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1. Introduction

Notwithstanding the undeniable and fortunate decrease in crashes, deaths and injuries in European road traffic, the extent of human suffering and economic loss still remains unacceptable. Over 42,000 road users are killed in European Union (EU) countries annually and around 3,5 million are injured, when under-reporting is taken into consideration. This accounts for an annual cost of over 160 billions Euros (European Commission, 2001). In the past, the effectiveness of casualty reduction programmes was largely attributed to measures such as crash protection and drunk/drive measures. Road safety engineering measures had a rather limited impact on casualty reduction. This may in part be due to the high cost of such measures. As a result, infrastructure improvement and enforcement campaigns are not expected to significantly contribute towards the 50% reduction of road fatalities, which is set as target for the EU for 2010 (European Commission, 2003). The use of new technologies may be required to achieve this policy goal, especially since the combination of new technologies with existing infrastructure, or with limited improvements of it, may lead to much more cost-effective solutions.

The pan-European project Infrastructure and Safety (IN-SAFETY) involved the participation of 29 partners from 12 European countries and was aimed at using intelligent, intuitive and cost-efficient combinations of new technologies and traditional infrastructure best practice applications in order to enhance the forgiving and self-explaining nature of roads, thereby contributing to a set of EU transport policy objectives, in particular regarding road safety. Forgiving roads (FOR) and self-explaining roads (SER), two notions explained below, were considered the main concepts instrumental to improving road safety. The authors contribution to the IN-SAFETY project, as described here in this paper, consisted of performing an evaluation and prioritisation of a large number of potential measures describing future FOR and SER environments that could materialize in the future. This selection/prioritization is performed in order to allow various stakeholders with special emphasis on public policy makers to understand which types of future states of FOR and SER environments command the highest expected 'value added' from the community of stakeholders in its entirety, thereby uncovering information on the probability of successful implementation. The methodology used for this purpose is the multi-actor / multi-criteria-analysis (MAMCA).

A self-explaining road (SER) can be defined as a road which is designed and constructed to evoke correct expectations from road users (Theeuwes and Godthelp, 1992), eliciting proper driving behaviour, in this way reducing the likelihood of driver errors and enhancing driving comfort. Drivers have to cope with increasingly complex traffic environments, including different types of road lay-out and all kinds of sign posting, many of which are supported by telematics. In some cases this may impose a critical workload to the driver, such as trying to read the variable message sign (VMS) while seeking the proper route in an unfamiliar environment (often in a foreign language and even with unfamiliar signs), attempting to detect the required relevant piece of information among an abundance of information sources (like in-car navigation systems, traffic management and information centre or radio announcements, VMS, road signs, messages from advanced driver assistance systems [ADAS], etc.).

A forgiving road (FOR) is defined as a road that is designed and built in such a way as to interfere with or block the development of driving errors and to avoid or mitigate negative consequences of driving errors, once started (Wegman and Aarts, 2005). To develop a forgiving road environment certain characteristics must be included and measures should be taken. These measures involve applications related to either the infrastructure or telematics. The assumption is that it is the combination of infrastructure and telematics measures that can provide a more cost-efficient solution, as expensive infrastructure works may be substituted by telematics or other innovative systems.

The MCA methodology as an evaluation approach has a long tradition and has its roots in operational research (OR) (Charness and Cooper, 1961). More recently, however, MCA has been applied in the context of economics-driven project evaluation. This appears useful especially when a neo-institutional approach to project evaluation is adopted and multiple stakeholders become relevant (De Brucker and Verbeke, 2007; Macharis, Stevens, De Brucker and Verbeke, 2006; Macharis, 2000; De Brucker, 2000).[1] MCA allows comparing a number of actions (for instance, projects or policy measures), or alternatives in terms of specific criteria. These criteria represent the operationalization of the policy objectives and

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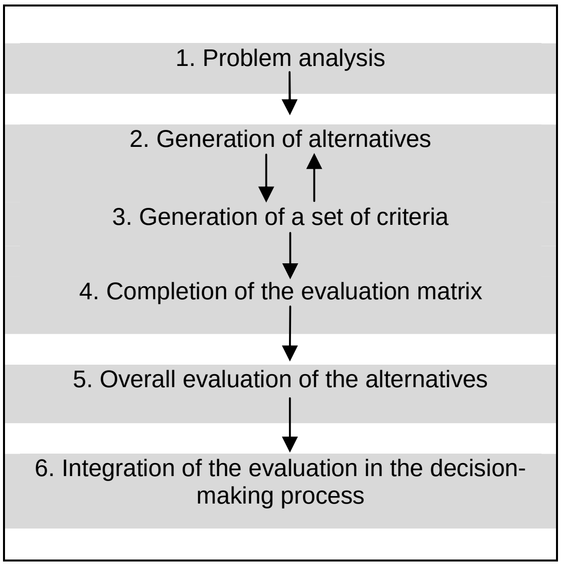
[1] The old institutional approach in economics to which the modern stakeholders' approach followed by the authors can be linked, goes back to Commons (1934). According to J. Commons, society is a complex entity of multiple actors with partly conflicting and partly converging interests. The various 'trade or social relations' involving the actors or stakeholders often lead to conflicts, given problems of economic scarcity. The essence of economics (or policy making) is then to solve – or at least manage – these social conflicts. Effective conflict management increases economic welfare. This can be achieved through 'collective action' and 'collective democratic planning' or an 'evolving system of rules', these are institutions (Commons [1934] 1959: 73ff, 108ff, Klein 1984; Mitchell 1969:719)

sub-objectives of decision makers and stakeholders participating in the decision-making process. As a policy tool, the MCA methodology is especially useful to structure complex decision problems according to their constituent parts (objectives, sub-objectives as measured by criteria) and to make comparisons among project alternatives. This approach appears especially useful when effects cannot be fully monetised, nor even quantified. Effects should not be viewed less relevant for policy making because it is difficult to quantify them. Forman and Selly (2001), quoting A. Einstein, argue that not everything that can be measured counts and that not everything that counts can be measured. It is usually possible to link specific stakeholders with specific criteria in the MCA, and by doing so stakeholder management can effectively be implemented, as described in Macharis (2000), Macharis (2004) and Macharis, Verbeke and De Brucker (2004). MCA can be viewed as an 'institution in action' capable of resolving conflicts between stakeholder interests and therefore contributing to the successful implementation of a project or policy measure. MCA as a decision procedure can be associated to what is called the 'rules of the game' in institutional economics and the stakeholders to the 'players of the game' (De Brucker and Verbeke, 2007).[2]

In general terms, the process-related steps to be followed in an MCA have a structure as shown in Figure 1.

Figure 1: Process-related steps in MCA



Source: designed by the authors

In the following sections the MCA methodology will be applied to prioritise a number of alternatives contributing to the creation of a FOR and a SER environment and thus contributing to a specific EU policy objective, namely increasing road safety. The structure of this paper will be analogous to the structure presented in Figure 1.

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[2] These two analogies ('rules of the game' and 'players of the game') are core concepts used by North (1990:3) to define the notion of 'institutions' within the institutional branch of economics.

2. Generation of alternatives to be selected/prioritised

Since the concepts of forgiving roads (FOR) and self-explaining roads (SER) turned out to be interdependent, the prioritisation of alternatives was done in parallel in the same MCA application, both in terms of FOR and SER environments. The future states of these two environments are interdependent because a number of parameters/conditions instrumental to creating a particular state for either of these two environments will also affect the state of the other.

An extensive set of alternatives has been identified based on an exploration of the error structure designed by the Bundesanstallt für Strassenwesen (BAST), this is the German Federal Highway Research Institute. In that error structure, four levels of errors were identified, namely : (1) *Level 1 errors and accidents*, which refer to the type of accident (for instance single vehicle accident, frontal collision, lateral collision, chain/rear collision, collision with parked vehicle, collision with animal), (2) *Level 2 errors and accidents*, which can be described by the accident causes that are due to failure of the driver (for instance speeding, wrong use of the road, violation against priority rules, failure when overtaking, failure when turning or entering, insufficient safety distance, load number of passengers, etc.), whereby one accident can have more than one cause, (3) *Level 3 errors and accidents* which refer to 'human' errors (these are the specific 'human'/'psychological' elements of the error), such as for instance information error (lack of perception, such as not having noticed the traffic sign while passing), diagnostic error (incorrect evaluation of available information) and performance error (incorrect execution of routine operations, such as for instance not having found the brake pedal) and finally (4) *Level 4 accidents*, which refer to the general physiological condition of the driver (for instance exhaustion, fatigue, disorders, intoxication, etc.). In addition, other conditions that also influence road safety, besides errors can be identified, such as weather conditions (for instance fog, rain, wind, etc.), road surface conditions (ice, oil, etc.), road conditions (grooves, etc.), technical or maintenance faults, improper behaviour of pedestrians, obstacles, etc.

