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Effectiveness of road safety measures at junctions

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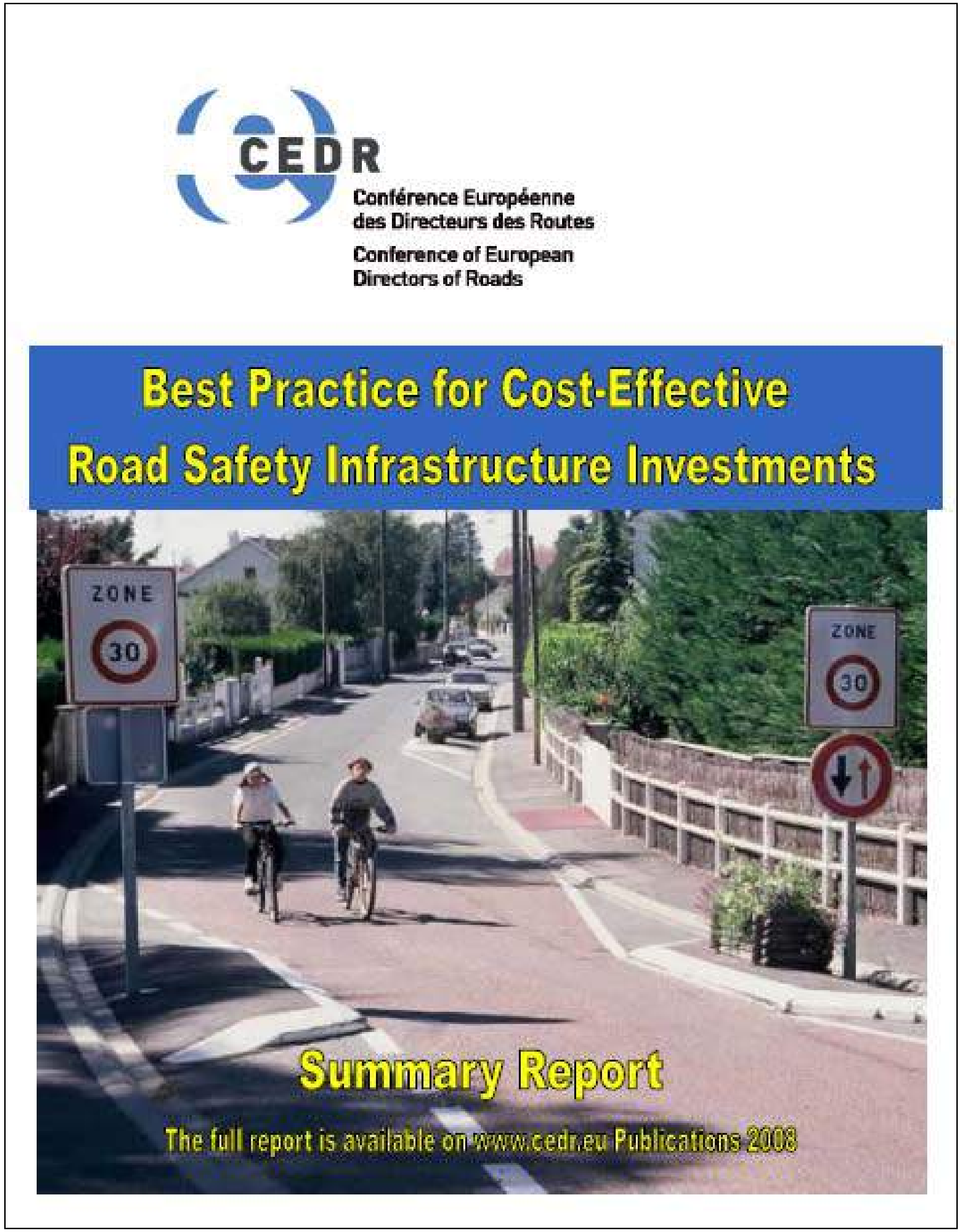
THE NEED FOR THE ASSESSMENT OF ROAD SAFETY MEASURES

Road Safety is a typical field

with high risk of important investments not bringing results

SCOPE

This research is part of
an NTUA research project
carried out for the
European Conference of
Road Directors (CEDR)
aiming to develop best practices
on cost-effective
road safety infrastructure investments.



OBJECTIVE

To provide Decision Makers a Best Practice Guide to assist them in their strategic initial choices for infrastructure related measures aiming to improve road safety, through:

- gathering available information in an exhaustive literature review,
- organizing & comparing existing experience based on the measures effectiveness,
- identifying and analysing the most promising sets of measures,
- suggesting the conditions for the optimum implementation of the selected measures.

This Best Practice Guide does not replace in any way the subsequent necessary specific studies for the selection, design and implementation of the measures which are suitable for each specific case.

