Chapter 4

Joint Road Safety Analysis in Open Roads and Tunnels

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Abstract

From the user's (drivers) point of view, a road is a unique linear infrastructure although it is clear for a driver that such a linear infrastructure consists of open terrain (open roads) and occasionally closed environment (tunnels). Since the two environments present different safety issues, the related analyses are usually conducted on the field by different experts; those conclusions are sometimes not well interlinked and harmonised, leading to safety gaps particularly, but not only, in the transition areas. Joint safety analyses conducted in the same time by a group of road safety and tunnel safety experts can fill such a gap and increase the safety level of the whole infrastructure. During the year 2016, an international group of road safety experts and tunnel experts visited five road sections with open roads and tunnel in Europe and performed joint safety analyses together with the infrastructure managers. Such analyses were conducted according to a predefined experimental procedure to check the effectiveness of the joint analyses with respect to the usual ones. The key results are that joint safety operations in tunnels and open roads are possible and extremely useful: their cost can be very low when well planned.

Keywords: road safety inspection, open roads, tunnels, transition areas, joint safety operations

1. Introduction

The issue of road safety inspections in tunnel was discussed in two workshops held at the European Social and Economic and Social Committee (EESC) by a group of international stakeholders in February and May 2013: a debate that was initiated about operations such as Road Safety Audit (RSA) during the design process or Road Safety Inspection (RSI)

after opening to traffic, according to the prescriptions of the Directive 2008/96/EC (Road Infrastructure Safety Management – RISM). Such operations could be beneficial for risk prevention in tunnels, but the Directive 2008/96/EC does not apply to road tunnels, which are covered by Directive 2004/54/EC (on tunnels safety management): a formal interpretation of the two Directives may lead to a barrier to the safety inspection of the whole infrastructure.

In fact, from the user's (drivers) point of view, a road is a unique linear infrastructure although it is clear for the driver that such a linear infrastructure consists of open terrain (open roads) and occasionally closed environment (tunnels). The driver wants to receive the same high safety levels, without being interested to know all the details of the 'infrastructure safety chain' that produces such safety.

On the other hand, from the infrastructure managers' point of view, the road is surely not a unique linear infrastructure, because producing and managing safety in a closed environment (tunnels) is much more demanding and extreme than in an open road infrastructure.

Due to different characteristics of a tunnel (e.g. level of visibility, design, enforcement of traffic regulations, etc.), it is important to look at the safety perception of drivers in this environment, otherwise called—subjective safety [1] in normal conditions, as well as in critical scenarios. The users' perspective was also analysed in 2010 [2], revealing several causes of fear induced to users.

In order to find a common harmonised approach in tunnel and open road safety management, during the year 2016, an international group of road safety experts and tunnel experts visited five road sections with open roads and tunnel in Europe and performed joint safety analyses together with the infrastructure managers in the framework of the European Project ECOROADS [3] (**Table 1**).

Test site, country	Dates of the joint visits	No. of experts (core team)	No. of observers	No. of other experts	Tunnel type and length	Length of open road inspected
Kennedy Tunnel, Belgium	07–08 March 2016	3	3	6	Two tubes, 690 m each	1200 m
Krrabe Tunnel, Albania	05–06 April 2016	4	4	5	Two tubes, 2230 and 2500 m	1500 m
Tunnel Rennsteig, Germany	17–18 August 2016	3	3	4	Two tubes, 7916 m each	400 m
Tunnel Strazevica, Serbia	27–28 September 2016	3	1	12	Single tube 745 m	650 m
Tunnel Demir Kapija, Former Yugoslav Republic of Macedonia	18–19 October 2016	4	0	9	Single tube 554 m	400 m

Table 1. Basic data of the five joint safety operations.

Such analyses were conducted according to a predefined experimental procedure foreseeing the figure of a 'facilitator' in charge to maintain the contacts between the group of experts, several external observers, and the infrastructure manager, as well as to ensure an adequate feedback after the visit (**Figure 1**).

The effectiveness of the joint analyses respect to the usual ones was fully confirmed, and their main aspects related to the definition of the transition area and common check lists are reported in the following sections.

