FINNISH ROAD ADMINISTRATION

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SAFETY EFFECTS OF INSTALLING NEW GUARDRAILS AND IMPROVING EXISTING GUARDRAILS

Summary

The following recommendation has been reached based on the study carried out at the Laboratory of Highway Engineering of Helsinki University of Technology (*Kelkka, M., Performance of guardrails and the requirements for guardrail development, Espoo 2002, in Finnish)*:

The following measures should be considered in order to improve the roadside safety on current main roads:

1. Modifying old guardrails to correspond to the current standard (EN 1317-2, N2)
2. Replacing existing ramped guardrail ends with crashworthy terminals
3. Increasing the lengths of old guardrails in front of bridge piers, cantilever/gantry supports and underpasses
4. Building a new guardrail in front of rock cuts

Table 1 Number of personal injury accidents (PIA, including fatal accidents) per year per 100 units, and the efficiency of measures (1. modifying old guardrail, 2. replacing ramped end with crashworthy terminal, 3. increasing the length of guardrail or 4. building a new guardrail). The statistical loss of injury accident scan be taken into account by multiplying the figures by number 2,0 (figures in brackets)

Crash object	Annual PIA's on motorways / 100 units			Annual PIA's on other main roads / 100 units		
	Before the measure	After the measure		Before the measure	After the measure	
		Reduction (PIA/100)	Reduction (per cent)		Reduction (PIA/100)	Reduction (per cent)
Guardrail, 100 km (1)	1.7 (3.4)	0.55 (1.11)	32 %	1.3 (2.4)	0.04 (0.07)	29 %
100 guardrail ends (2)	0.2 (0.3)	0.06 (0.10)	39 %	0.04 (0.07)	0.02 (0.04)	53 %
100 bridge piers and cantilever/gantry supports (3)	0.2 (0.4)	0.10 (0.16)	44 %	0.09 (0.14)	0.04 (0.06)	39 %
100 underpasses, median (3)	0.3 (0.5)	0.11 (0.16)	33 %	-	-	-
100 underpasses, right edge (3)	0.3 (0.6)	0.22 (0.44)	71 %	0.04 (0.06)	0.02 (0.03)	45 %
100 rock cuts (4)	0.8 (1.5)	0.37 (0.70)	46 %	0.08 (0.16)	0.04 (0.08)	49 %
Rock cut, 100 km (4)	6.7 (12.5)	3.1 (5.8)	46 %	1.3 (2.4)	0.6 (1.2)	49 %

The average severity of personal injury (incl. fatalities) varies strongly in different crashes to roadside obstacles (see table 6). This should be taken into account when estimates of the efficiency of measures are carried out.

ACCIDENT DATA

All fatal accidents In Finland are examined by the Boards of Inquiry of Traffic Damages. The Boards of Inquiry consist of specialists of different fields and their task is to clarify the course, risk factors, consequences and conditions of an accident in order to establish the causes for the accident and to make required proposals for roadside safety measures. All board of inquiry reports for the years 1994 to 1999 have been reviewed one by one for the acquisition of the running-off-the-road accident documentation of this study.

Other accidents can be studied as they have been reported by the police. This study includes run-off accidents leading to injury from districts of Uusimaa, Turku, Häme, South-East Finland and Savo-Karjala, which include more than half of Finland. The documentation comprises all individual accidents having occurred on the main roads in 1994 – 1996 where the speed limit has been 80 km/h or higher.

FREQUENCY OF RUNNING-OFF-THE-ROAD ACCIDENTS

Fatal run-off accidents in 1994 – 99

A total of 455 fatal run-off accidents occurred in Finland in 1994 – 99. Of these 413 were running-off-the-road events of passenger cars or delivery vans. The most serious injury was caused either by crashing into some obstacle in the roadside area or by roll-over of a vehicle due to some element in the border environment (Table 2).

The guardrail, with regard to its character, deviates completely from other crash objects since its sole purpose is to prevent the vehicle from running off into some other object supposedly more dangerous than the guardrail. Therefore, all cases where the guardrail has in one way or another caused the emergence of the most serious consequences are classified as guardrail accidents.

Table 2 Frequency of fatal run-off accidents occurring in Finland in 1994 – 99 on different road types, total lengths and traffic outputs of road types in 1997 and frequency of accidents leading to death in a year per road kilometre and traffic output. .

