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TA3 ITS - HUNGARY

RADAR – Risk Assessment on Danube Area Roads

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3.0	26.02.2021	Corrections based on KFV review (2nd round)	Gábor Pauer, KTI Szilárd Szigeti, KTI

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Abbreviation list

AADT	Annual Average Daily Traffic
AALC	Average Accident Loss Value of a Road Category
ALS	Accident Loss value
AR	Accident Rate
ARM	A family of reduced instruction set computing (RISC) architectures for computer processors
BCR	Benefit-Cost Ratio
FSI	Fatal and Serious Injuries
HGV	Heavy Goods Vehicle
iRAP	International Road Assessment Programme
KTI	KTI Institute for Transport Sciences Non-profit Ltd.
PA	Pilot Action
PI	Potential for Improvement
PP	Project Partner
PV	Present Value
RADAR	Risk Assessment on Danube Area Roads
SRIP	Safer Road Investment Plan
SRS	Star Rating Score
ViDA	Online road safety software platform of iRAP

1 Executive summary

The RADAR (*Risk Assessment on Danube Area Roads*) project implements learning and transnational cooperation activities at different levels to help the responsible road safety organizations in the Danube area identify risk on their road networks and also helps them reduce risk systematically, by improving infrastructure and road layout. RADAR addresses all road users but pays particular attention to vulnerable road users as well as to safety on major roads near schools. It also holistically approaches the issue of safety and tackles speed as a major risk on roads.

The fifth Work Package of the project aims to give the project partners practical experience in using techniques, information and countermeasures to reduce road casualties. With the help of Pilot Actions (PA), testing of best practice and methodologies become possible. PP3-KTI as a project partner is responsible for the third thematic area, namely ITS and speed-management. Accordingly, Pilot Actions have been carried out by KTI to examine and demonstrate the effects of two selected speed management devices:

i. vehicle activated speed warning signs, and
ii. fixed site speed cameras,

which work as speed reducing tools. The efficacy of the devices has been measured and estimated considering the evidence of the correlation between speed reduction, and reduction in crashes.

As the first step, a complex methodology has been used to identify the most dangerous road sections on the Hungarian road network (based on Risk Maps), to illustrate where Pilot Actions may be implemented with highest potential benefits. Our PA focused on the I. and II. class main roads of the network.

The potential effects of vehicle activated speed warning signs and fixed site speed cameras have been determined based on speed measurements at 7 different locations. Speed data have been analysed using mathematical-statistical methods. According to our results, both devices result in the reduction of average and v85 speed of the traffic.

Based on this work, Implementation-Ready Road Layout Concept Plans for speed management have been elaborated for 2 locations, selected from the previously identified dangerous road sections. The potential effects of the interventions have been determined based on the correlation between speed and accident risk, as well as by the iRAP Star Rating methodology (with the ViDA software).

Data along the implementation of the PA was collected, and all steps and results are described in detail in this document.

2 Identification of the most dangerous road sections in Hungary

According to the Directive 2008/96/EC on road infrastructure management „*the identification of sections for analysis in network safety ranking takes into account their potential savings in accident costs. Road sections shall be classified into categories. For each category of roads, road sections shall be analysed and ranked according to safety-related factors, such as accidents concentration, traffic volume and traffic typology. For each road category, network safety ranking shall result in a priority list of road sections where an improvement of the infrastructure is expected to be highly effective.*"

Based on the recommendations of the Directive, we have elaborated a complex method for safety ranking of the elements of the Hungarian road network. It combines historical accident and traffic data, and the potential savings in accident costs. The method provides the ranking of network elements by road categories, listing those sections where an improvement of the infrastructure is expected to be the most effective. The main steps are the following:

- subdivision of the network into sections (creating homogeneous sections),
- assigning crash and traffic data to sections,
- estimating risk rates for each section (accident rate),
- estimating the potential accident savings ("potential for improvement") for each section,
- combination of the accident rate and potential for improvement to identify the most critical road sections.

Steps of our methodology consider procedures recommended in the technical specification of RAP Crash Risk Mapping[1]. However, some modifications have been applied:

- while the RAP Crash Risk Mapping protocol concentrates only on fatal and serious road accidents, we have included also data of slight injury accidents into our analysis,
- the results of risk mapping based on the accident rate (number of crashes per vehicle kilometres) and potential accident savings have been combined when identifying the most dangerous road sections of the network.

Detailed description of our methodology has been summarized in this chapter, as well as the results of the analysis on the I. and II. class main roads of Hungary, with appointed sections where Pilot Action can result in the highest road safety benefits.

2.1 Applied methodology for network safety ranking

This subchapter provides a detailed description of the method that has been used for network safety ranking and for determining the most dangerous road sections of the network.

2.1.1 Basic data of the analysis

A map data set of the Hungarian road network was available from the status at the end of year 2018. The most recent available traffic and accident data are also from the year 2018. Traffic

[1] European Road Assessment Programme (EuroRAP). RAP Crash Risk Mapping: Technical Specification. January 2020 update. RAP-RM-2.1.

data are collected by the state-owned road operator company (Hungarian Public Road Nonprofit Plc.), based on measurements at 823 road section, and estimations by them in case of the sections that are not measured (the proportion of measured cross sections was 12.2%). In the analysis, we used accident data for the last 3 years (2016-2018), which is collected by the Hungarian Police and published by the National Statistical Office

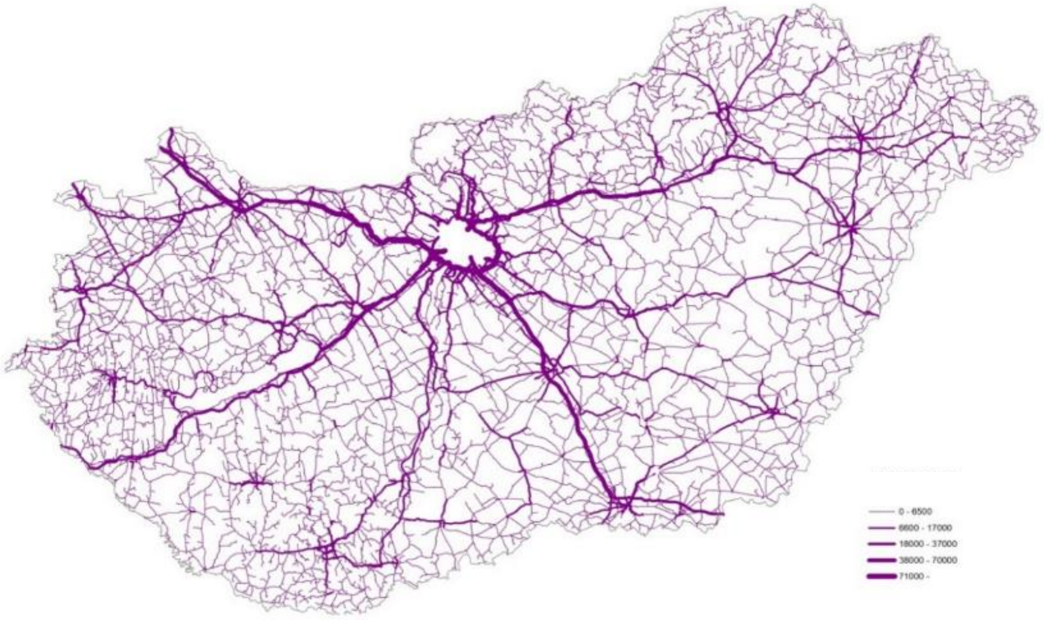

Figure 1: Traffic volumes on national road network in 2018 (AADT [vehicle units/day])

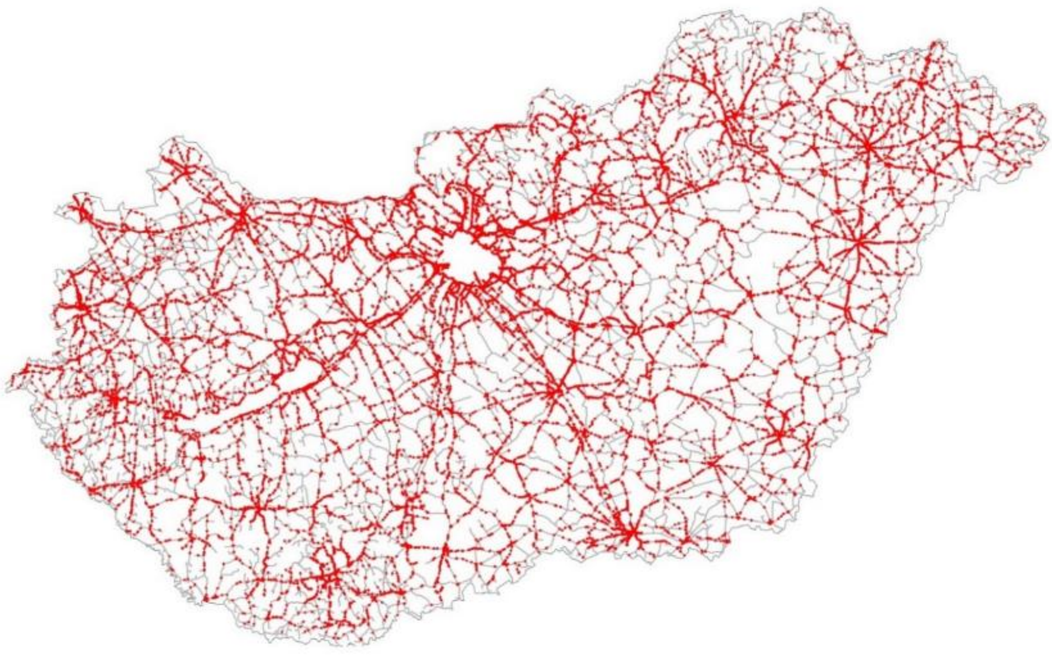

Figure 2: Road accidents with personal injury on the national road network (2016-2018)

2.1.2 Subdivision of the network into sections

In our methodology, the road network has been divided into homogeneous road sections. The aspects that have been considered during this procedure were:

- identification number of the road,
- nature of road section (urban/rural),
- annual average daily traffic (AADT),
- total motorized traffic per day,
- total number of heavy good vehicles per day,
- lane code (left/right lane of divided road/undivided road),
- road category.

These parameters were available related to the whole national road network. If any of these parameters changed, a new road section had been created.

2.1.3 Estimation of risk rates

For each road section, the risk rate has been calculated based on the previously introduced basic data. Risk rates have been expressed by the accident rate (AR) as follows:

$$AR_{ji} = \frac{ACC \cdot 10^6}{365 \cdot \mathrm{AADT}_{ji} \cdot \mathrm{L}_{ji} \cdot \mathrm{T}} \quad [\frac{ACC}{10^6} vkm]$$

where:

ACC – total number of road accidents with personal injury during the observation period T,

AADT – average annual daily traffic [vehicle units/day],

T – observation period [year],

L – length of road section [km],

j – group index (for road categories),

i – section index.

Results have been illustrated in the following figure.

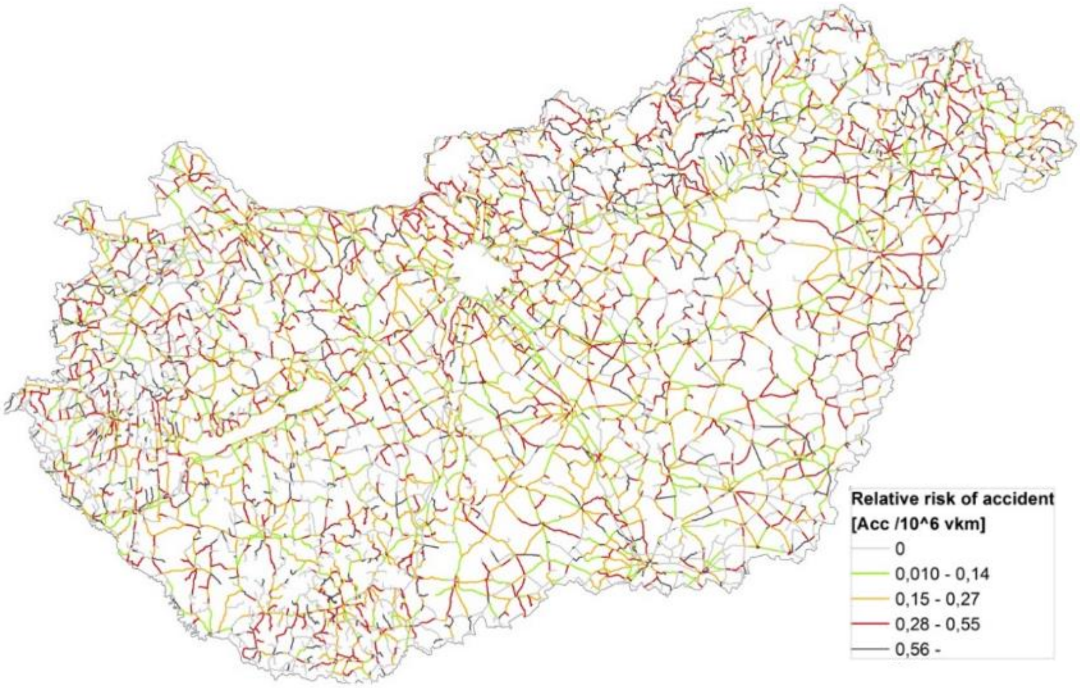

Figure 3: Accident rates of the national road network sections (based on accident data from 2016-2018)

2.1.4 Estimation of the potential accident savings ("potential for improvement")

For each road section, the potential accident savings (potential for improvement) has also been calculated. We considered the potential for improvement (PI) as the difference between the accident loss value of the road section and the average accident loss value characterizing the road category to which the specific road section belongs.

For the calculations, national economic casualty cost values of year 2017 were used (cost per casualty: fatal 273.264.044 Ft/person, serious 66.364.125 Ft/person, slight 5.954.611 Ft/person; approximately 759.000 Eur/person, 184.350 Eur/person and 16.540 Eur/person, respectively). The calculations are described by the following formulas.

Accident loss value of a road section (ALS):

$$ALS_{ji} = \frac{C_f \cdot N_f + C_s \cdot N_s + C_k \cdot N_k}{365 \cdot \mathrm{AADT}_{ji} \cdot \mathrm{L}_{ji} \cdot \mathrm{T}}$$

where:

C_f - economic casualty cost of a road death,

C_s - economic casualty cost of a serious injury,

C_k - economic casualty cost of a slight injury,

N_h - number of road deaths on the section,

N_s - number of serious injuries on the section,

N_k - number of slight injuries on the section.

Average accident loss value of a road category (AALC) can be calculated as the average accident loss value of all sections of the road category, weighted by the length of the sections:

$$AALC_j = \frac{\sum_{i=1}^{n}\left(\frac{C_f \cdot N_f + C_s \cdot N_s + C_k \cdot N_k}{365 \cdot \mathrm{AADT}_{ji} \cdot \mathrm{T} \cdot \mathrm{L}_{ji}} \cdot \mathrm{L}_{ji}\right)}{\sum_{i=1}^{n} \mathrm{L}_{ji}}$$

The potential for improvement (PI) is calculated as the difference between ALS and AALC:

$$PI_{ji} = ALS_{ji} - AALC_j$$

The value of PI represents the potential economic saving if the risk of the examined road section would be reduced to the average level characterizing the road category of the section.

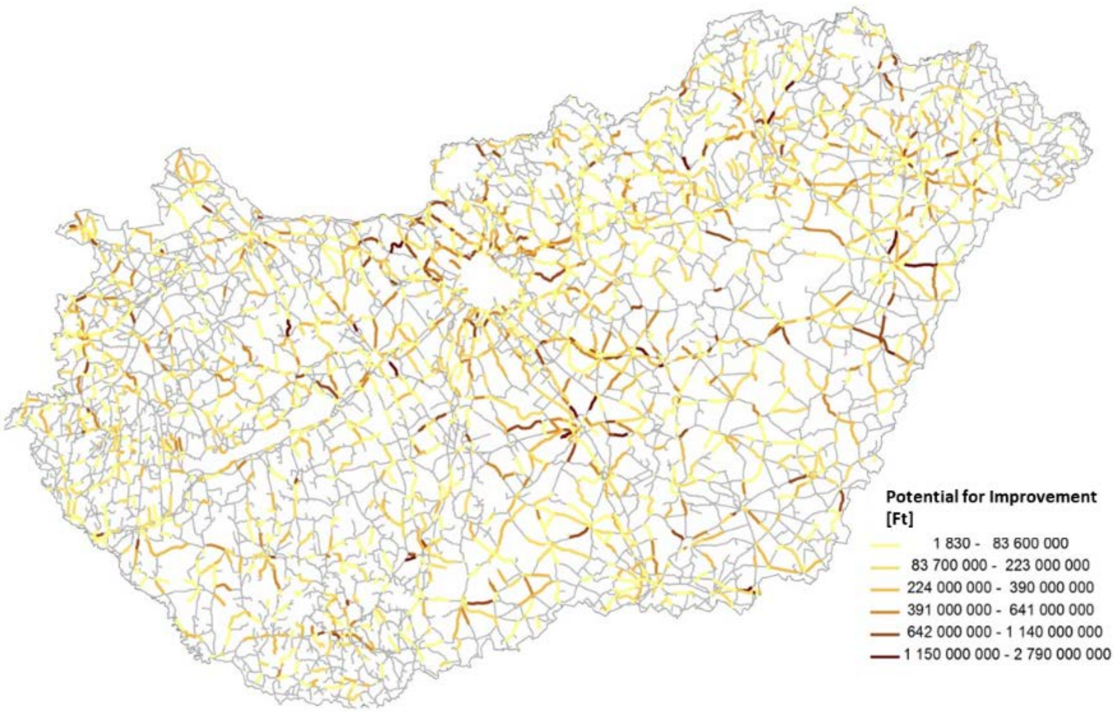

Figure 4: Potential for improvement of the national road network sections (based on accident data from 2016-2018)

2.1.5 Complex road safety ranking based on the combination of the results

Based on the previous calculations, we determined a complex road safety ranking taking into account both the risk rate and the potential for improvement of the sections.

In the first step, we had to define threshold values of accident rates for all road categories. Values above this threshold identify sections of the specific road category with highest AR values. Based on statistical considerations and ex-post evaluation of results we have applied the 70th percentile threshold.

Besides that, we only took the identified sections into consideration if the PI values of them were above 0, thereby combining the calculated indicators.

On this basis, we created the safety ranking of sections of the I. and II. class main roads. The threshold AR values of these categories had been determined as 0.38 for I. class, and 0.40 for II. class main roads.

2.2 Safety ranking of sections of the I. class main roads in Hungary

The identified, most dangerous road sections of the I. class main roads in Hungary are presented in the next table.

Table 1: The most dangerous sections of the I. class main roads (based on accident data from 2016-2018)

No. of road	Carriageway	Starting km section	End km section	AR [acc/ 10^6 vkm]	PI [10^9 Ft/ 3 years]	No. of accidents	No. of fatalities	No. of serious injuries	No. of slight injuries
1	single	2+548	3+802	0.40	0.28	8	2	3	4
1	single	48+995	50+921	0.53	0.39	9	2	2	10
1	dual (right)	125+466	126+107	1.21	0.20	10	0	3	13
1	dual (left)	125+466	126+112	0.84	0.22	7	0	4	3
2	single	17+334	20+165	0.40	0.77	28	2	9	20
2	single	36+390	37+945	0.39	0.32	8	1	6	5
2	single	57+242	62+094	0.39	0.01	6	0	2	6
3	single	55+544	57+596	0.60	0.14	13	0	7	9
3	single	58+728	60+549	0.44	0.06	9	0	6	7
4	dual (right)	121+006	123+547	0.41	0.74	8	2	4	11
4	dual (right)	273+445	274+555	0.53	0.02	6	0	1	5
5	single	113+207	115+106	0.39	0.23	6	2	0	5
5	single	139+000	140+976	0.78	0.13	8	0	4	4
5	single	159+975	161+465	0.45	0.09	6	1	2	5
6	single	88+386	89+277	0.51	0.12	2	1	0	1
6	single	95+690	97+476	0.43	0.14	3	1	0	4
6	single	193+693	194+687	0.55	0.07	17	1	2	26
6	single	200+675	201+926	0.41	0.43	10	2	5	7
6	single	233+566	236+240	0.48	0.25	3	1	2	0
6	single	257+028	258+696	0.57	0.13	3	1	0	3
7	single	32+431	35+741	0.43	0.33	10	1	5	11
7	single	66+774	68+701	0.38	0.08	16	0	7	18
7	single	111+680	112+936	0.79	0.01	11	0	5	9
7	single	113+137	114+120	0.39	0.01	4	1	1	3
7	single	190+269	193+391	1.04	0.18	4	0	5	2
7	single	222+385	224+110	0.54	0.06	5	0	3	4
7	single	226+190	229+831	0.49	0.77	8	3	1	7
10	single	10+702	13+733	0.48	0.72	29	1	12	24
10	single	44+865	46+043	1.03	0.20	5	1	1	4
10	single	59+047	60+811	0.46	0.01	5	0	5	3
21	dual (right)	10+740	11+989	0.49	0.01	4	0	2	2
21	dual (right)	23+816	26+447	0.78	0.28	8	1	1	12
21	dual (right)	26+447	27+006	0.46	0.02	1	0	2	2
21	dual (right)	50+410	51+309	0.57	0.05	3	0	1	4
43	single	17+905	20+546	0.53	0.13	6	0	4	4
44	single	49+769	50+762	0.86	0.01	8	0	5	3
403	single	14+008	14+970	0.58	0.01	2	0	2	5

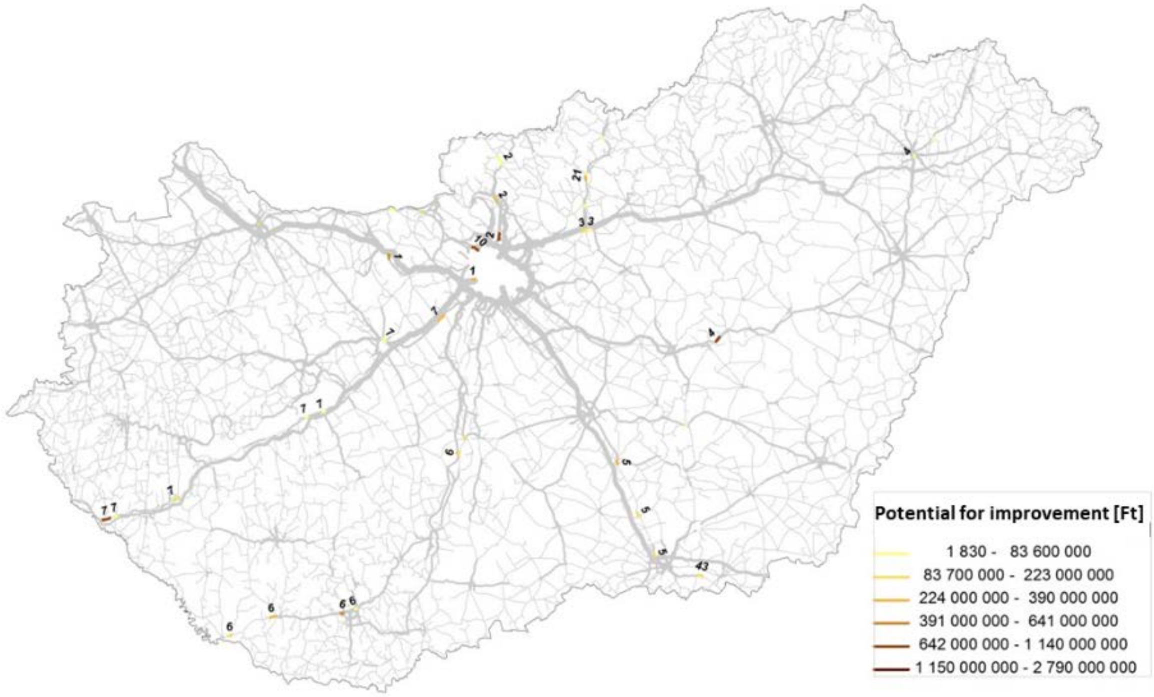

Figure 5: Examples of the most dangerous sections of the I. class main roads (based on accident data from 2016-2018)

2.3 Safety ranking of sections of the II. class main roads in Hungary

The identified, most dangerous road sections of the II. class main roads in Hungary are presented in the next table.