As regards the identification of a set of tools that have the potential to improve road safety by creating a FOR environment or a SER environment, it was decided to start by analysing the so-called 'level 2 errors and accidents' described above, these are the errors and accidents that are related to a failure of the driver. The aim of the tools or alternatives to be developed is to assist the driver in her or his complex driving task so as to create a safer driver environment, which is considered an important objective in EU transport policy.

The set of alternatives was finally developed by analysing and expanding on the five most important causes for accidents ('level 2 errors') identified in the German and European accident statistics (Brookhuis *et al.*, 2006 and Wiethoff *et al.*, in prep.), namely : (1) *speeding*, (2) *violation of priority rules*, (3) *wrong use of the road*, (4) *failure when overtaking* and (5) *insufficient safety distance*. In addition one more specific error related to speeding was identified by experts, namely : (6) *too fast in unexpected sharp bends*. For these six accident types innovative systems were identified that could remedy these errors and reduce the number of accidents. The innovative systems were designed by combining the former six errors with three dimensions along which tools can be developed, namely : (1) *the vehicle* ('autonomous in-vehicle tools', this are systems that work with information from in-vehicle sensors only and that do not need any data communication with off-vehicle devices such as other vehicles or infrastructure), (2) *the infrastructure* ('autonomous infrastructure-based measures', this are measures that create or change road infrastructure elements) and (3) *a co-operative tool* (these are systems that exchange data between in-vehicle and off-vehicle devices, such as the infrastructure; these systems are considered to be examples of so-called 'ambient intelligence'). A systematic overview of the systems to be prioritised is given in Table 1. The first row contains the three dimensions (vehicle, infrastructure and the cooperative version); the first column contains the six top errors in the category 'level 2 errors’ and the remaining cells contain the actual alternatives or tools to be studied. The alternatives as presented here should be viewed as ‘generic’ ones, since they refer to a main group or category of alternatives.

Table 1 : Generation of alternatives by combining errors and dimensions along which tools can be developed

Dimension Error	In-vehicle tool	Infrastructure-based tool	Cooperative tool vehicle-infrastructure (‘ambient intelligence’)
Too fast in unexpected sharp bends	Unexpected sharp bends are registered red in a digital map of the navigation-system and presented to the driver	Vehicle is ‘analysed’ (for instance speed), VMS signals the danger of the bend depending on the actual speed	Electronic beacons (special reflection posts) give additional information on displays in the vehicle about the road (for instance warning: sharp bend)
Speeding	Speed alert system functioning by recognition of traffic signs	Speed limit is presented to the driver by VMS under consideration of special environmental circumstances	Speed alert system, based on digital maps containing legal speed limits with additional info on recommended safe speed
Violation of priority rules	Traffic sign recognition	Traffic signs	Traffic light status information emission to car
Wrong use of the road	LDWA (Lane Departure Warning Assistant)	Audible delineation	Adaptive LDWA; Sensitivity of LDWA is adapted in special conditions such as road works, tunnels
Failure when overtaking	Blind spot detection system warning driver if a vehicle is approaching from behind	Separation of lanes by rumble strips where overtaking is forbidden	Cooperative system warning of oncoming vehicles by vehicle-to-vehicle communication
Insufficient safety distance	Advanced Cruise Control (ACC)	Fog detection warning system; VMS warning	ACC set by local (on-site) weather system: Dynamic ACC

Source : IN-SAFETY project team

A more detailed description of these generic alternatives is given in Table 2. This description also includes parameters such as the type of drivers (for instance young drivers, old drivers, etc.), the type of vehicle (for instance passenger car, heavy vehicle, etc.) and the environmental preference in terms of traffic conditions, road type, special road section, lighting and weather.

Table 2 : Overview of alternatives contributing to the concepts of SER and FOR

		Syst.type				Driver								Vehicle								Environment preference																		
						Skill				Age				Vehicle type				Vehicle owne				Traffic cond.				Road type				Spec.rd.sect.				Lighting				Weather		
Code	Adressed level 2 error	Autonomous vehicle	Auton. Infrastructure	Coop. V&I Amb. Intell.	Alternatives description	All	New driver	Average driver	Professional driver	All	Young (18-29)	Middle age (30-50)	Old (over 50)	All	Passenger car	Heavy vehicle	Bus	All	Private	Fleet owner	Driving school	All	Light density	Medium density	Heavy density	All	Motorway	Rural road	Urban road	All	Tunnel	Road Construction	Others	All	Normal	Night with light	Night without light	All	Normal	Adverse weather
1.1	Too fast in unexpected sharp bends on rural roads	x			Unexpected sharp bends are registered red in a digital map of the navigation-system and presented to driver	x				x				x				x					x					x					x		x		x	x		
1.2	Too fast in unexpected sharp bends on rural roads		x		vehicle is "analysed" (e.g. speed), VMS signalize the danger of the bend depending on the actual speed	x				x				x				x					x					x					x		x		x	x		
1.3	Too fast in unexpected sharp bends on rural roads			x	electronical beacons (special reflexion posts) give additional information on displays in the vehicle about the road (e.g. warning: sharp bend)	x				x				x				x					x					x					x		x		x	x		
2.1	Speeding	x			Speed Alert System functioning by recognition of traffic signs	x				x				x				x				x				x				x				x	x			x	x	
2.2	Speeding		x		Speed Limit is presented to the driver by VMS under consideration of special environmental circumstances	x				x				x				x				x			x		x	x		x	x	x		x				x		x
2.3	Speeding			x	Speed Alert Syst. based on digit.maps containing legal speed limits with add. info. on recommended safe speed	x	x			x	x			x		x		x				x			x	x				x				x				x		x
3.1	Wrong use of road	x			LDWA (Lane Departure Warning Assistant)	x			x							x	x	x		x		x	x				x	x						x				x		
3.2	Wrong use of road		x		Audible delineation	x								x				x				x					x	x						x			x	x		x
3.3	Wrong use of road			x	Adaptive LDWA; Sensitivity of LDWA is adapted in special conditions., such as road works, tunnels	x			x					x		x	x	x		x		x					x	x				x		x						x
4.1	Violation of priority rules	x			Traffic Sign recognition	x								x				x				x						x	x					x				x		
4.2	Violation of priority rules		x		Traffic signs	x								x				x				x				x								x				x		
4.3	Violation of priority rules			x	Traffic light status information emission to car	x								x				x							x			x	x					x						x
5.1	Failure when overtaking	x			Blind spot detection syst. warning driver if a vehicle is approaching from behind	x				x			x	x		x	x	x		x		x				x	x			x				x				x		
5.2	Failure when overtaking		x		Separation of lanes by rumble strips where overtaking is forbidden	x	x			x	x			x				x				x						x		x		x		x		x	x	x		x
5.3	Failure when overtaking			x	Cooperative system warning of oncoming vehicles by veh.-to-veh. communication				x	x				x		x		x		x		x				x		x		x				x				x		x
6.1	Insufficient safety distance	x			Advanced Cruise Control ACC	x			x	x				x				x				x					x	x		x				x				x		
6.2	Insufficient safety distance		x		Fog detection warning system; VMS warning	x				x				x				x				x					x	x		x				x						x
6.3	Insufficient safety distance			x	ACC set by local (on-site) weather system: "Dynamic ACC"	x				x				x				x				x					x	x		x				x						x

Source : IN-SAFETY consortium partners (BAST, TUDarm, TUDelft and USTUTT)

3. Generation of a set of criteria

The next phase in the MCA methodology is the construction of a set of criteria for the evaluation and selection/prioritisation of alternatives contributing to forgiving road (FOR) and self-explaining road (SER) environments. For this purpose, a two-step procedure was followed. First, a special workshop[3] with leading experts coming from IN-SAFETY consortium partners was organised. At the end of this workshop, the experts agreed on a decision tree as presented in Figure 2.