Type of road	Motorway	Motor traffic way	Other main road	Lower class road	Street or planned road	Private road	Total
road length (km)	444	226	12 399	65 467	23 593	213 070	315199
traffic-output mill. car km/year	3082	879	13376	10818	streets and private roads tot. 15370		43525
Crash object							
tree	1		21	50	18	3	93
ditch	4	2	15	56	1	5	83
pole	6		10	25	18		60
culvert, private road junction			20	25	4		49
guardrail*	9	4	20	9	4	2	48
stone			5	21	1	2	29
rock cutting	3		8	11	3		25
bridge pier/support	3	1	4	8	2		18
gantry	1		6	1	3		11
building, fence			2	3	5		10
underpass	3	2	1	1	1		8
water channel			1	3	2		6
over median against another car	4						4
slope			1	2	1		4
adv. direction sign			1		1		2
curb, platform				1	1		2
wildlife fence	2						2
mo centre lane	1						1
Total	37	10	115	216	65	12	455
Share of all	8 %	2 %	25 %	47 %	15 %	3 %	100 %
Acc. / km (1 yr.)	0.0139	0.0074	0.0015	0.0005	0.0005	0.00001	0.0002
Acc. / 100 mill. car km (1 yr.)	0.20	0.19	0.14	0.33	(0.08)		0.17

- all events whereby a guardrail has affected the consequences of running off the road

Running-off-the-road accidents of passenger cars and delivery vans in urban areas

With regard to densely populated areas running-off-the-road events of passenger cars and delivery vans have been reviewed (Table 3). In densely populated areas the most common fatal crash object has been a tree. A lighting column has been almost as common. Crashes against these two objects comprise more than a half of all running-off-the-road accidents in densely populated areas. Compared to the entire documentation, death when running off the road into a ditch has been very rare in densely populated areas.

Table 3 *Number of fatal run-off accidents of passenger cars and delivery vans in urban areas in 1994 – 99.*

Crash object	main street	other street	Total
tree	6	11	17
lighting column	7	6	13
other poles		1	1
culvert, private road junction.		4	4
building, fence		4	4
gantry	3		3
guardrail*		2	2
water channel	1	1	2
rock cutting		1	1
bridge pier/suppt.		1	1
ditch		1	1
stone		1	1
slope	1		1
adv. dir. sign		1	1
underpass	1		1
curb, platform	1		1
Total	20	34	54
Share of all	37 %	63 %	100 %

* all events whereby a guardrail has affected the consequences of running off the road

In densely populated areas in 1994 – 99 only two running-off-the-road accidents of a passenger car or a delivery van leading to death have occurred whereby a guardrail has influenced the consequences of running off the road. The share of these accidents is less than 4 % of all running-off-the-road accidents in densely populated areas.

Running-off-the-road accidents of passenger cars and delivery vans on public roads

With regard to public roads, running-off-the-road accidents of passenger cars and delivery vans have been reviewed in the same manner as densely populated areas. Table 4 presents fatal run-off accidents grouped by road classes having occurred when driving a passenger car or a delivery van. Only slightly less than half of these accidents have taken place on main roads. The most common crash objects on roads other than main roads are trees and ditches (total 48 %). Accidents against a pole are divided fairly evenly between the main road network and lower road classes. Accidents against guardrails, bridge piers and rock cuttings, running off the road into a underpass and running over median against an oncoming car are clearly focused on the main roads.

Table 4 Number of fatal run-off accidents when driving a passenger car or a delivery van on public roads in 1994 – 99.

Crash object	Motorway	Motor-traffic road	Other main road	Lower class road	Total
Road length (km)	444	226	12 399	65 467	78 536
tree	1		20	45	66
ditch	4	2	9	45	60
culvert, private road junction			20	22	42
guardrail*	8	4	17	9	38
pole	5	1	10	18	34
- lighting column	5	1	10	7	23
- electric pole				7	7
- telephone pole				4	4
stone			5	21	26
rock cutting	3		7	8	18
bridge pier/suppt.	3	1	4	8	16
gantry	1		6	1	8
underpass	3	2	1	1	7
over median against other car	4		1		5
building, fence			2	2	4
slope			1	2	3
water channel			1	2	3
wildlife fence	2				2
motorway median	1				1
adv. direction sign			1		1
curb, platform				1	1
Total	35	10	105	185	335
Share of all	11 %	3 %	31 %	55 %	100 %

* all events where a guardrail has affected the consequences of running off the road

In 1994 – 1999 38 guardrail accidents leading to death have taken place when driving a passenger car or a delivery van. Table 5 presents a more detailed description of the fatal impacts on a safety barrier, in most cases a steel guardrail. In all these cases the guardrail type involved was the old type of the Finnish Road Administration. The new guardrail type was tested in crash tests 1994 and 1999.