Table 2: The most dangerous sections of the II. class main roads (based on accident data from 2016-2018)

No. of road	Carriageway	Starting km section	End km section	AR [acc/ 10^6 vkm]	PI [10^9 Ft/ 3 years]	No. of accidents	No. of fatalities	No. of serious injuries	No. of slight injuries
11	single	26+476	27+302	0.59	0.01	7	1	1	6
12	single	21+877	25+455	0.40	0.35	4	1	3	2
13	single	0+943	2+007	0.66	0.23	7	1	5	1
22	single	23+255	29+078	0.62	0.15	20	0	5	19
22	single	42+007	44+342	0.92	0.12	6	0	3	10
23	single	12+529	15+996	0.47	0.41	6	1	5	3
23	single	23+734	31+338	0.45	0.20	10	0	4	12
24	single	1+860	4+829	0.98	0.05	9	0	2	9
24	single	6+808	15+205	0.56	0.62	15	1	6	14
24	single	18+295	24+277	0.85	0.45	11	1	4	8
24	single	24+277	28+022	0.62	0.02	5	0	2	4
24	single	42+673	53+069	0.58	0.25	12	0	5	9
24	single	53+069	59+600	0.42	0.14	12	0	4	14
25	dual (right)	7+332	8+979	0.71	0.01	5	0	0	7

25	single	8+979	10+766	0.59	0.21	9	0	8	10
25	single	10+822	12+907	0.40	0.15	15	0	7	9
25	single	17+067	18+845	0.42	0.01	17	0	4	18
25	single	18+845	26+297	0.57	1.40	29	3	11	25
25	single	44+396	50+844	0.52	0.04	6	0	2	7
25	single	55+629	62+291	0.51	0.14	16	0	4	15
25	single	62+291	64+984	0.48	0.07	7	1	1	5
25	single	72+680	77+051	0.43	1.14	9	4	3	10
25	single	77+051	80+600	0.47	0.57	8	2	3	6
26	single	20+943	26+116	0.50	0.34	20	1	5	18
27	single	5+656	10+971	0.55	0.33	20	0	8	17
27	single	12+539	15+628	0.62	0.25	6	1	1	8
31	single	55+618	56+622	0.74	0.03	5	0	5	0
32	single	73+824	75+584	0.58	0.54	12	2	5	6
34	single	8+115	12+821	0.46	0.16	6	0	4	5
34	single	34+710	35+422	0.42	0.01	1	0	2	1
36	single	48+663	50+131	0.97	0.29	23	0	8	22
36	dual (right)	50+573	51+330	0.48	0.05	4	0	2	3
36	dual (left)	50+573	51+330	0.48	0.06	4	0	2	2
36	dual (right)	51+627	52+463	0.60	0.01	5	0	1	7
37	dual (left)	0+000	0+993	0.46	0.07	3	0	1	3
37	single	27+838	28+426	0.47	0.04	4	1	2	1
38	single	17+596	24+103	0.44	0.63	17	0	12	23
39	single	1+293	4+912	0.49	0.22	4	1	1	3
40	single	3+152	8+368	0.58	0.46	17	0	10	16
40	single	21+535	30+715	0.44	0.74	12	2	4	10
46	single	2+426	4+253	0.49	0.39	9	2	3	4
46	single	64+000	66+187	0.63	0.01	7	0	4	6
47	single	35+305	37+644	1.30	1.03	33	1	15	24
47	single	50+013	51+608	0.50	0.01	2	0	2	1
47	single	55+200	60+530	0.55	0.49	7	1	5	4
48	single	1+800	3+967	0.52	0.02	13	0	5	10
49	single	2+039	2+989	1.42	0.02	7	1	0	8
49	single	6+335	8+058	0.45	0.08	3	1	0	3
51	single	155+902	158+452	0.44	0.14	7	1	02	5
51	single	159+953	160+555	1.19	0.09	10	1	2	10
51	single	179+300	184+240	0.61	0.14	5	0	4	1
52	dual (right)	3+804	4+345	0.42	0.03	2	0	2	0
52	single	52+096	53+631	0.45	0.11	7	1	3	3
55	single	0+351	1+100	0.69	0.01	7	1	1	6
56	single	5+544	6+180	0.89	0.06	8	0	6	5
56	single	9+980	14+274	0.51	0.19	10	0	5	12
56	single	23+053	29+093	0.58	0.30	6	1	2	4
56	single	35+179	38+200	0.96	0.22	5	0	5	4
58	single	1+215	2+950	0.52	0.31	14	1	5	13
61	single	187+715	189+925	0.46	0.21	5	1	2	3
64	single	0+000	1+497	0.56	0.06	4	0	4	2
66	single	1+891	3+756	0.44	0.20	12	1	3	16
66	single	5+550	9+543	0.41	0.39	17	1	6	16
67	single	7+198	9+607	0.98	0.06	12	0	4	16
67	single	20+726	22+650	0.63	0.02	4	0	2	3
67	single	33+137	36+252	0.48	0.30	5	1	2	4
67	dual (right)	38+990	39+686	1.54	0.15	8	0	3	9
67	dual (left)	38+997	39+686	1.17	0.02	6	0	1	6

68	single	50+412	51+560	1.77	0.22	5	1	1	3
71	single	86+323	90+266	0.42	0.14	7	0	5	4
74	single	53+394	57+095	0.57	0.09	10	0	4	7
74	single	74+205	75+145	0.57	0.05	3	1	1	2
75	single	0+024	2+059	0.52	0.21	13	0	8	8
75	single	34+788	37+516	0.68	0.02	3	0	2	3
76	single	42+910	45+512	0.51	0.24	15	0	8	14
76	single	74+591	76+650	0.73	0.78	7	3	2	6
77	single	27+551	29+096	0.78	0.02	4	0	2	4
81	single	74+519	76+893	0.47	0.89	12	2	10	10
82	single	6+039	10+103	0.44	0.53	16	1	8	18
82	single	21+331	30+099	0.74	1.58	32	2	16	31
83	single	41+380	45+424	0.48	0.62	9	1	8	4
83	single	61+006	64+605	0.59	0.41	23	1	5	30
84	single	50+876	52+567	0.47	0.13	6	1	3	6
84	single	78+755	81+250	0.65	0.18	9	1	2	12
84	single	88+250	89+826	0.42	0.14	5	1	2	5
85	single	42+077	43+160	0.41	0.05	6	1	2	3
86	single	77+920	79+047	0.47	0.22	7	1	4	9
86	single	80+393	85+976	0.46	0.01	7	0	1	12
86	single	89+798	90+682	0.56	0.08	2	0	4	4
86	single	105+138	107+824	0.58	0.06	3	0	3	0
86	single	116+288	117+054	4.01	0.01	3	0	2	2
86	single	135+358	136+131	3.07	0.07	3	0	3	1
111	single	4+186	5+485	0.60	0.09	10	1	2	9
111	single	5+485	7+556	0.46	0.01	12	0	5	7
117	single	10+289	12+579	0.47	0.76	8	2	8	10
253	single	8+904	12+123	0.42	0.22	5	1	2	4
311	single	0+833	2+471	0.96	0.05	5	0	2	8
311	single	13+025	15+547	0.40	0.07	5	0	4	3
402	single	0+000	1+438	0.59	0.12	14	0	6	16
441	single	1+831	4+664	0.50	0.34	12	1	6	7
441	single	30+440	31+525	0.60	0.07	9	1	2	6
446	single	1+504	2+867	0.81	0.23	13	1	4	10
446	single	3+152	4+668	0.75	0.21	12	1	4	8
471	single	0+088	1+570	0.60	0.32	22	0	9	16
471	single	66+664	70+000	0.43	0.05	14	0	4	27
610	single	5+659	8+086	0.41	0.91	21	3	5	22
760	dual (left)	6+267	7+902	0.75	0.37	4	1	2	4
760	single	7+902	8+961	0.58	0.19	4	1	3	3
832	single	10+151	11+885	0.51	0.14	2	1	0	1
834	single	30+148	31+743	0.51	0.49	3	2	2	4
834	single	37+975	40+886	0.74	0.18	8	0	5	10

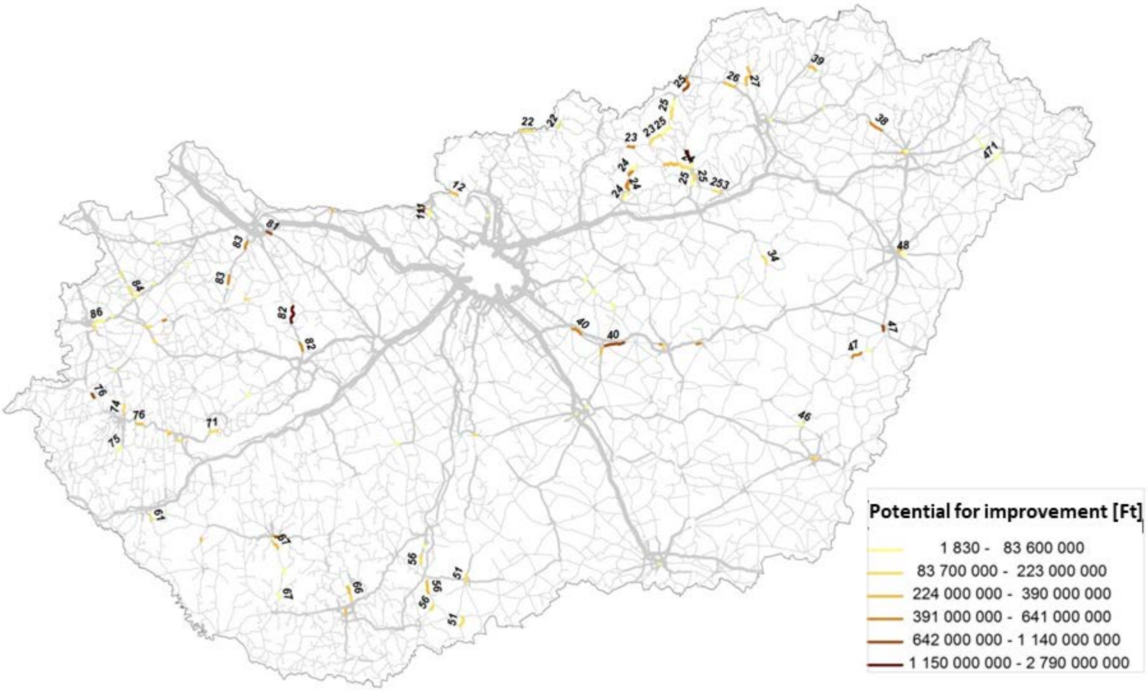

Figure 6: Examples of the most dangerous sections of the II. class main roads (based on accident data from 2016-2018)

3 Determination of effects of vehicle activated speed warning signs and fixed speed cameras by measurements

In the following chapter, we have examined the effects of vehicle activated speed warning signs and fixed site speed cameras (later referred to as 'devices'). After a short review of existing literature, we present our methodology of evaluation. The measuring equipment, methodology of measurements and evaluation, the selected locations and results are all described in detail.

3.1 Results from literature

Impact of vehicle activated speed warning signs were investigated in a British study[2] in 2002 mainly on rural roads in Norfolk, Kent, West Sussex and Wiltshire. These types of signs were investigated:

- speed limit roundel (just inside the speed limit terminal signs) - mainly village sites;
- bend warning;
- junction warning;
- safety camera repeater sign (displaying a camera logo);

According to their results, speed limit roundel signs reduced traffic speed by 5-14.5 km/h. The largest reduction was measured where speed limit was also reduced by 10 miles/h (16 km/h). Where the speed limit was not changed, reduction of mean speed was 6.4 km/h.

Junction and bend warning signs reduced mean speed by 11.3 km/h, and safety camera repeater signs by 6.4 km/h. In all the locations in Norfolk, the number of accidents was also reduced by one-third compared to the accident numbers without signs.

Their results showed that drivers reduce their speeds if they are specifically targeted. Fixed road signs have less effect on traffic speed. Vehicle activated speed warning signs were more effective in reducing both speeds and the ratio of drivers exceeding the speed limit.

In an Australian study[3] six vehicle activated speed displays were examined in selected rural intersections. They showed the speed of the coming vehicle with the help of a sensor. Traffic speeds measured in these locations were compared to speeds at selected sites where fixed speed signs were present. Statistically significant speed reductions of 0.8 - 6.9 km/h were found at four sites. Increases in mean speeds of between 0.5 and 3.4 km/h were observed at the remaining two sites.

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[2] Winnett, M. A., Wheeler, A. H. (2002) Vehicle-activated signs – a large scale evaluation TRL Report TRL548 https://trl.co.uk/sites/default/files/TRL548.pdf

[3] Bradshaw, C L., Bui, B., Jurewicz, C (2013) Vehicle activated signs: an emerging treatment at high risk rural intersections. Australasian Road Safety Research Policing Education Conference, 2013, Brisbane, Queensland, Australia. https://trid.trb.org/view/1286899

In 2008, the effectiveness of vehicle activated speed displays were investigated in South London[4]. Devices were installed at 10 sites. Speeds were measured for 1-3 weeks. Vehicle speeds were decreased by 2.2 km/h; the proportion of vehicles exceeding the speed limit was also reduced. Yet mean vehicle speeds increased to the former level one week after the signs were removed.

Hungarian researchers investigated the impact of different speed signs on vehicle speeds in 2007[5]. The impact of three different vehicle activated speed warning signs and speed limit signboards were evaluated at four locations. All the four locations were in inhabited areas with fixed speed measuring points nearby. Speed measurements were made before and two weeks after the devices have been placed.

According to the results all the speed measurement devices had significant impact on traffic speed. Mean speed decreased significantly (by 4-13%) after the devices had been placed. As for the type of the speed measuring devices, the vehicle activated speed limit signs had more positive effect than vehicle activated displays that showed the actual speed of a vehicle. The effectiveness of the devices depends on type and operation mode of the device and mostly on the place of application.

However, authors highlighted that these devices were the first in the country, and the effects were measured not long after the implementation. Therefore, new measurements are necessary to study the effects after the novelty of the devices disappear and drivers get used to the solution.

3.2 Methodology of the measurements

For the evaluation of the effects of vehicle activated speed warning signs, we have carried out speed measurements at 5 different locations. The locations varied according to their characteristics (type of area, reason of being placed), and according to the type of the devices (showing the speed limit, or the speed of the vehicle, colour, etc). Investigating different scenarios was important to be able to choose the device for our Pilot which proves to be the most effective:

- 9121 Győrszemere, road 83, 63+390 km section (47.5955862, 17.58716091)
- 1038 Budapest, Ezüsthegy street 34-42. (47.600180, 19.046550)
- 1097 Budapest, Határ road 30. (47.458197, 19.118598)
- 2162 Őrbottyán, road 2104, 12+770 km section (47.690259, 19.257157)
- 2162 Őrbottyán, road 2103, 7+980 km section (47.700312, 19.295032)

For modelling the effects of fixed site speed cameras, we have used a FamaLaser III (VHT-507/DVRM-G) speed camera and carried out measurements at 2 different locations:

- 2330 Dunaharaszti, road 510, 16+850 km section (47.373785, 19.099045)
- 1116 Budapest, Hunyadi Mátyás street 57. (47.448422, 19.024794)

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[4] Walter, L., Broughton, J. (2011) Effectiveness of speed indicator devices: An observational study in South London. Accident Analysis & Prevention Volume 43, Issue 4, July 2011, Pages 1355-1358

[5] Megalapozó vizsgálatok Sebességkijelzők hazai Szabványának elkészítéséhez. Biztonságkutató mérnöki iroda, Budapest, 2007. November

According to our assumptions, the used speed camera placed at a clearly visible place near the road is appropriate for modelling fixed cameras, which are also well known and visible for the drivers, especially for those who travel at the road section regularly. The main reason of this surrogate was that it made it possible to make speed measurements at the selected road sections also without the device. Detailed introduction of the locations can be found in chapter 3.3.

Figure 7: Using FamaLaser III to model a fixed site speed camera

3.2.1 Time of measurements

Measurements have been done in July and August of 2020, at weekdays, avoiding peak hours (to avoid distortion of potential congestions).

At each location (5 locations with vehicle activated speed warning signs, 2 locations with FamaLaser III speed camera):

- 9 hours of measurement have been carried out at 3 different weekdays with the speed signs operating / speed camera placed on the roadside;
- 9 hours of measurement have been carried out at 3 different weekdays when the speed signs didn't operate / speed camera was not placed on the roadside.

Vehicles approaching the devices were measured in one half of the measurement period, and vehicles leaving the devices was measured in the other.

We have cooperated with local municipalities and road operators, who arranged the shutdown of the vehicle activated speed warning signs for the duration of the measurements. The measurements were approved by the competent authorities.

3.2.2 Measuring equipment

For the measurements we used a digital Falcon Plus II intelligent microwave detector with an ARM[6] based computer (self-developed by KTI's subcontractor). The measurement principle of this detector is based on the Doppler effect. The detector unit is bouncing a microwave signal off to a desired target and analysing how the motion of the object has changed the frequency of the returned signal. Calculations of the Doppler effect accurately determine the velocity of the detected objects. Our unit has both a counting and tracking function. The equipment can also detect if the vehicle is arriving or leaving, therefore it is able to detect movement either uni- or bidirectional. During the measurement, the computer is recording the exact time and location of the measurement and the time vs. speed data continuously in microsecond intervals from the first moment the vehicle is within the range until it is detectable. Several speed samples are available for each vehicle, therefore speed vs. time or distance curves can be also generated. The radar unit is also equipped with a sophisticated communication module to provide the data remotely even during the measurement real time or afterwards.

Figure 8: The measuring equipment - Falcon Plus II intelligent microwave detector

3.2.3 Data processing

The maximum range of the equipment is 50 meters, but can vary according to weather conditions, colour and size of the measured vehicle, etc. The equipment can detect vehicles almost up to its own location (line), therefore we considered the last measured point 1 meter away from the equipment.

[6] ARM – a family of reduced instruction set computing (RISC) architectures for computer processors

Based on the above consideration and recorded time and speed data, the elaborated data processing software was able to calculate the distance of the vehicles from the measuring equipment in case of each fixed measurement time moment. For the analysis, the vehicle speeds were determined for every integer meter value by linear interpolation, starting from 1 meter away from the line of the measuring equipment. Note, that the measuring equipment was in line with the vehicle activated speed warning sign (they were mounted on the same column), or the speed camera.

Due to the operating principle of the equipment, the following difficulties had to be overcome:

- It is not possible to set up the equipment to see only one traffic direction. However, the speeds in different directions are recorded with different signs (arriving vehicles: positive; leaving vehicles: negative). This made it possible to remove unnecessary data measured in the undesired direction.
- In case of different directions, or sufficient following distance between two vehicles in the same direction, the equipment recognizes automatically if it measures a new vehicle. However, it cannot distinguish between vehicles moving close to each other in the same direction. Thus, it records the data in case of an arriving group of vehicles continuously, without interruption. We dealt this phenomenon using the counted distance values: in case of a close group of cars in the same direction, the distances calculated starting from the line of the equipment become high due to the large amount of continuously recorded data. As the maximum range of the instrument is 50 meters, data points calculated for a greater distance have been deleted. With this approach (assuming that the difference in speed within the close group of vehicles is minimal), we kept the data of the last vehicle of the group for each group of vehicles.

During the procession of the measurement data, further data filtering has been performed as follows:

- Measurements were deleted if the equipment did not “see” the vehicle at a distance of at least 20 meters.
- Measurements were deleted if the equipment did not record at least 10 measurement points (time moments) of a vehicle.
- Measurements were deleted if the distance between two adjacent measurement points for the same vehicle was higher than 5 meters. (In these cases, the coherent data probably belong to two different vehicles).
- Measurements were deleted if the average speed of a vehicle was lower than 40 km/h where the speed limit was 60 km/h, or was lower than 30 km/h if the speed limit was 50 km/h. (These values arose probably from traffic issues and distort the analysis).
- Measurements were deleted if the standard deviation of speed values of a vehicle was higher than 10% of the speed limit. (For some data sets, there was an unrealistic standard deviation due to measurement error).

3.3 Results of the measurements – vehicle activated speed warning signs

In the next section, locations of measurements are described in detail together with the results in separate sub-chapters.