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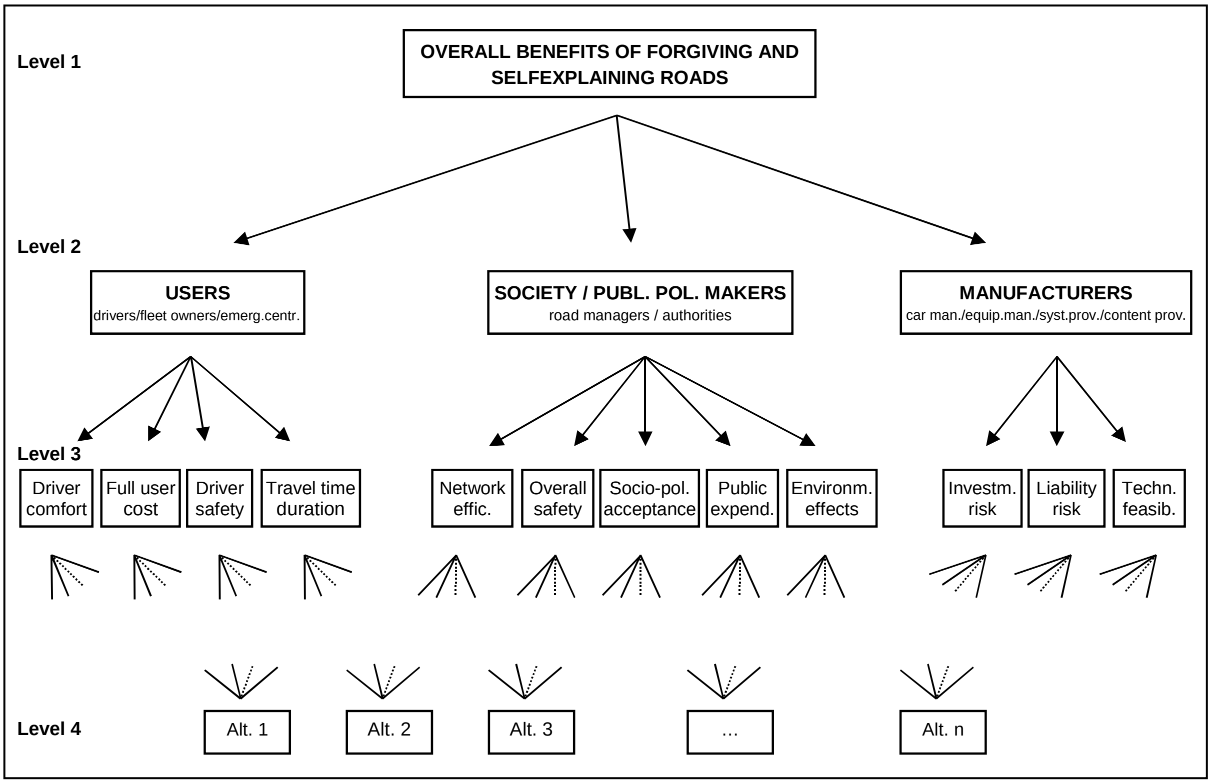
[3] This workshop took place at the Technical University of Delft (TUDelft), on 6 and 7 February 2006 and welcomed experts from the Bundesanstallt für Strassenwesen (BAST), this is the German Federal Highway Research Institute, the Technical University of Darmstatt (TUDarm), the University of Stuttgart (USTUTT) and the TUDelft itself.

Figure 2 : Decision hierarchy for the prioritisation of FOR and SER alternatives



Source : IN-SAFETY project team

The top level of the decision tree shown in Figure 2 represents the focus or overall policy objective, namely creating benefits by making the road environment more forgiving and more self-explaining. At the second level, three groups of main stakeholders are shown, namely (1) the users, (2) society/public policy makers and (3) manufacturers. Within each group of stakeholders, a number of sub-categories could be identified such as drivers, fleet owners and emergency centres (for the main category ‘users’), road managers and authorities (for the main category ‘authorities’) and car manufacturers, equipment manufacturers, system providers and content providers (for the main category ‘manufacturers’). As regards these sub-categories, it turned out that it was not necessary to include them as separate groups, since the preferences of these sub-groups were not substantially different from each other and since some of these sub-groups were not organised in such a way so as to exert a substantial influence on policy making. At the third level, the criteria are listed that these main stakeholders consider relevant. At the lowest level, the alternatives are shown that need to be prioritised. These alternatives were identified as described in section 2.

It should be noted that the second stakeholder (at level 2) in Figure 2 represents the point of view of public policy in general. The sub-system that is formed by this stakeholder and all its lower level elements is the most important sub-system from a public policy point of view, since it represents the overall societal point of view. The two remaining sub-systems, formed by the users (this is the demand side of the market), respectively the manufacturers (this is the supply side) and their lower level elements, are also important but in another context, since successful implementation of alternatives by public policy makers (this is the middle sub-system in Figure 2) is indeed only possible when the decisions made or the options chosen by these public policy makers are concordant, at least to a certain extent, with the interests of the other stakeholders. If this is the case, then the public policy objective will be facilitated by the actions taken by the other stakeholders and it will be easier for public policy makers to have their policies implemented. This way of using stakeholder management as facilitating (or obstructing) public policy implementation is fully in line with the actual definition of the concept of ‘stakeholder’ by Freeman (1984) who defined a stakeholder as any individual or group who can affect an organization’s performance or who is affected by the achievement of this organization's objectives. Mitchell *et al.* (1997) classified stakeholders based upon three attributes, namely power, legitimacy, and urgency. In their model, stakeholder salience, as perceived by decision makers, is positively related to the cumulative impact of these three stakeholder attributes. It should, therefore, be clear now that the MCA procedure followed here, this means building upon stakeholder interests, is not merely a tool for assessing the potential of new product development, but that, in essence, it serves public policy making, especially as regards road safety in this case. The MCA that will be performed in the following sections, therefore, needs to be designed in such a way so as to be able to investigate to which extent the solutions chosen within the second sub-system (public policy view) are concordant with the solutions preferred by the users and the manufacturers. In a perfect market (which is the standard assumption in neo-classical economics), the priorities derived at the demand side of the market would be expected to be fully concordant with the ones derived at the supply side, and government or public policy intervention (this is the middle sub-system in Figure 2) would not be an important issue (what would be good for users would also be good for society). This is definitely not the case here and several reasons can be identified for this. First, there are a number of external effects (such as effects on safety, including third part safety effects such as effects on pedestrians and cyclists, environmental effects, etc.), which are also relevant for EU transport policy making. Second, infrastructure and also safety have the character of a public good, which can only be financed with government funds to be provided by public policy makers. Third, there may be bounded rationality and consumer preferences may be inconsistent over time (consumers often prefer to consume goods which result in an immediate, but temporary award, but which may result in a large cost or sacrifice in the future, for instance road accidents, often underestimated at the time the decision is made). This means that intervention in the market by public policy makers is highly necessary here. Fourth, the tools or systems analysed are highly innovative and the market still has to be developed. In such case, government incentives or an active supply policy by government may be instrumental to stimulating and structuring the institutional structures of this evolving market. The decision problem which public policy makers are confronted with here is, therefore, not a simple one but a complex one and the decision tree developed here (Figure 2) should be viewed as an attempt to order this complexity.

In a second step, the draft decision tree presented in Figure 2 was presented to a forum of public policy makers, users and manufacturers for validation purposes. This forum was organised at the premises of the Intertraffic Conference[4] that took place in Amsterdam. A special IN-SAFETY workshop with representatives from policy makers, users and manufacturers was organised during that conference in order to validate the decision tree and to derive policy weights. A total of about 80 participants (consortium members included), all invited by POLIS[5], took part in this workshop. The way in which that workshop was organised in practice will be described more in detail in section 5.2. The participants taking part in the workshop carefully examined the decision tree and made some suggestions for additional criteria.

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[4] The Intertraffic Conference took place at the RAI Congress and Exhibition Center in Amsterdam from 4 to 7 April 2006 (RAI is the abbreviation for ‘*Rijwiel Automobiel Industry*’ [Cycle Automobile Industry]). The special IN-SAFETY workshop took place on 6 April 2006.

[5] ‘POLIS’ is the abbreviation for ‘Promoting Operational Links with Integrated Services’ and forms a network organisation of leading European cities and regions working together for the development of innovative technologies and policies in local transport (http://www.polis-online.org/).

4. Completion of the evaluation matrix: scoring of alternatives on each criterion

After having identified the policy criteria and the alternatives, the next step is then to perform a partial evaluation, this is an evaluation in terms of each specific criterion. Therefore, for each alternative a score (e_{ij}) should be derived expressing the contribution of that alternative (a_i) to that specific criterion (c_j).

