ROAD SAFETY AUDIT FINDINGS ON TWO-LANE ROAD: CASE STUDY IN GREECE

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ABSTRACT

Greek legislation (Presidential Decree104/2011) in line with the European Directive 2008/96/EC plans to implement Road Infrastructure Safety Management (RISM) for the road network of Greece. The procedure of Road Safety Audit (RSA) is one of the main RISM procedures as a means for preventing accidents. This paper addresses the RSA findings on a national 2-lane, 2-way road network in Greece, as a reactive approach to identifying safety issues and infrastructure deficiencies. The examined road network is a typical road in Greece and the presented approach analysis may operate as a report to roadway authority officials to gain a better understanding on the current state assessment of the typical type of road. The RSA conducted by a team of auditors who was experienced in road design as well as in road safety engineering and user driving behaviour. The RSA team developed checklists for the specific roadway, according to the Greek legislation, checking the conformity of road layout to Road Design Specifications, potential violations of driver expectancies related to roadway design, and risk potential accidents points. The findings were categorized into groups taking into account the analysis of human factors. The proposed remedial measures are based on behavioural studies and they presented in qualitative evaluation. However, cost-benefit and cost-effectiveness analyses combined with the specifics in each case are imperative for the key issues to be addressed.

Keywords: 2-lane road, accidents, human factor, road safety audit.

1 INTRODUCTION

In recent years, the road safety approaches as Vision Zero, Sustainable Safety and Safe System, proposed by developed countries like Sweden, the Netherlands and Australia, were based on the fundamental principle of the long-term vision for a developed society, where no one is killed or seriously injured in a road transport. In 2008, ITF/OECD published a research report "Towards Zero: Ambitious Road Safety Targets and the Safe System Approach", an international attempt to present a new framework for road safety policies [1]. The main ambitious target was to progressively eliminate all fatalities and seriously injured. The basic principles of achieving this main target are shared responsibility, between road users and providers of the elements affecting the safety of system and prevention. The stakeholders and the main authorities of the road transport system are responsible to road safety level in the long term. The typical "blame the road user" view has been replaced. It is recognized that road users make mistakes that may lead to road accidents. A road transport system has to support human error, making the road environment more forgiving and self-explaining. A more proactive than re-active approach to road infrastructure design and construction is desired, where road safety is taken into consideration in all the stages of a road life cycle [2,3].

In the European Union, the Directive 2008/96/EC legally specified tools and procedures for a pro-active approach to Road Infrastructure Safety Management (RISM), providing policy guidance to improve the road safety of a road network [4]. OECD [2,3] and Persia et al. [5] present ten RISM procedures that support a road authority in decision making related to road safety improvement of a road network. These procedures are aimed to enhancing road

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safety at the different stages of a road infrastructure life cycle; some of them can be applied to existing infrastructures (a more re-active approach) and other are used in the early stages, i.e. planning and design (a more pro-active approach). Among the ten RISM procedures, the road safety audits, road safety inspections, management of high-risk sites and road impact assessments are the main procedures for identifying safety issues and providing measures in all stages of design, construction and operation.

Road safety audit (RSA), as procedure for preventing accidents, originated in Great Britain and is now being spread in several countries around the world [6]. RSA is a formal safety performance examination of an existing or future road by an independent, multidisciplinary team. RSA has been broadly recognized as a successful preventive tool for minimizing future accident occurrence and is a part of Safe System approach to road safety. Austroads (2009, 2018) includes the examination of existing roads in RSA as well as, noting that it is a reactive approach finding any potential hazards the design may unwittingly hide [7,8].

However, the Directive 2008/96/EC was amended in 2019 with the Directive (EU) 2019/1936 which will apply to roads not only which are part of the trans-European road network but to motorways and to other primary roads, whether they are at the design stage, under construction or in operation [9].

This paper addresses the RSA findings on a national two-lane road network in Greece, as a re-active approach to identifying safety issues and infrastructure deficiencies. It is mainly focused on providing the general framework of RISM and a general description of the identified road safety problems based on human factors approach.

2 METHOD

Internationally, the main RSA guidelines are those published in the USA (2006) by Federal Highway administration (FHWA) [10], in Britain (2008), published by British Institution of Highways and Transportation (HIT) [11] and in Australia (2009) published by Austroads [7]. The RSA carried out by a multidisciplinary auditing team comprising two or more well-trained and accredited road safety engineers who are not part of the design team. It is worth noting that the independence of the auditor team performing the RSA is absolutely necessary. The identification of potentially dangerous features of the roadway environment and potentially misleading or missing information points are the main principles of the procedure.