METHODOLOGY

1. INTRODUCTION

2. ABOUT COST EFFECTIVENESS ASSESSMENT OF ROAD SAFETY INVESTMENTS

3. REVIEW OF ROAD SAFETY INVESTMENTS

4. SELECTION OF MOST PROMISING INVESTMENTS

5. IN-DEPTH ANALYSIS OF MOST PROMISING ROAD SAFETY INVESTMENTS

6. PROPOSAL OF BEST PRACTICES

REFERENCES

MEASURES ASSESSMENT - A COMPLEX TASK

Economic appraisal: important tool in the hands of decision makers but also a complex issue:

- difficulties in isolating the safety effect of a specific measure;

- difficulties in aggregating information/data due to high diversification of the measures;

- difficulties in comparing information/data among countries:
  - differences in road traffic environments
  - differences in the actual measure costs among the countries
  - differences in methodologies of safety effect calculation

EFFICIENCY ASSESSMENT METHODOLOGIES

- **Cost-effectiveness** analysis:

$$\text{Cost - effectiveness} = \frac{\text{Number of accidents prevented by a given measure}}{\text{Unit costs of implementation of measure}}$$

- **Cost-benefit** analysis:

$$\text{Benefit - cost ratio} = \frac{\text{Present value of all benefits}}{\text{Present value of implementation costs}}$$

Safety Effect:

- Expected **reduction in target accidents/casualties** following the implementation of a treatment, given in the form of a percentage.
- Estimation of the safety effect: "**Before-after studies**"

MEASURES SELECTION CRITERIA

1. Measures that are **mainly related to road infrastructure**.
2. Measures which are **common among EU countries** and **frequently implemented**.
3. Balance between measures of different **size, implementation cost and scale of implementation**.
4. Measures must be **comprehensive and concise**. A complete description of the basic components for the efficiency assessment of the measure should be available.
5. Measures for which adequate information was **impossible or very difficult to be obtained** are not retained, independently of their ad-hoc implementation and assessment in specific cases.

REFERENCE DOCUMENTS

- CEDR Reports of Roads (*Most Effective Short-, Medium- and Lon-Term Measures to Improve Safety on European Roads*).
- European and National projects (ROSEBUD, PROMISING, VESIPO, etc.).
- Key publications:
  - R.Elvik, T.Vaa - The Handbook of Road Safety Measures,
  - PIARC - Road Safety Manual,
  - NHTSA - Highway Safety Manual
- An important number of scientific papers, Reports and national studies

INFRASTRUCTURE CATEGORIES & MEASURE AREAS

Motorways:
- Development of motorways
- Interchanges

Rural roads:
- Horizontal Curvature treatment (various individual measures)
- Cross-section treatment (various individual measures)
- Roadside treatment (various individual measures)
- Traffic Control and Operational Elements (various individual measures)
- E-Safety systems
- Road surface treatment (various individual measures)
- Lighting treatment
- Rail / road crossings treatment

Junctions:
- Roundabouts
- Junctions layout (various treatments)
- Traffic control at junctions (various individual measures)

Urban areas:
- Urban traffic calming schemes
- Bypasses
- Improvement of land use rules

INFRASTRUCTURE CATEGORIES & MEASURE AREAS

- A complete list of 56 examined road safety measures
- Classified according to 15 measure areas, into 4 groups (motorways, rural roads, junctions, urban areas).
- Applied on simple road sections, on bend sections and on junctions, but also in more than one infrastructure elements.

Preliminary review of each road safety measure:

- Description of the measure
- Safety effect of the measure
- Other effects (mobility, environmental etc.)
- Measures costs
- CEA/CBA results

PRELIMINARY SELECTION OF MOST PROMISING MEASURES

Implementation costs		Safety effect: High	Safety effect: Low
Implementation costs	Low	Implementation of guardrails Replacing guardrails with softer ones Changing from unrestricted speed to speed limit Reducing speed limit Creation of speed transition zones Traffic signs (regulatory) Traffic signs (warning) Rumble-strips Implementation of artificial lighting Improving existing lighting Protection of rail/road level crossings Junctions channelization Implementation of stop signs Improvement of existing traffic lights Traffic calming schemes Improvement of land use rules	Traffic signs (guide) Traffic signs (warning) Delineators and road markings Raised road markers Chevrons Post-mounted delineators Navigation routing Implementation of yield signs
Implementation costs	High	Development of motorways Development of interchanges Increasing curve radii Introduction of transition curves Superelevation treatment Reducing gradient Improvement of sight distances Increasing lane width Introduction of shoulder Increasing shoulder width Introduction of median Increasing median width Flattening side-slopes Establishment of clear zones Creation of speed transition zones Weather info VMS Congestion info VMS Individual info VMS Ordinary re-surfacing Improving friction Implementation of artificial lighting Introduction of rail/road grade crossings Development of roundabouts Junctions staggering Junctions re-alignment Implementation of traffic lights Traffic calming schemes Development of bypasses Improvement of land use rules	Reducing the frequency of curves (horizontal) Reducing the frequency of curves (vertical) Superelevation treatment Increasing the number of lanes Development of 2+1 roads Increasing median width Individual info VMS Improving road surface evenness Improving road surface brightness Junctions re-alignment

PRELIMINARY SELECTION OF MOST PROMISING MEASURES

- Measure areas and individual measures with **high safety effect** and **low implementation cost** are the most interesting.

- **High cost/high safety effect** measures are also considered, due to increased safety effect.

- **Low cost/low safety effects** measures are only exceptionally considered in specific cases (i.e. minor and local road safety issues).