Since the alternatives developed in section 2 are mostly very innovative and since some of the technologies associated with these alternatives have not yet been commercialised in the market place, it is not possible at present to derive a quantitative score directly on a ratio or interval scale for each alternative and for each criterion. It was, therefore, decided to use an ordinal scale in the first stage, this is a scale expressing the ranking of the alternatives with respect to one another. It is only in a second stage, when these scores (partial evaluations) have to be aggregated into an overall score (overall evaluation) that the transformation of the ordinal scores to a ratio scale based score will take place. This will be described in more detail in section 5.

The scores that are necessary here, in this first stage, have to be determined taking into account the results of the existing research. Within the IN-SAFETY project, a number of work packages were related to the development of models describing the possible impact of FOR and SER alternatives. The scoring that is needed here, in this stage of the prioritisation process, was given by the experts[6] within the IN-SAFETY project who developed the alternatives, but taking into account the insights from the models. The ordinal scale that was used to perform the scoring in this stage, is presented in Table 3.

Table 3 : Ordinal scale
used for partial evaluations

Ordin. score	Meaning of the ord. score
+ + +	very high positive impact
+ +	high positive impact
+	moderate positive impact
0	no impact
–	moderate negative impact
– –	high negative impact
– – –	very high negative impact

Source : designed by the authors

The 18 alternatives developed in section 2 were scored by the experts, on the basis of expert judgment. These final scores are presented in Table 4 using the ordinal scale presented in Table 3.

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[6] These experts were the same as those who participated in the special workshop set up for the development of the decision tree, described in section 3

Table 4 : Scoring of alternatives on specific criteria

		System type				EVALUATION (cells below to be filled in with : '+++' / '++' / '+' / '0' / '-' / '- -' / '- - -'). '+++' = very high positive impact / '++' = high positive impact / '+' = moderate positive impact / '0' = neutral effect status quo / '-' = moderate negat											
						Users				Society/Authorities					Manufacturers		
Code	Adressed level 2 error	Autonomous vehicle	Autonomous infrastructure	Cooperative V & I "Ambient Intelligent"	Alternatives description	**Driver Comfort** To which extent does this tool/alternative improve driver comfort ?	**Full user cost** What will be the order of magnit. of the extra in-vestments to be made by user in order to acquire and maintain this tool/alt.?	**Driver Safety** To which extent does this tool/ alternative improve driver safety ?	**Travel time duration** What will be the influence of this tool/alternative on tavel time duration?	**Network efficiency** What will be the influence of this tool/alt. on net-work efficiency? (measures same thing as travel time duration)	**Overall safety** What will be the influence of this tool/alternative on the overall traffic safety (of all road users)?	**Socio political acceptance** To what extent will implementation of this tool/ alt. be acceptable for the public and for political parties?	**Public expenditure** What will be the order of magnit. of public investm. (in infrastruct.) necess. to imple-ment and maintain this tool?	**Environmental effects** What will be the order of magnit. of the environm. effects associated with this tool/ alt.?	**Investment risk** What will be the order of magnit. of the investm. risk associated with this tool/ alternative?	**Liability risk** What will be the order of magnitude of the liabiltity risk associated with this tool/ alternative?	**Technical feasibility** What will be the level of technical feasibility for this tool/ alternative ?
						'+++/++/+' : means driver comfort will be enhanced as compared to present situation	'+++/++/+' : means full user cost will be lower (=better) as compared to present sit.	'+++/++/+' : means driver safety will be enhanced as compared to present sit.	'+++/++/+' : travel time duration will be lower (=better) as compared to present sit.	'+++/++/+' : means network efficiency will be enhanced as compared to present situation	'+++/++/+': means overall safety will be enhanced as compared to present situation.	'+++/++/+' : means socio polit. accept. will be (very) high. '---'/--/-' : it will be (very) low	- - - / - - / -' : means public expenditure will be (very) high.	+++/++/+': means tool will improve envir. '---/--/-': means it will deteriorate environm.	+++/++/+' : means inv. risk will be (very) low. '---/--/-': risk will be (very) high	+++/++/+' : means liab. risk will be (very) low. '---/--/-': risk will be (very) high	+++/++/+' : means techn. feasib. will be (very) high '---/--/-': it will be (very) low
1.1	Too fast in unexpected sharp bends on rural roads	x			Unexpected sharp bends are registered in a digital map of the navigation-system and presented to the driver	+ + +	-	+ + +	0	0	+	++	+ +	+	+ +	-	+ + +
1.2	Too fast in unexpected sharp bends on rural roads		x		vehicle is "analysed" (e.g. speed), VMS signalize the danger of the bend depending on the actual speed	+ + +	0	+ + +	0	0	+	+	-	+	+ +	0	+ + +
1.3	Too fast in unexpected sharp bends on rural roads			x	electron.beacons (spec.reflexion posts) give addit.info on displays in the vehicle about the road,e.g.warning:sharp bend	+ + +	-	+ + +	0	0	+	+ +	-	+	+ +	-	+ + +
2.1	Speeding	x			Speed Alert System functioning by recognition of traffic signs	+ +	-	+ +	-	-	+ +	+ +	+ +	+	+ +	-	+ +
2.2	Speeding		x		Speed Limit is presented to the driver by VMS under consideration of special environmental circumstances	+ + +	-	+ + +	-	-	+ + +	+	-	+	+ +	0	+ + +
2.3	Speeding			x	Speed Alert System based on digital maps containing legal speed limits with addit, info on recommended safe speed	+ +	-	+ +	-	-	+ +	+	+ +	+	+ +	-	+ + +
3.1	Wrong use of road	x			LDWA (Lane Departure Warning Assistant)	+ +	-	+	0	0	+	+ +	+ +	0	+	-	+ + +
3.2	Wrong use of road		x		Audible delineation	+ +	0	+	0	0	+	+ +	- -	0	+	0	+ + +
3.3	Wrong use of road			x	Adaptive LDWA; Sensitivity of LDWA is adapted in special conditions, such as road works, tunnels	+ +	-	+ +	0	0	+	+ +	+	0	+	-	+ + +
4.1	Violation of priority rules	x			Traffic Sign recognition	+ +	- -	+ +	0	0	+ +	+ +	0	0	+	-	++
4.2	Violation of priority rules		x		Traffic signs	0	0	+ +	0	0	+ +	+ + +	-	0	+ +	+	+ + +
4.3	Violation of priority rules			x	Traffic light status information emission to car	+	0	+	0	0	+	+	-	0	-	-	+
5.1	Failure when overtaking	x			Blind spot detection syst. warning driver if a vehicle is approaching from behind	+ + +	-	+ + +	0	0	+ +	+ +	+ +	0	+ +	- - -	+ + +
5.2	Failure when overtaking		x		Separation of lanes by rumble strips where overtaking is forbidden	+	0	+ + +	0	0	+ +	+ +	-	0	+ +	0	+ + +
5.3	Failure when overtaking			x	Cooperative syst. warning of oncoming vehicles by veh.-to-veh. communication	+ +	- -	+ + +	0	0	+ +	+	+ +	0	+ +	- - -	+
6.1	Insufficient safety distance	x			Advanced Cruise Control ACC	+ + +	-	+	0	0	+	+	++	0	+ +	-	+ + +
6.2	Insufficient safety distance		x		Fog detection warning system; VMS warning	+ +	0	+ +	0	0	+	+ +	-	0	+ +	-	+ + +
6.3	Insufficient safety distance			x	ACC set by local (on-site) weather system: "Dynamic ACC"	+ + +	-	+ +	0	0	+	+ +	-	0	+ +	-	+ +

Source : IN-SAFETY consortium partners (BAST, TUDarm, TUDelft and USTUTT)

5. Overall evaluation of the alternatives : deriving priorities

The overall evaluation of alternatives was performed using the MCA methodology, esp. the analytic hierarchy process (AHP) of Saaty (1977, 1986, 1988, and 1995). Applied to the case of FOR alternatives and SER alternatives, the starting base for this exercise is the decision tree (Figure 2). The AHP methodology requires two types of inputs. First, the impact of the alternatives on the criteria should be evaluated and second the relative importance of these criteria for each stakeholder should be known. For both cases the pairwise comparison mechanism of the AHP is used. This is a comparison mechanism whereby the relative importance of one element (the row element) is compared with that of another element (the column element). This is done using a nine point ratio scale (also known as the Saaty scale) as presented in Table 5.