In Greece, for the implementation of integrated RISM, Presidential Decree 104/2011 defines: “specific procedures related to the training and responsibilities of auditors, the data which are collected and utilized, as well as the relevant good practices that should be used to tackle the road safety issues that have been identified”. RSA is one of the proposed measures of the Strategic Plan to improve road safety in Greece 2011–2020 and is considered mandatory for the Trans European Road Network. Regarding to the training of auditors, there was an official effort for the training and certification of highway engineers, working in the private and public sector, from an organized RSA training program in order engineers to be certified as road safety auditors [12].

The training of auditors was based on the implementation of the Safe System approach and human factors in road design. Human factors are stable psychological and physiological threshold limit values that influence the performance and safety of technical systems used by humans, as typical limitations of the perception system, information processing, learning or decision making of all human beings [13,14]. It is important, in the framework of RSA, the auditor has to take into consideration the natural laws of human perception, the processing of information and the regulation of action programs whenever an onsite safety evaluation is made. Auditors have to understand how the road design influences driving behaviour and how the environment contributes to driver errors and collisions [15]. Numerous studies have been conducted worldwide to examine specific risky behaviours of drivers, which can be directly related to the occurrence of traffic accidence. The reason for conducting these studies is the fact that 90%–95% of traffic accidents occur due to human factors [16–18]. Driver behaviour is a very complex matter that is influenced by one's knowledge, abilities and skills on the one hand and personality traits such as volition, values and motives on the other [19,20]. It is a combination of both typical behaviour and maximal performance in demanding situations. There are several theories and models of driver behaviour or performance in order to predict typical behaviour or the limits of maximal behaviour [21]. Although the driver behaviour is governed by several factors and their interactions, and many of these operate at subconscious level, theories and model of driver behaviour are essential to understand how changes in vehicle, roadway, social and legal environment can affect driver behaviour [21].

PIARC's reports [22,23], mention that there are three classes of human factors in the man-road interface that trigger accidents: (a) the 6-s rule: the design and construction of the layout of the road should give the driver enough reaction time (4–6 s) to adapt to a new driving requirement, (b) the field of view-rule: a good quality field of view effectively keeps drivers over his lane and (c) the logic rule: the road has to follow drivers' expectation and orientation formed by their experience and recent perceptions.

The above principles can be used in the quality planning and design process or investigation and completion the on-the-spot checklist during the RSA procedure.

The examined road in this study is a national two-lane road network in Greece. The team of auditors was experienced in road design as well as in road safety engineering and user driving behaviour. The findings were categorized into groups taking into account the analysis of human factors. The examined road network is a typical two-lane two-way road in Greece and the presented approach analysis may operate as a report to roadway authority officials to gain a better understanding on the current state assessment of the typical type of road.

3 CASE STUDY

The case study examined in this paper is the roadway "Amphipoli-Drama", a 50 km interurban road, located in the Northern Greece. It is the main connection of Egnatia Odos Highway with town of Drama (Fig. 1). Mainly, it is a two-lane, two-way road network, without separated directions and 0.5–1.2 m. shoulders. Along the network of the road, there are 19 unsignalized intersections. The roadway course is passing through seven built-up areas, as shown in Fig. 1. The speed limit is 90 km/h except the area of built-up areas where the speed limit is 50 km/h. The importance of the provided connection of this road is high as it facilitates the high volume of traffic. An average traffic volume is about 35,000 heavy vehicles per year.

The safety data of the part of 20 km of this road, near the town Drama, is presented in Table 1. The data of the other part of the road was not available from the Traffic Office. The main causes of the accidents were the excessive, over-limit speeding, the absence of lighting in intersections, the restricted field of view of driver and other causes based on human factors. The RSA was carried out by an independent team of road safety engineers with appropriate experience and qualifications in road safety. Specifically, one member of the team is certified road safety auditor. All the members have experience in road design and construction, basic principles of traffic operation and human factors knowledge. Before the field inspection, data for traffic volumes, traffic accidents and high risk sites, the design standards that were used, ortho photomaps, road design software were examined and analysed.