Based on the results of the speed measurements, the following data have been calculated and presented both for the cases when the devices were operating and non-operating:

- average speeds (calculated for every 5 meters, starting from 1 m away from the device; both in case of the road section in front of, and behind the speed display device);
- v85 speeds (calculated for every 5 meters, starting from 1 m away from the device; both in case of the road section in front of, and behind the speed display device);
- ratio of vehicles exceeding the speed limit (calculated at the following distances from the devices: -50 m, -30 m, -1 m, 30 m, 50 m);
- Ratio of vehicles reducing speed (in case of vehicles approaching the device - from first measured point to -1 m)
- Ratio of vehicles reducing speed by at least 10% of speed limit (in case of vehicles approaching the device - from first measured point to -1 m)
- Ratio of vehicles reducing speed, in case of drivers who exceeded the speed limit when entering (in case of vehicles approaching the device - from first measured point to -1 m)
- Ratio of vehicles reducing speed by at least 10% of speed limit, in case of drivers who exceeded the speed limit when entering (in case of vehicles approaching the device - from first measured point to -1 m)
- Ratio of vehicles increasing speed (in case of vehicles leaving the device - from 1 m to last measured point)
- Ratio of vehicles increasing speed by at least 10% of speed limit (in case of vehicles leaving the device - from 1 m to last measured point)

3.3.1 Győrszemere, road 83

Location: 9121 Győrszemere, road 83, 63+360 km section

GPS: 47.5955862, 17.58716091

Type of area: Rural

AADT: 11305 vehicle units/day (share of HGVs: 12.4%)

Type of the device: 60 km/h speed limit, ”Lassíts!” (“Reduce speed!”) text and flashing yellow dots - only if speed limit is exceeded

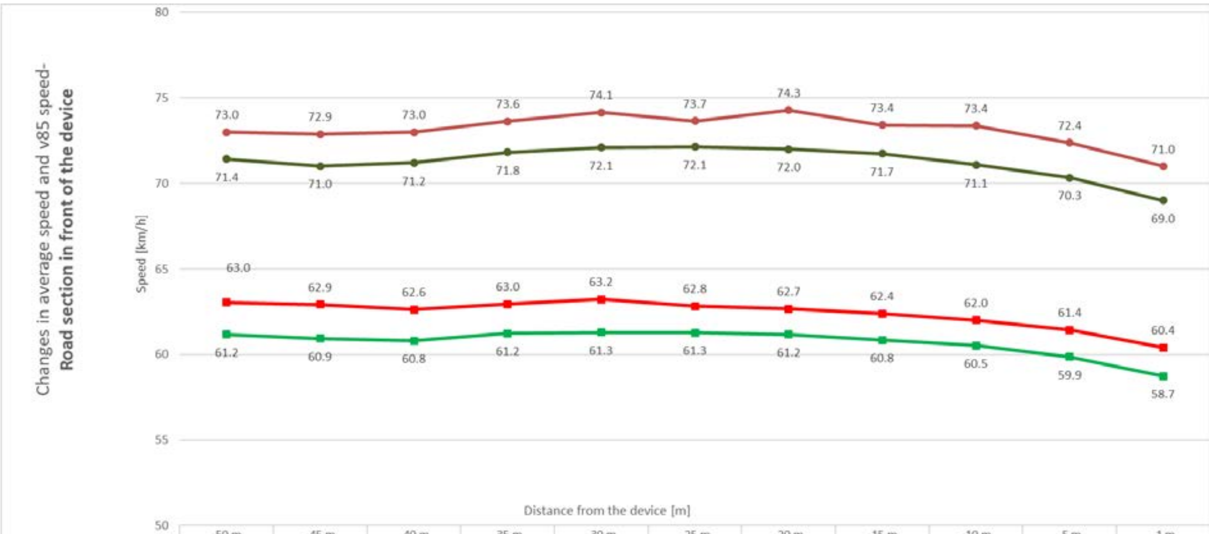
3.3.1.1 Description of the location

Figure 9: Measured section on road 83 with vehicle activated 60 km/h speed limit display

The measured road section is located in a rural area near the town of Győrszemere, on road 83 at the 63+360 km section. The section is on a 2x1 lane road and located before a small radius right curve. The 60 km/h speed limit board was placed there recently 60 m from the curve, in company of the 60 km/h speed limit sign 130 m from the curve. “No overtaking”, “Right hand curve” and “Narrow road ahead” warning traffic signs are also placed before the curve. The “No overtaking” sign is 130 m before, the “Right hand curve” and “Narrow road ahead” traffic signs are 220 m ahead of the curve. These fluorescent backgrounded traffic signs and the speed limit board aim to warn drivers for the small radius turn and to reduce the number of accidents at the location. There were many accidents at this location in recent years. Therefore, an additional “Other danger - accidents” traffic sign was placed, 170 m before the right turn.

3.3.1.2 Results of speed measurement

Values of the average and v85 speeds at different distances (both in case of the road section in front of, and behind the speed limit display) have been presented in the following Figure. Red lines indicate those cases when the device was not operating, green lines indicate data measured while the speed display was in operation. The number of measured vehicles has also been indicated.



	-50 m	-45 m	-40 m	-35 m	-30 m	-25 m	-20 m	-15 m	-10 m	-5 m	-1 m
average speed - device is not operating	63.0	62.9	62.6	63.0	63.2	62.8	62.7	62.4	62.0	61.4	60.4
v85 speed - device is not operating	73.0	72.9	73.0	73.6	74.1	73.7	74.3	73.4	73.4	72.4	71.0
num of vehicles - device is not operating	388	426	467	508	564	588	610	610	610	610	610
average speed - device is operating	61.2	60.9	60.8	61.2	61.3	61.3	61.2	60.8	60.5	59.9	58.7
v85 speed - device is operating	71.4	71.0	71.2	71.8	72.1	72.1	72.0	71.7	71.1	70.3	69.0
num of vehicles - device is operating	485	542	626	703	767	809	830	830	830	830	830

	-50 m	-45 m	-40 m	-35 m	-30 m	-25 m	-20 m	-15 m	-10 m	-5 m	-1 m
average speed - device is not operating	63.0	62.9	62.6	63.0	63.2	62.8	62.7	62.4	62.0	61.4	60.4
v85 speed - device is not operating	73.0	72.9	73.0	73.6	74.1	73.7	74.3	73.4	73.4	72.4	71.0
num of vehicles - device is not operating	388	426	467	508	564	588	610	610	610	610	610
average speed - device is operating	61.2	60.9	60.8	61.2	61.3	61.3	61.2	60.8	60.5	59.9	58.7
v85 speed - device is operating	71.4	71.0	71.2	71.8	72.1	72.1	72.0	71.7	71.1	70.3	69.0
num of vehicles - device is operating	485	542	626	703	767	809	830	830	830	830	830

Figure 10: Average and v85 speeds in front of/behind the device- Győrszemere, road 83

It can be clearly seen in the figure that both v85 and average speeds were slightly lower when the speed limit display was in operation (the difference in both cases was about 2 km/h), which indicates that the device is effective. The average speeds were somewhat above the allowed 60 km/h limit, however, when the device was in the operating state, they were only 58.7 km/h in the line of the digital display. The v85 speeds were well above the allowed speed limit.

There was no significant difference in the shape of the different curves in the measured road sections. In both the operating and non-operating states of the device, vehicle speeds were slightly reduced until the line of the speed limit display (by about 2-2.5 km/h). They increased 10 meters behind the display and then decreased somewhat again (probably) due to the sharp curve on the road.

The existing difference in speeds of arriving vehicles 50 meter away from the device, as well as the similar shape of the curves suggests that the speed reducing effect of the device arises more than 50 meters away from the line of the digital display. The characteristics of the location (the display can be seen from afar) can explain this phenomenon. Further data indicating the behaviour of drivers have been calculated and included in the next Tables.

Table 3: Ratio of vehicles exceeding the speed limit at different distances from the device - Győrszemere, road 83

	Distance from the device	-50 m	-30 m	-1 m	30 m	50 m
Ratio of vehicles exceeding the speed limit	**Device is not operating**	58.5%	56.9%	42.9%	48.7%	35.4%
	Device is operating	51.1%	49.3%	28.5%	30.2%	24.9%
	Difference	-7.4%	-7.6%	-14.4%	-18.5%	-10.5%

Table 4: Data characterizing driver behaviour in front of/behind the device - Győrszemere, road 83

Direction of vehicles	Data	**Device is not operating**	**Device is operating**	Difference
Vehicles approaching the device	Ratio of vehicles reducing speed (from first measured point to -1 m)	79.2%	80.7%	+1.5%
	Ratio of vehicles reducing speed by at least 10% of speed limit (from first measured point to -1 m)	20.7%	21.8%	+1.1%
	Ratio of vehicles reducing speed, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	88.9%	90.7%	+1.8%
	Ratio of vehicles reducing speed by at least 10% of speed limit, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	28.7%	32.6%	+3.9%
Vehicles leaving the device	Ratio of vehicles increasing speed (from 1 m to last measured point)	49.9%	56.2%	+6.3%
	Ratio of vehicles increasing speed by at least 10% of speed limit (from 1 m to last measured point)	5.2%	7.1%	+1.9%

Quite a high proportion of vehicles exceeded the speed limit at the measured road section (25-59% at the different sections). Based on the data, the digital speed limit display has proven to be effective in reducing the proportion of speeding vehicles. In the approach to the curve, speed also decreased when the display was not operating, as did the proportion of speeding vehicles. However, the decrease in the proportion of speeding vehicles was much more substantial when the device was in operation (only 28.5% drove above 60 km/h in the line of the device, when the display was operating, compared to 42.9%, when it wasn't). 50 meters behind the device, the proportion of speeding vehicles was even lower due to the start of the curve.

No significant differences were found in case of the further data on driver behaviour. Most of the drivers reduced their speed (79-80%) while they were approaching the device, due to the characteristics of the road section. However, when the device was in operation, a slightly higher proportion of drivers reduced their speed. The biggest difference (3.9%) was observed in the ratio of vehicles reducing speed by at least 6 km/h, among the drivers who exceeded the speed limit at the first measured point. However, it should also be noted that in case of the operating state of the device, the proportion of vehicles increasing speed when leaving the line of the display was higher. Compared to the non-operating state, this suggests that there were drivers who only slowed down/drove at a lower speed until the line of the device, and they accelerated after passing it.

3.3.2 Budapest, Határ road 30.

Location: 1097 Budapest, Határ road 30.

GPS: 47.458197, 19.118598

Type of area: Urban

AADT: no data

Type of the device: Green coloured speed display if driver is under speed limit (50 km/h). Red coloured speed display and "Lassíts!" ("Reduce speed!") text if the speed limit is exceeded.

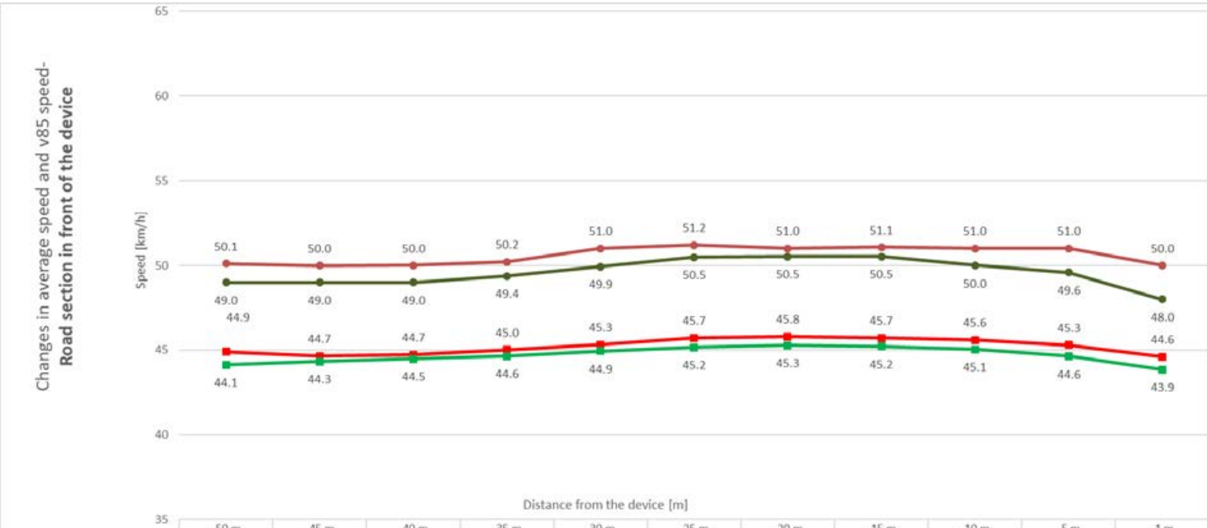
3.3.2.1 Description of the location

Figure 11: Határ road with vehicle activated speed warning sign

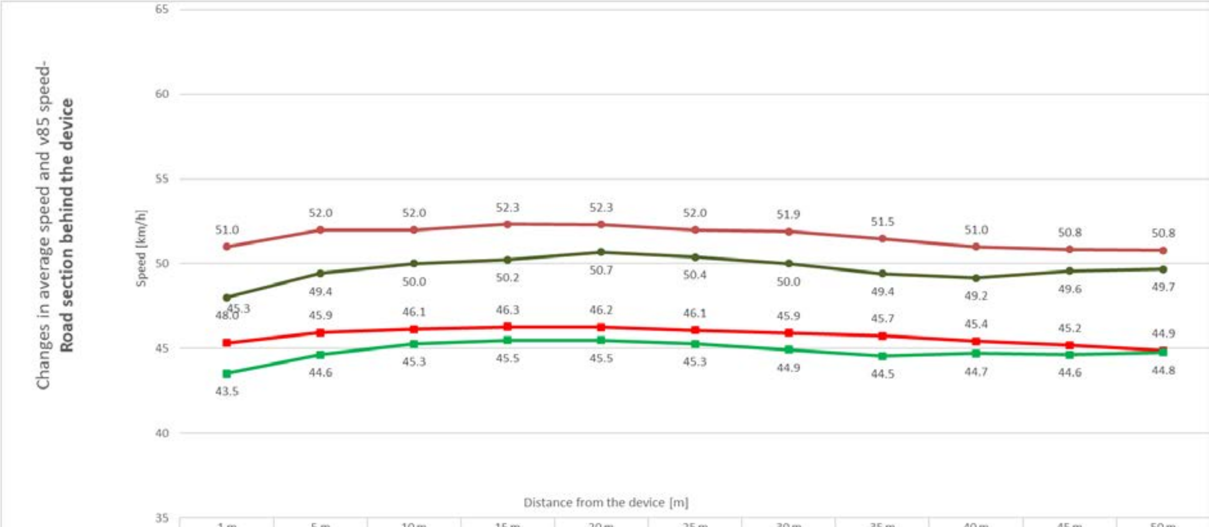
The Határ road is located in Budapest, at the north western boundary of the 19th district. It is a long, 2x1 layout straight road, with a heavy traffic including both passenger cars and heavy goods vehicles. The vehicle activated speed display board is mounted on a public lighting pole. The allowed speed is 50 km/h, valid on inhabited areas, but it is not indicated here with any particular traffic sign. Other danger or limiting traffic signs are not placed around. On the left side of the road there are only plants along the street, on the right side a pedestrian sidewalk and houses are located. The Határ road has priority over the connecting streets, so drivers may choose higher speeds, which can be dangerous. That was the reason of placing the speed display board over here.

3.3.2.1 *Results of speed measurement*

Values of the average and v85 speeds at different distances (both in case of the road section in front of, and behind the speed display) have been presented in the following Figure. Red lines indicate those cases when the device was not operating, green lines indicate data measured while the speed display was in operation. The number of measured vehicles has also been indicated.



	-50 m	-45 m	-40 m	-35 m	-30 m	-25 m	-20 m	-15 m	-10 m	-5 m	-1 m
average speed - device is not operating	44.9	44.7	44.7	45.0	45.3	45.7	45.8	45.7	45.6	45.3	44.6
v85 speed - device is not operating	50.1	50.0	50.0	50.2	51.0	51.2	51.0	51.1	51.0	51.0	50.0
num of vehicles - device is not operating	428	467	501	563	657	732	770	770	770	770	770
average speed - device is operating	44.1	44.3	44.5	44.6	44.9	45.2	45.3	45.2	45.1	44.6	43.9
v85 speed - device is operating	49.0	49.0	49.0	49.4	49.9	50.5	50.5	50.5	50.0	49.6	48.0
num of vehicles - device is operating	428	474	523	599	702	798	871	871	871	871	871



	1 m	5 m	10 m	15 m	20 m	25 m	30 m	35 m	40 m	45 m	50 m
average speed - device is not operating	45.3	45.9	46.1	46.3	46.2	46.1	45.9	45.7	45.4	45.2	44.9
v85 speed - device is not operating	51.0	52.0	52.0	52.3	52.3	52.0	51.9	51.5	51.0	50.8	50.8
num of vehicles - device is not operating	857	857	857	857	857	814	771	717	660	592	542
average speed - device is operating	43.5	44.6	45.3	45.5	45.5	45.3	44.9	44.5	44.7	44.6	44.8
v85 speed - device is operating	48.0	49.4	50.0	50.2	50.7	50.4	50.0	49.4	49.2	49.6	49.7
num of vehicles - device is operating	934	934	934	934	934	784	666	562	488	420	373

Figure 12: Average and v85 speeds in front of/behind the device- Budapest, Határ road

Compared to the first location (Győrszemere, road 83) which was at a rural road section, both average and v85 speeds were much lower at this location. Even v85 speeds were not, or only slightly above the speed limit. Here also both the v85 and average speeds were slightly lower when the digital speed display was in operation, but the difference was only about 0.5-1 km/h.

At this location, there wasn't any factor (a sharp curve, pedestrian crossing, etc.) influencing traffic at the measured road section (except for the vehicle activated speed display). We can see that the average and v85 speeds were fairly constant both 50 meters in front of, and 50 meters behind the device. However, the biggest difference in the shape of the red and green curves can be observed at the line of the speed display (at 1 m, and -1 m), where speeds were lower when the device was operating. Note that in this case, the speeds were increasing behind the device, reaching the same (or even slightly higher) speed level that was measured 50 meters in front of the device.

The main differences of the observed data from the previous location may be explained also by the following facts: due to higher traffic level, speeding is less common here. Furthermore, the drivers may see their own speed on the display only late due to traffic, so the speed reducing effect of the device arises later, only at the line of the display. These assumptions are also supported by the data of the following table. While the proportion of speeding vehicles was 25-50% at the rural road, this value ranged between 9 and 22% in this downtown section. The ratio of vehicles exceeding the speed limit was 4-8% lower in the different sections when the speed display was operating.

Table 5: Ratio of vehicles exceeding the speed limit at different distances from the device- Budapest, Határ road

	Distance from the device	-50 m	-30 m	-1 m	30 m	50 m
Ratio of vehicles exceeding the speed limit	**Device is not operating**	15.2%	18.0%	17.4%	21.9%	17.2%
	Device is operating	10.3%	14.1%	9.0%	14.4%	11.5%
	Difference	-4.9%	-3.9%	-8.4%	-7.5%	-5.7%

Table 6: Data characterizing driver behaviour in front of/behind the device- Budapest, Határ road

Direction of vehicles	Data	**Device is not operating**	**Device is operating**	Difference
Vehicles approaching the device	Ratio of vehicles reducing speed (from first measured point to -1 m)	63.9%	66.0%	+2.1%
	Ratio of vehicles reducing speed by at least 10% of speed limit (from first measured point to -1 m)	10.8%	7.8%	-3.0%
	Ratio of vehicles reducing speed, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	79.4%	83.0%	+3.6%
	Ratio of vehicles reducing speed by at least 10% of speed limit, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	21.9%	15.6%	-6.3%
Vehicles leaving the device	Ratio of vehicles increasing speed (from 1 m to last measured point)	54.1%	72.3%	+18.2%
	Ratio of vehicles increasing speed by at least 10% of speed limit (from 1 m to last measured point)	8.6%	15.2%	+6.6%

By examining the additional data of Table 6, we can conclude that the ratio of vehicles decreasing speed when approaching the device was higher when the display was operating. However, a higher proportion of drivers performed a significant slowdown (at least 5 km/h speed reduction) when the device was not operating, which cannot really be explained by the speed data. The ratio of vehicles reducing speed were somewhat lower (64-66%) than in case of the previously introduced rural road section (79-81%), but this can be explained by the lower average speed and much fewer speeding vehicles.

As we could see in the previous Figure also, the speeds were lower at the line of the device when it was operating, but speeds and the ratio of vehicles increasing speed were increased in this case behind the device. This also suggests that some drivers only slowed down at the line of the device, and accelerated right after passing it.

3.3.3 Budapest, Ezüsthegy street 34-42.

Location: 1038 Budapest, Ezüsthegy street 34-42.

GPS: 47.600180, 19.046550

Type of area: Urban

AADT: no data

Type of the device: 50 km/h speed limit, "Lassíts!" ("Reduce speed!") text and flashing yellow dots - only if speed limit is exceeded

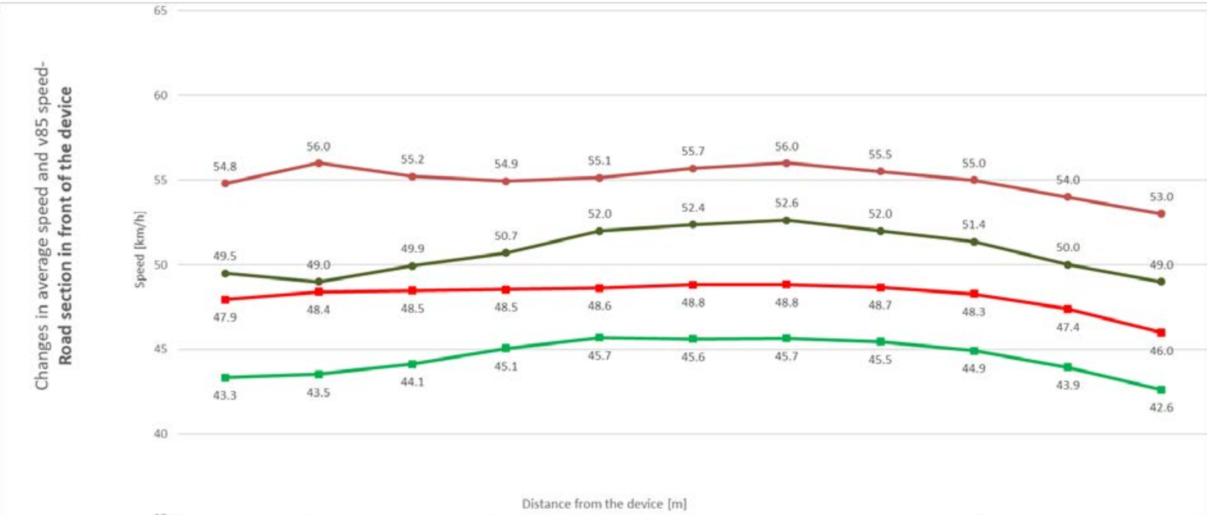
3.3.3.1 Description of the location

Figure 13: Measured section in Ezüsthegy street with vehicle activated speed warning sign

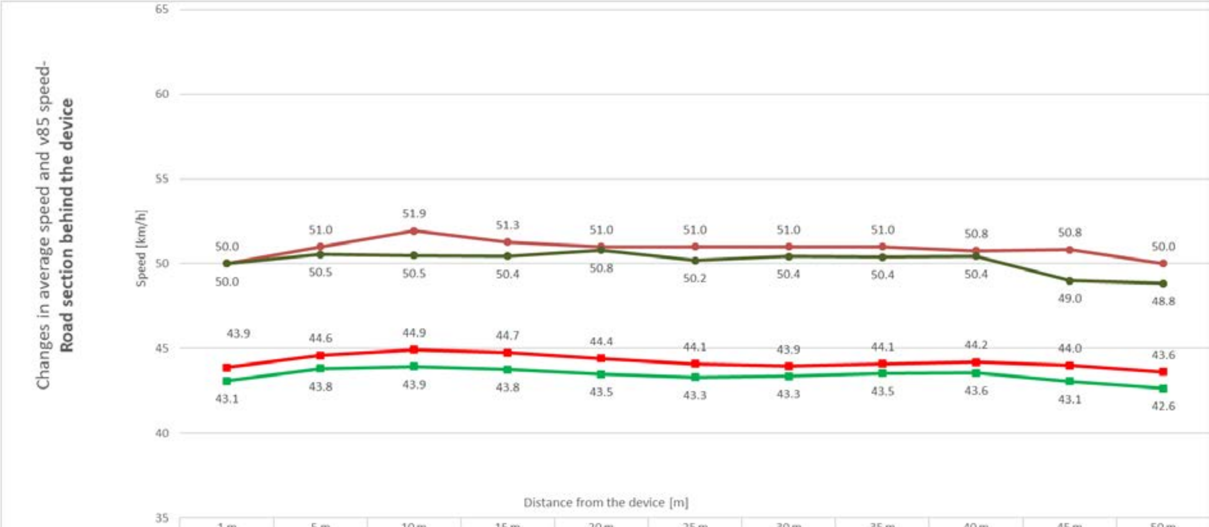
The device is located in the third district of Budapest, in an urban environment. The allocation of the road is 2x1 lanes. The vehicle activated 50km/h speed limit board is located at Ezüsthegy street, house number 38, on the opposite side of the family houses. The speed limit is 50 km/h in the city, there is no additional speed limit traffic sign. “Children crossing” and “Pedestrian crossing” danger traffic signs are placed 70 m from both sides before a pedestrian crossing. On the surface of the road, “Pedestrian crossing” pavement marking from both directions also grabs attention of the drivers. There is also an elementary school, which explains the need of the danger signs. The main reason why the device was placed here is the pedestrian crossing with a refuge island right after this straight road section (about 50 meters behind the device). The placement of the device is not quite appropriate, as it is in the middle of a bus stop. The pole falls within the opening range of the buses first door and makes it harder to get on and off the bus.