The ramped end of a steel guardrail has in several cases been a contributing factor in a running-off-the-road event leading to death. The ramped end itself has not been the fatal crash object, but it has acted as a contributing factor in the bouncing of a car against another crash object. Mere car roll-overs leading to death and caused by a ramped end have thus not occurred.

Table 5 Frequency of guardrail accidents on public roads in 1994 – 1999 and a car's behaviour when hitting a guardrail

Car's action at guardrail crash	steel guard-rail	ramped end	bridge rail end post	wooden railing	temp. con-crete barrier	total (share) nbr
to top of guard-rail		9				(24 %) 9
bouncing into air		6				(16 %) 6
crashed into	5		1		1	(19 %) 7
through the bar-rier	2					(5 %) 2
over the rail	4			1		(14 %) 5
under the rail						(0 %) 0
bouncing to driveway	7					(16 %) 7
other	2					(6 %) 2
total	20	15	1	1	1	38
share	52 %	39 %	3 %	3 %	3 %	100 %

The severity of crash objects can be assessed by the ratio of the fatal accidents and the other reported injury accidents, as in table 6. By far not all modest injuries come to the knowledge of the police and, therefore, the actual frequency of accidents leading to injury is distinctly higher than the figures in accordance with police reports presented in the table.

Table 6 *Frequency of fatal or injury run-off accident of passenger cars or delivery vans, occurring on main roads: average annual figures of accidents against the most significant crash objects. Due to statistical loss a more realistic number of accidents leading to injury is derived by multiplying the figures in question by 2 – 3.(documentation: running-off-the-road events leading to death in 1994 – 99 and statistically compiled running-off-the-road events resulting in injury in 1994 – 96 where the sample is 5 road districts, documentation compiled by the police, converted by the ratio of traffic outputs to cover the whole country.* **Statistical loss has not been corrected.***)*

Crash object	accidents on motorways / year			accidents on other main roads / year		
	acc. leading to death	compiled acc. leading to injury	injury acc. / death acc.	acc. leading to death	comp. acc. leading to injury	injury acc. / death acc.
ditch	0,7	23,2	33	1.8	160.9	89
rock cutting	0.5	3.6	7	1.2	11.8	10
lighting column	0.8	5.7	7	1.8	20.0	11
electric/teleph. pole	0.0	0.0	-	0	5.3	-
gantry	0.2	0.7	3.5	1.0	0.5	0.5
bridge pier/support	0.5	0.4	0.8	0.8	2.1	2.6
tree	0.2	2.1	11	3.3	26.7	8
culvert, private road junction	-	-	-	3.3	26.9	8
guardrail*	0.3	11.1	37	2.7	16.7	62
ramped end *	1.0	1.8	1.8	0.8	5.2	7
stone	0	0.0	-	0.8	2.0	2.5
underpass, median	0.5	0.4	0.8	0.2	0.0	-
underpass, right edge	0.0	0.7	-	0.3	0.8	(mdn+right) 1.6
water channel	0	0.0	-	0.2	2.1	11
Total	4.7	50	(av) 11	18.2	281	(av) 15

* all events whereby a guardrail or its ramped end has influenced the consequences of running off the road

IMPROVEMENTS

General

The crash safety of the new weak-post W-beam guardrail is better then one of the old strong-post W-beam guardrails appearing in the accident data of this study. The Helsinki University of Technology made crash tests in 1993 – 1999 for the Finnish Road Administration and the manufacturer. On the basis these tests the structure of the guardrail has been improved.

a) Installation of guardrail at a place where there has been no guardrail before

b) Increasing the length of an old guardrail i.e. extension of guardrail

c) Modernisation of old guardrails: (U-160) posts are weakened, additional posts are installed, post screws (M16) are replaced by weaker ones (M12) in order to allow the post to detached from the rail at a crash), lifting the post and the rail into the right height, improving the joints of the rail, strengthening the end anchorage.

d) Replacing the ramped end by a crashworthy terminal or turning the guardrail into a slope.