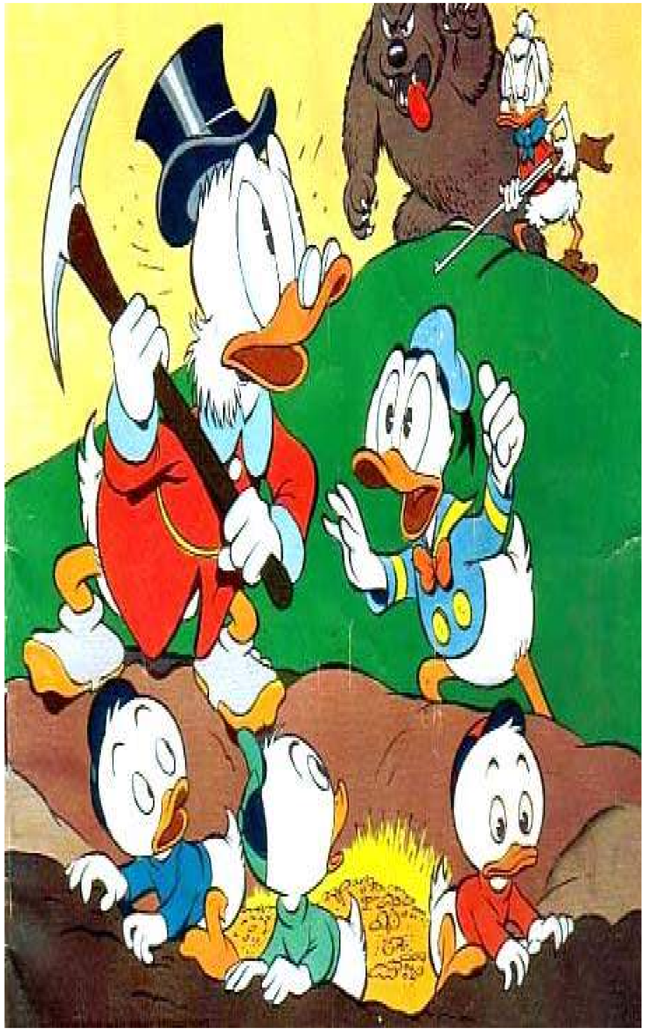
- **High cost/low safety effect** measures should only be considered under certain circumstances.

MOST PROMISING MEASURES FOR FURTHER ANALYSIS

- **Roadside treatments**
  (clear zones, guardrails)
- **Speed limits**
- **Junction layout**
  (roundabouts, re-alignment, staggering, channelization)
- **Traffic control at junctions**
  (traffic signs, traffic signals)
- **Traffic calming schemes**
- **Lighting treatments**

METHODOLOGY FOR IDENTIFYING BEST PRACTICES

- In-depth quantitative analysis of most promising measures:
  - only statistically significant results
  - specific figures



- **Description**
- **Safety effects**
- **Implementation costs**
- **Other effects**
- **Benefit / cost ratio**
- **Strengths and weaknesses**
- **Implementation barriers**

A total of 166 cases were examined.

REFERENCE CASES
FOR MOST PROMISING MEASURES

	Total References	CEDR Questionnaire
Roadside Treatment	24	7
Speed Limits	31	-
Junctions Layout	60	20
Traffic Control at Junctions	26	7
Traffic Calming Schemes	14	2
Lighting Treatment	11	-
Total	166	36

JUNCTION LAYOUT - MEASURES

- **Converting junctions to roundabouts**

- **Re-designing junctions**
  - changing the junction angle
  - reducing gradients on approach
  - increasing sight triangles

- **Staggered junctions**

- **Junctions channelization**
  - introducing left- or right-turn lanes
  - painted or physical channelization
  - partial or full channelization

JUNCTION LAYOUT - SAFETY EFFECTS (1/2)