3.3.3.2 Results of speed measurement

Values of the average and v85 speeds at different distances (both in case of the road section in front of, and behind the speed limit display) have been presented in the following Figure. Red lines indicate those cases when the device was not operating, green lines indicate data measured while the display was in operation. The number of measured vehicles has also been indicated.



	-50 m	-45 m	-40 m	-35 m	-30 m	-25 m	-20 m	-15 m	-10 m	-5 m	-1 m
average speed - device is not operating	47.9	48.4	48.5	48.5	48.6	48.8	48.8	48.7	48.3	47.4	46.0
v85 speed - device is not operating	54.8	56.0	55.2	54.9	55.1	55.7	56.0	55.5	55.0	54.0	53.0
num of vehicles - device is not operating	209	242	289	344	425	484	564	564	564	564	564
average speed - device is operating	43.3	43.5	44.1	45.1	45.7	45.6	45.7	45.5	44.9	43.9	42.6
v85 speed - device is operating	49.5	49.0	49.9	50.7	52.0	52.4	52.6	52.0	51.4	50.0	49.0
num of vehicles - device is operating	220	253	318	451	598	736	814	814	814	814	814



	1 m	5 m	10 m	15 m	20 m	25 m	30 m	35 m	40 m	45 m	50 m
average speed - device is not operating	43.9	44.6	44.9	44.7	44.4	44.1	43.9	44.1	44.2	44.0	43.6
v85 speed - device is not operating	50.0	51.0	51.9	51.3	51.0	51.0	51.0	51.0	50.8	50.8	50.0
num of vehicles - device is not operating	738	738	738	738	738	631	564	505	445	386	318
average speed - device is operating	43.1	43.8	43.9	43.8	43.5	43.3	43.3	43.5	43.6	43.1	42.6
v85 speed - device is operating	50.0	50.5	50.5	50.4	50.8	50.2	50.4	50.4	50.4	49.0	48.8
num of vehicles - device is operating	504	504	504	504	504	490	415	315	254	204	160

Figure 14: Average and v85 speeds in front of/behind the device- Budapest, Ezüsthegy street

At this location, average speeds were lower than, and v85 speeds were somewhat over the speed limit. Compared to the previous locations, the difference between speeds beside the operating/non-operating state of the speed limit sign was bigger. The v85 and average speeds were 3-7 km/h lower when the speed limit display was in operation. The biggest difference could be observed at about 40-50 meters in front of the device.

At about 70 meters in front of the device there is a pedestrian crossing, and then a junction with a small street with car parking places immediately after that. This can have effect on the traffic arriving to the speed limit display. However, when the device was not operating, the measured speed weren't lower at the beginning of the measured section than in the line of the device. So we assume that the difference in the values of the green and red curves of the diagram arose mainly from the effect of the speed limit sign. It is interesting to observe that the speed reducing effect of the device arose here also more than 50 meters away (just like in case of the previous locations). However, the difference in speeds decreased from 7 km/h (distance from device: 40-50 m) to 3 km/h (distance from device: 0-30 m) as the vehicles were approaching the speed limit display.

Behind the device there were no big differences. When the speed limit sign was operating, the measured speeds were only 0.5-1 km/h lower.

We can conclude that, because of lower traffic level, the average and v85 speeds were somewhat higher here than in case of the other measured urban section (Határ road). In parallel we found that the effect of the vehicle activated speed limit sign was higher. The significant speed reducing effect (especially at 40-50 meters in front of the device) can also be seen based on the data of the following tables.

Table 7: Ratio of vehicles exceeding the speed limit at different distances from the device- Budapest, Ezüsthegy street

	Distance from the device	-50 m	-30 m	-1 m	30 m	50 m
Ratio of vehicles exceeding the speed limit	**Device is not operating**	32.1%	39.5%	14.2%	17.4%	14.2%
	Device is operating	12.7%	21.2%	11.3%	16.6%	11.3%
	Difference	-19.4%	-18.3%	-2.9%	-0.8%	-2.9%

Table 8: Data characterizing driver behaviour in front of/behind the device- Budapest, Ezüsthegy street

Direction of vehicles	Data	**Device is not operating**	**Device is operating**	Difference
Vehicles approaching the device	Ratio of vehicles reducing speed (from first measured point to -1 m)	80.0%	78.4%	-1.6%
	Ratio of vehicles reducing speed by at least 10% of speed limit (from first measured point to -1 m)	25.4%	28.3%	+2.9%
	Ratio of vehicles reducing speed, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	87.6%	96.4%	+8.8%
	Ratio of vehicles reducing speed by at least 10% of speed limit, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	28.8%	60.7%	+31.9%
Vehicles leaving the device	Ratio of vehicles increasing speed (from 1 m to last measured point)	55.1%	52.6%	-2.5%
	Ratio of vehicles increasing speed by at least 10% of speed limit (from 1 m to last measured point)	11.5%	13.5%	+2.0%

30-50 meters in front of the device, 32-40% of the drivers were speeding when the speed limit sign was not in operation. These values were 18-19% lower in the operating period. The ratio was even lower in the line of, and after the device.

80% of drivers reduced their speed also when the device was not operating (mainly due to traffic reasons, and because of the pedestrian crossing 50 meters behind the speed limit sign). Data of Table 8 indicates that the speed reducing effect was especially high in case of drivers who exceeded the speed limit when they entered the measured section (almost all, 96.4% of speeding vehicles reduced their speed when the device was operating, the reductions were at least 5 km/h in case of 60.7% of the measured vehicles).

About a half of vehicles increased speed after the device, which was a lower share than in the case of Határ road, but as we have mentioned earlier, the pedestrian crossing behind the device affected the traffic flow).

3.3.4 Őrbottyán, road 2104

Location: 2162 Őrbottyán, road 2104, 12+770 km section

GPS: 47.690259, 19.257157

Type of area: Urban, with rural nature

AADT: 6702 vehicle units/day (share of HVGs: 13.9%)

Type of the device: Blank display if driver is under the speed limit (50 km/h). Speed display with red light and "Lassíts!" ("Reduce speed!") text if speed limit is exceeded.

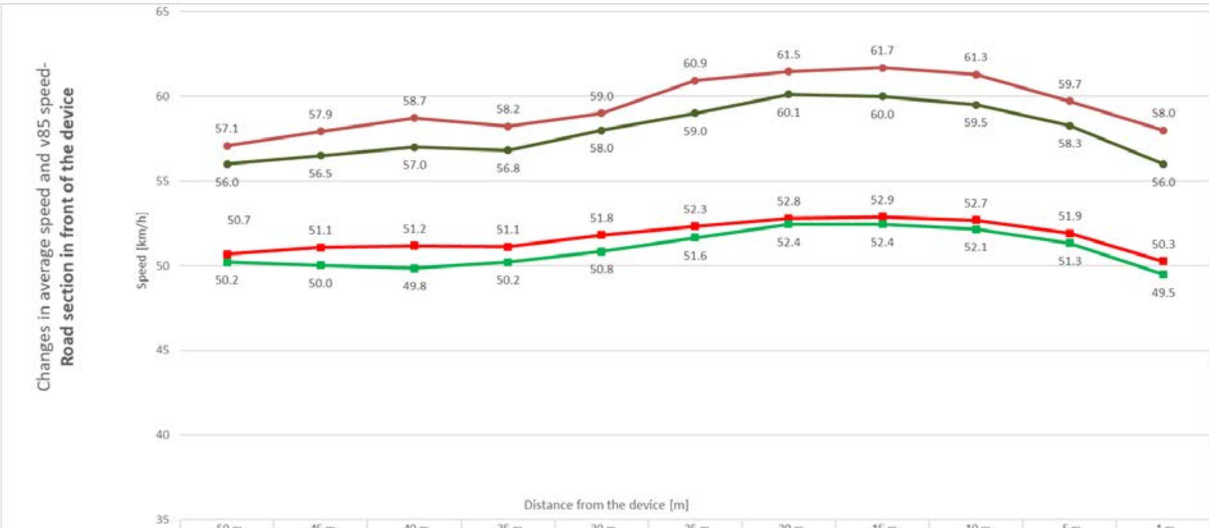
3.3.4.1 Description of the location

Figure 15: Őrbottyán (road 2104) with vehicle activated speed warning sign

The speed display board is located in the city of Őrbottyán, approximately 200 m after the boarder of the settlement. The number of the road is 2104, a 2x1 lane road. The device is a speed display board with “Lassíts” (“Reduce speed!”) text under the value of speed. The allowed speed limit inside the city is 50 km/h, the board is activated only if it is exceeded. There is no particular speed limit traffic sign or any other danger or limiting traffic sign around the section. Although the device is inside the city border, the nearby environment shows rural territorial character that encourages drivers to drive on higher speeds, which carries higher risk of accidents.

3.3.4.2 Results of speed measurement

Values of the average and v85 speeds at different distances (both in case of the road section in front of, and behind the speed display device) have been presented in the following Figure. Red lines indicate those cases when the device was not operating, green lines indicate data measured while the speed display was in operation. The number of measured vehicles has also been indicated.



	-50 m	-45 m	-40 m	-35 m	-30 m	-25 m	-20 m	-15 m	-10 m	-5 m	-1 m
average speed - device is not operating	50.7	51.1	51.2	51.1	51.8	52.3	52.8	52.9	52.7	51.9	50.3
v85 speed - device is not operating	57.1	57.9	58.7	58.2	59.0	60.9	61.5	61.7	61.3	59.7	58.0
num of vehicles - device is not operating	131	165	219	265	321	469	608	608	608	608	608
average speed - device is operating	50.2	50.0	49.8	50.2	50.8	51.6	52.4	52.4	52.1	51.3	49.5
v85 speed - device is operating	56.0	56.5	57.0	56.8	58.0	59.0	60.1	60.0	59.5	58.3	56.0
num of vehicles - device is operating	105	138	168	194	252	429	603	603	603	603	603

Figure 16: Average and v85 speeds in front of/behind the device- Őrbottyán, road 2104

Similar to the results of Határ road, only a very slight speed reduction was observed here (speeds were 1-1.5 km/h lower when the vehicle activated speed display was operating), even though the average and v85 speeds were high compared to the previous two urban road sections. There was no significant difference in the shape of the curves, in both the operating and non-operating states of the device, the vehicles slightly increased speed at the measured first 30 meters, and then reduced it until the line of the device. In case of vehicles leaving the device, speeds in case of the operating state of the device were higher than in the other case. These values suggest that this device (placed inside the city border but close, with an environment that shows rural territorial character) had only very limited effect on vehicle speeds.

Based on the data of the following table, the ratio of speeding vehicles was around 50-57% at the section in front of the device, which is quite similar to the data of the rural road section near Győrszemere. At that section vehicles reduced speed after the device due to the speed limit sign and the curve on the road. However, at this location, the average speed and the ratio of speeding vehicles were even higher behind the speed sign.

Table 9: Ratio of vehicles exceeding the speed limit at different distances from the device- Őrbottyán, road 2104

	Distance from the device	-50 m	-30 m	-1 m	30 m	50 m
Ratio of vehicles exceeding the speed limit	**Device is not operating**	57.3%	55.1%	50.8%	66.1%	65.8%
	Device is operating	49.5%	50.0%	50.1%	67.5%	68.5%
	Difference	-7.8%	-5.1%	-0.7%	+1.4%	+2.7%

Table 10: Data characterizing driver behaviour in front of/behind the device- Őrbottyan, road 2104

Direction of vehicles	Data	**Device is not operating**	**Device is operating**	Difference
Vehicles approaching the device	Ratio of vehicles reducing speed (from first measured point to -1 m)	74.8%	79.9%	+5.1%
	Ratio of vehicles reducing speed by at least 10% of speed limit (from first measured point to -1 m)	21.7%	26.2%	+4.5%
	Ratio of vehicles reducing speed, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	84.2%	90.7%	+6.5%
	Ratio of vehicles reducing speed by at least 10% of speed limit, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	31.5%	37.1%	+5.6%
Vehicles leaving the device	Ratio of vehicles increasing speed (from 1 m to last measured point)	82.4%	83.6%	+1.2%
	Ratio of vehicles increasing speed by at least 10% of speed limit (from 1 m to last measured point)	25.0%	23.8%	-1.2%

Table 10 shows some positive effects of the speed display, but these mainly arise from the fact that these values are calculated from the first measured point, which was around 20-30 meters in many cases. Close to the device, the reduction of v85 and average speeds could be observed, but this effect was gone at the line of the display. 82-83% of vehicles increased speed after the device which is a much higher ratio than in the case of the previously introduced road sections.

The data shows that if there is no physical reason to slow down (e.g., a curve, pedestrian crossing, etc.), only the traffic rules demand this, then the vehicle activated speed display does not have any great effect on the road section behind the device.

3.3.5 Őrbottyán, road 2103

Location: 2162 Őrbottyán, road 2103, 7+980 km section

GPS: 47.700312, 19.295032

Type of area: Urban

AADT: 2234 vehicle units/day (share of HVGs: 6.5%)

Type of the device: Blank display if driver is under the speed limit (50 km/h). Speed display with red light and "Lassíts!" ("Reduce speed!") text if speed limit is exceeded.

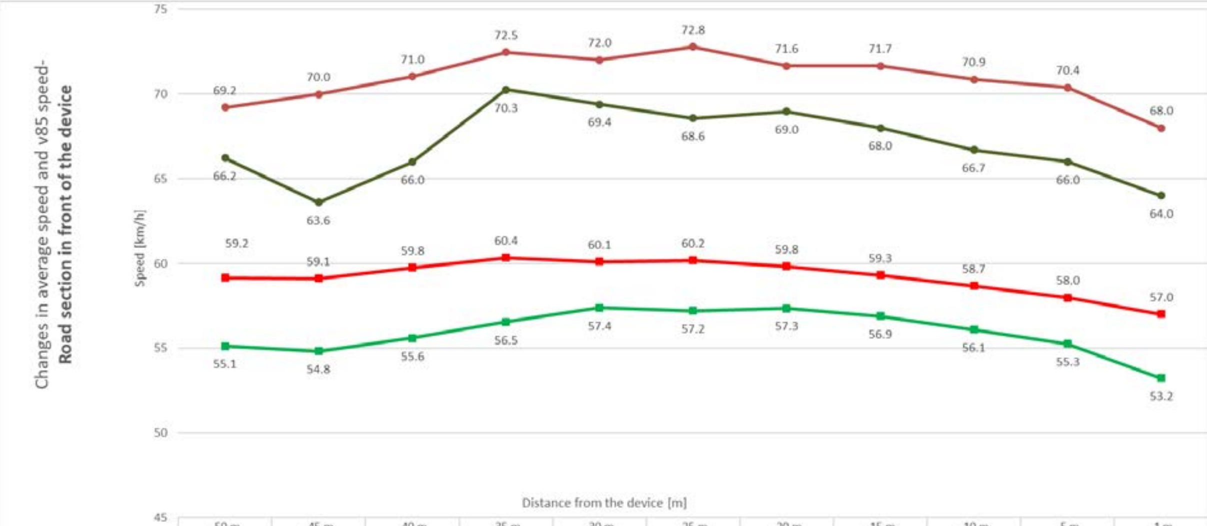
3.3.5.1 Description of the location

Figure 17: Őrbottyán (road 2103) with vehicle activated speed warning sign

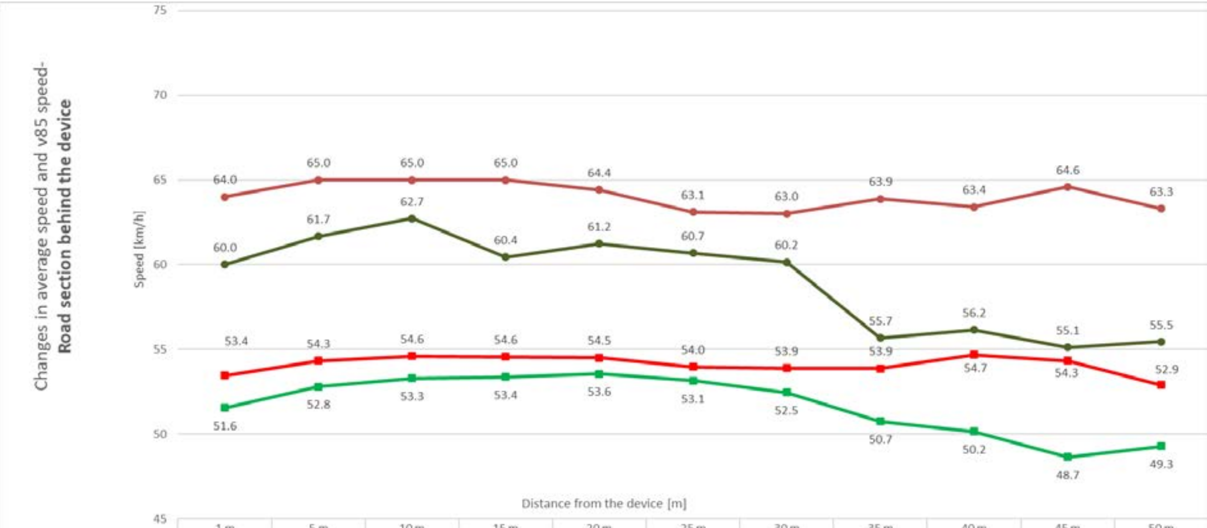
The last measurement of a vehicle activated speed display was carried out in Őrbottyán, on the road 2103. The layout of the road is 2x1 lanes. The device is a vehicle activated speed display board, which only displays actual speed and "Lassíts!" ("Reduce speed!") text if the speed limit is exceeded. The board is placed right after the residential area sign, on Rákóczi Ferenc street at house number 213, that is part of road 2103 inside the city. The speed limit here is 50 km/h, without any additional speed limit traffic sign. No other danger or limit warning traffic signs are applied around the spot. On the one side of the road there are only trees, and houses on the other side are quite far away from the road. This environment can imply higher vehicle speeds. There is no high traffic on this road section.

3.3.5.2 Results of speed measurement

Values of the average and v85 speeds at different distances (both in case of the road section in front of, and behind the speed display device) have been presented in the following Figure. Red lines indicate those cases when the device was not operating, green lines indicate data measured while the speed display was in operation. The number of measured vehicles has also been indicated.



	-50 m	-45 m	-40 m	-35 m	-30 m	-25 m	-20 m	-15 m	-10 m	-5 m	-1 m
average speed - device is not operating	59.2	59.1	59.8	60.4	60.1	60.2	59.8	59.3	58.7	58.0	57.0
v85 speed - device is not operating	69.2	70.0	71.0	72.5	72.0	72.8	71.6	71.7	70.9	70.4	68.0
num of vehicles - device is not operating	97	121	137	161	172	183	186	186	186	186	186
average speed - device is operating	55.1	54.8	55.6	56.5	57.4	57.2	57.3	56.9	56.1	55.3	53.2
v85 speed - device is operating	66.2	63.6	66.0	70.3	69.4	68.6	69.0	68.0	66.7	66.0	64.0
num of vehicles - device is operating	40	52	73	100	146	164	169	169	169	169	169



	1 m	5 m	10 m	15 m	20 m	25 m	30 m	35 m	40 m	45 m	50 m
average speed - device is not operating	53.4	54.3	54.6	54.6	54.5	54.0	53.9	53.9	54.7	54.3	52.9
v85 speed - device is not operating	64.0	65.0	65.0	65.0	64.4	63.1	63.0	63.9	63.4	64.6	63.3
num of vehicles - device is not operating	199	199	199	199	199	189	159	128	96	69	48
average speed - device is operating	51.6	52.8	53.3	53.4	53.6	53.1	52.5	50.7	50.2	48.7	49.3
v85 speed - device is operating	60.0	61.7	62.7	60.4	61.2	60.7	60.2	55.7	56.2	55.1	55.5
num of vehicles - device is operating	78	78	78	78	78	64	46	31	22	15	14

Figure 18: Average and v85 speeds in front of/behind the device- Őrbottyán, road 2103

Among the urban road sections, this location was characterized by the highest average and v85 speeds, well above the allowed 50 km/h (same level as at the rural section with 60 km/h speed limit). The device has been placed right after the residential area sign, the visual appearance of the location implies higher vehicle speeds. As it can be seen from the measured number of vehicles, the traffic here is very low. Authors assume that the small sample size can also affect here the conclusions of the measurements; To address this, we only examine the speed at the road section 30 metres in front of and behind the device, where we had data of at least 100 vehicles.

Both the v85 and average speeds were lower when the digital speed limit display was in operation (the difference was about 2.5-4 km/h), indicating the effectiveness of the device. However, even at the line of the device, the average speed was above the speed limit.

In both the operating and non-operating states of the device, vehicle speeds were slightly reduced until the line of the speed limit display (by about 3-5 km/h, from the measured point 30 meter in front of the device). This speed remained fairly constant also behind the device.

Further data indicating the behaviour of drivers have been calculated and included in the next Tables.