Table 5 : Pairwise comparison scale in the AHP

Intensity of importance $Pg_j(a_i,a_{i'})$	**Definition**	**Explanation**
1	Both elements have equal importance	Both elements contribute equally to the criterion considered
3	Moderately higher importance of row element (RE) as compared to column element (CE)	Experience and judgment reveal a slight preference of row element (RE) over column element (CE)
5	Higher importance of RE as compared to CE	Experience and judgment reveal a strong preference of RE over CE
7	Much higher importance of RE as compared to CE	RE is very strongly favoured over CE, and its dominance has been demonstrated in practice
9	Complete dominance in terms of importance of RE over CE	The evidence favouring RE over CE is of the highest possible order
2, 4, 6, 8 (Intermediate values)		An intermediate position between two assessments
1/2, 1/3, 1/4, ... 1/9 (reciprocals)		When CE is compared with RE, it receives the reciprocal value of the RE/CE comparison
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix
1.1-1.9	For tied activities	RE and CE are nearly indistinguishable; moderate is 1.3 and extreme is 1.9

Source: Saaty (1988, p. 73), adapted by the authors.

5.1 Prioritisation of alternatives in terms of criteria

As regards the first step, prioritisation of alternatives in terms of specific criteria, the evaluation table constructed in section 4 (Table 4) is used as the starting base. The scale used in that table is an ordinal scale, this is a scale expressing the ranking of the alternatives with respect to one another. The concordance between the scores of that table and the ratio inputs that are necessary for the AHP model as described in Table 5 is shown in Table 6. For instance, the value 3 (shaded cell in Table 6) means that the row element (+++) is considered to be three times more preferred than (or to have a 'weak dominance' over) the column element (+). The 'concordance table' (Table 6) was used for all the criteria. The computer program ExpertChoice applied below, made it possible to define such a concordance table only once and then to use it for all the criteria.

Table 6 : Concordance between ordinal scores included in scoring table and preference intensities in pairwise comparison matrices[7]

		very high pos. impact + + +	high. pos. impact + +	moderate pos. impact +	neutral impact O	moderate neg. impact –	high neg. impact – –	very high neg. impact – – –
very high pos. impact	+ + +	1	2	3	5	6	8	9
high. pos. impact	+ +		1	2	3	5	7	8
moderate pos. impact	+			1	2	3	5	7
neutral impact	O				1	2	3	5
moderate neg. impact	–					1	2	3
high neg. impact	– –						1	2
very high neg. impact	– – –							1

Inconsistency ratio : 0.02

Source : designed by the authors

5.2 Deriving weights for the criteria : prioritising the criteria

The next step in the AHP methodology is to derive policy weights for the criteria (shown at level 3 of Figure 2). In order to obtain the inputs necessary for these pairwise comparison matrices, a forum of policy makers and representatives of the users and manufacturers was created. As said before, this forum was organised at the premises of the Intertraffic Conference. For the workshop to elicit weights, the room was rearranged to facilitate a Group Decision Room (GDR) session. A GDR consists of a network of computers running Group Systems software, which enables policy makers participating in the session to express their opinion anonymously, and to be heard without having to draw the attention to themselves. A total of 27 participants actively participated in the GDR session. Table 7 shows the number of participants for each stakeholder group.[8] The participants representing the stakeholder 'society' (this is the middle sub-system in Figure 2) constituted by large the most important group of participants in that GDR session.

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[7] When two extreme ordinal scores are compared (namely '– – –' and '+++'), the value 9 ('absolute dominance') is given. When this difference is rather small (for instance for the comparison between 'O' and '+'), the value 2 is given and for a comparison between for instance 'O' and '++', the value 3 is given. But when ordinal scores of the order '+++' or ('– – –') are compared with the neutral score 'O', the value 5 is given (in stead of 4), since comparisons where the ordinal score '+++' (or '– – –') is involved are really considered to be associated with a large difference. This is the reason why the scores in Table 6 do not follow an arithmetic progression with progression factor 1, why not all values from the pairwise comparison scale (1-9) are included in the table and why there is a very small inconsistency (0,02).

[8] The number of participants, these are the policy makers anonymously interviewed in the GDR, shown in Table 7 can be considered quite high for MCA related surveys. Indeed, inputs into MCA do not need to be based on large surveys as is the case in standard market research. The reason is that in MCA it are the policy makers who are interviewed instead of individual consumers. These policy makers express the points of view of large group of the individual persons (such as users, manufacturers and even the public or society in general) whom they legitimately represent and by whom they were legitimately elected. The representatives of the users represent the interests of car users, the representatives of the manufacturers represent manufacturer interests and the public policy makers (representing societal interests) represent the overall public interest. Hence, it are the latter who pay attention to external effects, such as third party safety effects (these are safety effects for pedestrians and cyclists).

Table 7 GDR session participants

Stakeholder group	Participants
Users	7 car drivers 1 fleet owner 1 other Total: 9
Society / Publ. pol.makers	5 road managers 3 policy makers 1 enforcement 2 other Total: 11
Industry / Manufacturers	3 equipment manufacturers 3 system providers 1 car manufacturer Total: 7
Total	27

Source : designed by the authors

All these stakeholder representatives had to compare the importance of the criteria in pairs, using the pairwise comparison scale presented in Table 5. In order to synthesize the various pairwise comparisons given by each representative, the geometric mean was calculated as proposed by Saaty (1995:265). The geometric mean (and not the arithmetic mean) is the statistical measure that is relevant in this case, since the average of ratios is to be calculated here.[9] Also the spread was calculated using the traditional statistical variables such as mean, mode, highest and lowest score and standard deviation. The final results of all these pairwise comparisons made by each representative of the various stakeholders and synthesised using the GDR software are shown in Table 8, Table 9 and Table 10. Part A of these tables shows the synthesis (the geometric mean) of the various pairwise comparisons and Part B contains the final relative priorities for the criteria (these are the criterion weights) calculated on the basis of these pairwise comparisons.

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[9] The numbers (1-9 and 1/9-1) in Table 5 and Table 6 can also be viewed as ratios, expressing how much more important one element (for instance the row element) is as compared to another element (for instance the column element) in terms of contribution to the higher level element or criterion. When various estimates for this order of magnitude are given (for instance by different experts) and one wants to calculate the average or mean of these estimates in order to neutralise possible estimation errors, then one should calculate the geometric mean instead of the arithmetic mean. The geometric mean is also the relevant statistical measure when for instance growth rates in time series have to be averaged. The geometric mean is obtained by multiplying the ratio scores and then taking the n-th root, whereas the aritmetic mean is calculated by adding all the scores and dividing the overall score by n (n being equal to the number of scores or estimates).

Table 8 Pairwise comparison matrix and relative priorities for the criteria from the point of view of the stakeholder ‘users’

	Part A : Pairwise comparisons				Part B Relat. prior.
stakeholder ‘users’	driver comfort	full user cost	driver safety	travel time duration	
driver comfort	1	1/3	1/5	1/2	0,087
full user cost		1	1	1	0,282
driver safety			1	4	0,452
travel time duration				1	0,179

Inconsistency ratio : 0,06

Source: designed by the authors

Table 9 Pairwise comparison matrix and relative priorities for the criteria from the point of view of the ‘society’

	Part A : Pairwise comparisons					Part B Relat. prior.
stakeholder society/authorities	network efficiency	overall safety	socio-pol. accept.	public expendit.	environm. effects	
network efficiency	1	1/5	2	4	1	0,171
overall safety		1	5	5	3	0,509
socio-pol. accept.			1	1	1/2	0,082
public expenditure				1	1/3	0,068
environm. effects					1	0,170

Inconsistency ratio: 0,04

Source: designed by the authors

Table 10 Pairwise comparison matrix and relative priorities for the criteria from the point of view of the ‘manufacturers’

	Part A : Pairwise comparisons			Part B Relat. prior.
stakeholder society/authorities	investment risk	liability risk	technical feasibility	
investment risk	1	1/2	2	0,276
liability risk		1	5	0,595
technical feasibility			1	0,128

Inconsistency ratio: 0,01

Source: designed by the authors

Table 8, Table 9 and Table 10 represent the relative priorities of the criteria, these are the priorities in terms of the overall objective of one specific stakeholder, resp. ‘users’, ‘society/public policy makers’ and ‘manufacturers’.[10] The users gave the highest weight to