Source	Measure				Changing from	To	Country / Region	Road network		Number of sites	Year	Evaluation period	Evaluation method			Safety effect (%)				
	Roundabouts	Re-designing junctions	Staggered junctions	Channelization				Rural	Urban / residential				meta-analysis	before/after (control group)	statistical model	Best estimate	95% conf.int.	all accidents	fatalities	injury accidents
Elvik and Vaa, 2004	●				4-leg, stop controlled	roundabout	-	-	-	-	-	-	●			-41	(-47;-34)			●
Elvik and Vaa, 2004	●				T-junction, stop controlled	roundabout	-	-	-	-	-	-	●			-31	(-45; -14)			●
Elvik and Vaa, 2004	●				4-leg, signalized	roundabout	-	-	-	-	-	-	●			-17	(-22;11)			●
Elvik and Vaa, 2004	●				T-junction, signalized	roundabout	-	-	-	-	-	-	●			-11	(-40;+32)			●
Hyden and Varhelyi, 2000	●				various	roundabout	Vaxjo, Sweden		●	2	1991	5 years later		●		-50	s.s			●
Hyden and Varhelyi, 2000	●				various	roundabout	Vaxjo, Sweden		●	21	1991	6 months later		●		-44	s.s			●
Persaud et al. 2001	●				Single lane, stop controlled	roundabout	USA		●	8	1992-1997	15 months later			●	-88	s.s			●
Persaud et al. 2001	●				Single lane, stop controlled	roundabout	USA	●		5	1992-1997	15 months later			●	-82	s.s			●
Persaud et al. 2001	●				Signalized	roundabout	USA	●		4	1992-1997	15 months later			●	-74	s.s			●
Persaud et al. 2001	●				Single lane, stop controlled	roundabout	USA		●	8	1992-1997	15 months later			●	-72	s.s	●		
Persaud et al. 2001	●				Single lane, stop controlled	roundabout	USA	●		5	1992-1997	15 months later			●	-58	s.s	●		
Persaud et al. 2001	●				Signalized	roundabout	USA	●		4	1992-1997	15 months later			●	-35	s.s	●		
CEDR (Questionnaire 2)	●				various	roundabout	Ireland	-	-	5	-	-				-100			●	
CEDR (Questionnaire 2)	●				various	roundabout	France	-	-	41						-83			●	
CEDR (Questionnaire 2)	●				various	mini-roundabout	UK	-	-	6	-	-				-71		●		
CEDR (Questionnaire 2)	●				various	roundabout	France	-	-	41						-71		●		
CEDR (Questionnaire 2)	●				various	roundabout	Netherlands	-	-	-	-	-				-55		●		
CEDR (Questionnaire 2)	●				various	roundabout	South Belgium	-	-	122	-	-				-32			●	
CEDR (Questionnaire 2)	●				various	roundabout	South Belgium	-	-	122	-	-				-23		●		
CEDR (Questionnaire 2)	●				various	roundabout	Ireland	-	-	5	-	-				-9		●		
CEDR (Questionnaire 2)		●			various	general transformation	Spain	-	-	-	-	-				-100			●	
CEDR (Questionnaire 2)		●			various	general transformation	France, Loire Atlantique	-	-	57	-	-				-89			●	
CEDR (Questionnaire 2)		●			various	general transformation	France, Loire Atlantique	-	-	57	-	-				-74		●		
CEDR (Questionnaire 2)		●			various	general transformation	Spain	-	-	-	-	-				-70		●		
CEDR (Questionnaire 2)		●			uncontrolled junction	Improvement of secondary branches	UK	-	-	14	-	-				-69		●		
CEDR (Questionnaire 2)		●		●	various	signs, revised layout, left-turn lane, increased sight triangles	Ireland	-	-	118	-	-				-54			●	
Elvik and Vaa, 2004		●			Angle 90 degrees	Angle >90 degrees	-	-	-	-	-	-	●			-50	(-70;-20)			●
Elvik and Vaa, 2004		●			4-leg junction	Increased sight triangles	Nordic counties and USA	-	-	-	-	-	●			-48	n/a			●
Elvik and Vaa, 2004		●			-	Reduced gradient on approach	-	-	-	-	-	-	●			-17	(-30;-3)			●
Elvik and Vaa, 2004		●			-	Increased sight triangles	Nordic countries	-	-	-	-	-	●			-3	(-18;+14)			●
Elvik and Vaa, 2004		●			t-junction	Increased sight triangles	Nordic counties and USA	-	-	-	-	-	●			+29	n/a			●
Elvik and Vaa, 2004		●			Angle <90 degrees	Angle 90 degrees	-	-	-	-	-	-	●			+80	(+20;+170)			●
Highway Safety Manual, 2005*		●			-	Increased sight triangles	UK	-	-	11	-	-				-73				
CEDR (Questionnaire 2)			●		4-leg junction, heavy minor road traffic	two t-junctions	Nordic counties and USA	-	-	-	-	-	●			-33	(-43;-21)			●
Elvik and Vaa, 2004			●		4-leg junction, signalized, heavy minor road traffic	two t-junctions	California, USA		●	45	-	7 years			●	-25	s.s			●
Elvik and Vaa, 2004			●		4-leg junction, low minor road traffic	two t-junctions	Nordic counties and USA	-	-	-	-	-	●			+35	(+10;+70)			●

JUNCTION LAYOUT - SAFETY EFFECTS (2/2)