Table 11: Ratio of vehicles exceeding the speed limit at different distances from the device- Őrbottyán, road 2103

	Distance from the device	-50 m	-30 m	-1 m	30 m	50 m
Ratio of vehicles exceeding the speed limit	**Device is not operating**	75.3%	75.6%	57.8%	62.9%	58.3%
	Device is operating	70.0%	72.6%	47.4%	60.9%	57.1%
	Difference	-5.3%	-3.0%	-10.4%	-2.0%	-1.2%

Table 12: Data characterizing driver behaviour in front of/behind the device- Őrbottyan, road 2103

Direction of vehicles	Data	**Device is not operating**	**Device is operating**	Difference
Vehicles approaching the device	Ratio of vehicles reducing speed (from first measured point to -1 m)	91.4%	91.1%	-0.3%
	Ratio of vehicles reducing speed by at least 10% of speed limit (from first measured point to -1 m)	44.1%	40.8%	-3.3%
	Ratio of vehicles reducing speed, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	94.6%	95.3%	+0.7%
	Ratio of vehicles reducing speed by at least 10% of speed limit, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	50.0%	48.8%	-1.2%
Vehicles leaving the device	Ratio of vehicles increasing speed (from 1 m to last measured point)	55.3%	69.2%	+13.9%
	Ratio of vehicles increasing speed by at least 10% of speed limit (from 1 m to last measured point)	13.1%	12.8%	-0.3%

This location had the highest ratio of speeding vehicles 30 meters in front of the device (75.6%, 72.6%). The values decreased when approaching the line of the device. In case of the operating state of the speed display, 47.4% speeded there, much fewer than in case of the non-operating state (57.8%). However, the ratio of speeding vehicles increased again behind the device.

Due to arriving at the residential area at high speed, almost all vehicles decreased speed even without the operation of the device. In case of this data, there was no difference between the two states of the speed display. Note, that behind the device, more vehicles speeded up in case of the operating state, similarly to the observations of many previous locations.

3.3.6 Conclusions – Effects of vehicle activated speed warning signs

To summarize the main conclusions of the measurements carried out at locations of vehicle activated speed warning signs, the main data have been collected at the following table from the different locations.

Table 13: Main results and conclusions of measurements at locations of vehicle activated speed warning signs

<table>
<tr><th>Location:</th><th>1.Győrszemere, road 83</th><th>2. Budapest, Határ road 30</th><th>3. Budapest, Ezüsthegy street 34-42.</th><th>4. Őrbottyán, road 2104</th><th>5. Őrbottyán, road 2103</th></tr>
<tr><td>Type of area:</td><td>rural</td><td>urban, heavy traffic</td><td>urban, lower traffic</td><td>urban, with rural nature, close to city border</td><td>Urban, close to city border, low traffic</td></tr>
<tr><td>Speed limit:</td><td>60 km/h</td><td>50 km/h</td><td>50 km/h</td><td>50 km/h</td><td>50 km/h</td></tr>
<tr><td>Type of the device:</td><td>speed limit display (60 kmh)</td><td>speed display (speeding: red numbers, below limit: green numbers)</td><td>speed limit display (50 km/h)</td><td>speed display (speeding: red numbers, below limit: blank)</td><td>speed display (speeding: red numbers, below limit: blank)</td></tr>
<tr><td>Other factors affecting traffic:</td><td>curve behind the device</td><td>heavy traffic, HVGs</td><td>pedestrian crossing in front of, and behind the device</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">Main conclusions from speed diagram (vehicles approaching the devices):</td><td>- avg. speeds were slightly above the speed limit
- avg. and v85 speeds were 2 km/h lower when the device was operating
- vehicle speeds decreased by about 2-2.5 km/h (from -50m to the line of the device)</td><td>- avg. speeds were much lower than the speed limit
- avg. and v85 speeds were only 0.5-1 km/h lower when the device was operating
- vehicle speeds remained constant in front of the device</td><td>- avg. speeds were slightly lower than the speed limit
- avg. and v85 speeds were 3-7 km/h lower when the device was operating
- vehicle speeds decreased by about 3 km/h (from -30m to the line of the device)</td><td>- avg. speeds were slightly above the speed limit
- avg. and v85 speeds were 1-1.5 km/h lower when the device was operating
- vehicles slightly increased speed at the measured first 30 meters, and then reduced it until the line of the device</td><td>- avg. speeds were above the speed limit
- avg. and v85 speeds were 2.5-4 km/h lower when the device was operating
- vehicle speeds were reduced by 3-5 km/h until the line of the speed limit display
- small sample size can affect the conclusion</td></tr>
<tr><td colspan="5">speed reducing effect of the devices arose more than 50 meters away from the line of the digital display in all cases</td></tr>
<tr><td>Main conclusions from speed diagram (vehicles leaving the devices):</td><td colspan="5">- the results in all cases suggest that there were many drivers who only slowed down/drove at a lower speed until the line of the device, and accelerated after passing it
- average and v85 speeds didn't increase behind the device only if there were physical reason to keep speed lower (e.g. curve, pedestrian crossing behind the device)</td></tr>
<tr><td>Ratio of vehicles exceeding the speed limit at the line of device</td><td>- device was not operating: 42.9%
- device was operating: 28.5%
- decrease: 33.6%</td><td>- device was not operating: 17.4%
- device was operating: 9.0%
- decrease: 48.3%</td><td>- device was not operating: 14.2%
- device was operating: 11.3%
- decrease: 20.4%</td><td>- device was not operating: 50.8%
- device was operating: 50.1%
- decrease: 1.4%</td><td>- device was not operating: 57.8%
- device was operating: 47.4%
- decrease: 18.0%</td></tr>
</table>

According to our measurements, the most favourable effects of the vehicle activated speed warning signs could be observed at the 1. and 3. location (and the 5. location, but the sample size there were small). At these locations, vehicle speeds were much lower in the operating state of the device, than in the other case. At the 3. location, the decrease in average and v85 speeds were higher, while at the 1. location a bigger decrease was achieved in the ratio of vehicles exceeding the speed limit (at the line of the device).

These two locations (Győrszemere and Ezüsthegy street) had two similar properties:

- These were the only locations, where a vehicle activated speed limit sign was placed (and not a speed display sign). This result, i.e. vehicle activated speed limit signs seem to be more effective in reducing vehicle velocities than speed display signs – is in line with previous studies from literature.
- At both locations, a physical reason (a curve / a pedestrian crossing) can be found, justifying the application of the device.

We have found from our results that average and v85 speeds didn't increase behind the device only if there were any physical reason to keep speed lower, which also highlight the importance of these two locations.

The difference between the 1. and 3. location was that the first location is a rural road section with 60 km/h speed limit (the default 90 km/h speed limit is reduced at the section), and the average speeds were above this speed limit; while the third location is inside the city and the vehicle activated speed limit sign only confirms the default 50 km/h speed limit. Average speeds here were slightly lower than the speed limit even in the case when the device was not operating.

3.4 Results of the measurements – fixed speed cameras

Locations of measurements and results related to fixed site speed cameras are presented in this sub-chapter. The same data have been calculated as in the previous cases. When measuring the vehicle speeds at these locations, the measuring radar was hidden behind the windscreen of a civil car, parking near the road. The FamaLaser representing the fixed speed camera has been placed in the line of the hidden radar, between the civil car and the road.

3.4.1 Dunaharaszti, road 510 (speed camera)

Location: 2330 Dunaharaszti, road 510, 16+850 km section

GPS: 47.373785, 19.099045

Type of area: Urban (with rural nature)

AADT: 16689 vehicle units/day (share of HVGs: 3.8%)

Type of the device: FamaLaser III (VHT-507/DVRM-G) speed camera

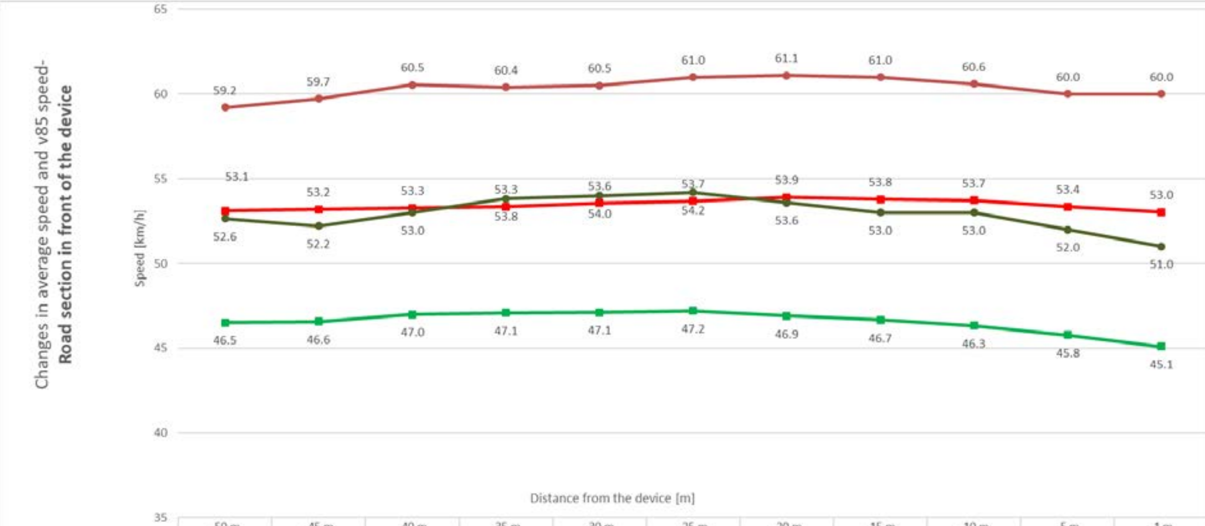
3.4.1.1 Description of the location

Figure 19: Measured section in Dunaharaszti

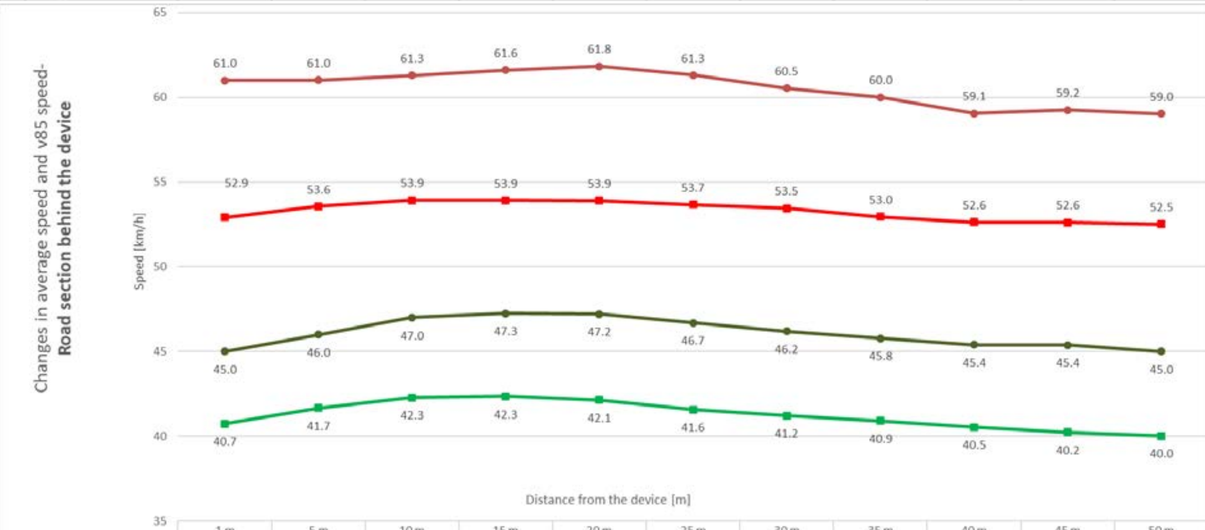
The location of the speed measurement was in the city of Dunaharaszti, on road 510. The road layout here is 2x1 lanes. The speed measuring device was placed at the 16+850 km section, on the right side of the road, according to ascending sectioning. The speed limit is 50 km/h due to the inhabited area, there are no added speed limiting traffic signs. Furthermore, there are no other limitations or danger warning signs. The environment seems rural because the houses are quite far from the road on the one side of the road, on the other side there are only trees (and a guard rail) alongside. A sidewalk is placed near the houses. No pedestrian traffic can be expected across the road.

3.4.1.2 Results of speed measurement

Values of the average and v85 speeds at different distances (both in case of the road section in front of, and behind the speed camera) have been presented in the following Figure. Red lines indicate those cases when the speed camera was not placed on the roadside, green lines indicate data measured while the speed camera was placed there. The number of measured vehicles has also been indicated.



Distance from the device [m]	-50 m	-45 m	-40 m	-35 m	-30 m	-25 m	-20 m	-15 m	-10 m	-5 m	-1 m
average speed - without speed camera	53.1	53.2	53.3	53.3	53.6	53.7	53.9	53.8	53.7	53.4	53.0
v85 speed - without speed camera	59.2	59.7	60.5	60.4	60.5	61.0	61.1	61.0	60.6	60.0	60.0
num of vehicles - without speed camera	220	250	270	304	340	386	414	414	414	414	414
average speed - with speed camera	46.5	46.6	47.0	47.1	47.1	47.2	46.9	46.7	46.3	45.8	45.1
v85 speed - with speed camera	52.6	52.2	53.0	53.8	54.0	54.2	53.6	53.0	53.0	52.0	51.0
num of vehicles - with speed camera	367	416	456	506	557	620	661	661	661	661	661



Distance from the device [m]	1 m	5 m	10 m	15 m	20 m	25 m	30 m	35 m	40 m	45 m	50 m
average speed - without speed camera	52.9	53.6	53.9	53.9	53.9	53.7	53.5	53.0	52.6	52.6	52.5
v85 speed - without speed camera	61.0	61.0	61.3	61.6	61.8	61.3	60.5	60.0	59.1	59.2	59.0
num of vehicles - without speed camera	842	842	842	842	842	764	676	589	531	468	409
average speed - with speed camera	40.7	41.7	42.3	42.3	42.1	41.6	41.2	40.9	40.5	40.2	40.0
v85 speed - with speed camera	45.0	46.0	47.0	47.3	47.2	46.7	46.2	45.8	45.4	45.4	45.0
num of vehicles - with speed camera	730	730	730	730	730	593	524	452	387	343	313

Figure 20: Average and v85 speeds in front of/behind the speed camera- Dunaharaszti, road 510

Significant effect of the speed camera on both the v85 and average speeds can be clearly seen in the figures. The v85 speeds were 6.5-7.5 km/h lower, while the average speeds were 6.5-7 km/h lower, when the speed camera was on the roadside. The difference was even bigger close to the device: the average speed was 7.5-8 km/h lower there. These differences are much bigger than in case of the vehicle activated speed warning signs. With the speed camera on the roadside, even the v85 speeds were just slightly above the allowed speed limit (average speeds were only around 45-47 km/h).

The differences could be observed also 50 meters in front of the device, indicating that the speed reducing effect arise more than 50 meters away. However, while the average speed was constant in the measured section in front of the device without the speed camera, a 2km/h speed reduction could be observed from -25 meters until the line of the camera in the other case.

The speeds did not increase significantly in the 50-meter-long section behind the camera.

The positive effects of the speed camera can also be seen from the data in the next tables.

Table 14: Ratio of vehicles exceeding the speed limit at different distances from speed camera- Dunaharaszti, road 510

	Distance from the device	-50 m	-30 m	-1 m	30 m	50 m
Ratio of vehicles exceeding the speed limit	**Without speed camera**	69.5%	67.6%	58.7%	66.1%	61.6%
	With speed camera	24.0%	28.0%	4.5%	4.2%	3.5%
	Difference	-45.5%	-39.6%	-54.2%	-61.9%	-58.1%

Table 15: Data characterizing driver behaviour in front of/behind the speed camera- Dunaharaszti, road 510

Direction of vehicles	Data	**Without speed camera**	**With speed camera**	Difference
Vehicles approaching the speed camera	Ratio of vehicles reducing speed (from first measured point to -1 m)	58.9%	78.2%	+19.3%
	Ratio of vehicles reducing speed by at least 10% of speed limit (from first measured point to -1 m)	7.5%	18.0%	+10.5%
	Ratio of vehicles reducing speed, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	62.0%	89.0%	+27.0%
	Ratio of vehicles reducing speed by at least 10% of speed limit, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	9.5%	30.9%	+21.4%
Vehicles leaving the speed camera	Ratio of vehicles increasing speed (from 1 m to last measured point)	54.2%	66.8%	+12.6%
	Ratio of vehicles increasing speed by at least 10% of speed limit (from 1 m to last measured point)	6.5%	10.7%	+4.2%

This was the location where the ratio of speeding vehicles was the highest in the base case (59-69%). With the speed camera on the roadside, these ratios were greatly reduced. In the line of the device only 4.5% of drivers exceeded the speed limit, which is lower than in any case from the previous locations with vehicle activated speed warning signs. The ratio remained low also behind the camera.

Much bigger positive effects could be observed in further data on the behaviour of drivers also, than in case of the locations with vehicle activated speed warning signs. The ratio of vehicles reducing speed increased by 19.3%. Almost 90% of speeding vehicles reduced speed when the camera was on the roadside (compared to the 62% without the device). However, with the speed camera on the roadside, the proportion of vehicles increasing speed as leaving the line of the device was higher than in the reference case without the speed camera.

3.4.2 Budapest, Hunyadi Mátyás street 57. (speed camera)

Location: 1116 Budapest, Hunyadi Mátyás street 57.

GPS: 47.448422, 19.024794

Type of area: Urban

AADT: no data

Type of the device: FamaLaser III (VHT-507/DVRM-G) speed camera

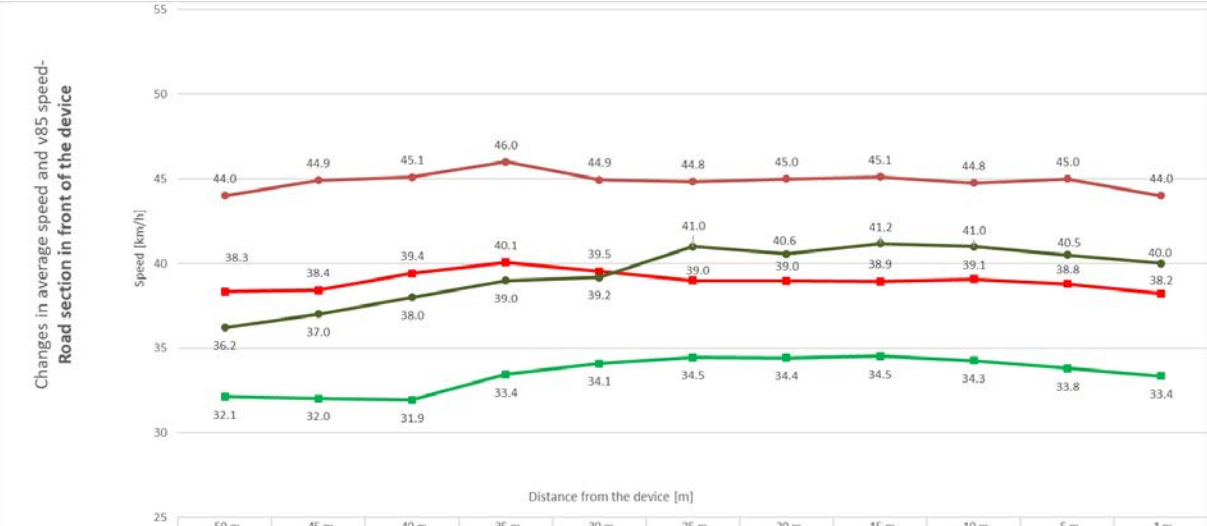
3.4.2.1 Description of the location

Figure 21: Measured section in Budapest, Hunyadi Mátyás street

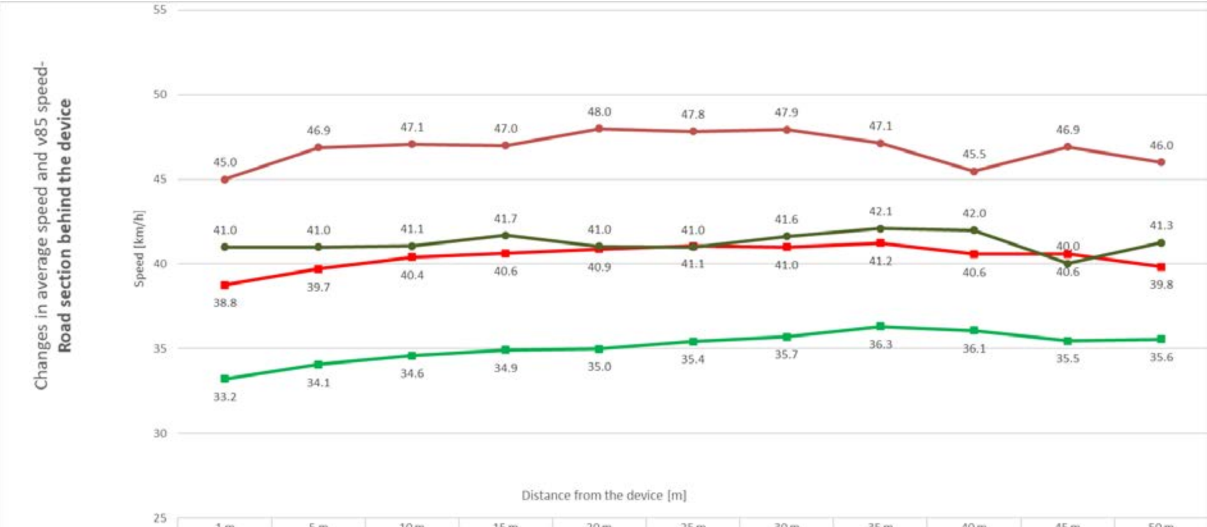
The spot of the speed measurement was in the 11th district of Budapest, at Hunyadi Mátyás street 57. The device was placed alongside the 2x1 lane layout road. The speed limit is 40 km/h along the Hunyadi Mátyás street, the 40 km/h traffic signs are placed at every intersection. There are no other limiting or danger warning traffic signs near the section, except the "No stopping" traffic signs on the other side of the street. There is a sport centre on the side of the street separated with a concrete fence, and a bus stop nearby. On the other side, channel ditches, sidewalks and houses are located. The sport centre and the bus stop generates pedestrian traffic, children often walk in the area. Due to the fact that it is a straight, wide road with priority, drivers often ignore speed limit, which means higher risk of accidents. However, the police often make speed measurements here also; therefore, some drivers expect to be checked. We did not consider that as a distortion factor as most of the drivers know the places of fixed site speed cameras also.

3.4.2.2 Results of speed measurement

Values of the average and v85 speeds at different distances (both in case of the road section in front of, and behind the speed camera) have been presented in the following Figure. Red lines indicate those cases when the speed camera was not placed on the roadside, green lines indicate data measured while the speed camera was placed there. The number of measured vehicles has also been indicated.