The current guardrail in compliance with the Finnish Road Administration’s type drawing 3/51 fulfils Class N2 requirements of the EN-1317-2 standard.

Impacts of improvement measures

<u>Building or extending of guardrail</u>

The consequences of all bridge pier, gantry, underpass and water channel accidents could have been influenced by installing a new or extending the existing guardrail and by modernising the existing section. In practice, this means that the guardrails protecting bridge piers, underpasses and water channels have been too short. The cantilever/gantry supports in the documentation had not been protected by guardrails at all. In similar manner, 80 % of accidents against rock cuttings could have been influenced by using guardrails. Modernisation of guardrails would have affected around 80 % of motorway guardrail accidents and slightly more than half of guardrail accidents taking place on other main roads.

The following significant benefits can be achieved on motorways:

- 1 fatal accident less each year if guardrails are extended at bridge piers and underpasses
- 0.4 fatal accidents less each year if rock cuttings are protected by guardrails
- 0.2 fatal accidents less each year if gantrys are protected by guardrails

The following benefits can be achieved on other main roads:

- 1.5 fatal accidents less each year if guardrails are extended at bridge piers and underpasses
- 1 fatal accident less each year if rock cuttings are protected by guardrails
- 1 fatal accident less each year if gantrys are protected by guardrails

Modernisation of guardrail and its ramped end

In guardrail end accidents improvement measures can influence on 90 % of the events on an average. In other guardrail accidents an average of 50 % of events can be influenced by improving the guardrail.

Changing of ramped ends to crashworthy terminals (or turning the ends into a slope) would have possibly influenced the consequences of 4…5 accidents on motorways and the consequences of 4…5 accidents on other main roads. These were all events whereby the vehicle had ascended from the ramped end to the top of the guardrail or bounced flying to the air.

By weakening old U-160 guardrail posts the crash into the guardrail can be softened and bouncing of the car on the lane of the opposite driving direction can be reduced. These measures would have possibly influenced the consequences of 1…2 accidents on motorways and the consequences of 2…3 accidents on other main roads.

By increasing the height of the old guardrails from c. 0.5 m to 0.7 m and by weakening post screws cars would have been prevented from running over the guardrail. This measure would have influenced the consequences of 0…1 accidents on the motorways and on the consequences of 2…3 accidents on other main roads.

Reducing the deflection by additional posts and improving the joints and end anchorage it is possible to reduce the breaking risk, which would have had influence on one accident occurring on another main roads.

The following benefits could be achieved by implementing all repair measures of current guardrails:

- on motorways 1 fatal running-off-the-road accident less each year
- on other main roads 1.5…2 fatal running-off-the-road accidents less each year

COST-BENEFIT ANALYSIS FOR PUBLIC ROADS

General

The following contains assessment of the profitability of some measures improving running-off-the-road safety on the main roads. The given values of the cost calculations are derived from accident data on fatal and injury run-off accidents, the building costs of guardrails and the inventory data on the quantities of roadside hardware (crash objects) obtained from the Finnish Road Administration.

Accident costs by crash objects

The total costs of accidents having resulted in personal injury and the costs per individual crash object are calculated in Table 7. The costs of accidents leading only to property damages have not been taken into account in the calculations. The prices of the accidents are based on the publication *Tieliikenteen ajokustannukset 2000 (Finnish Road Administration 2001)* and they take into account the loss of statistical compilation. The prices of accidents used are following:

- Accident leading to death 2 430 000 €

- Accident leading to disability 315 000 €

Table 7 Accident costs in a year per crash object or old guardrail metre adjusted by the representative coefficients of personal injury accidents. The road lengths represent year 1999.