Source	Measure				Changing from	To	Country / Region	Road network		Number of sites	Year	Evaluation period	Evaluation method			Safety effect (%)				
	Roundabouts	Re-designing junctions	Staggered junctions	Channelization				Rural	Urban / residential				meta-analysis	before/after (control group)	statistical model	Best estimate	95% conf.int.	all accidents	fatalities	injury accidents
Bared and Kaisar, 2001				●	T-junction	plus painted left-turn lane	Nordic counties, UK and USA	-	-	-	-	-	●			-22	(-45;+11)			●
Elvik and Vaa, 2004				●	4-leg junction	plus painted full channelization	Nordic counties, UK and USA	-	-	-	-	-	●			-57	(-68;-42)			●
Elvik and Vaa, 2004				●	T-junction, stop controlled	plus painted left-turn lane	USA	●		280	-	9-13 years		●		-44	s.s	●		
Elvik and Vaa, 2004				●	T-junction	plus physical left-turn lane	Nordic counties, UK and USA	-	-	-	-	-	●			-27	(-48;-3)			●
Elvik and Vaa, 2004				●	4-leg junction	plus physical full channelization	Nordic counties, UK and USA	-	-	-	-	-	●			-27	(-37;-15)			●
Elvik and Vaa, 2004				●	T-junction, signalized	plus painted left-turn lane	USA	●		280	-	9-13 years		●		-15	s.s	●		
Elvik and Vaa, 2004				●	4-leg junction	plus physical right-turn lane	Nordic counties, UK and USA	-	-	-	-	-	●			-13	(-83;+348)			●
Elvik and Vaa, 2004				●	4-leg junction	plus physical left-turn lane	Nordic counties, UK and USA	-	-	-	-	-	●			-4	(-25;+22)			●
Elvik and Vaa, 2004				●	T-junction	plus physical right-turn lane	Nordic counties, UK and USA	-	-	-	-	-	●			-2	(-50;+90)			●
Elvik and Vaa, 2004				●	T-junction	plus physical full channelization	Nordic counties, UK and USA	-	-	-	-	-	●			+16	(0;+36)			●
Elvik and Vaa, 2004				●	4-leg junction	plus painted left-turn lane	Nordic counties, UK and USA	-	-	-	-	-	●			+28	(-14;+92			●
CEDR (Questionnaire 2)				●		plus left-turn lane	UK	-	-	22	-	-				-68		●		
CEDR (Questionnaire 2)				●		plus left-turn lane	France	-	-	27	-	-				+60			●	
CEDR (Questionnaire 2)				●		plus left-turn lane	France	-	-	27	-	-				-26		●		
CEDR (Questionnaire 2)				●		plus left-turn lane	Netherlands	-	-	-	-	-				-20		●		
CEDR (Questionnaire 2)				●		plus right-turn lane	Netherlands	-	-	-	-	-				-1		●		
Harwood et al., 2002				●	T-junction, stop controlled	plus painted left-turn lane	USA		●	280	-	9-13 years		●		-33	s.s	●		
Harwood et al., 2002				●	4-leg, stop controlled	plus painted left-turn lane	USA	●		280	-	9-13 years		●		-28	s.s	●		
Harwood et al., 2002				●	4-leg, stop controlled	plus painted left-turn lane	USA		●	280	-	9-13 years		●		-27	s.s	●		
Harwood et al., 2002				●	4-leg, signalized	plus painted left-turn lane	USA	●		280	-	9-13 years		●		-18	s.s	●		
Harwood et al., 2002				●	Stop controlled	plus painted right-turn lane	USA	●	●	280	-	9-13 years		●		-14	s.s	●		
Harwood et al., 2002				●	4-leg, signalized	plus painted left-turn lane	USA		●	280	-	9-13 years		●		-10	s.s	●		
Harwood et al., 2002				●	T-junction, signalized	plus painted left-turn lane	USA		●	280	-	9-13 years		●		-7	s.s	●		
Harwood et al., 2002				●	Signalized	plus painted right-turn lane	USA	●	●	280	-	9-13 years		●		-4	s.s	●		

n/a: not available
s.s: statistically significant
* draft edition

JUNCTION LAYOUT - SUMMARY (1/2)

Measure: Junctions layout

- Converting junctions to roundabouts
- Re-designing junctions (mainly rural areas)
- Staggered junctions (mainly rural areas)
- Junctions channelization

Network: Rural / Urban

Maximum safety effect:

- Converting junctions to roundabouts
- Junctions channelization (the more extensive the channelization, the highest the safety effect)

Minimum (or negative) safety effect:

- Junctions channelization (painted channelizations)
- Staggered junctions (low traffic on minor road)

Max B/C ratio:

- Converting junctions to roundabouts 2:1 to 3:1
- Re-designing junctions 3:1
- Junctions channelization 2.5:1

Min B/C ratio:

- High cost re-designing junctions or channelizations

JUNCTION LAYOUT - SUMMARY (2/2)

Implementation costs per unit:

● Converting junctions to roundabouts	650,000-1,300,000 €
● Development of mini roundabout	12,000 €
● Re-designing junctions	from 785,000 €
● Staggered junctions	1,000,000-10,000,000 million €
● Junctions channelization	65,000-1,650,000 €

Other effects:

- improved mobility (except left-right staggered junctions, for channelizations only when traffic is high)
- reduced noise and emissions
- in some cases the total junction area increases

strengths:

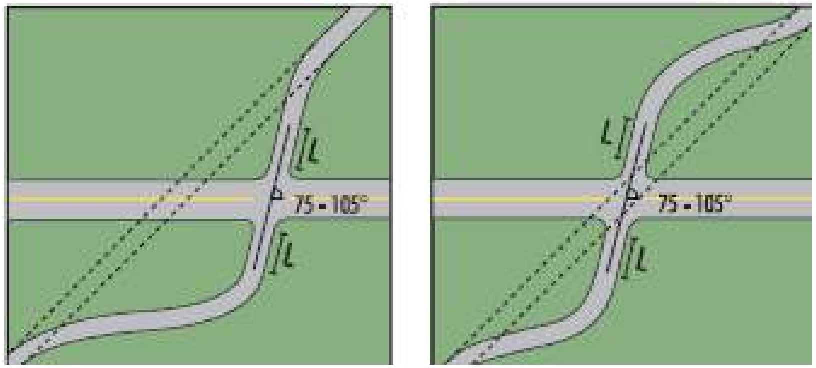
- well-documented effect for all types and particular cases of treatments

weaknesses:

- cost-effectiveness decreases rapidly for more extensive treatments due to increase in implementation costs
- difficult to establish general rules due to the high number of particular cases

