rating to be valid.

Risk Calculation

The risk is the product of combining the vulnerability and threat, multiplying the values that have been previously assigned, and this new value represents the possible effect caused by an accident and its severity.

The risk is classified as low, medium and high as shown with the colours in Figure 3 where the threat and vulnerability combinations are displayed. Since each analysed point can have various findings, the point will have a mean risk value. The scale to classify this value is as follows.

- Low risk: $1 \leq R < 3$
- Medium risk: $3 \leq R < 6$
- High risk: $6 \leq R \leq 9$

Where R represents the risk.

RISK		VULNERABILITY		
		Low (1)	Medium (2)	High (3)
THREAT	High (3)	3	6	9
	Medium (2)	2	4	6
	Low (1)	1	2	3

FIGURE 3 Risk matrix

This analysis is of the utmost importance because of the consequence that the risk variable represents in the ranking process that is explained in the next section.

Ranking

In this section, the variables related to the prioritization process are described, and in Table 1 their weights are shown. These weights are used in the calculation of the final weighted average that defines the ranking order of all the road network points analysed.

For each variable, a 10-point qualification is given as the maximum possible value and it will decrease proportionally if the variable is quantitative or will be either 10 or 0 if the variable is a true/false type.

TABLE 1 Prioritization Variables and Weights

Variable ID	Name	Weight
1	Mean risk	25,0%
2	Offender pedestrian percentage	7,5%
3	Vulnerable offender pedestrian percentage	7,5%
4	Maximum speed compliance	10,0%
5	Number of speed infringements	15,0%
6	Safe school zone definition	10,0%
7	Motorcycle percentage	5,0%
8	Offender motorcycle percentage	5,0%
9	Nearby public transport stops	5,0%
10	V-P / V-V conflict ratio	5,0%
11	Temporal / permanent investment ratio	2,5%
12	Site location	2,5%

- Variable No. 1. Mean risk. After the risk analysis, the site with the highest mean risk is given a 10 points qualification and that value is used as the maximum reference.

- Variable No. 2. Offender pedestrian percentage. Using the pedestrian counting field work, the maximum value of pedestrians who didn't comply with the road rules, compared to the total number of pedestrians (percentage), is used as the maximum reference.

- Variable No. 3. Vulnerable offender pedestrian percentage. This variable is a subset of the previous one. This variable only counts the offender pedestrians that are considered vulnerable. The conditions that distinguish a vulnerable pedestrian may vary among cities or countries, but they will be mainly the age (young or old), and the physical ability to react.

- Variable No. 4. Maximum speed compliance. This variable uses the observed mean speed on site and is given 10 points if the maximum speed limit is surpassed or 0 points otherwise.

- Variable No. 5. Number of speed infringements. This variable uses the number of infringements detected per hour in each site and the one with the highest value is given 10 points.

- Variable No. 6. Safe school zone definition. When the site presents a nearby school, or any institution with young people attending in a regular basis, a safe zone is defined in the adjacent sectors. When this zone is needed in the site analysis, it will be given 10 points as qualification in this variable and 0 otherwise.

- Variable No. 7. Motorcycle percentage. In the variable definition process, the motorcycles become an important factor as they are involved in a lot of accidents and the consequences of these are often serious. This variable will be the percentage of motorcycles from the vehicle counting.

- Variable No. 8. Offender motorcycle percentage. While doing the vehicle counting field work, it was observed that the motorcycles, due to their agility, could manoeuvre in dangerous manners to avoid some road obstacles. For this reason, it was registered in the counting the number of motorcycle offenders.

- Variable No. 9. Nearby public transport stops. 10 points are given to this variable if a nearby public transport stop is detected or 0 if it is not present around the analysed site.

- Variable No. 10. Vehicle-pedestrian / vehicle-vehicle conflict ratio. The possible movements of the intersection are all analysed and each conflict is counted as vehicle-pedestrian (V-P) or vehicle-vehicle (V-V) for each type of encounter. The number of V-P conflicts is divided by the V-V conflicts, and this ratio becomes this variable.

- Variable No. 11. Temporal / permanent investment ratio. While analysing the vulnerabilities and threats in each site, an intervention is proposed to correct these failures, then, a budget is calculated for each intervention and these are classified into temporal and permanent interventions. This classification depends on the useful life of the intervention, since it will either have a short-term or long-term impact. The budget sum for the temporal interventions is divided by the budget sum for the permanent interventions and this ratio becomes this variable.