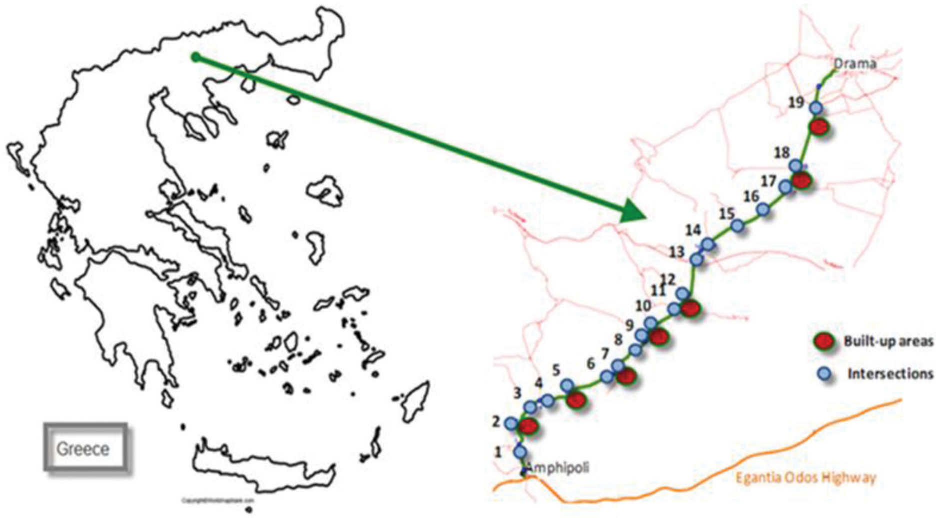


Figure 1: The interurban road Amphipoli-Drama in northern Greece.

Table1: Road safety data of 20 km of Amphipoli-Drama roadway.

	2014	**2015**	**2016**	**2017**	**2018**
Traffic accidents	23	22	28	23	19
Fatalities	1	1			3
Injuries	11	8	3	4	7
Only damages	13	16	25	19	11

The inspection of the road was carried out in daylight and at night-time, in wet and dry conditions, from the point of view of all road users and included all movements at each interchange. The RSA team developed checklists for the specific roadway, according to the Greek legislation, checking the conformity of road layout to road design specifications, potential violations of driver expectancies related to roadway design and risk potential accidents points.

4 RESULTS

The RSA team identified several safety issues. In the inspection process, auditors took emphasis on how drivers might perceive the road environment, adjust their driving behaviour to the geometric characteristics of the roadway or the geometric layout of roadway might provide wrong information to drivers. The main safety issues were categorized in groups, considering human factors analysis, in specific topic areas and are presented as following:

4.1 Road function

A critical situation in respect of road safety is the mixture of functions of roads. Road classification provides a categorization of roads design in order roads to cater for a defined function. The examined road, a national interurban road, has a flow function which allows efficient

Figure 2: Road with mixed functions.

throughput of long-distance motorized traffic. The critical areas where the road passes through villages creates situations of mixture of functions (Fig. 2). There is no clear distinction between the flow function of the interurban road and the access function of urban road. In case the road geometry, from one environment to another, keeps unchanged, the driver behaviour has to be changed as may cause serious problems in road safety with conflicts with vulnerable road users.

4.2 Access control

Along examined road strong access control is the basis of road safety. Access control is the planned and regulated interaction between the roadway network and property access (Fig. 3). Different local traffic activities allow actual access to properties alongside the road overwhelming the trough route function of the road. These activities along the road such as public and private transport of goods and people, shopping, parking decrease the level of road safety and increase the accidents figures especially in vulnerable road users such as pedestrians and cyclists.

The appropriate management has main goal to limit and separate conflicts points between property access and efficient transport system. The limitations of access points reinforce the flow function of the main road and the concentration of uncontrolled turning movements at a single junction which can be properly designed for such movements upgrade the level of safety.

4.3 Consistency in road horizontal and vertical elements

From the review of road design plans, it is remarked that the design of horizontal and vertical element is not compatible with the road design principles. In the horizontal alignment, an inconsistent alignment with a combination of large with small radius horizontal curves makes the road course to be not predictable. Drivers are surprised by sudden changes of the curvature and they misinterpret the poor coordination of the horizontal and vertical curvature (Fig. 4). Unexpectedly tight horizontal curves may lead to drivers to drive through them at speed higher than that of the dynamic equation of the curve especially after a long straight section. There is no sufficient sight distance, in many cases, for overtaking or breaking and stop in case of obstacle. It may be difficult for a driver to estimate the sight distance on a curve crest and he may overtake when he does not have sufficient length to do so safely.