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[10] These relative priorities or weights were calculated on the basis of the eigenvector method ($A.W=\lambda_{max}.W$), whereby the vector of the weights (W) is given as the right eigenvector corresponding to the highest eigenvalue (λ_{max}). The matrix of the pairwise comparisons (shown in Table 8, Table 9 and Table 10, Part A) corresponds to the matrix A. The vector W (shown in Part B of the same tables) was calculated using the computer program ExpertChoice. The same computer program makes it possible to calculate the consistency

the criterion ‘driver safety’ (45,2%), followed by ‘full user cost’ (17,9%). They gave less weight to ‘travel time duration’ (17,9%) and still less to ‘driver comfort’ (8,7%). Manufacturers gave the highest weight to the criterion ‘liability risk’ (59,5%), then ‘investment risk’ (27,6%) and technical feasibility received a much lower priority (12,8%). From the societal point of view (this is from a public policy point of view), the criterion ‘overall safety’ turned out to be the most important criterion (50,9%). This is quite in line with the expectations, since improving traffic safety is considered a very important policy objective in EU transport policy. The criteria ‘network efficiency’ and ‘environmental effects’ received a lower weight, but are nearly ex aequo (resp. 17,1% and 17,0%). ‘Socio-political acceptance’ and ‘public expenditure’, received the lowest weight (resp. 8,2% and 6,8%).

5.3 Deriving overall relative priorities for the alternatives from each stakeholder’s point of view

The last step in the overall evaluation phase consists of deriving overall relative priorities for the alternatives in terms of each stakeholder’s point of view. These final relative priorities indicate the degree to which the alternatives contribute to the overall objective or focus of that specific stakeholder.

It should be noted, however, that the stakeholder ‘society/public policy makers’ is in fact not a stakeholder sensu stricto, since that stakeholder represents the societal point of view. The two other stakeholders, namely the ‘users’ and the ‘manufacturers’ are indeed stakeholders sensu stricto, since they reflect the objectives of only one specific group of people in society. The overall relative priorities in terms of the society’s point of view (middle part in Figure 2), therefore, correspond to the policy point of view. These are the overall relative priorities that should be taken as a starting base for policy purposes. The overall relative priorities for the two other stakeholders, users and manufacturers (the demand, respectively the supply side of the market), are indeed also very relevant, esp. for implementation issues, since these priorities make it possible to test to which extent the policy-based ranking of alternatives is sustained by these stakeholders. This is indeed the essence of the stakeholder oriented MCA methods (multi-actor/multi-stakeholder MCA). The success of the implementation of specific alternatives strongly supporting public policy as regards road safety, indeed largely depends on the degree to which the stakeholders (these are the ‘players of the game’) find these alternatives good or acceptable to them. If this is the case, then the public policy objective will be facilitated by the actions taken by the other stakeholders and it will be easier for public policy makers to have their policies implemented. It should indeed once again be clear now that MCA is a tool for public policy making building upon active stakeholder management. The overall relative priorities of the users correspond with the user needs, and may therefore indicate the user acceptance of alternatives. The overall relative priorities of the manufacturers correspond with the market potential of the alternatives, meaning that if priorities correspond to those of society the respective alternatives can be realized by the market, and if not, government regulation may be needed. Some bias enters in the prioritization for manufacturers through the fact that some manufacturers are either involved in infrastructure alternatives or in vehicle alternatives. The overall or global relative priorities of the various alternatives for each stakeholder are presented in Figure 3, Figure 4 and Figure 5.

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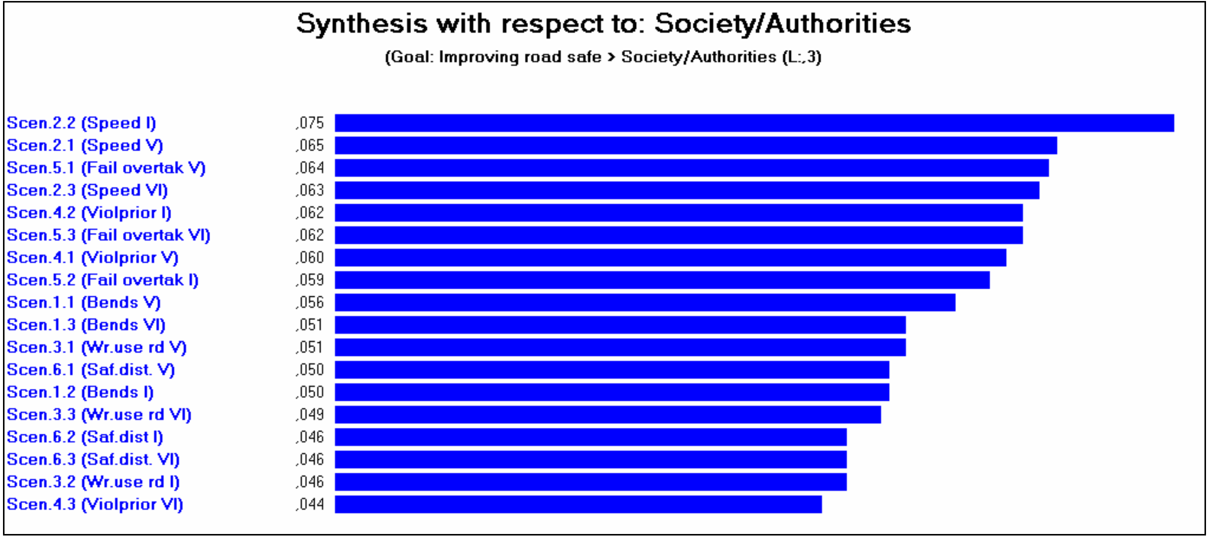
ratio for all the pairwise comparisons in a matrix. This ratio, which is shown at the bottom of each pairwise comparison table, should be less than 0,10 (10%) (Saaty, 1995:81-85).

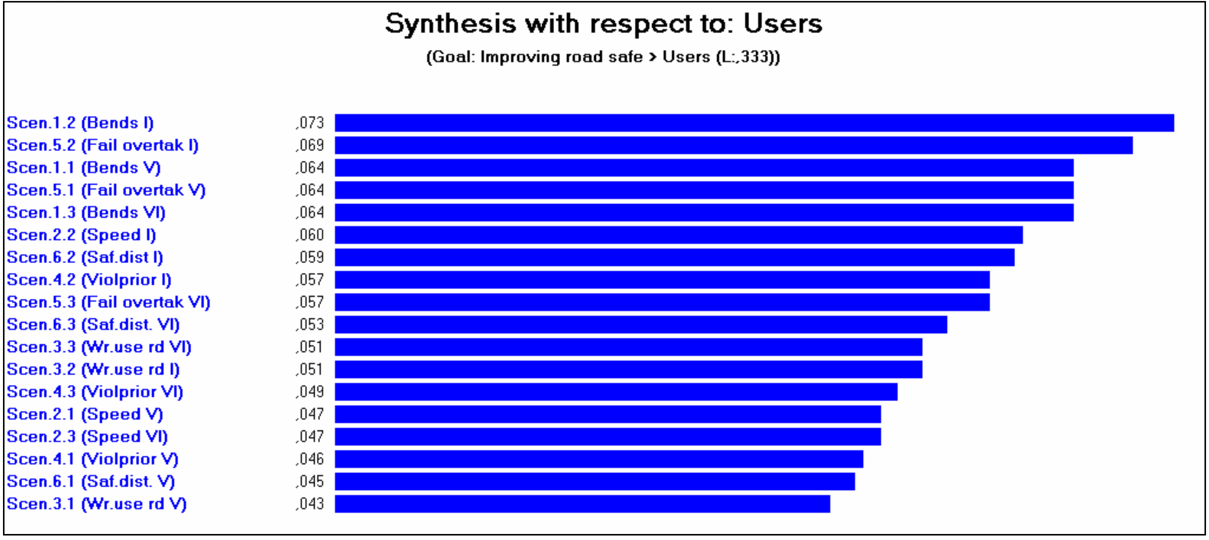
Figure 3 : Global priorities of alternatives from the point of view of the stakeholder 'society/public policy makers'



Source : own computation, using ExpertChoice

From the societal point of view, alternatives focused on speeding (for instance speed limit presented to the driver by variable message signs (VMS), speed alert system by recognition of traffic signs, etc.) are considered the most desirable. Speeding related alternatives, as is shown in Figure 4 and Figure 5, are, however, not considered desirable from the point of view of the manufacturers or users. When the three alternatives regarding speeding are compared with each other, it turns out that, both from a users' and a manufacturers' point of view, the autonomous infrastructure alternative (for instance speed limit presented to the driver by VMS) is less undesirable than the autonomous in-vehicle alternative (for instance speed alert system by recognition of traffic signs), or the cooperative alternative (for instance speed alert system based on digital maps containing legal speed limits with additional info on recommended safe speed).