- Variable No. 12. Site location. If the road network point is located inside the urbanized area of the city it is given 10 points and if on the contrary it is located in a rural zone it is given 0 points.

After all variables and their weights have been defined and values assigned to all of them for each site, the weighted mean is calculated and ordering this result from highest to lowest value will yield the prioritization order to implement the proposed interventions to reduce the safety risk I the road network.

RESULTS

In this section, we present an example of the results obtained in the analysis of the 12 variables considered in the prioritization process. The values and ratings for each variable can be seen in Table 2. When reviewing the results, it is possible to see that the risk value, although important, is not definitive in the final rating.

In the example values shown, the site 1 has a mean risk qualification equal to 8.3, being the highest of the four, but in other variables it has lower qualifications than the site 2, thus ranking second in the final rating.

TABLE 2 Prioritization Results

Site	Var. No. 1 Mean Risk		Var. No. 2 Offender pedestrian percentage		Var. No. 3 Vulnerable offender pedestrian percentage		Var. No. 4 Maximum speed compliance	
	Value	Rating	Value	Rating	Value	Rating	Value	Rating
1	8.3	10.0	68%	6.8	16%	7.7	NO	0.0
2	7.8	9.5	67%	6.7	20%	10.0	NO	0.0
3	7.8	9.5	100%	10.0	0%	0.0	YES	10.0
4	7.1	8.5	100%	10.0	0%	0.0	NO	0.0

Site	Var. No. 5 Number of speed infringements		Var. No. 6 Safe school zone definition		Var. No. 7 Motorcycle percentage		Var. No. 8 Offender motorcycle percentage	
	Value	Rating	Value	Rating	Value	Rating	Value	Rating
1	92.6	7.3	NO	0.0	40%	10.0	49%	10.0
2	127.2	10.0	YES	10.0	33%	8.3	40%	8.1
3	0.0	0.0	NO	0.0	32%	8.0	0%	0.0
4	0.0	0.0	NO	0.0	38%	9.5	0%	0.0

Site	Var. No. 9 Nearby public transport stops		Var. No. 10 V-P / V-V conflict ratio		Var. No. 11 Temporal / permanent investment ratio		Var. No. 12 Site location		Final rating
	Value	Rating	Value	Rating	Value	Rating	Value	Rating	
1	YES	10.0	1.7	10.0	0.2	3.6	URBAN	10.0	7.0
2	YES	10.0	0.6	3.8	0.4	7.5	URBAN	10.0	8.1

Site	Var. No. 9 Nearby public transport stops		Var. No. 10 V-P / V-V conflict ratio		Var. No. 11 Temporal / permanent investment ratio		Var. No. 12 Site location		Final rating
	Value	Rating	Value	Rating	Value	Rating	Value	Rating	
3	YES	10.0	0.4	2.3	0.6	10.0	RURAL	0.0	5.4
4	YES	10.0	1.0	6.0	0.1	1.8	RURAL	0.0	4.2

In the same way, we could include as many network points as needed and have them ranked in order of importance according to the factors evaluated by the audit team. This calculation will result in a prioritized list that can be followed and executed as the resources allow, generating the highest impact in the shortest time possible.

CONCLUSIONS

The prioritization values cannot be compared between different studies due to the way these are calculated. This is because the results are relative to the maximum in each variable. If new points were to be included in the study, it would be necessary to group the old and the new ones and recalculate each variable rating.

Another limitation of the methodology is that the vulnerability and threat classification is subject to the audit team particular considerations, which makes it susceptible to variations in time and between cities.

Despite these limitations, the methodology application is pertinent in a local environment, particularly for medium-sized cities that can consider a homogenous behaviour among the road network. The methodology is suitable for cities that have an urgent necessity to address the high accident rates of the network because it allows for a factor flexibility that can accommodate the public policy directive effectively.

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REFERENCES

(1) Manizales Cómo Vamos. Informe de calidad de vida Manizales 2016. http://manizalescomovamos.org/wp-content/uploads/2016/08/ICV_2016-1.pdf. Accessed July 6, 2017.

(2) Tripp, H. A. Progress in road safety measures. *Police Journal. London*, No. 11, 1938, pp. 428–449.