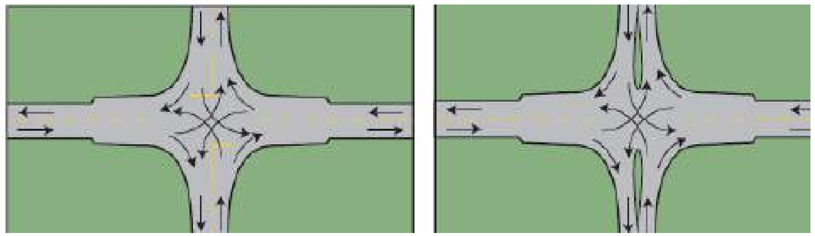
JUNCTION LAYOUT - BEST PRACTICES (1/2)

- The relatively high implementation cost of **junction layout** treatments does not always compromise their cost-effectiveness



- Very satisfactory benefit / cost ratios were found in the large majority of cases. However, there are specific cases where the safety effects may be significantly reduced or even negative

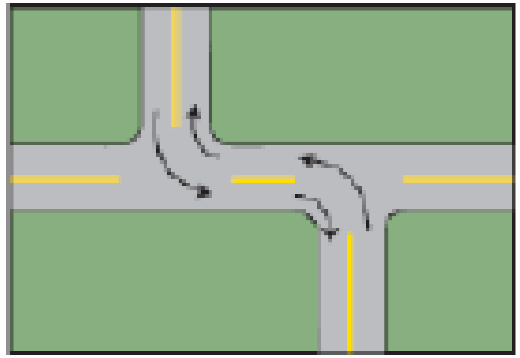
- For example, **channelizations** may have negative safety effects when applied on t-junctions; on the other hand, they always have positive effects when applied on 4-leg junctions

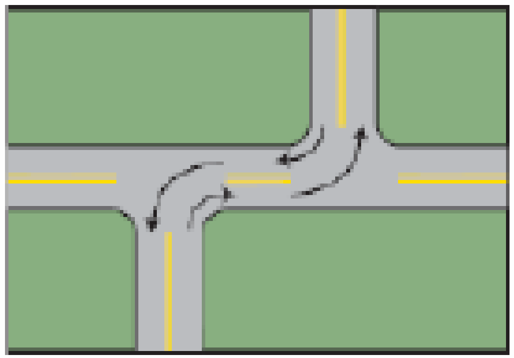


- The more extensive the channelization (e.g. full physical) the maximum the safety effect

JUNCTION LAYOUT - BEST PRACTICES (2/2)

- **Re-designing junctions** involves increased costs. However, the safety effects are positive and satisfactory benefit / cost ratios may be achieved
- Minimum safety effects for the **reduction of gradients** on approach, maximum safety effects for **junction angle treatments** (changes from angle of 90 degrees to higher) *The opposite (i.e. changing from angle lower than 90 degrees to 90 degrees) has important negative effects on road safety*
- There is some uncertainty with respect to **sight triangles** treatments
- Replacing junctions by **roundabouts** is associated with consistently positive safety effects and satisfactory cost-effectiveness
- Minimum safety effect for signalized t-junctions and maximum for uncontrolled or stop controlled 4-leg junctions





TRAFFIC CONTROL AT JUNCTIONS- MEASURES

- **implementation of "yield" signs**
- **implementation of "stop" signs**
- **implementation of traffic signals**
- **upgrade of traffic signals**
  - re-timing traffic signals
  - introducing separate left-turn phase
  - introducing mixed or separate pedestrian phase
  - *right-turn permission during red signal (rarely)*