Crash object	accident cost per year (€ tot.)		accident cost per year (€ / crash object)	
	motorway (512 km)	other main road (12762 km)	motorway (512 km)	other main road (12762 km)
guardrail*	4 230 000	11 820 000	6 €/rail-m	8 €/rail-m
ramped end*	3 000 000	3 580 000	1 700	240
bridge pier	1 340 000	2 610 000	2 100	2 600
underpass, median	1 340 000	-	4 900	-
underpass, right edge	220 000	980 000	1 000	320
gantry	710 000	2 590 000	4 300	680
rock cutting	2 350 000	6 630 000	4 600	430

* all events whereby a guardrail or ramped end has affected the consequences of the running-off-the-road event

Profitability of improvement measures

The following contains assessment of reductions in the accident figures for passenger cars and delivery vans generated by building and modernisation of guardrails. Based on the accident documentation the benefit derived from building or improvement of a guardrail has been assessed in different types of running-off-the-road accidents.

With regard to replacement of guardrails it has been assumed that in 50 % of the cases replacement of guardrail and in 90 % of the cases replacement of terminal can influence the consequences of an accident. In these cases 2/3 (67%) of guardrail accidents leading to death change into accidents leading to injury and, likewise, 2/3 (67%) of guardrail accidents leading to injury change to mere property damages.

All accidents leading to death can be influenced through protection of bridge piers, underpasses and gantrys by a guardrail and 80 % of accidents leading to death can be influenced by protecting rock cuttings by a guardrail. These have been assumed to change into accidents leading to injury. In the manner of improving guardrails it has been assumed that 67% of accidents leading to injury will change into mere property damages.

Table 8 presents the reductions in the annual frequencies of accidents achieved by improving, extending or building of guardrails.

Table 8 Estimate of the benefit generated by improvement measures related to guardrails in running-off-the-road accidents. It has been assumed that if by replacing a guardrail or terminal it is possible to influence the consequences of an accident, 2/3 (67%) of fatal guardrail accidents will change into injury accidents and, similarly, 2/3 (67%) of guardrail accidents leading to injury will change into mere property damages. Building a guardrail in front of some other crash object will change fatal run-off accidents into injury accidents and, in the manner of improving guardrails, 67% of accidents leading to injury into property damages.

Crash object before improvement measures	Crash object after improvement measures	estimated share of accidents influenced by the measure *	reduction in number of motorway accidents per year (percentage reduction in brackets)		reduction in number of accidents per year of other main roads (percentage reduction in brackets)	
		motorway / other main road	fatal	other injuries	fatal	other injuries
old guardrail	improved guardrail	50 %	0.1 (34 %)	3.6 (32 %)	0.9 (33 %)	4.7 (28 %)
ramped end of guardrail	crashworthy terminal	90 %	0.6 (60 %)	0.5 (28 %)	0.5 (63 %)	2.7 (52 %)
bridge pier	new/extended guardrail	100 %	0.5 (100 %)	-0.2 (- %)	0.8 (100 %)	0.6 (29 %)
underpass, median	new/extended guardrail	100 %	0.5 (100 %)	-0.2 (- %)	-	-
underpass, right edge	new/extended guardrail	100 %	0.0 (100 %)	0.5 (71 %)	0.3 (100 %)	0.2 (25 %)
gantry	new/extended guardrail	100 %	0.2 (100 %)	0.3 (43 %)	1.0 (100 %)	-0.7 (- %)
rock cutting	new guardrail	80 %	0.4 (80 %)	1.5 (42 %)	1.0 (80 %)	5.4 (46 %)

* assumed that by replacing/building a guardrail it is not possible to influence in an event whereby running off the road has taken place at a very high speed, at a steep angle or corresponding.

Table 9 Annual cost savings of running-off-the-road accidents on the main roads attainable by building new guardrails and by improving and extending current guardrails.

Improvement measure	acc. cost saving per year (€ tot.)		acc. cost saving (€ / crash object or re-paired rail-m / yr.)		acc. cost saving (€ / edge-km / yr.)	
	motorway	other main road	motorway	other main road	motorway	other main road
repair of old guardrail / m	1 380 000	3 680 000	2.1	2.4	680	140
crashworthy terminal to replace ramped end	1 620 000	2 010 000	910	130	790	80
extended guardrail in front of bridge pier	1 140 000	2 140 000	1 800	2 100	560	80
extended guardrail at underpass (median)	1 140 000	-	4 100	-	1 100	-
extended guardrail at underpass (right edge)	150 000	800 000	660	260	140	30
build. / ext. of guardrail in front of gantry	570 000	2 220 000	3 500	580	280	90
building of guardrail in front of rock cutting	1 450 000	4 020 000	2 800	260	1 400	160

From Table 9 it can be observed that the largest annual accident cost savings are attainable on motorways by improving terminals and on other main roads by protecting rock cuttings by guardrails. Cost savings calculated per edge kilometre of a road are largest for protections of rock cuttings. However, the most significant aspect is perhaps that the largest cost saving per individual running-off-the-road event is achieved on motorways by protecting underpasses by guardrails (by guardrails longer than at present) and on other main roads by protecting bridge piers by guardrails. The cost saving at bridge piers is significant even if possible suicidal accidents were deducted from the figure.