Distance	-50 m	-45 m	-40 m	-35 m	-30 m	-25 m	-20 m	-15 m	-10 m	-5 m	-1 m
average speed - without speed camera	38.3	38.4	39.4	40.1	39.5	39.0	39.0	38.9	39.1	38.8	38.2
v85 speed - without speed camera	44.0	44.9	45.1	46.0	44.9	44.8	45.0	45.1	44.8	45.0	44.0
num of vehicles - without speed camera	50	67	100	137	189	239	279	279	279	279	279
average speed - with speed camera	32.1	32.0	31.9	33.4	34.1	34.5	34.4	34.5	34.3	33.8	33.4
v85 speed - with speed camera	36.2	37.0	38.0	39.0	39.2	41.0	40.6	41.2	41.0	40.5	40.0
num of vehicles - with speed camera	37	45	61	90	122	175	217	217	217	217	217



Distance	1 m	5 m	10 m	15 m	20 m	25 m	30 m	35 m	40 m	45 m	50 m
average speed - without speed camera	38.8	39.7	40.4	40.6	40.9	41.1	41.0	41.2	40.6	40.6	39.8
v85 speed - without speed camera	45.0	46.9	47.1	47.0	48.0	47.8	47.9	47.1	45.5	46.9	46.0
num of vehicles - without speed camera	322	322	322	322	322	289	240	166	111	73	49
average speed - with speed camera	33.2	34.1	34.6	34.9	35.0	35.4	35.7	36.3	36.1	35.5	35.6
v85 speed - with speed camera	41.0	41.0	41.1	41.7	41.0	41.0	41.6	42.1	42.0	40.0	41.3
num of vehicles - with speed camera	301	301	301	301	301	282	248	209	160	110	93

Figure 22: Average and v85 speeds in front of/behind the speed camera- Budapest, Hunyadi Mátyás street

Similar effects of the speed camera were measured in this location as at Dunaharaszti. Here, the speed limit was only 40 km/h, the v85 speeds were above it, the average speeds were slightly below without the speed camera. As the number of measured vehicles was quite low, we only examine the speed at the road section 30 meters in front of the device, where we had data of at least 100 vehicles.

The speed camera has positive effects, the v85 speeds were 4-4.5 km/h lower, while the average speeds were 5-6 km/h lower, when the device was on the roadside. In this case, even the v85 speeds were just slightly above the allowed speed limit (average speeds were only around 33-34 km/h).

The differences could be observed here also in the first measured points also, indicating that the speed reducing effect arise more than 50 meters away. No difference in the shape of the red and green curves was found here investigating the 30-meter-long section in front of the device.

In case of the operating speed camera, the average speed behind the device increased by 2.4km/h.

Further data indicating the behaviour of drivers have been calculated and included in the next Tables.

Table 16: Ratio of vehicles exceeding the speed limit at different distances from the speed camera- Budapest, Hunyadi Mátyás street

	Distance from the device	-50 m	-30 m	-1 m	30 m	50 m
Ratio of vehicles exceeding the speed limit	**Without speed camera**	36.0%	45.5%	35.1%	53.3%	44.9%
	With speed camera	2.7%	12.3%	15.6%	23.0%	20.4%
	Difference	-33.3%	-33.2%	-19.5%	-30.3%	-24.5%

Table 17: Data characterizing driver behaviour in front of/behind the speed camera- Budapest, Hunyadi Mátyás street

Direction of vehicles	Data	**Without speed camera**	**With speed camera**	Difference
Vehicles approaching the speed camera	Ratio of vehicles reducing speed (from first measured point to -1 m)	57.3%	63.1%	+5.8%
	Ratio of vehicles reducing speed by at least 10% of speed limit (from first measured point to -1 m)	11.1%	20.7%	+9.6%
	Ratio of vehicles reducing speed, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	68.5%	84.2%	+15.7%
	Ratio of vehicles reducing speed by at least 10% of speed limit, in case of drivers who exceeded the speed limit when entering (from first measured point to -1 m)	14.4%	36.8%	+22.4%
Vehicles leaving the speed	Ratio of vehicles increasing speed (from 1 m to last measured point)	83.5%	79.4%	-4.1%

	Ratio of vehicles increasing speed by at least 10% of speed limit (from 1 m to last measured point)	30.4%	30.2%	-0.2%

The ratio of speeding vehicles was around 35-53% in the different sections without the speed camera and was significantly lower (around 12-23%) with the device on the roadside. In the line of the device, 15.6% of drivers exceeded the speed limit. The ratio increased behind the camera.

The positive effects could be observed in case of all further data on the behaviour of drivers. The ratio of vehicles reducing speed increased, especially in case of drivers who arrived to the measured section by a speed higher than the allowed maximum (84.2% of speeding vehicles reduced speed when the camera was on the roadside). Here the ratio of vehicles increasing speed after the camera was not higher with the device on the roadside. However, as we have seen from the previous data, the average speed increased there.

3.4.3 Conclusions – Effects of fixed speed cameras

To summarize the main conclusions of the measurements carried out at speed cameras, the main data have been collected at the following table from the different locations.

Table 18: Main results and conclusions of measurements at speed cameras

Location:	**6. Dunaharaszti, road 510**	**7. Budapest, Hunyadi Mátyás street 57.**
Type of area:	urban (with rural nature)	urban
Speed limit:	50 km/h	40 km/h
Type of the device:	speed camera	speed camera
Other factors affecting traffic:	-	40 km/h speed limit
Main conclusions from speed diagram (vehicles approaching the devices):	- avg. speeds were 3-4 km/h above the speed limit (without camera) - avg. and v85 speeds were 6.5-8 km/h lower when the device was operating - vehicle speeds decreased by about 2 km/h (from -25m to the line of the device) - speed reducing effect of the camera arose more than 50 meters away from the line of the device	- avg. speeds were slightly under the speed limit (without camera) - avg. and v85 speeds were 4-6 km/h lower when the device was operating - speed reducing effect of the camera arose more than 50 meters away from the line of the device
Main conclusions from speed diagram (vehicles leaving the devices):	- the speeds didn't increase significantly in the 50-meter-long section behind the camera.	- the average speed behind the device increased by 2.4km/h.
Ratio of vehicles exceeding the speed limit at the line of device	- device was not operating: 58.7% - device was operating: 4.5% - decrease: 92.3%	- device was not operating: 35.1% - device was operating: 15.6% - decrease: 55.6%

In case of both locations, significant effect of speed cameras could be measured. The positive changes were a little bit higher in case of Dunaharaszti, the urban section with rural nature and higher speeds (bigger decrease in speeds and further decrease on the measured 50-meter-long section in front of the device; bigger decrease in the ratio of speeding vehicles).

4 Elaboration of the Pilot Actions in Hungary

Details of the Pilot Actions in Hungary are described as follows in this chapter. Our aim was to apply two Pilot Actions at the most dangerous road sections of the Hungarian road network, and evaluate the potential effects of them:

1. The first Pilot Action aims to introduce a strict speed limit enforced by the installation of a vehicle activated speed limit sign.
2. The second Pilot Action aims to install a fixed speed camera.

4.1 First Pilot Action – 60 km/h speed limit strengthened by vehicle activated speed limit signs, near Cegléd, road 40

According to the results of the speed analysis at the area of vehicle activated speed warning signs, the following considerations have been applied when selecting the location and other characteristics of our first Pilot Action, to get the most positive potential results of the intervention:

- a location has to be chosen from the previously introduced, most dangerous road sections of the I. or II. class main road network of Hungary;
- a location where the danger of the section arises from a physical barrier (e.g. a curve, pedestrian crossing, etc.), which requires vehicles to reduce their speed in front of the dangerous point of the road has to be found;
- a vehicle activated speed limit sign is needed to be applied, instead of a display that shows the current speed of vehicles;
- a 2-7 km/h decrease in average and v85 speeds can be expected 50 meters in front of the device, and from there a further 2-3 km/h decrease until the line of the device;
- if a lower speed limit is also applied beside the introduction of a vehicle activated speed limit sign:
  - the average speeds can be expected around, or slightly above the speed limit 50 meters in front of the operating device, which will be reduced to or slightly under the allowed maximum speed;
  - based on the results of measurements at Győrszemere, and Ezüsthegy street, the v85 speed is 15-17% higher than the average speed;
- the device has to be placed close to the physical barrier (e.g. curve, pedestrian crossing) to avoid drivers speeding up right after the device.

Keeping in mind the above mentioned considerations the identified dangerous road sections have been investigated using Google Maps. We primarily aimed to choose from the locations with the highest number of road accidents in the previous years. It was also an important aspect to choose a location where there wasn't any road safety intervention applied for years. Consultations in this regard have been carried out also with the road operator company of the national road network. The selected road section is introduced in the next sub-chapter in detail.

4.1.1 Introduction and analysis of the location of the first Pilot Action

Location: 2700 Cegléd, road 40, 27+320 km section, both directions

GPS: 47.182424, 19.889272

Type of area: Rural, speed limit is 90 km/h

AADT: 3304 vehicle units/day (share of HVGs: 8.4%)

4.1.1.1 Description of the location

Figure 23: Area of Pilot Action 1 near Cegléd, on road 40 – 1. direction

Figure 24: Area of Pilot Action 1 near Cegléd, on road 40 – 2. direction

The first selected road section is located in a rural area near the town of Cegléd, on road 40 at 27+320 km section. The section is on a 2x1 lane road and contains a small radius curve. Currently the allowed maximum speed is not restricted here, so vehicles are allowed to travel at up to 90 km/h. Overtaking is also allowed along the whole section. From one side, "Left hand curve" is signed 200 m before the curve, from the other direction "Right hand curve" traffic sign is located 120 m before the start of the curve. Both traffic signs are duplicated on the left side of the road as well. Also, deceleration cross stripes are painted on the road from both sides, but these seem quite old and worn. The shoulders of the road are also heavily worn, there is a substantial step downwards from the asphalt. There were many accidents here before (see the next sub-chapter).

4.1.1.2 Results of speed measurements at the location

We have carried out speed measurements at the selected area. At both directions, the measuring equipment was placed at the planned section of the vehicle activated speed limit signs. The measured average and v85 speeds were exactly the same at the two directions:

- average speed: 75 km/h,
- v85 speed: 86 km/h.

4.1.1.3 Road accident history of the location

To examine the safety level of the selected location we have collected the main data of road accidents happened in the road section 300 meter in front of and behind the examined curve on the road, in the last eight years (2012-2019).

As indicated in Table 19, 10 road accident happened on the examined road section, with 13 participants, 3 of them died, 2 seriously, and 9 slightly injured. All of the accidents happened in daylight.

In case of 8 accidents the primary reason was the inappropriate choice of speed, which clearly indicates the main problem of the selected road section and implies that a speed management intervention can be the most effective solution to increase the road safety level here. 7 cases were single-vehicle accidents (vehicle leaving the road), 3 cases were head-on collisions of vehicles.

Table 19: Data of road accidents happened in the area of the location of Pilot 1(road 40, between 27+020 and 27+620 km sections; years 2012-2019)

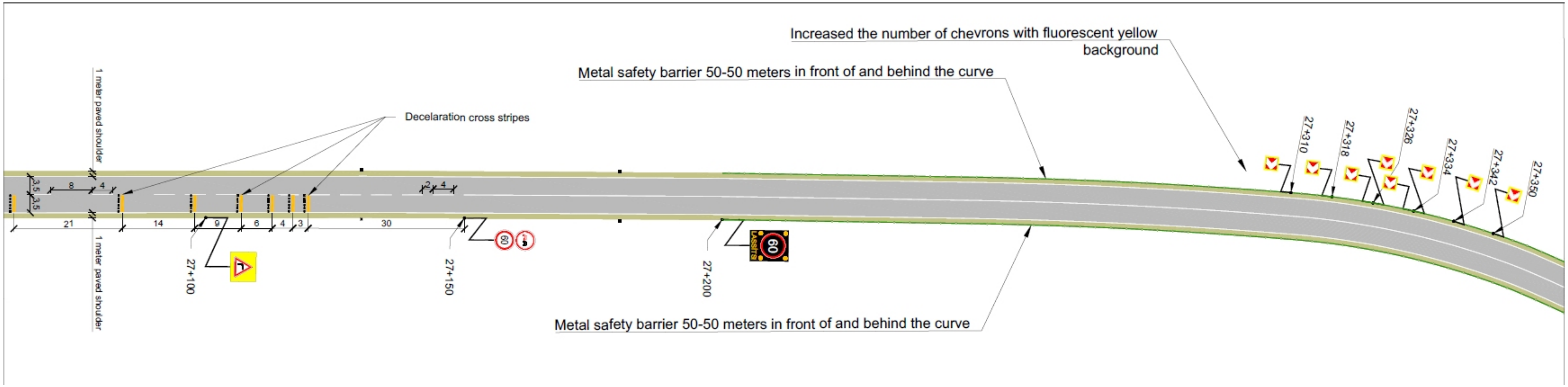
Date and time	*Number of participants*	*Number of deaths*	*Seriously injured*	*Slightly injured*	*Nature of accident*	*Type of accident*	*Primary cause of accident*	*Direction of travel*	*Visibility conditions*	*Km section*
2012.06.28 16:30	1	0	0	1	leaving the road without colliding with a solid object	single-vehicle accident (leaving the road on the left side)	inappropriate choice of speed	east	daylight, natural light	27+377
2013.09.14 14:58	1	1	1	0	leaving the road without colliding with a solid object	single-vehicle accident (leaving the road on the right side)	inappropriate choice of speed	east	daylight, natural light	27+420
2014.05.14 7:05	2	0	0	2	head-on collision	head-on collision of vehicles traveling straight	inappropriate choice of speed	both	daylight, natural light, but limited visibility	27+300
2014.10.19 14:55	1	0	0	1	leaving the road and colliding with a solid object	single-vehicle accident (leaving the road on the left side)	inappropriate choice of speed	east	daylight, natural light	27+500
2016.07.17 6:25	1	0	0	1	leaving the road and colliding with a solid object	single-vehicle accident (leaving the road on the left side)	inappropriate choice of speed	east	daylight, natural light	27+400
2016.12.09 11:12	1	0	1	0	leaving the road and colliding with a solid object	single-vehicle accident (leaving the road on the right side)	inappropriate choice of speed	west	daylight, natural light	27+578
2017.10.23 16:50	1	0	0	1	leaving the road and colliding with a solid object	single-vehicle accident (leaving the road on the left side)	inappropriate choice of speed	east	daylight, natural light	27+500
2017.11.15 7:20	2	1	0	0	head-on collision	head-on collision of vehicles traveling straight	error while changing direction, turning	both	daylight, natural light	27+250
2018.05.27 17:50	1	0	0	2	leaving the road without colliding with a solid object	single-vehicle accident (leaving the road on the right side)	inappropriate choice of speed	west	daylight, natural light	27+284
2018.11.26 11:35	2	1	0	1	head-on collision	head-on collision of vehicles traveling straight	error while changing direction, turning	both	daylight, natural light	27+350

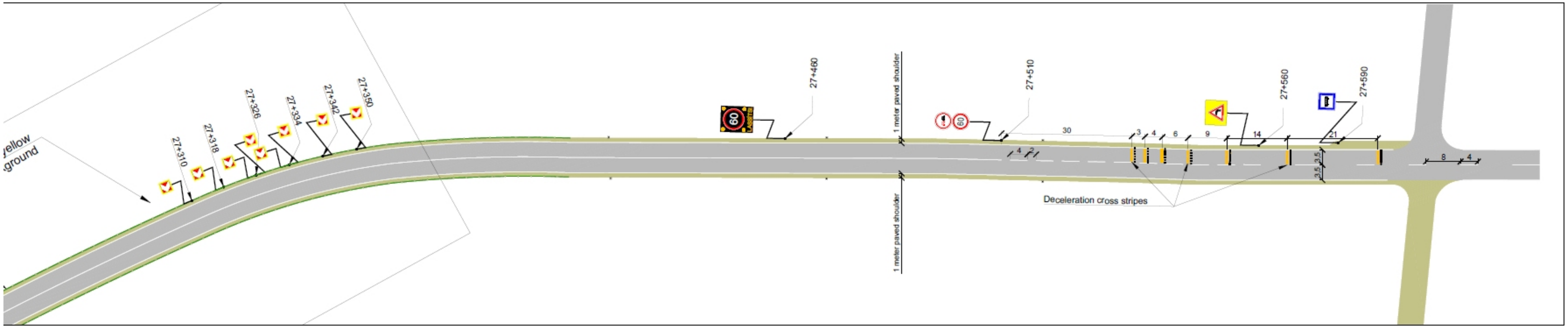
4.1.2 Road Layout Concept Plan

Our first Pilot Action has been performed at road 40, in the area of a dangerous curve at 27+320 km section. The aim of the Pilot Action was to introduce a 60 km/h speed limit strengthened by the installation of a vehicle activated speed limit sign in both directions; to reduce the high number of accidents happened here because of the inappropriate choice of speed.

The applied interventions are the following:

- providing a yellow background for already existing dangerous curve traffic signs in both directions on the right side (and removing them from the left side);
- introduction of 60 km/h speed limit signs in both directions, 100 meters in front of the curve;
- prohibition of overtaking in the area of the curve indicated by solid centre line, and traffic signs in both directions (100-100 metres);
- introduction of vehicle activated speed limit displays (60 km/h and “Lassíts” (reduce speed) text) 50 metres in front of the curve in both directions, detecting the arriving vehicles from 50 metres distance;
- increased number and yellow backgrounded chevrons along the curve;
- introduction of metal safety barriers in the curve (50-50 meters in front of and behind the curve) on both sides of the road;
- introduction of 1.0 metre paved shoulder on both sides of the road in the area of the curve;
- improvement of road surface condition and skid resistance;
- aligning the position and strengthening the paintings of the already existing yellow deceleration cross stripes with reflective prisms according to the new speed limit.


Increased the number of chevrons with fluorescent yellow background
Metal safety barrier 50-50 meters in front of and behind the curve
Decelaration cross stripes
1 meter paved shoulder
1 meter paved shoulder
27+100
27+150
27+200
27+310
27+318
27+326
27+334
27+342
27+350
Metal safety barrier 50-50 meters in front of and behind the curve


27+310
27+318
27+326
27+334
27+342
27+350
27+460
1 meter paved shoulder
1 meter paved shoulder
27+510
27+560
27+590
Deceleration cross stripes

4.2 Second Pilot Action – Fixed speed camera to reduce speeds of vehicles arriving in the city of Martonvásár, on road 7

Based on the measurements with speed camera, the following considerations have been applied when selecting the location and other characteristics of our second Pilot Action:

- a location has to be chosen from the previously introduced, most dangerous road sections of the I. or II. class main road network of Hungary;
- a location has to be found which is at a straight urban road section, but with rural characteristics, implying higher vehicle speeds;
- the fixed speed camera need to be applied possibly to a section where many vehicles exceed the speed limit, to have bigger influence on the traffic;
- a 6.5-8 km/h decrease can be expected in average and v85 speeds 25 meters in front of the device, and from there a further 2 km/h decrease until the line of the device.

The above mentioned conditions have greatly narrowed the range of possible locations. The help of the road operator company has been asked to advice the appropriate road section. The location has been chosen according to their suggestions since the local municipality was also interested in speed management solutions at the selected town. As later will be presented, this road section is not an accident black spot (2 accidents happened between 2012 and 2019), however the presence of vulnerable road users (cyclists and pedestrians), the frequent high vehicle speeds due to a slope and rural nature, as well as the special interest of the local municipality justifies the need to elaborate a road safety measurement at the site. This is confirmed by the fact that the Hungarian Police performs speed measurements regularly at the road section, especially in the summer period, when the vehicle and bicycle traffic is much greater (travellers can reach Lake Balaton and Lake Velence on the road from Budapest).

4.2.1 Introduction and analysis of the location of the second Pilot Action

Location: 2462 Martonvásár, road 7, 33+539 km section (towards the city centre)

GPS: 47.305684, 18.780898

Type of area: Urban, with rural nature, right after the border of the city, speed limit is 50 km/h

AADT: 8634 vehicle units/day (share of HVGs: 5.8%)

4.2.1.1 Description of the location

Figure 25: Area of Pilot Action 2 at Martonvásár, on road 7

The second selected road section is located in an urban area, right after the border of Martonvásár city, on road 7. The section is on a 2x1 lane road, a bicycle lane just starts at the selected section on both sides of the road. Bicycle traffic is remarkable especially in summer, as also Lake Balaton and Lake Velence can be reached on this road from Budapest.

The suggested device would be a fixed speed camera on the 33+539 km section, placed on the right side according to ascending sectioning of road 7. Only one direction was examined, the one from which the vehicles enter the city. At this direction, the road section has a slight downwards slope, which together with the rural characteristics and the closeness of the city border implies high vehicle speeds.

Currently there is the common 50 km/h speed limit as usually applied in urban areas, but no particular speed limit traffic signs draw attention to this. Other restrictive traffic signs can be found starting after the planned cross section of the fixed speed camera. These are "No overtaking" (33+490 km section), "Pedestrian crossing" and "Other danger – refuge island" (33+475 km section) traffic signs due to a pedestrian crossing nearby (33+422 km section). The pedestrian peak-hour flow is around 12-15 across the road.

4.2.1.2 Results of speed measurements at the location

The speed of arriving vehicles has been measured at the planned section of the fixed speed camera. At this location, not only the current speeds have been examined, but we have carried out measurements also placing the previously introduced mobile speed camera on the roadside, to support the determination of the effects of speed cameras. The following values were observed:

- average speed without speed camera: 51 km/h,
- v85 speed without speed camera: 57 km/h,
- average speed with speed camera: 41.5 km/h,
- v85 speed with speed camera: 47 km/h.

The measured 9.5-10 km/h reduction is perfectly in line with the effects determined by the two previous measurements (Dunaharaszti, road 510; Budapest, Hunyadi Mátyás street 57), where a 6.5-8 km/h decrease in average and v85 speeds could be observed 25 meters in front of the device, and from there a further 2 km/h decrease until the line of the device.

4.2.1.3 Road accident history of the location

As our second Pilot action aims to reduce the speeds of vehicles entering the city of Martonvásár, we have analysed the road accident history of the road section only in this direction, at a 800 meter long section starting from the city border. Data have been summarized in the following Table.