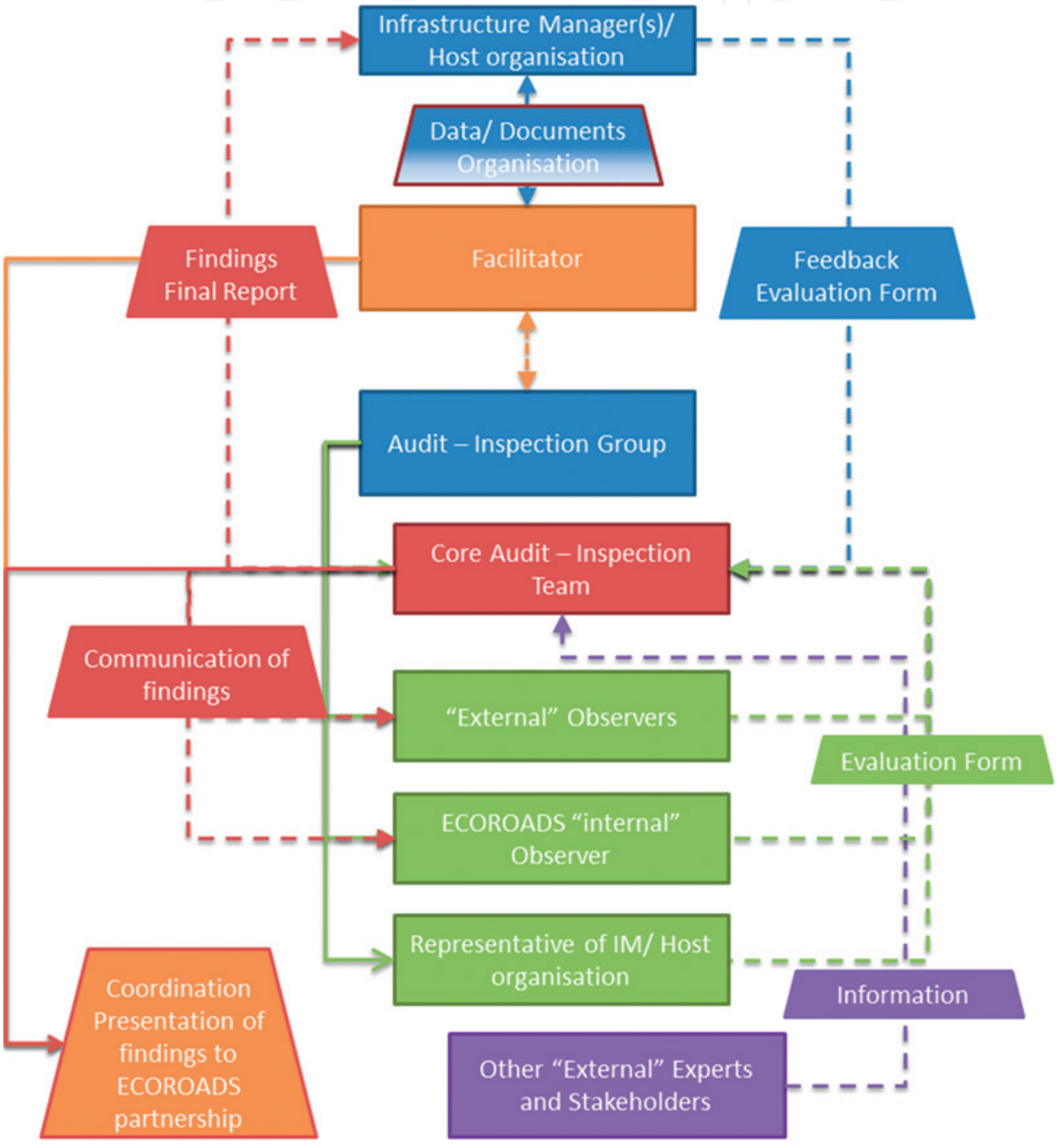

Figure 1. Roles and responsibilities of parties involved in the joint safety operations.

2. Definition of the 'transition area'

For the scope of the joint safety analysis, the transition area between an open road and a tunnel covers areas both inside and outside the tunnel.