Table 10 reviews the profitability of the measures. The observation period is 20 years and interest is 6 %. The building of a new guardrail has been assumed to cost 27 €/m and the improvement of an old guardrail 15 €/m.

Table 10 Profitability and unit costs of guardrail use improvement measures: building costs and 20 years' current values of savings achievable in accident costs.

Improvement measure	acc. cost saving in 20 years, interest 6 % (€ / crash object)		investment cost (€ / crash object)	
	motorway (512 km)	other main road (12762 km)	motorway (512 km)	other main road (12762 km)
repair of guardrail / m [1)]	24	28	15	15
crashworthy terminal [2)]	10 400	1 500	3 400	3 400
extended guardrail in front of bridge pier [3)]	20 600	24 000	3 000	1 600
extended guardrail at underpass (median) [4)]	47 400	-	3 800	-
extended guardrail at underpass (right edge) [5)]	7 500	3 000	2 800	1 900
build. / ext. of guardrail in front of gantry [6)]	40 000	6 700	2 200	1 400
building of guardrail in front of rock cutting [7)]	32 600	3 000	5 400	3 200

1) Improvement measure: raising the height of the barrier by pulling up the posts, weakening of posts, replacement of post screws by weaker screws, improving the rail joints

2) Improvement measure: replacement of ramped ends by crashworthy terminals or corresponding measure (á 3 400 €)

3) Motorways: at the time of the accident documentation in 90 % of cases the bridge piers guardrails too short and in 10 % of cases the guardrail is missing and thus the need for a new guardrail approximately 0.45x120 m + 0.45x80 m + 0.10x180 m = abt. 110 m: 3 000 €. Other roads: extension or building of guardrail on an average 60 m = 1 600 €

4) Improvement measure: extension of guardrails by an average of 120 m = 3 200 € + repair 40 m = 600 €

5) Improvement measure: extension of guardrails on motorways by an average of 80 m = 2 200 € + repair 40 m = 600 € and on other roads extension 60 m = 1 600 € + repair 20 m = 300 €

6) Improvement measure: building or extension of guardrails on motorways by an average of 80 m: 2 200 € and on other roads 50 m: 1 400 €

7) Protection of rock cutting by a guardrail: on motorways on an average 200 m (incl. bevels) = 5 400 € and on other main roads 120 m (incl. bevels) = 3 200 €

Table 11 contains calculation of the current values of total costs of accidents over a period of 20 years and the total costs of improvement, extension and building of guardrails.

Table 11 Profitability and total costs of guardrail use improvement measures: building costs and 20 years' current values of savings achieved in accident costs.

Improvement measure	saving of accident costs in 20 years tot., interest 6 % (€)		investment cost tot. (€)	
	motorway (512 km)	other main road (12762 km)	motorway (512 km)	other main road (12762 km)
repair of guardrail	15 900 000	42 200 000	9 800 000	23 000 000
crashworthy terminal	18 500 000	23 000 000	6 100 000	51 200 000
extended guardrail in front of bridge pier	13 100 000	24 500 000	1 900 000	1 600 000
extended guardrail at un-derpass (centre lane)	13 100 000	-	1 100 000	-
extended guardrail at un-derpass (right edge)	1 700 000	9 200 000	600 000	5 800 000
build. / ext. of guardrail at in front of gantry	6 500 000	25 500 000	400 000	5 400 000
building of guardrail in front of rock cutting	16 700 000	46 100 000	2 800 000	49 000 000

On the basis of tables 10 and 11 it can be stated that on motorways clearly profitable improvement measures related to guardrails comprise better use of guardrails than at present at the locations of bridge piers, underpasses, gantrys an rock cuttings. Similarly – partly related to the aforementioned – improvement of the crash safety of terminals by using crashworthy terminals or other measures is profitable. Repair of motorway guardrails to meet modern requirements is also well-founded, but not the first priority. It is also clearly the most expensive measure with respect to total costs.