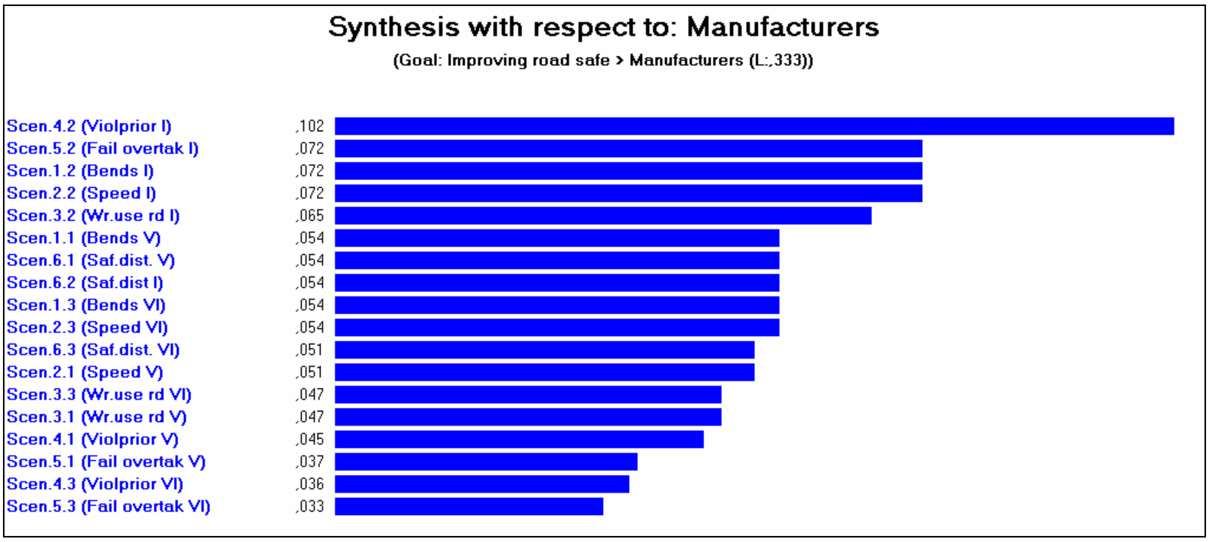
Figure 4 : Global priorities of alternatives from the point of view of the stakeholder 'users'



Source : own computation, using ExpertChoice

Users most often rank the vehicle related alternatives (for instance advanced cruise control, lane departure warning assistant) at the bottom (with the exception of alternatives regarding bends and failure while overtaking). To a large extent, this is caused by the costs accruing to the user, and also to the relatively smaller effects on driver safety, as these are the most important criteria for the user.

Figure 5 : Global priorities of alternatives from the point of view of the stakeholder 'manufacturers'



Source : own computation, using ExpertChoice

Manufacturers consider the autonomous, infrastructure based alternatives (for instance traffic signs, separation of lanes by rumble strips where overtaking is forbidden, VMS signaling the danger of the bend depending on actual speed and type of vehicle approaching, audible delineation) to be the most desirable, not only with regards to the speeding related alternatives, but regarding all alternatives. This is mainly caused by the liability problems involved in vehicle alternatives, which is the most important criterion for the manufacturers. However, not all alternatives belong to the feasible set of alternatives for each type of manufacturer: vehicle system suppliers are not directly involved in infrastructure alternatives and vice versa. This should be taken into account when judging the results of the prioritization.

5.4 Comparison of stakeholder priorities

Table 11 shows the top five priority alternatives of the society compared to the priorities the other two stakeholder groups have with respect to these alternatives. VMS speed warning and priority traffic signs are also relatively high prioritized by both the users and the manufacturers, which would mean that these alternatives are likely to be accepted by these stakeholders. Speed alert by signal recognition and speed alert by digital map are less high prioritized by both other stakeholders, meaning that government actions (for instance regulations) may be necessary to implement these systems. Blind spot detection is high prioritized by the users as well, but not by the manufacturers. The main barrier for the manufacturers is the liability risk of this system.

Table 11 : Top 5 priorities of society compared to other stakeholders

Society	Alternative	User	Manufacturer
1	VMS speed warning	6	4
2	Speed alert by signal recognition	14	12
3	Blind spot detection	4	16
4	Speed alert by digital map	15	10
5	Priority traffic signs	8	1

Source : own computation, using ExpertChoice

The priorities of society in Table 11 show the possibilities for government policy on implementation of safety systems. Safety systems may also be introduced autonomously by the market. The systems that may have market potential are those that satisfy both user and manufacturers objectives, which represent the demand, respectively the supply side of the market. In Table 12, therefore, the priority alternatives of the users are compared with those of the manufacturers. The user is chosen as a starting point here (only for this type of comparison), as user demand is a major market driver. We do comment that VMS sharp bend warning and rumble strips for overtaking are infrastructure alternatives and cannot be decided for by the market, because the user has no decision power for implementation. For beacon transmitting sharp bend warning it could even be more complex. Digital map sharp bend warning may have market potential, and blind spot detection as well, presuming that the liability problems may be solved.

Table 12 : Top 5 priorities of user compared to manufacturers

User	Alternative	Manufacturer
1	VMS sharp bend warning	3
2	Rumble strips for overtaking	2
3	Digital map sharp bend warning	6
4	Blind spot detection	16
5	Beacon transmitting sharp bend warning	9

Source : own computation, using ExpertChoice

6. Conclusion

A multi-actor, multi-criteria analysis (MCA), based on the analytic hierarchy process (AHP) of Saaty was performed in this paper in order to obtain a selection and a ranking of alternatives or tools that can potentially contribute to increasing road safety by creating a more forgiving road (FOR) or more self-explaining road (SER) environment. The multi-actor MCA (MAMCA) was thus used as a policy instrument here, since it allows to assess to which extent the various FOR and SER environments developed in this paper contribute to an important objective in EU road transport policy, namely the improvement of road safety. The selection/prioritization performed through the application of this policy instrument allows various stakeholders with an interest in improving the present state of FOR and SER environments (especially policy makers representing the overall or societal point of view) to understand which types of future states command the highest expected ‘value added’ from the community of stakeholders in its entirety, thereby uncovering information on the probability of successful implementation and its contribution to one of the major objectives in EU road transport policy, namely the improvement of road safety. The MCA as applied here can be seen as an ‘institution in action’ capable of resolving conflicts between stakeholder interests and therefore contributing to the successful implementation of the innovative systems described in this paper. The MCA, as applied in this paper, can be associated to what is called the ‘rules of the game’ (to be set be public policy makers) in institutional economics and the stakeholders to the ‘players of the game’.

The multi-stakeholder or multi-actor multi-criteria analysis (MAMCA) applied in this paper revealed that there are substantial differences in the rankings of alternatives depending on the point of view of the stakeholder groups ‘society/public policy makers’, ‘users’ and ‘manufacturers’. From societal point of view, alternatives based on speeding receive the highest priority, but this is not true from a users or a manufacturers point of view. Manufacturers generally prefer autonomous infrastructure based alternatives, in stead of autonomous in-vehicle or cooperative systems, because of liability issues. Liability risk is indeed considered an important barrier to market penetration by manufacturers. Users most often give low priority to vehicle-related alternatives because of the high user cost and the relatively small effect on driver safety, which are important criteria for users.