As a minimum requirement, it is intended to be the sum of:

a. The distance calculated as the distance covered in 10 s by a vehicle travelling at the speed limit before the tunnel portal, and

b. the stopping distance inside the tunnel after the portal, for a vehicle travelling at the speed limit, if not identical with design speed. Such a distance has been defined in the ECORO-ADS project by using a longitudinal friction coefficient of 0.40 (wet surface, high speed) and a 2-s reaction time. This gives the following stopping distances from various vehicle speeds (**Table 2**):

This minimum rule obviously applies to the opposite direction and also—maybe slightly modified due to reduced speed within the tunnel—at the exit of the tunnel and in the same direction (**Figure 2** for each direction).

This area, actually its length, may only be extended after a common agreement of the expert team during a joint safety operations' briefing meeting, who provided a sound justification for its modification. This need may emerge from other parameters, such as the speed mentioned above, road marking, signage, lighting, infrastructure design, and should then be considered.

Approaching speed (85th percentile)	70 km/h	90 km/h	120 km/h
Stopping distance (with t = 2 s, fl = 0.40, no grade %)	87 m	130 m	208 m

Table 2. Stopping distances.

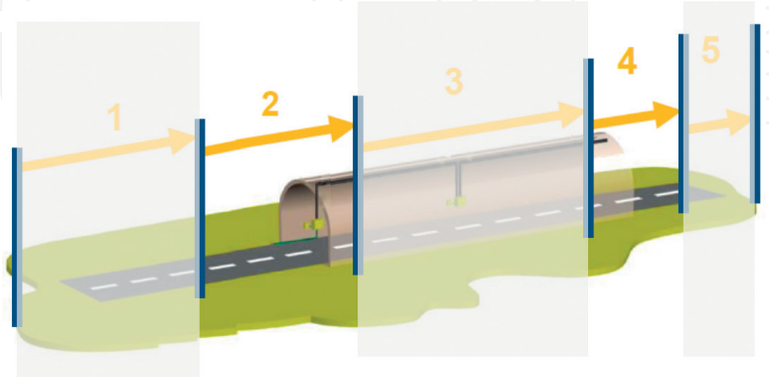

Figure 2. Transition areas are represented by sections 2 and 4.

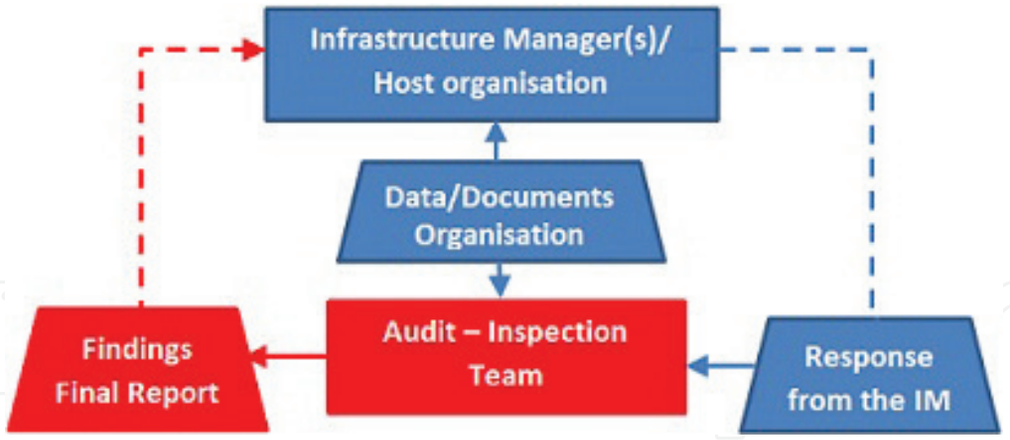

Figure 3. Simplified scheme of the joint safety operations.

Five joint safety operations performed during the ECOROADS project highlighted that such transition areas often presented the more critical road safety issues.

Since the common procedures adopted by the project have been validated through the success of the joint safety operations, the simplified scheme in **Figure 3** can be successfully adopted by each infrastructure manager by using the checklist described in Section 4.