On other main roads (excl. motorways) clearly profitable measures include better than the present protection measures by guardrails of gantrys and bridge piers. Also repair of guardrails and better than the present protection of underpasses can be considered profitable measures according to the calculations. Protection of rock cuttings by guardrails is justified at least when the traffic volume clearly exceeds the average daily traffic of single-driveway main roads (during the period under observation approximately abt. 3000 vehicles/day). Improvement of the crash safety of guardrail terminals is not on an average economically profitable on single-driveway main roads.

The results of Tables 10 and 11 are significantly influenced by the number of accidents and crash objects. The frequency of accidents used in the calculations contains inaccuracy as regards accidents leading to injuries. Due to poor coverage of statistical compilation it is very likely that the actual number of accidents leading to injuries is somewhat larger compared to the adjusted values now used in the calculations (the adjustment has been made on the unit costs of accidents). In practice this means that accident costs – as well as the savings achieved in them – would be somewhat higher than the values now used in the calculations.

The estimated quantities of crash objects directly influence the accident costs calculated per crash object and the total costs of building guardrails. With regard to the results of the profitability calculations this has significance on motorways as regards repair of guardrails and on other main roads as regards repair of guardrails and protection of rock cuttings.

The profitability calculations have not taken into account the maintenance costs of guardrails. Statistically compiled data is not available on maintenance costs. However, in this regard e.g. 50 % may be added to the investment costs presented in Tables 10 and 11. This has an impact on the profitability of repairing guardrails on all main roads and, in addition, on single-driveway main roads on the profitability of the better than present use of guardrails at rock cuttings and underpasses.

CONCLUSIONS

In Finland both improving the existing guardrails and the wider use of new guardrails are effective methods for reducing the consequences run-off accidents. The most urgent are improvement measures on busy main roads. The measures can be divided into three categories: modernisation of strong-post guardrails which are older than Finnish Road Administration's type guardrail Ty 3/51 of 1994, extension of existing guardrails and building of new guardrails.

The following savings can be achieved on motorways through the aforementioned measures:

- 0.5 fatal run-off accidents each year when the steel guardrails are modernised (no replacement of guardrail terminals)
- abt.1 fatal run-off accident each year when ramped ends are changed to crashworthy terminals (note! another way is to turn the guardrail to the centre lane or into a slope; there are no experiences of crash safety as to yet). However, the current ramped ends have been absolutely safer than the previously used blunt unyielding ends where a car could become "pierced through".
- 1 fatal run-off accident each year when old guardrails at bridge piers and underpasses are extended
- abt. 0.5 fatal run-off accidents less each year when rock cuttings and still unprotected cantilever/gantry supports are protected by guardrails.

The aforementioned measures can achieve the following savings on other main roads (including motor-traffic roads):

- 2 fatal run-off accidents less each year when steel guardrails are modernised (no replacement of guardrail terminals)
- 0.5…1 fatal run-off accidents each year when ramped guardrail ends are changed to crashworthy terminals (note! another way is to turn the guardrail into a slope; researched data is not yet available on crash safety)
- 1.5 fatal run-off accidents each year when old guardrails at bridge piers and underpasses are extended and guardrails are built in front of still unprotected bridge piers.
- 1 fatal run-off accident each year when rock cuttings are protected by guardrails
- 1 fatal run-off accident each year when still unprotected cantilever/gantry supports are protected by guardrails.

Previous numbers:

1. Break-away lighting columns, current practice in Finland in 1993
2. Foundations of luminare supports. The effect of backfill on the strains in foundations.
3. The need of space for snow remover from carriageways in Finland.
4. Acoustic performance of simple board and plywood fences.
5. Break-away lighting columns, current practice in Finland in 1996
6. Break-away lighting columns, current practice in Finland in 1998
7. The effect of openings on the insertion loss of noise barriers
8. Improving roadside safety on old roads
9. Break-away Iighting colurnns in Finland, years 2001

10A. Opta2e.xls tool for the desing of supports for vertical signs

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SAFETY EFFECTS OF INSTALLING NEW GUARDRAILS AND IMPROVING EXISTING GUARDRAILS

New edition www.tiehallinto@fi/finnra.htm

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