The scope of the multi-actor multi-criteria-analysis (MAMCA) performed here was to firstly focus on the society’s priorities, especially in terms of overall safety in order to contribute to the entire society’s interests, rather than those of only one party or stakeholder. The interests of the two remaining stakeholders (users and manufacturers) are, however, also considered relevant information for public policy making, since the implementation of policy decisions by public policy makers will be much easier when the priorities of the public policy makers concord or coincide with these of the other main stakeholders, namely users and manufacturers. Stakeholder interests are considered an instrument either facilitating or obstructing public policy. Indeed, users’ comfort was also considered important in this study, since the users represent the demand side of the market, they are the consumers, and must be willing to pay. Such willingness to pay is critical to the manufacturers’ investment risks. Manufacturers’ objectives (this is the supply side of the market) are also considered important, but in this reasoning a third priority. The final conclusion of this paper is that the following generic alternatives merit further study in order to be implemented on the market : (1) *infrastructure based alternatives addressing the problem of speeding*, (2) *in-vehicle based alternatives addressing the problem of speeding* (3) *in-vehicle based alternatives aimed at reducing failures when overtaking*, (4) *infrastructure-based alternatives addressing the problem of unexpected sharp bends*, (5) *infrastructure based alternatives aimed at reducing failures when overtaking and* (6) *in-vehicle based alternatives addressing the problem of unexpected sharp bends*. These generic alternatives should be further developed and tested, since both their contribution to the main policy objective (this is improving road safety), as well as their implementation potential has been proven to be high, taking into account the preferences of the main stakeholders, namely (1) society (represented by public policy makers) which was considered the most important element in the decision structure, and then (2) users and (3) manufacturers.

APPENDIX 1

GENERIC OVERVIEW OF THE METHODOLOGY OF MULTI-CRITERIA ANALYSIS (MCA) (ANALYTIC HIERARCHY PROCESS - AHP) USED FOR ALTERNATIVE SELECTION/ PRIORITISATION

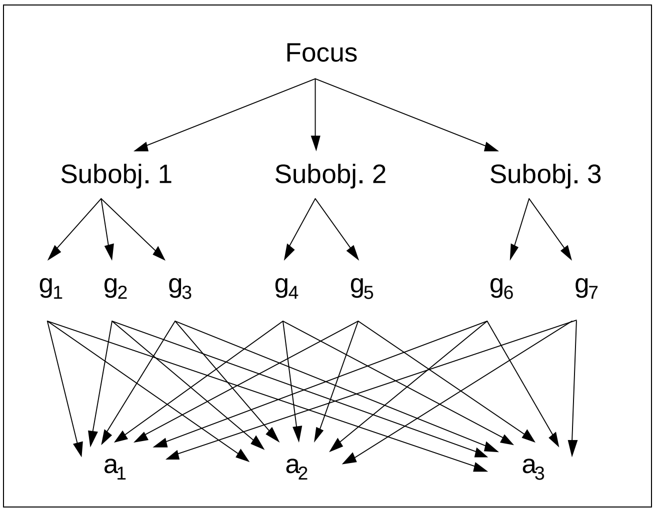
The process-related steps to be followed in an MCA were discussed in the main text and visualised in Figure 1 (in the main text). The steps 1, 2, 3 and 4, as well as step 6 were discussed quite well in detail there. As regards step 5, reference was made to the analytic hierarchy process (AHP) of Saaty. In this short Appendix, some more details will be given about this fifth step in the MCA and the application of the AHP in particular.

The fifth step is the step in which the information in the evaluation matrix (Table 4 in main text) needs to be aggregated. The information represented in that matrix seldom makes it possible to select one alternative in an unambiguous fashion. In most cases, the scores obtained by the alternatives on the various criteria (partial evaluations) are conflicting, which means that they do not unanimously point to a single ‘best’ alternative, which would be superior in terms of all criteria. An aggregation method is, therefore, needed in most cases to synthesize the conflicting information. Each aggregation method relies on specific assumptions regarding the comparability of the partial evaluations and the relations between criteria. In most cases, criteria should be given explicit weights by policy makers. Here, analysts can introduce an interactive tool (such as the pairwise comparison mechanism of the AHP) to help policy makers when reflecting on relative weights, but ultimately it is the decision makers themselves who must give the policy weights. Within each aggregation method, several MCA approaches can be used to aggregate the partial evaluations.

High quality overviews of a number of MCA methods are provided in Belton and Stewart (2002) and Figueira et al. (2005) (both in English) or De Brucker et al. (1998) (in Dutch). The AHP method of Saaty (1977, 1986, 1988, 1995) is one of these methods. It has has been used in a wide variety of policy applications, including other EU funded research projects, such as for instance the ADVISORS project (De Brucker et al., 2002; Macharis et al., 2004 and Macharis et al., 2006). The AHP method is based on three principles: (1) construction of a hierarchy, (2) priority setting and (3) logical consistency.

A hierarchy (as shown in Figure 6 for a generic case) is a complex system in which the constituent parts are hierarchically structured. The top of the hierarchy consists of a single element, which represents the overall policy objective or focus. The intermediate levels represent sub-objectives and their constituent parts (if possible, measured by operational criteria, these are $g_1 \ldots g_7$ in Figure 6). The lowest level consists of the final actions or alternatives considered. The arrows represent causal relationships within the hierarchy. Hierarchies can be constructed top-down or bottom-up.

Figure 6 : Example of a hierarchy in the AHP



Source: designed by the authors, based on Saaty (1995)

The relative priorities given to each element in the hierarchy are determined by comparing all the elements at a lower level in pairs, in terms of contribution to the elements at a higher level with which a causal relationship exists, as illustrated in Table 13 for a generic case.

Table 13 Pairwise comparison matrix in the AHP

g_j	a_1	…	…	$a_{i'}$	…	a_n
a_1	1					
…		[1]				
a_i			[1]	$Pg_j(a_i,a_{i'})$		
…				[1]		
…					[1]	
a_n						1

Source: designed by the authors, based on Saaty (1995)

$Pg_j(a_i,a_{i'})$ represents the preference intensity for a specific pair of (sub-)objectives (a_i, $a_{i'}$) in terms of the higher level element (objective or criteria [g_j]) with which a causal relationship exists. This preference intensity is measured on a scale from 1 to 9 (and from 1/9 to 1) as Presented in Table 5 (main text). A similar approach is followed for the constituent components within each objective and sub-objective (criterion).

Within each sub-system of the hierarchy, the relative priorities of the elements are determined through the pairwise comparison mechanism described above. The relative priorities (weights) are given by the right eigenvector (W) corresponding to the highest eigenvalue (λ_{max}) as shown in formula 1. The pairwise comparison matrix is represented by the letter A. Its standard element is $Pg_j(a_i,a_{i'})$.

$$A.W = \lambda_{\max}.W \qquad (1)$$

Since in each pairwise comparison matrix, a number of pairwise comparisons are redundant, it is possible to neutralize possible estimation errors that may have occurred in the other pairwise comparisons of the same matrix on the one hand and to obtain a measure of consistency for the pairwise comparisons of the same matrix on the other hand.

In order to synthesize all local priorities (these are the relative priorities in terms of a sub-system or one specific matrix), the various priority vectors are weighted by the global priorities of the parent criteria and synthesized. One starts this process at the top of the hierarchy. By doing so, the final or global relative priorities for the lowest level elements (these are the actions or alternatives) are obtained. These final relative priorities indicate the degree to which the alternatives contribute to the overall policy objective or focus. These global priorities form a synthesis of the local priorities, and thereby integrate the various inputs into the decision-making process. In addition, one may as well perform a partial analysis (and synthesis) by doing the pairwise comparisons only from one specific point of view, this means taking into account only one sub-objective (or one stakeholder's point of view) (for instance sub-objective 1 in Figure 6). In the specific case described in the main text, such (partial) evaluations were performed for the three stakeholders, namely 'users', 'society' and 'manufacturers'. The priorities in terms of society were considered to represent the overall societal point of view and the priorities of the other stakeholders were calculated only to investigate to which extent these were concordant or not with the societal priorities. The priorities of the other stakeholders were therefore not integrated into an overall priority expressed in terms of contribution to the focus (at level 1 of the hierarchy shown in Figure 2 in the main text).

The AHP is a powerful decision-making tool. This method makes it possible to decompose decision-making problems into their constituent parts. According to a carefully designed decision-making process, a decision is constructed step by step, by making pairwise comparisons. This step-by-step process eventually results in a synthesis in the form of overall or global relative priorities for the final alternative. In spite of the very structured process, there is ample room for learning, creativity and interactions among the analyst, the decision maker and the stakeholders.

The AHP makes it possible create 'ordered complexity' in the decision-making process. Indeed, most policy problems are complex, since they often involve multiple objectives from multiple stakeholders, with some objectives related to effects that cannot be accurately quantified or monetised. Explicitly accounting for these multiple objectives and related effects and weighing their relative importance using the pairwise comparison mechanism makes it possible to achieve 'agreed upon subjectivity' or 'subjectivity made objective' in these policy processes.

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