Figure 3: Uncontrolled access points.

Figure 4: A combination of small radius vertical crest with horizontal curve.

4.4 Excessive speed

Long straight sections of the road course encourage drivers to drive at higher speed than is safe for that location according to design and operational speed of the road. The combination of straight sections with low gradients along the road and low level of horizontal and vertical curvature encourage speed and lead to a rise in accidents (Fig. 5). Moreover, the cross-section profile plays significant role; the width of lanes or shoulders greater than the limits of the design specifications also encourage speed.

In residential area, where the interurban road functions as urban road, the type of cross-section should be different. The main problem is that a driver when enters in area with lower speed limit, generally underestimate his speed, especially after a higher speed driving period. This fact makes him unable to reduce his speed enough to comply with the lower speed limit. Appropriate engineering infrastructure measures can help to indicate the transition from one traffic environment to another, and thus help drivers adjust to the lower speed.

4.5 Maintenance of the road

Maintenance of the road in full profile impacts the safety situation. Adequately maintaining road assets is essential to preserve and enhance the provision of safe and efficient travel of people and goods. There are many critical positions where it is remarked a deterioration and

Figure 5: A combination of small radius vertical crest with horizontal curve.

Figure 6: Lack of maintenance of pavement and signing.

defects on pavement; low skid-resistance, asphalt cracks, potholes and deformation. Some main reasons for that is the harsh weather condition, the lack of appropriate maintenance and heavy daily traffic which may cause adverse impacts on pavement condition (Fig. 6).

The road marking was faded at many locations while old markings controlling temporary traffic had not been removed effectively. Poorly signed positions do not clearly inform drivers about dangerous road conditions. Many signs are obscured by overgrowing vegetation and the driver has no opportunity to take notice of the instruction given by the sign. Many signs are not visible at night because of poor illumination, lack of maintenance, inappropriate position. Signs should be sited far enough in advance for drivers to react in the required way (Fig. 6).

Concerning the lighting system, there are many positions where there is no lighting. In locations where there are high proportions of vulnerable users (in built-up areas) or in areas of intersections have to provide lighting. Careful attention needs to be paid to the sitting of lamp posts as they can be hazardous for an errant vehicle and it should be protected by barriers system.

Well designed and located barriers systems reduces the number and the severity of traffic accidents. Many accidents on rural roads involve accidents leaving the road and colliding with hazardous obstacles. There are many positions where there are damaged barriers or missed barriers or barriers which are a series of unconnected short pieces or with faulty connection or termination (Fig. 7).

Figure 7: Damaged restrained systems.

Figure 8: Roadside obstacles.

4.6 Roadside features

A roadside is defined as the area beyond the edge traffic lanes of roadway. Different single fixed or continuous obstacles at the edge of traffic lanes create potential danger of collisions leading to accidents or increasing accident severity. Some of these obstacles are trees or other vegetation, utility poles, sign and lighting posts and supports, abutments, overpasses, rocks on the nearside, drainage features, embankments and slopes, ditches, kerbs, canals (Fig. 8). Consideration all these roadside obstacles as a component of the driver’s field of view, which governs the driver’s behaviour is crucial. According to PIARC Human Factors Guidelines, a well-designed field of view helps enhance road safety.

4.7 Intersections

A junction is required wherever two or more roads cross, so that vehicles can pass through the junction in ways that are safe and understandable for all road users. According to the inspections of all the 19 intersections, many findings were recorded. Recognizing road user’s limitations in capabilities and the point of view of driver in all directions, the auditors considered how the potential for a collision can be reduced and in which locations there are misleading or missing information (Fig. 9).

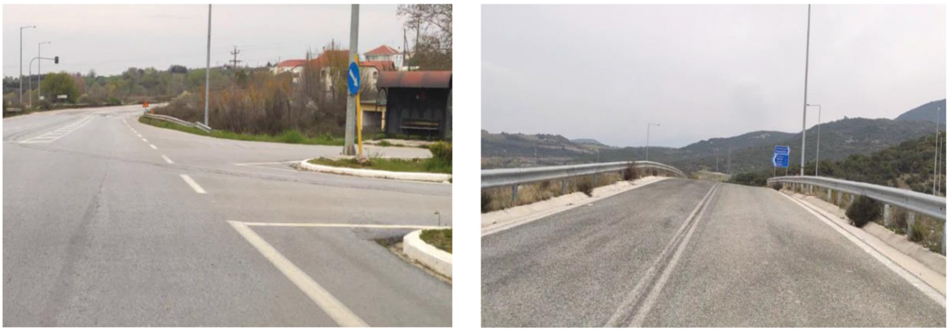


Figure 9: (a) Uncontrolled intersection and (b) intersection in vertical crest curve; limited visibility.