3. Conclusions

When managing the real traffic flows in the real infrastructure, there is a need for coordinated actions. This particularly applies to the transition areas where two different infrastructures ('open roads' and 'tunnels') meet, which leads to the need to develop a harmonised safe traffic management.

During the operations in the five test sites, there was a good level of involvement of infrastructure managers (of tunnels and open roads) and the core group as defined in the scheme of the previous **Figure 1**.

A multitask procedure was adopted to allow an experimental deployment of a multidisciplinary and multifunctional team of international experts.

ECOROADS has been funded by the HORIZON 2020 Programme [5]; the project collected 42 feedback forms from the expert group. Due to the rotation of the figures involved, all the members of the core groups were observers in at least one joint safety operation. There was widespread consensus on the following added value of the joint safety operations:

- Working in a mixed team (safety/tunnel experts), mixture of experiences from different countries

- Common/coordinated approach for open roads—transition area—tunnel in one project that guarantees a harmonised safety approach in the traffic management, respecting the different technical characteristics in each area
- Exchange of knowledge and best practices
- Opportunity to visit and see the tunnel from inside and see traffic and driver's behaviour both inside and outside the tunnel ('feel the traffic on my own')
- Opportunity to examine the tunnel without traffic
- Close collaboration between road safety experts and tunnel safety experts regarding the common view of the transition area as a whole
- Mainly, the view of road safety experts on the part of the road in the tunnel with its specific characteristics can be very conducive to evaluate the total safety of the road in a closed environment (tunnel).

Acknowledgements

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A. Appendix: check list for transition areas

Before and after tunnel entrance/exit, according to **Figure 2**; checklists for open roads can be found in [4], and the ones for tunnels can be found in [3].

Site: ….

Direction: ….

Date: … … ….. Time: … ..

Weather conditions: … … … …..

Traffic conditions: … … ….

Expert's name: … ….

Role (Roads/Tunnels): ….

Transition Area (open road tunnel or vice versa): from km …. + …..… to km …. + …..….

Please use a separate check list for the opposite direction or in the case of multiple road-tunnel sections (**Table 3**).

Characteristics	No.	Questions	Yes (✓) No (X)	Comments
1. Function, operating elements, and surrounding/ road environment	1	Is there any information about previous RSA/ RSI or other safety assessment (Tunnel Safety Inspection) final results **relevant to this area**? Have these results and the relevant recommendations been taken into consideration?		
	2	Are there any issues from accident data if available?		
	3	Is the Tunnel - a twin tube tunnel (two monodirectional tubes), - a single tube tunnel, bidirectional - an urban Tunnel		
	4	Is the design or the current situation of the tunnel according to its category?		
	5	Are there radio rebroadcasting frequencies and is the radio frequency adequately communicated to the users?		
	6	Is there information provided to the users about their correct behaviour while driving through a tunnel (use headlights, avoid sunglasses, keep distances, observe signs and signals, switch the radio on, and tune to indicated frequency)?		
	7	Is there information provided to users about the possible incidents in tunnels and appropriate reaction of the users?		
	8	Are there special lanes for HGVs or reduced speed limit for trucks? Is this affecting traffic flow? Is overtaking of trucks prohibited?		
	9	Is there water supply provided near portals?		
	10	Is there gradual reduction of speed from open road to the tunnel speed limit?		
	11			
	12			
	13			
2. Portal	1	Does the tunnel portal have a safe design for all vehicle types? Funnel shape and gradual height reduction is recommended.		
	2	Is there a risk of heavy vehicles hitting the tunnel ceiling or walls?		
	3	Are the portals sufficiently shielded?		
	4	Does the entrance have a slowing down effect due to its design (not informative, dangerous, confining)?		
	5			
	6			
	7			