TRAFFIC CONTROL AT JUNCTIONS - SAFETY EFFECTS

Source	Measure				Description	Country / Region	Road network			Evaluation period	Evaluation method		Safety effect (%)						
	Yield signs	Stop signs	Traffic signals	Upgrade of traffic signals			Rural	Urban / residential	Number of sites		meta-analysis	before/after (control group)	Best estimate	95% conf.int.	all accidents	fatalities	injury accidents	pedestrian accidents	rear-end accidents
CEDR (Questionnaire 2)	●	●			general improvement of signs	Spain	-	-		-			-23			●			
CEDR (Questionnaire 2)	●	●			general improvement of signs	UK	-	-	7	-			-68		●				
CEDR (Questionnaire 2)	●	●			general improvement of signs	Spain	-	-		-			-14		●				
Elvik and Vaa, 2004	●				intriducing yield signs at junctions	Nordic countries, USA and Australia	-	-		-	●		-3	(-9;+3)			●		
Elvik and Vaa, 2004	●				replacing STOP signs with yield signs	Nordic countries, USA and Australia	-	-		-	●		+39	(+19;+62)			●		
Elvik and Vaa, 2004		●			4-leg junctions, introducing four way STOP	Nordic countries, USA and Australia	-	-		-	●		-45	(-49;-40)			●		
Elvik and Vaa, 2004		●			4-leg junctions, introducing two way STOP	Nordic countries, USA and Australia	-	-		-	●		-35	(-44;-25)			●		
Elvik and Vaa, 2004		●			T-junctions, introducing one way STOP	Nordic countries, USA and Australia	-	-		-	●		-19	(-38;+7)			●		
Persaud, 1997		●	●		replaing traffic signalsby two-way STOP, one way roads	Philadelphia, USA		●	71	1978-1992		●	-18	s.s.				●	
Persaud, 1997		●	●		replaing traffic signalsby two-way STOP, one way roads	Philadelphia, USA		●	71	1978-1992		●	-24	s.s.	●				
CEDR (Questionnaire 2)			●		introducing traffic signals	France			6				-67			●			
CEDR (Questionnaire 2)			●		introducing traffic signals	UK			11				-38		●				
CEDR (Questionnaire 2)			●		introducing traffic signals	France			6				-36		●				
Golias, 1997			●		4-leg junctions, introducing traffic signals	Athens, Greece		●	48	1985-1997		●	-36	(-44;-28)					●
Elvik and Vaa, 2004			●		4-leg junctions, introducing traffic signals	Nordic countries, USA and Australia	-	-		-	●		-30	((-35;-25)			●		
Elvik and Vaa, 2004			●		T-junctions, introducing traffic signals	Nordic countries, USA and Australia	-	-		-	●		-15	(-25;-5)			●		
Elvik and Vaa, 2004				●	intriducing left-turn phase-separate	Nordic countries, DE, NL, UK, USA and Australia	-	-		-	●		-58	(-64;-50)	●				
Elvik and Vaa, 2004				●	introducing pedestrian signal - mixed phase	Nordic countries, DE, NL, UK, USA and Australia	-	-		-	●		+8	(-1;+17)				●	
Elvik and Vaa, 2004				●	introducing pedestrian signal - separate phase	Nordic countries, DE, NL, UK, USA and Australia	-	-		-	●		-30	(-40;-15)				●	
Elvik and Vaa, 2004				●	vehicle-actuated phase changes	Nordic countries, DE, NL, UK, USA and Australia	-	-		-	●		-25	(-33;-15)	●				
Elvik and Vaa, 2004				●	coordinated signals (green wave)	Nordic countries, DE, NL, UK, USA and Australia	-	-		-	●		-19	(-22;-15)			●		
Retting et al. 2002				●	re-timing traffic signals	New York, USA	●	●	122	1991-1997			-12	s.s.			●		
Retting et al. 2002				●	re-timing traffic signals	New York, USA	●	●	122	1991-1997			-37	s.s.				●	
Elvik and Vaa, 2004				●	intriducing left-turn phase	Nordic countries, DE, NL, UK, USA and Australia	-	-		-	●		-10	(-15;-5)	●				
Elvik and Vaa, 2004				●	right-turn permission during red signal	Nordic countries, DE, NL, UK, USA and Australia	-	-		-	●		+60	(+50;+70)			●		
CEDR (Questionnaire 2)				●	introducing pedestrian signal - separate phase	UK	-	-	6	-			-53		●				

TRAFFIC CONTROL AT JUNCTIONS - SUMMARY (1/2)

Measure: Traffic control at junctions

- implementation of "yield" signs
- implementation of "stop" signs
- implementation of traffic signals (mainly urban areas)
- upgrade of traffic signals (mainly urban areas)

Network: Rural / Urban

Maximum safety effect:

- implementation of traffic signals
- upgrade of traffic signals (introducing separate left-turn or pedestrian phases)

Minimum (or negative) safety effect:

- implementation of traffic signals (mixed pedestrian phase or right-turn permission during red signal)

Max B/C ratio:

● implementation of "stop" signs	6.8:1 at rural t-junctions
● implementation of traffic signals	8:1 at 4-leg junctions
● upgrade of traffic signals	8.6:1

Min B/C ratio:

● implementation of "stop" signs	may be negative at 4-leg junctions
● implementation of traffic signals	may be negative at t-junctions

TRAFFIC CONTROL AT JUNCTIONS - SUMMARY (2/2)

Implementation costs per unit:

● signposting	250-700 € per sign
● implementation of traffic signals	56,000 € for a rural junction
	4,000 € yearly maintenance costs

Other effects:

- increased delays (except for the main road when yield or stop signs are implemented on the minor road)
- increased noise and emissions (except green-wave traffic signals)

strengths:

- significant, consistent and well-documented safety effects

weaknesses:

- sensitive to environmental effects in urban areas

implementation barriers:

- low acceptablitiy

TRAFFIC CONTROL AT JUNCTIONS - BEST PRACTICES (1/2)

- **Traffic control at junctions** related treatments are very cost-effective in general. However, there are specific cases where the safety effects may be significantly reduced or even negative

- For example, **stop signs** at uncontrolled junctions have minimum safety effect for the case of one-way stop at t-junctions, and maximum safety effect for the case of all-way stop at 4-leg junctions.

- The results for **yield signs** are less consistent and less statistically significant

TRAFFIC CONTROL AT JUNCTIONS - BEST PRACTICES (2/2)

- Maximum safety effect of **introducing traffic signals** is again associated with 4-leg junctions
- Maximum safety effects of traffic signal upgrades concerns re-timing of traffic signals, introduction of separate pedestrian phase and introduction of separate left-turn phase.
- Any modification in traffic signals operation that involves introduction of mixed phases (e.g. mixed pedestrian phase, right-turn permission during red signal) may result in important increase of road accidents; such measures are nowadays rarely implemented in most countries.
- In any case, the above positive safety effects are associated with very satisfactory benefit / cost ratios

COMPARATIVE OVERVIEW OF MOST PROMISING MEASURES (1/2)