5 DISCUSSION

In order to the main safety issues to be addressed, recommended measures for improvement and upgrading the level of safety are presented. The effectiveness of the methods that take into account the user's driving behaviour and the forgiving road namely a safe and self-explanatory design consistent with the expectations of road users while recognizing their needs, limitations and capabilities of information has to be examined.

The proposed remedial measures are based on behavioural studies [24–27] and they presented in qualitative evaluation. Behavioural studies consider the medialization of users' choice with behavioural theory [28].

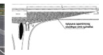
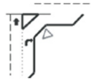
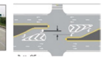
5.1 Road safety infrastructure investments

- Although the road course, inside built-up areas, fulfil mixture of functions, a clear distinction between flow function of interurban road and the function of connection, access and stopover has to be implemented. As the construction of by-pass road around the built-up area is an expensive solution, the implementation of different countermeasures is significant for upgrading the level of road safety. Some of them are full space separation of traffic with local activities, well-designed intersections, separation of pedestrian lanes (pedestrian bridges or protected pedestrian zones), separation of the shoulder by barriers, different calming traffic measures (islands in the centre of the road, roundabouts, narrowing of the lanes) in order to reduce the level of speed.
- Closing of direct access to main road and the uncontrolled turning movements to minimize the possibility for accident is important. However, the connectivity to the surrounding land has to be examined.
- Inspection for keeping the sufficient sight distance for drivers. Improved signing, warning signs, chevron signs in sharp curves, overtaking forbidden by suitable road markings and signs, improved marking are low cost solutions. Moreover, it is important to improve the sight distance in curves removing obstacles or vegetation.
- Concerning the speed management, local improvements in the most dangerous locations it is imperative. Some measures are signing about speed limit, separation of traffic travelling in opposite directions using median barriers (where there is enough space), speed cameras,

shoulder or centreline rumble strips (tactile warning devices). In built-up areas the implementation of many physical engineering restrictions encourages drivers to slow down; gates at the entrance of the village, central traffic islands, roadside refuges, narrowing the width of the lanes, speed humps, small roundabouts.
- An important aspect for cost-effective maintenance over the pavement life cycle is the selection and timing of maintenance activities. Using the right maintenance treatment at the right time, depending the condition of the pavement, will get the maximum benefit.
- Replacement of new signing with modern signs, reflectorized that provide excellent visibility in all weathers. It is recommended variable message signs in critical positions where it is absolutely necessary.
- Improved and clean road markings provide appropriate information to the drivers. Centrelines indicate locations where overtaking is forbidden. Where it is necessary, it is recommended centre and edge lining reinforced using studs or reflective glass beads.
- Lighting is expensive to install and maintain but usage of cheaper LED lighting and solar power lighting system or any other energy saving system may reduce costs. Proper maintenance is needed (changing and cleaning lamps). Protection of the lamp posts via installation of appropriate barrier systems (according to EN-1317 specifications).
- Appropriate restrained barrier system installation, along the two sides of the road, according to European Standards EN1317 (Greek guidelines Road Restraint Systems OMOE-SAO) is imperative. According to the technical guideline OMOE-SAO, the installation of safety barriers on the road requires the consideration of the relevant study to determine the obstacles at the edge of the pavement, the critical distance of each obstacle, the required containment level depending on the degree of danger and the permitted speed. Special consideration should be taken in end-treatments of barriers, transition from one category of barrier to another, appropriate length before and after obstacles, crush cushions at dangerous locations.
- The main approach for the management the roadside obstacles is to design a forgiving roadside in order to reduce the consequences of an accident caused by driving errors, vehicle malfunctions or poor roadway conditions. The main categories of management of roadside obstacles the removing or relocation of potentially dangerous roadside objects, the modification of objects and the shielding of objects. Thoroughly examination is needed in each dangerous point.
- Redesign and reconstruction of intersections is imperative to be safe and understandable for all road users. Proposed countermeasures for the examined intersections are presented in Table 2 to prevent future accidents. The road specifics of each case combined with cost-benefit and cost-effectiveness analyses determine the priority of the implementation of these measures. In Table 2, the priority of each measure implemented in each intersection is presented taking into account the low cost of measure combined the effectiveness.