(3) Shalom Hakkert, A., and V. Gitelman. Thinking about the history of road safety research: Past achievements and future challenges. *Transportation Research Part F: Traffic Psychology and Behaviour*, No. 25, 2014, pp. 137–149.

https://doi.org/10.1016/j.trf.2014.02.005

(4) Sitran, A., Delhaye, E., and I. Uccelli. Directive 2008/96/EC on road infrastructure safety management: an ex-post assessment 5 years after its adoption. *Transportation Research Procedia*, No. 14, 2016, pp. 3312–3321.
https://doi.org/10.1016/j.trpro.2016.05.279

(5) Hagenzieker, M. P., J. J. F. Commandeur, and F. D. Bijleveld. The history of road safety research: A quantitative approach. *Transportation Research Part F: Traffic Psychology and Behaviour*, No. 25, 2014, pp. 150–162.
https://doi.org/10.1016/j.trf.2013.10.004

(6) Tingvall, C., N. Haworth. Vision Zero - An ethical approach to safety and mobility. 1999.

(7) Belin, M.-Å., P. Tillgren, and E. Vedung. Vision Zero – a road safety policy innovation. *International Journal of Injury Control and Safety Promotion*, Vol. 19, No. 2, 2012, pp. 171–179.
https://doi.org/10.1080/17457300.2011.635213

(8) Theeuwes, J., and H. Godthelp. Self-explaining roads. *Safety Science*, Vol. 19, No. 2–3, 1995, pp. 217–225.
https://doi.org/10.1016/0925-7535(94)00022-U

(9) Agarwal, P. K., P. K. Patil, and R. Mehar. A Methodology for Ranking Road Safety Hazardous Locations Using Analytical Hierarchy Process. *Procedia - Social and Behavioral Sciences*, No. 104, 2013, pp. 1030–1037.
https://doi.org/10.1016/j.sbspro.2013.11.198

(10) Amundsen, A. H., and R. Elvik. Effects on road safety of new urban arterial roads. *Accident Analysis & Prevention*, Vol. 36, No. 1, 2004, pp. 115–123.
https://doi.org/10.1016/S0001-4575(02)00133-1

(11) Subirats, P., Y. Goyat, B. Jacob, and E. Violette. A New Road Safety Indicator Based on Vehicle Trajectory Analysis. *Transportation Research Procedia*, No. 14, 2016, pp. 4267–4276.
https://doi.org/10.1016/j.trpro.2016.05.398

(12) Yannis, G., A. Dragomanovits, A. Laiou, T. Richter, S. Ruhl, F. La Torre, L. Domenichini, D. Graham, N. Karathodorou and H. Li. Use of Accident Prediction Models in Road Safety Management – An International Inquiry. *Transportation Research Procedia*, No. 14, 2016, pp. 4257–4266.
https://doi.org/10.1016/j.trpro.2016.05.397

(13) Canoquena, J. M. da C. Reconceptualising policy integration in road safety management. *Transport Policy*, No. 25, 2013, pp. 61–80.
https://doi.org/10.1016/j.tranpol.2012.09.003

(14) Jackett, M., and W. Frith. Quantifying the impact of road lighting on road safety — A New Zealand Study. *IATSS Research*, Vol. 36, No. 2, 2013, pp. 139–145.
https://doi.org/10.1016/j.iatssr.2012.09.001

(15) Grote, G., and C. Künzler. Diagnosis of safety culture in safety management audits. *Safety Science*, No. 34, 2000, pp. 131–150.
https://doi.org/10.1016/S0925-7535(00)00010-2

(16) Esposito, T., R. Mauro, F. Russo, and G. Dell'Acqua. Speed prediction models for sustainable road safety management. *Procedia - Social and Behavioral Sciences*, No. 20, 2011, pp. 568–576.
https://doi.org/10.1016/j.sbspro.2011.08.063

(17) Wei, V. F., and G. Lovegrove. Sustainable road safety: A new (?) neighbourhood road pattern that saves VRU lives. Accident Analysis and Prevention, Vol. 44, No. 1, 2012, pp. 140–148.
https://doi.org/10.1016/j.aap.2010.12.005

(18) Wegman, F., F. Zhang, and A. Dijkstra. How to make more cycling good for road safety?. *Accident Analysis & Prevention*, Vol. 44, No. 1, 2012, pp. 19–29.
https://doi.org/10.1016/j.aap.2010.11.010

(19) Papadimitriou, E., and G. Yannis. Is road safety management linked to road safety performance? *Accident Analysis & Prevention*, No. 59, 2013, pp.593–603.
https://doi.org/10.1016/j.aap.2013.07.015

(20) Fardi, B., U. Neubert, N. Giesecke, H. Lietz, and G. Wanielik. (2008). A fusion concept of video and communication data for VRU Recognition. *Proceedings of the 11th International Conference on Information Fusion, FUSION 2008*.
https://doi.org/10.1109/ICIF.2008.4632293