Table 20: Data of road accidents happened in the area of the location of Pilot 2, only in the affected direction (road 7, between 32+900 and 33+700 km sections; years 2012-2019)

Date and time	2012.09.03 11:20	2017.06.13 20:00
Number of participants	1	2
Number of deaths	0	0
Seriously injured.	0	1
Slightly injured	1	0
Nature of accident	slipping, carving, overturning on the road	collision of vehicles traveling in the same direction
Type of accident	other type of accident	rear-end collision
Primary cause of accident	inappropriate choice of speed	inappropriate choice of speed
Visibility conditions	daylight, natural light	daylight, natural light
Km section	33+397	32+930

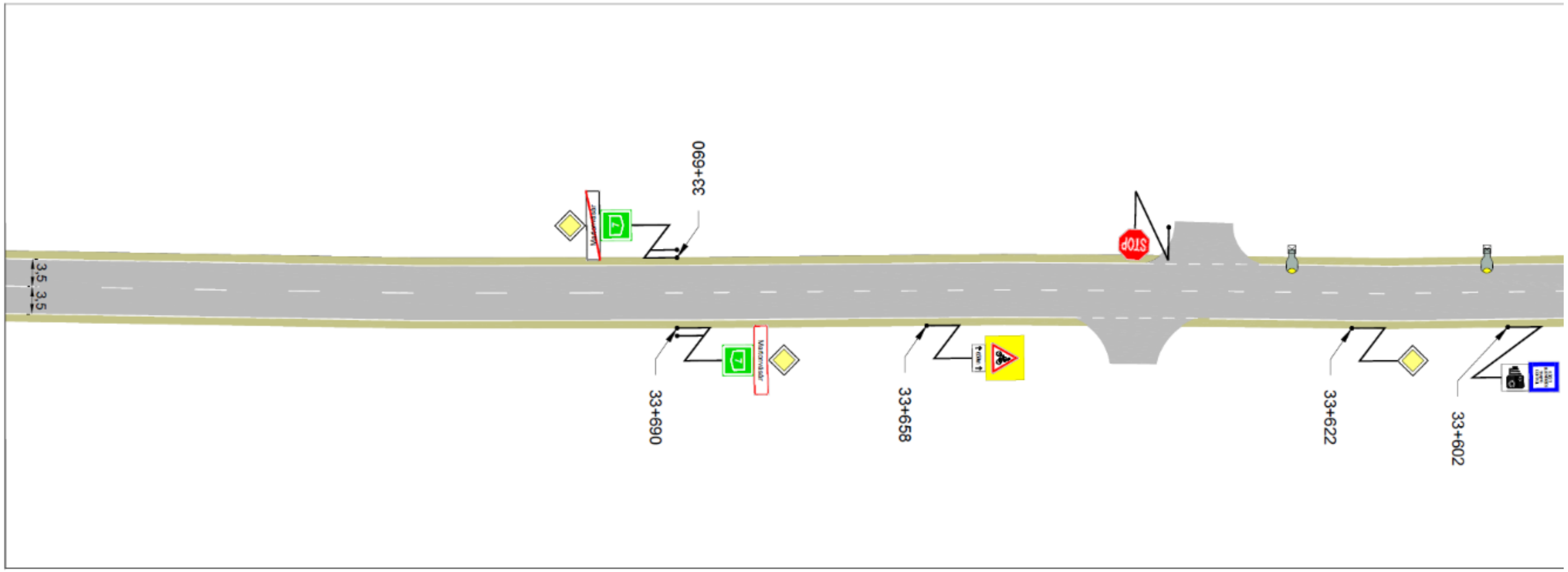
A slight and a serious accident happened on the investigated section, in the direction towards the city centre of Martonvásár. In both cases, inappropriate choice of speed was the primary cause of accident, the visibility conditions were good. In case of the accident with slight injury, a vehicle slipped because of high speed. In the other case, rear-end collision happened among two vehicles.

4.2.2 Road Layout Concept Plan

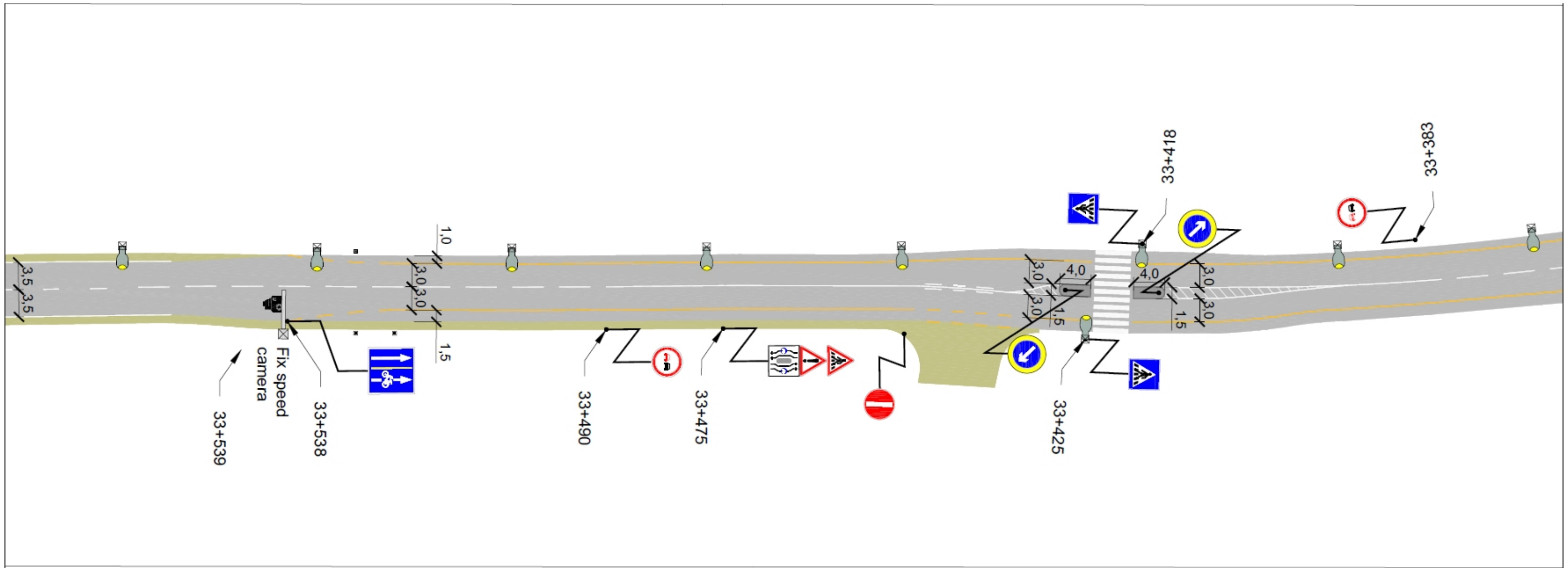
Our second Pilot Action has been performed at road 7, at 33+539 km section (after the city border and before a pedestrian crossing in the urban area). The aim of the Pilot Action was to introduce a fixed speed camera targeting the vehicles arriving in the city. The aim is to reduce vehicle speeds to protect cyclists and pedestrians (there is a bicycle lane at both sides; and a pedestrian crossing at the area).

The applied interventions are the following:

- providing a yellow background for the already existing danger of cyclists sign;
- placing of a sign that indicates the presence of the bicycle lane;
- placing of a fixed speed camera to km section 33+539 together with its indicator sign (33+602 km section).
- Redesign of the pedestrian crossing by building a refuge island. “Pass on right side” traffic signs are placed on the refuge islands from both sides.



33+690
33+690
33+658
33+622
33+602
3,5
3,5
STOP



3,5
3,5
33+539
Fix speed camera
33+538
1,0
3,0
3,0
1,5
33+490
33+475
33+425
33+418
4,0
4,0
1,5
33+383

5 Determining the potential effects of the Pilot Actions

The expected change in vehicle speeds has been determined based on the previously introduced measurements (vehicle activated speed limit sign, speed camera), as follows in the next Table.

According to the results of the speed analysis in the area of vehicle activated speed warning signs, we can expect to have the average speeds around or slightly under the allowed maximum speed, and the v85 speed will be 15-17% higher, after the implementation of the Pilot introducing a 60 km/h speed limit at the first location (near Cegléd, road 40).

At the second location (Martonvásár, road 7), both the speed measurements with and without the mobile speed camera, and the speed analysis at other similar locations (see Chapter 3.4) indicate that we can expect a 9.5-10 km/h reduction in average and v85 speeds in the line of the device.

Table 21: Current and expected vehicle speeds before, and after the implementation of the Pilot Actions

	Pilot Action 1	**Pilot Action 2**
Location	near Cegléd, road 40	Martonvásár, road 7
Current average speed	75 km/h	51 km/h
Current v85 speed	86 km/h	57 km/h
Expected average speed (after Pilot Action)	60 km/h	41.5 km/h
Expected v85 speed (after Pilot Action)	70 km/h	47 km/h
Change in average speed	-20%	-18.6%
Change in v85 speed	-18.6%	-17.5%

Based on the estimations, the potential effects of the proposed Pilot Actions have been evaluated according to two approaches:

1. models for the relationship of speed and accident risk have been used;
2. the iRAP Star Rating methodology has been used.

While the models for the relationship of speed and accident risk only take into account the changes in speed, the iRAP methodology also considers other planned interventions affecting road safety (e.g. the planned prohibition of overtaking, introduction of metal safety barriers, etc).

5.1 Evaluation based on the relationship of speed and accident risk

To evaluate the potential effects of the speed reduction on the accident risk, first, we have examined the existing literature.

In 30% of fatal road accidents speeding is considered a major contributory factor. First of all, driving over the speed limit increases the chance of getting involved in an accident, secondly it increases the severity of the injuries. Drivers need time to detect a potentially risky situation, make a decision about what to do, and react. At higher speeds, there is less time for all of these. In addition, at a higher speed, more energy is released when colliding with another vehicle, road user or obstacle.[7]

According to recent studies, a 1% increase of the speed leads to 3% increase in the number of road accidents. This depends also on the initial speed. The larger the increase in speed, the steeper the increase in accident risk. This relationship is true only in general, the exact connection between speed and accidents is affected by initial speed and the characteristics of the road also. Individual speed differences can be also relevant, faster drivers have higher accident risks.[7]

Some studies found that the rate of accidents increases faster with the increase of speed on minor roads than on major roads. The main characteristics that count are lane width, junction density and traffic flow, these had impact on speed-accident relationship.[8]

Nilsson, a Swedish researcher, has created a Model[9] for the relationship of speed and accident risk. It is called the Power Model. The theory is based on kinetic principles and empirical data. According to the theory, the change of the number of the accidents can be predicted from the change of speed with the help of a set of power functions. Accordingly, a 1 km/h increase of speed on a 120 km/h road increases the rate of accidents by 2%, on a 50 km/h road, by 3%.[10]

The Power Model's formula for relationship between speed and accident risk is the following:

$$A_2 = A_1\left(\frac{v_2}{v_1}\right)^2$$

In words: the number of the accidents after speed change (A_2) equals the number of the accidents before the speed change (A_1) multiplied by the new mean speed (v_2) divided by the former mean speed (v_1), raised to the square power.

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[7] European Commission, Speed and Speed Management, European Commission, Directorate General for Transport, February 2018. https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/ersosynthesis2018-speedspeedmanagement.pdf#page=28&zoom=100,78,104
[8] Aarts, L., Schagen, I. (2006) Driving speed and the risk of road crashes: A review Accident Analysis & Prevention Volume 38, Issue 2, March 2006, Pages 215-224
[9] Nilsson, G. (2004) Traffic safety dimensions and the power model to describe the effect of speed on safety. Bulletin 221, Lund Institute of Technology, Lund.
[10] Elvik, R., Høye, A., Vaa, T. & Sorensen, M. (2009) The handbook of road safety measures, 2nd edition. Amsterdam [etc.], Elsevier

There are similar results of British studies[11,12] where a 1 km/h speed change increased the number of accidents by 1-4% on urban roads, and 2.5-5.5% on rural roads. The lower numbers belonged to higher quality roads. The relationship between speed and accidents depends largely on characteristics of the road and traffic, and also on the behaviour and characteristics of drivers using the roads, like gender, age, drink driving and seat belt wearing.

The exponent in the formula changes in case of serious injuries and fatal accidents, in case of fatal accident the exponent is 4, according to Nilsson.[13]

Elvik and colleagues made a systematic literature research and meta-analysis of 96 studies that made 460 estimations about relationship of speed and accidents in order to inspect the validity of the formula[13]. Their results confirmed the Power Model with small modifications. In a more recent report[14], authors have established the following exponents for rural roads in case of each type of accidents:

Table 22: Proposed exponents for Power Model in case of different type of accidents on rural roads/freeways[14]

Accident or injury severity	Exponent	Interval
Fatalities	4.6	(4.0 – 5.2)
Seriously injured road user	3.5	(0.5 – 5.5)
Slightly injured road user	1.4	(0.5 – 2.3)
All injured road users (severity not stated)	2.2	(1.8 – 2.6)
Fatal accidents	4.1	(2.9 – 5.3)
Serious injury accidents	2.6	(-2.7 – 7.9)
Slight injury accidents	1.1	(0.0 – 2.2)
All injury accidents (severity not stated)	1.6	(0.9 – 2.3)
Property-damage-only accidents	1.5	(0.1 – 2.9)

The results verified that there is a strong connection between speed and accident risk.

The statistical connection does not necessarily mean that there is a causal relationship between the two components, but there are several proofs that the connection is causal:

- There is strong statistical connection between speed and accidents there are no other factors that can be assumed to be connected so strongly to accidents.
- When speed changes there is also a change in the number of accidents, it is a consistent relationship.

[11] Taylor, M., Lynam, D.A. & Baruya, A. (2000) The effect of drivers' speed on the frequency of accidents. TRL Report TRL421. Transport Research Laboratory, Crowthorne.
[12] Taylor, M., Baruya, A., & Kennedy, J.V. (2002) The relationship between speed and accidents on rural single carriageway roads. TRL Report TRL511. Transport Research Laboratory, Crowthorne.
[13] Elvik, R., Christensen, P., Amundsen, A. Speed and road accidents: an evaluation of the Power Model. TØI report 740/2004. Oslo, 2004.
[14] Elvik, R. The Power Model of the relationship between speed and road safety. Update and new analyses. TØI report 1034/2009. Oslo, 2009.

- There are several studies that verified the causal relationship between the two. The observed changes were independent from any other environmental characteristics.
- Also, the physical regularities support the causal connection.[13]

5.1.1 First Pilot Action – near Cegléd, road 40

Based on the accident data of the previous 8 years (2012-2019) and using Nilsson's Power Model with the different exponents proposed by Elvik and his colleagues, the expected number of injured and accidents for the next 8 years after the implementation (e.g. 2020-2027) can be estimated as follows.

Table 23: Estimated number of road accidents and injuries in the next 8 years, after implementing Pilot Action 1

	Between 2012 and 2019	8-year period after implementation of Pilot Action 1
Change in average speed (v_2/v_1)	60/75 = 0.8	
Fatalities (exp.=4.6)	3	1.1
Seriously injured road user (exp.=3.5)	2	0.9
Slightly injured road user (exp.=1.4)	9	6.6
All injured road users (exp.=2.2)	14	8.6
Fatal accidents (exp.=4.1)	3	1.2
Serious injury accidents (exp.=2.6)	1	0.6
Slight injury accidents (exp.=1.1)	6	4.7
All injury accidents (exp.=1.6)	10	7.0

According to the calculated values, the number of injured road users could almost be halved by the estimated 20% decrease in the average speed of vehicles. Two fatalities, a serious injury and 3 slight injuries could be prevented by the implementation of the proposed Pilot Action. The expected number of injury accidents is only 7 in an 8-year period after the implementation.

Using the economic cost values presented in chapter 2.1.4, the reduction in the number of fatalities (1.9), in the number of seriously injured (1.1) and in the number of slightly injured (3.4) would result in approximately 1.700.000 Euro cost avoided.

5.1.2 Second Pilot Action –Martonvásár, road 7

Between 2012 and 2019, only 2 accidents happened at the location of our second proposed Pilot Action. However, the high speeds of vehicles and the presence of vulnerable road users (pedestrian crossing, bicycle lane) supports the need of a road safety intervention to prevent a future increase in the number of accidents.

Table 24: Estimated number of road accidents and injuries in the next 8 years, after implementing Pilot Action 2

	Between 2012 and 2019	8-year period after implementation of Pilot Action 1
Change in average speed (v_2/v_1)	41.5/51 = 0.814	
Seriously injured road user (exp.=2.0)	1	0.7
Slightly injured road user (exp.=1.1)	1	0.8
All injured road users (exp.=1.4)	2	1.5
Serious injury accidents (exp.=1.5)	1	0.7
Slight injury accidents (exp.=1.0)	1	0.8
All injury accidents (exp.=1.2)	2	1.6

Exponents for urban/residential roads have been used in the table above[14]. According to the calculated values, the number of road accidents and the number of injured road users could be reduced by approximately 25% as a result of the speed reduction due to the proposed Pilot Action. The avoided cost is about 60.000 Eur based on this reduction.

5.2 Evaluation based on the iRAP Star Rating methodology

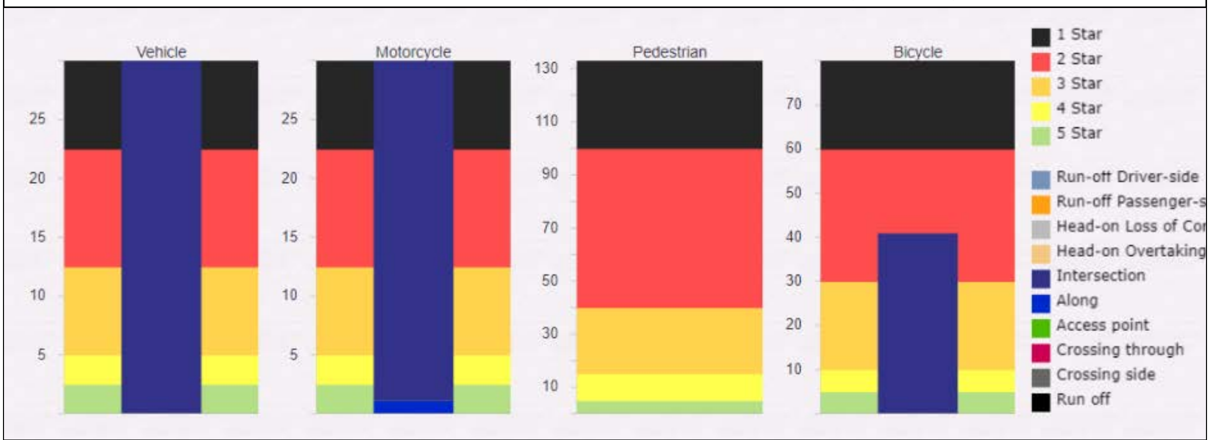
The potential effects of the Pilot Actions have been analysed also by making use of the iRAP Star Rating methodology. The Star Rating for Designs Tool has been used to evaluate the Star Rating Score (SRS) of the investigated road sections both before and after the implementation of the Pilot Actions. This tool is capable of taking into account not just the change in speed, but also other parameters affecting road safety (presence of safety barriers, roadside objects, condition of road surface, etc). The software also provides a detailed SRIP (Safer Road Investment Plan) for both cases.

5.2.1 First Pilot Action – near Cegléd, road 40

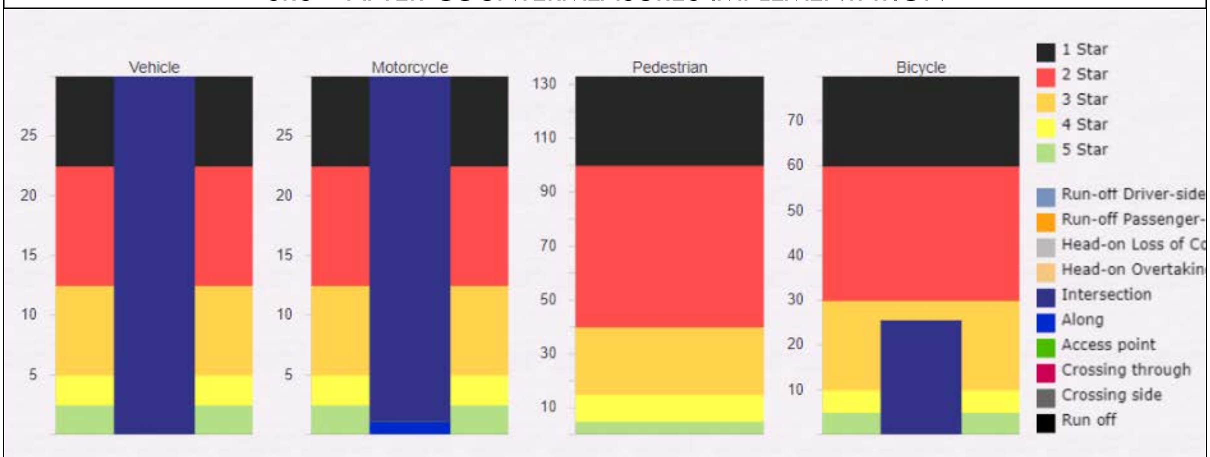
The selected road section has been analysed at a length of 700 meters (road 40; between 27+710 - 27+010 km sections), in 100-meter sections. We provide here the Star Rating Scores for each 100-meter-long section both before and after the implementation of our Pilot Action, to support the comparison of the different cases. For the first 100-meter-long section, all coded attributes are presented, later we only highlight those parameters where there is a difference in the before-after scenarios.