The proposed measures are: enhanced sign (I.1), improved maintenance of stop signs (I.2), enhanced pavement marking (I.3), flashing beacons at stop-controlled intersections (I.4), splitter islands on the minor road approach (I.5), transverse rumble strips (I.6), clear sight triangles on stop or yield controlled approaches (I.7), right turn lanes at intersections (I.8), left turn lanes at intersections (I.9),offset left-turn lanes at intersections (I.10), realign skewed intersection (I.11), improve visibility by proving lighting (I.12), roundabouts (I.13), delineation in islands (I.14), illumination signs at night.

Table 2: Proposed intersection countermeasures to prevent future accidents.

Intersection	Proposed countermeasures														
	I.1 	I.2 	I.3 	I.4 	I.5 	I.6 	I.7 	I.8 	I.9 	I.10 	I.11 	I.12 	I.13 	I.14 	I.15 
1	X		X		X	X									
2	X		X										X		X
3			X									X			
4			X	X		X								X	X
5	X	X	X	X				X	X				X	X	
6	X		X		X	X		X	X						X
7	X	X	X	X	X	X		X	X						X
8	X		X	X		X		X				X		X	X
9			X	X				X		X			X	X	X
10	X		X	X				X		X		X		X	X
11	X		X	X		X				X				X	X
12	X		X	X		X						X		X	
13			X			X		X						X	X
14			X	X		X		X						X	X
15	X		X									X		X	X
16	X		X	X				X	X					X	
17			X	X		X					X			X	X
18	X		X	X	X	X			X		X	X			X
19			X	X	X	X	X								X

The locations of the intersections 1–19 are predicted in the map of Figure 1.

	Top high priority
	High priority
	Medium priority

Table 3: Cost-effectiveness evaluation of infrastructure measures.

Measure	**Cost-effectiveness evaluation/cost**
Design of horizontal and vertical element	Not expected to be cost-effective in most cases, due to the increased implementation costs.
Engineering infrastructure measures-speed management	Expected to be >1:1 due to low implementation costs
Road marking	2.76:1 7,500 € per km
Signs	8.6:1 50,000€–300,000 € per junction
Lighting system	7:1 to 9:1
Barriers systems	8.7:1–32:1 130,000 €–220,000 € per km
Roadside features	7:1
Redesign and reconstruction of intersections	2.5:1 to 1 3.8:1 from 1,100,000 €

5.2 Cost-effectiveness assessment of measures

The selection between various infrastructure safety measures is usually based on economic evaluation. As budgets for road safety policies and activities are not infinite, politicians have to make decisions regarding the best implemented policies. The criteria used in most countries, when deciding about policies and budgets, are mainly suitability, lawfulness, legitimacy and efficiency [24]. Cost-effectiveness is a technique used for the evaluation of road safety investments. The cost-effectiveness ratio of a road safety measure is defined as the number of accidents prevented by the measure per unit cost of implementing the measure [29,30]. In Table 3, the cost-effectiveness evaluation of the proposed infrastructure safety measures are presented based on data of literature review. The suitability of an investment depends on the high safety effect with the low implementation cost.

6 CONCLUSIONS

The results of RSA were carried out on the 50 km long interurban road, "Amphipoli-Drama", with the aim of identifying features of the road network operating environment that may be potentially dangerous. The importance of the provided connection of this road is high as it facilitates the high volume of traffic. Emphasis was placed on the principles of positive guidance, forgiving road and self-explanatory design consistent with road users' expectations while recognizing their information needs, limitations and capabilities. The proposed improvement measures can be implemented to address various road safety issues raised. Road safety issues can rarely be solved with a single measure in general, a combination of measures covering different elements of the road system is required. Since there are no "magic recipes" for infrastructure related to road safety measures, cost-benefit and cost-effectiveness analyses combined with the specifics in each case are imperative for the key issues to be addressed.

The proposed procedure of RSA in a national road is a guide method identifying points that present high levels of accidents and areas that can improve on level of safety by addressing deficiencies concerning signalling, barriers and pavement condition.

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