Investment	Sub-investment	Safety effect (%) *		Implementation cost (€)		Benefit / Cost ratio	
		Min	Max	Min	Max	Min	Max
Roadside treatment	Clear zones	-23		*n/a*	*n/a*	< 1:1	*n/a*
	Side-slopes	-22	-42	*n/a*	*n/a*	< 1:1	*n/a*
	Guardrails	-30	-47	35,000 per km	220,000 per km	8:1	32:1
Speed limits	Introducing speed limits	-22		300 per km		> 1:1	*n/a*
	Reducing speed limits	-9	-67	300 per km		> 1:1	*n/a*
Junctions layout	Roundabouts	-11	-88	650,000 per junc.	1,300,000 per junc.	2:1	3:1
	Re-designing junctions	-17	-50	785,000 per junc.	*n/a*	3:1	
	Channelizations	+16	-57	65,000 per junc.	1,650,000 per junc.	< 1:1	2.5:1
Traffic control at junctions	STOP sings	-19	-45	250 per sign	700 per sign	< 1:1	6.8:1
	Introducing traffic signals	-15	-36	60,000 per junc.	*n/a*	< 1:1	8:1
	Upgrading traffic signals	+60	-37	*n/a*	*n/a*	< 1:1	8.6:1
Traffic calming	Area-wide traffic calming	-8	-50	1,300,000	3,000,000	2:1	4:1
Lighting treatment	Installing lighting	-28		26,500 per km	57,500 per km	7:1	9:1
	Increasing lighting level	-32		30,000 per km	32,500 per km	2.5:1	4:1

* on target injury accidents
n/a : not available

COMPARATIVE OVERVIEW OF MOST PROMISING MEASURES (2/2)

- Important **interrelations** exist between the six most promising measures.
- Roadside treatments, junction layout treatments and speed limit related interventions could be considered as a main set of most promising measures in interurban and rural roads.
- Traffic calming, junctions layout, traffic control at junctions and lighting treatments may be considered as a main set of most promising measures in urban areas.
- In any case, additional measures may be necessary.

- **There may seldom be a single answer to a specific road safety problem**; a set of infrastructure interventions will be required.
- The safety effects of the most promising measures can not be guaranteed; efficient planning and implementation of an measure requires that all related parameters have been examined and dealt with

COST-EFFECTIVENESS vs. SAFETY EFFECTS

- Overall cost-effectiveness is **not always in accordance** to the safety effect itself of a road safety infrastructure measure

- For instance, roundabouts have very high safety effects, which are not directly reflected in the Benefit / Cost ratios available.
- On the other hand, the Benefit / Cost ratios of lighting treatments are higher than those of roundabouts, although the safety effects of lighting treatments are much less impressive.
- In this case, a comparison of Benefit / Cost ratios only might lead the to the misleading conclusion that lighting treatments are more efficient than roundabouts.

- Consequently, **it is recommended that Benefit / Cost ratios and safety effects are always examined jointly**, in order to identify the optimal solution for a specific road safety problem in specific conditions and with specific objectives.

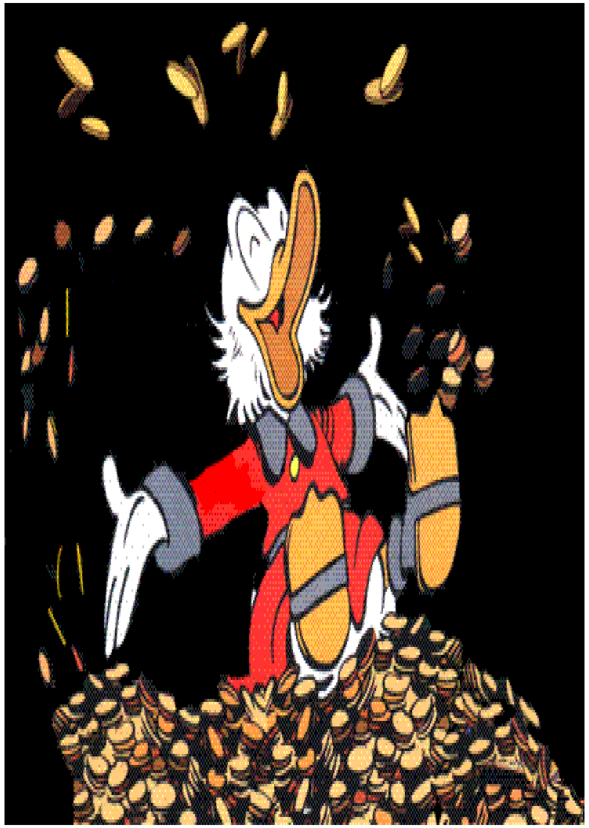
CONCLUSIONS (1/2)

- The in-depth analysis revealed the **range of safety effects, implementation costs and eventual cost-effectiveness** that can be expected with the most promising measures.

- The existing knowledge was exploited in an exhaustive analysis.

- Given that only statistically significant and well-documented results where taken into account in the above synthesis, the degree of uncertainty is minimized.

- These best practice examples could be optimally used as **an overall guide towards a more efficient planning of the measures.**



CONCLUSIONS (2/2)

- The above ranges of results may not apply in any application of these measures.

- It is always possible that particularities of the setting, the context and the implementation features may bring more or less different results in a different case.

- **Thorough analysis on a case-specific basis** is always required, in order to optimize the implementation of the measure in different countries or areas, according to the extent of the implementation, the implementation period and the specific national or local requirements.

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Effectiveness of road safety measures at junctions

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