Characteristics	No.	Questions	Yes (✓) No (X)	Comments
3. Cross section	1	Is the paved area narrowed and lateral clearance reduced at entrance causing speed reduction and driving in more distance to tunnel sidewalls?		
	2	Is the same number of traffic lanes maintained outside and inside the tunnel?		
	3	Are the different traffic lanes' widths sufficient?		
	4	Is crossing the central reserve ensured outside each portal?		
	5	In bidirectional tunnels, are appropriate means used along the median for separation of the two directions of traffic?		
	6			
	7			
4. Alignment, horizontal, and vertical	1	Is the alignment towards tunnel satisfactory (straight, not on curve)?		
	2	Is the crossfall appropriate?		
	3	Is the longitudinal gradient >3%? Is it ≤5%, according to the Directive? Or geographically this was not possible?		
	4			
	5			
	6			
	7			
	8			
	9			
5. Intersections/ Interchanges	1	Are there junctions inside or before-after the tunnel?		
	2	Is direction signing adequate?		
	3	Are there dangerous weavings?		
	4			
	5			
6. Traffic signals/ITS	1	Are there traffic signals?		
	2	Are signals well ahead the portal (150–200 m), where the drivers do not pay attention, as they are focused to the tunnel entrance?		
	3	Can drivers see the traffic signals ahead of the portals in good time? Are they before the entrances to ensure the closure of the tunnel in case of emergency?		
	4	Are there VMS systems? Which are there categories of information (congestion/breakdown/accident/fire/open-close-divert/speed limit/lanes allocation to vehicle categories)?		
	5	Are the VMS messages understandable? Are they only in text or accompanied by pictograms?		
	6	Is it possible to post speed limit signs at sufficient intervals to safely reduce driving speeds?		
	7	Is there need for ATC?		
	8			
	9			
	10			

Characteristics	No.	Questions	Yes (✓) No (X)	Comments
7. Traffic signing, marking, and lighting	1	Is there proper distance between signs, harmonised with the driving speed?		
	2	Are there any objects/reasons of distraction of drivers from concentrating on tunnel entrance (irrelevant signs/advertisements?		
	3	Are signs succinct in form and repeated for clarity?		
	4	Are signs perceivable, simple, readable, credible, reliable, memorable, and easily to understand (also for non-nationals)?		
	5	Are signs and signals well dimensioned, coloured, lighted, and repeated frequently in a proper way?		
	6	Is information system complicated? Are written instructions numerous?		
	7	Are there warning signs before the last interchange that a tunnel is ahead to avoid stressful driving, over-height vehicles, and provide exit of vehicles carrying dangerous loads?		
	8	Is horizontal signing used at the roadside edge?		
	9	Road markings – Are profiled markings used? Is there a need for LED lighting?		
	10	Are rumble strips (acoustic lane markings) located ahead of the portals?		
	11	Is the right illumination level chosen at the entrance zone, transition zone? Does the illumination level satisfy all lanes?		
	12	Is the entrance into the tunnel adequately lighted?		
	13	Is there adaptation lighting (adjustment of the light intensity level) at the beginning and end of the lighting/tunnel?		
	14	Are the sight conditions at entrance poor (ocular blinding, stray light, etc.)?		
	15	Is the vehicles' headlights usage obligatory and this clearly communicated with appropriate signing?		
	16	Is the entrance zone designed to provide as low adaptation luminance as possible?		
	17			
	18			
	19			

Characteristics	No.	Questions	Yes (✓) No (X)	Comments
8. Roadside features and passive safety installations (incl. plantings, civil engineering structures, and other obstacles)	1	Are there restraint systems/ guardrails?		
	2	Is there a need for guardrail in the portal zone? And is the guardrail in case well anchored and extended back both outside and inside the tunnel?		
	3	Are there passive objects for minimising the consequences of accident at the portal area? Are there crash cushions and impact attenuators? Of which type?		
	4	Are there lay-bys for emergency, height controls etc., ahead of the portal?		
	5	Are there emergency phones?		
	6	Are there buildings, installations, and equipment for operational reasons (e.g. winter service)? Are their location (distance from carriageway—more than 7 m aside, distance from portal—not more than 50 m), architectural design, access roads, and other characteristics appropriate?		
	7	Are there paths for service or emergency vehicles to U-turn before the tunnel entrance? Are they grade separated (bidirectional tunnels) or at grade (unidirectional)?		
	8	Is there need for refurbishment to avoid risks for users from degradation of outdated equipment?		
	9			
	10			
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	14			

Table 3. Check list.

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