Table 25: Star Rating Scores and coded attributes – Pilot Action 1; road 40; between 27+710 -27+610 km sections

SRS – BEFORE COUNTERMEASURES IMPLEMENTATION



SRS – AFTER COUNTERMEASURES IMPLEMENTATION



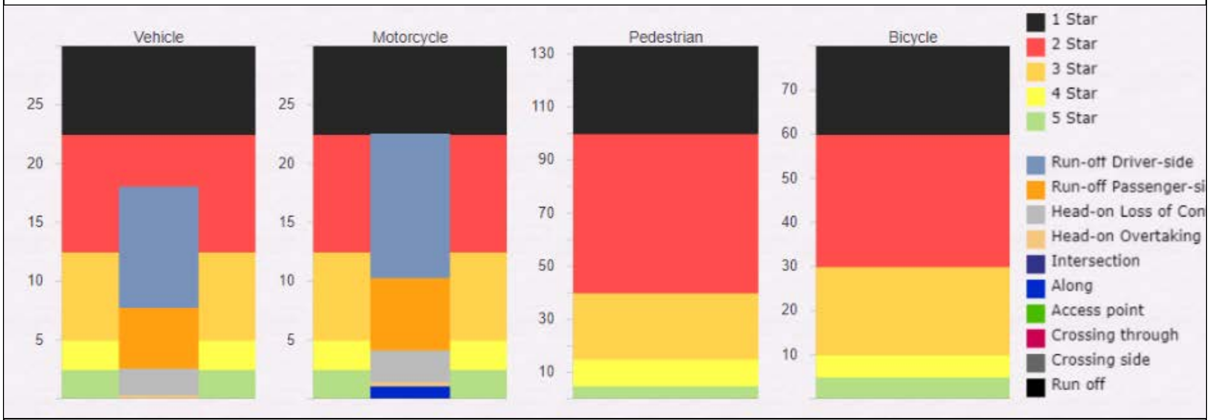
Road	Direction	Chainage
Road 40	2	27+710 – 27+610

Attribute Group	Before	After
ROADSIDE ATTRIBUTES		
Roadside severity - driver-side distance	1 to 5m	1 to 5m
Roadside severity - driver-side object	Tree >=10 cm dia.	Tree >=10 cm dia.
Roadside severity - passenger-side distance	1 to 5m	1 to 5m
Roadside severity - passenger-side object	Downwards slope	Downwards slope
Shoulder rumble strips	Not present	Not present
Paved shoulder - driver-side	None	None
Paved shoulder - passenger-side	None	None
MIDBLOCK ATTRIBUTES		
Carriageway label	Undivided road	Undivided road
Upgrade cost	Low	Low
Median type	Centre line	Centre line
Centreline rumble strips	Not present	Not present
Number of lanes	One	One
Lane width	Wide (>=3.25m)	Wide (>=3.25m)
Curvature	Straight or gently curving	Straight or gently curving
Quality of curve	Not applicable	Not applicable
Grade	0% to 7.5%	0% to 7.5%
Road condition	Medium	Good
Skid resistance / grip	Sealed - medium	Sealed - adequate
Delineation	Adequate	Adequate
Street lighting	Not present	Not present
Vehicle parking	None	None
Service road	Not present	Not present
Roadworks	No road works	No road works
Sight distance	Poor	Poor
INTERSECTION ATTRIBUTES		
Intersection type	4-leg (unsignalized) with no protected turn lane	4-leg (unsignalized) with no protected turn lane
Intersection channelization	Not present	Not present
Intersecting road volume	100 to 1,000 vehicles	100 to 1,000 vehicles
Intersection quality	Poor	Poor
Property access points	None	None
FLOW ATTRIBUTES		
Vehicle flow (AADT)	3304	3304
Motorcyclist %	1%-5%	1%-5%
Pedestrian peak hour flow across the road	0	0
Pedestrian peak hour flow along the road driver-side	0	0
Pedestrian peak hour flow along the road passenger-side	0	0
Bicyclist peak hour flow	0	0

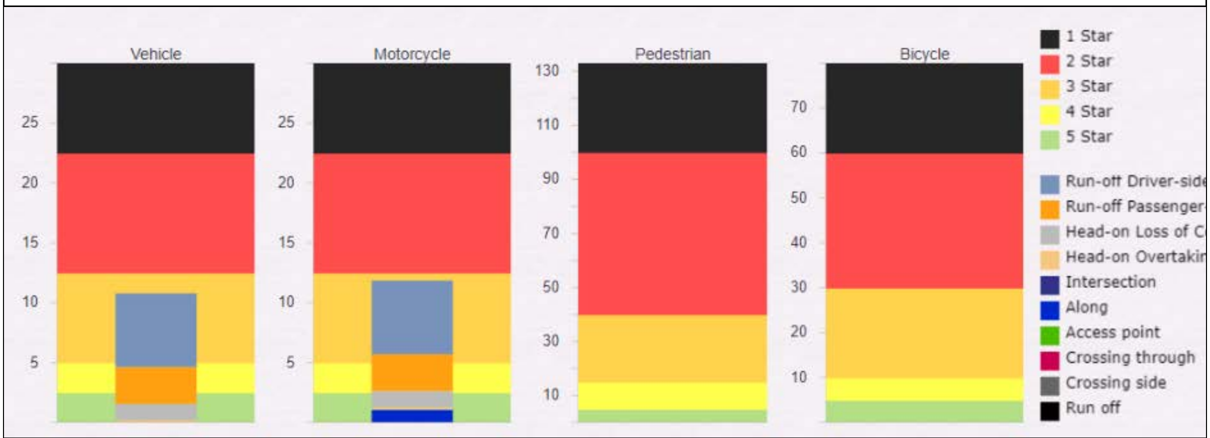
VRU FACILITIES AND LAND USE ATTRIBUTES		
Land use - driver-side	Farming and agricultural	Farming and agricultural
Land use - passenger-side	Farming and agricultural	Farming and agricultural
Area type	Rural/open area	Rural/open area
Pedestrian crossing facilities - inspected road	No facility	No facility
Pedestrian crossing quality	Not applicable	Not applicable
Pedestrian crossing facilities - intersecting road	No Facility	No Facility
Pedestrian fencing	Not present	Not present
Sidewalk - driver-side	None	None
Sidewalk - passenger-side	None	None
Facilities for motorised two wheelers	None	None
Facilities for bicycles	None	None
School zone warning	Not applicable	Not applicable
School zone crossing supervisor	Not applicable	Not applicable
SPEEDS		
Speed limit	90 km/h	90 km/h
Differential speed limits	Not present	Not present
Speed management / traffic calming	Not present	Not present
Operating Speed (85th percentile)	85 km/h	85 km/h
Operating Speed (mean)	75 km/h	75 km/h

Table 26: Star Rating Scores and coded attributes – Pilot Action 1; road 40; between 27+610 -27+510 km sections

SRS – BEFORE COUNTERMEASURES IMPLEMENTATION



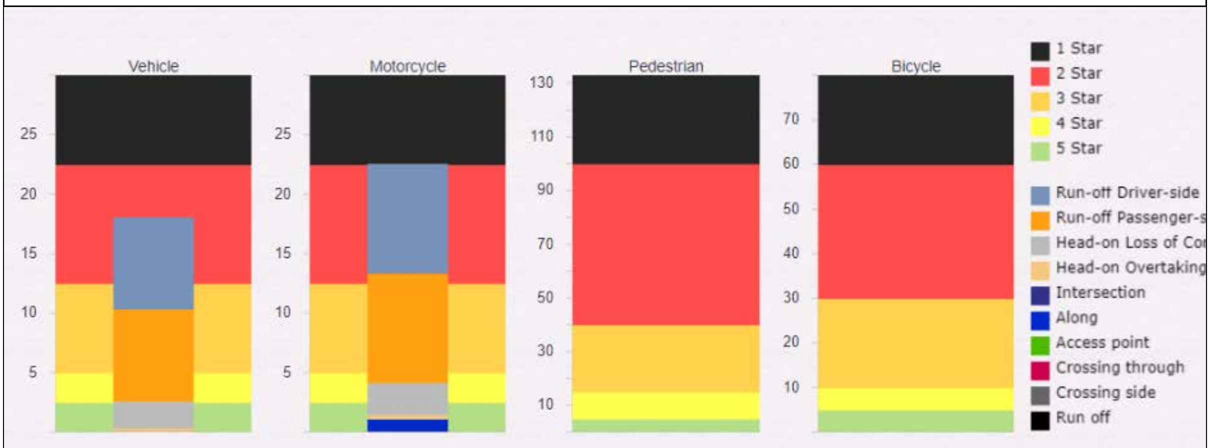
SRS – AFTER COUNTERMEASURES IMPLEMENTATION



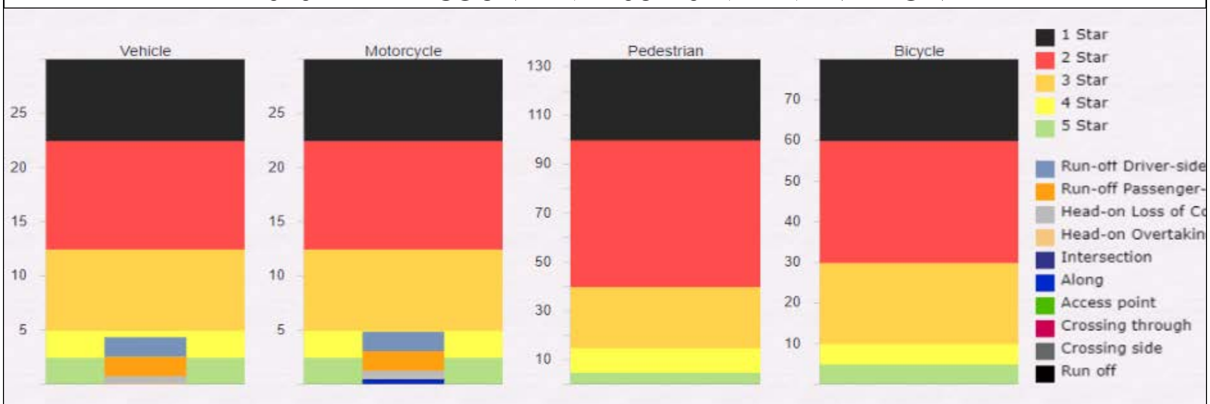
Road	Direction	Chainage
Road 40	2	27+610 – 27+510
Attribute Group	Before	After
MIDBLOCK ATTRIBUTES		
Road condition	Medium	Good
Skid resistance / grip	Sealed - medium	Sealed - adequate

Table 27: Star Rating Scores and coded attributes – Pilot Action 1; road 40; between 27+510 -27+410 km sections

SRS – BEFORE COUNTERMEASURES IMPLEMENTATION



SRS – AFTER COUNTERMEASURES IMPLEMENTATION

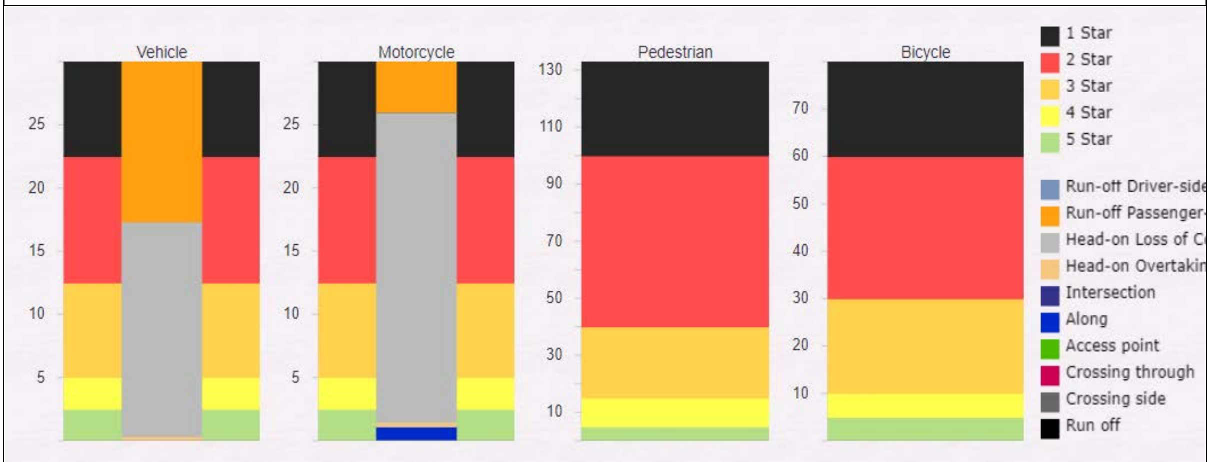


Road	Direction	Chainage
Road 40	2	27+510 – 27+410

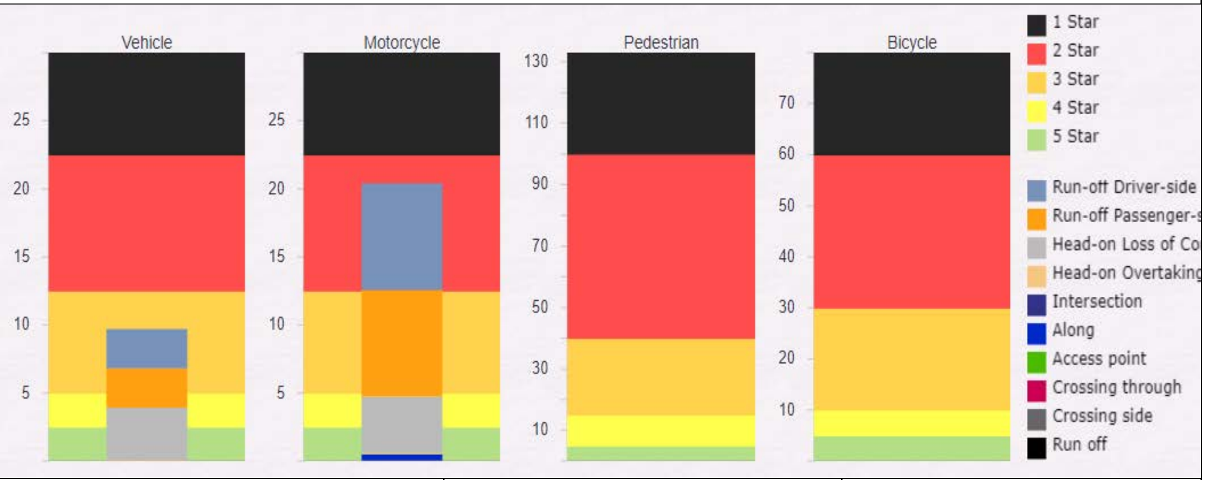
Attribute Group	Before	After
ROADSIDE ATTRIBUTES		
Paved shoulder - driver-side	None	Medium (>=1m to <2.4m)
Paved shoulder - passenger-side	None	Medium (>=1m to <2.4m)
MIDBLOCK ATTRIBUTES		
Road condition	Medium	Good
Skid resistance / grip	Sealed - medium	Sealed - adequate
SPEEDS		
Speed limit	90 km/h	60 km/h
Operating Speed (85th percentile)	85 km/h	70 km/h
Operating Speed (mean)	75 km/h	60 km/h

Table 28: Star Rating Scores and coded attributes – Pilot Action 1; road 40; between 27+410 -27+310 km sections

SRS – BEFORE COUNTERMEASURES IMPLEMENTATION



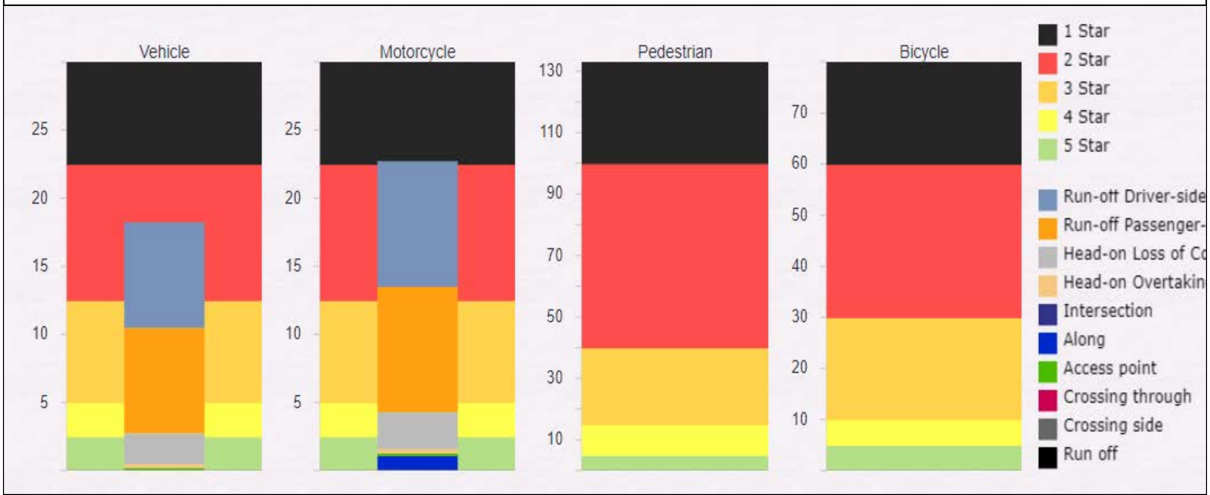
SRS – AFTER COUNTERMEASURES IMPLEMENTATION



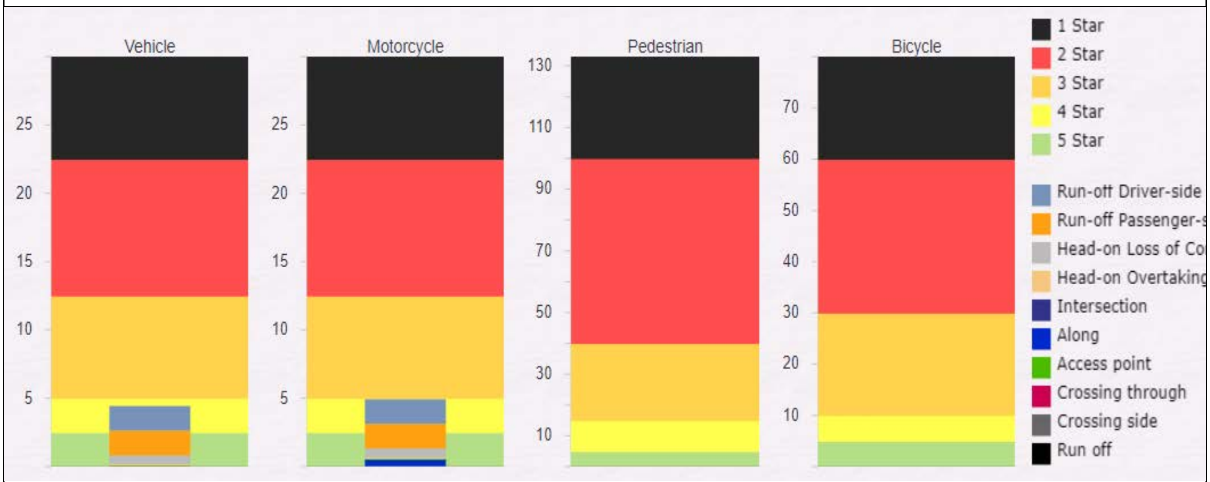
Road	Direction	Chainage
Road 40	2	27+410 – 27+310
Attribute Group	Before	After
ROADSIDE ATTRIBUTES		
Roadside severity - driver-side object	Downwards slope	Safety barrier - metal
Roadside severity - passenger-side object	Downwards slope	Safety barrier - metal
Paved shoulder - driver-side	None	Medium (>=1m to <2.4m)
Paved shoulder - passenger-side	None	Medium (>=1m to <2.4m)
MIDBLOCK ATTRIBUTES		
Quality of curve	Poor	Adequate
Road condition	Medium	Good
Skid resistance / grip	Sealed - medium	Sealed - adequate
SPEEDS		
Speed limit	90 km/h	60 km/h
Speed management / traffic calming	Not present	Present
Operating Speed (85th percentile)	85 km/h	70 km/h
Operating Speed (mean)	75 km/h	60 km/h

Table 29: Star Rating Scores and coded attributes – Pilot Action 1; road 40; between 27+310 -27+210 km sections

SRS – BEFORE COUNTERMEASURES IMPLEMENTATION



SRS – AFTER COUNTERMEASURES IMPLEMENTATION

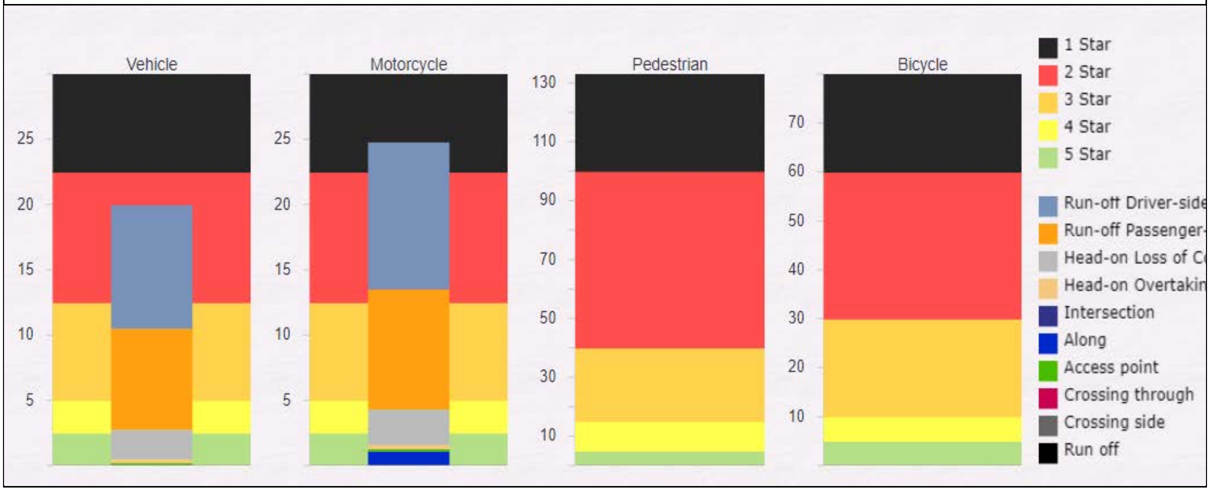


Road	Direction	Chainage
Road 40	2	27+310 – 27+210

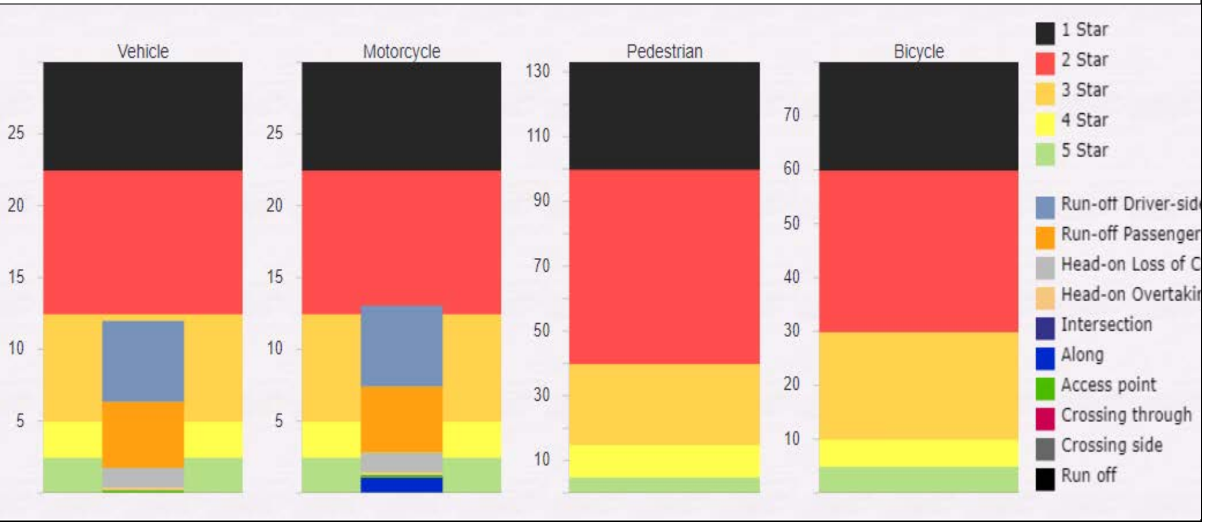
Attribute Group	Before	After
ROADSIDE ATTRIBUTES		
Paved shoulder - driver-side	None	Medium (>=1m to <2.4m)
Paved shoulder - passenger-side	None	Medium (>=1m to <2.4m)
MIDBLOCK ATTRIBUTES		
Road condition	Medium	Good
Skid resistance / grip	Sealed - medium	Sealed - adequate
SPEEDS		
Speed limit	90 km/h	60 km/h
Operating Speed (85th percentile)	85 km/h	70 km/h
Operating Speed (mean)	75 km/h	60 km/h

Table 30: Star Rating Scores and coded attributes – Pilot Action 1; road 40; between 27+210 -27+110 km sections

SRS – BEFORE COUNTERMEASURES IMPLEMENTATION



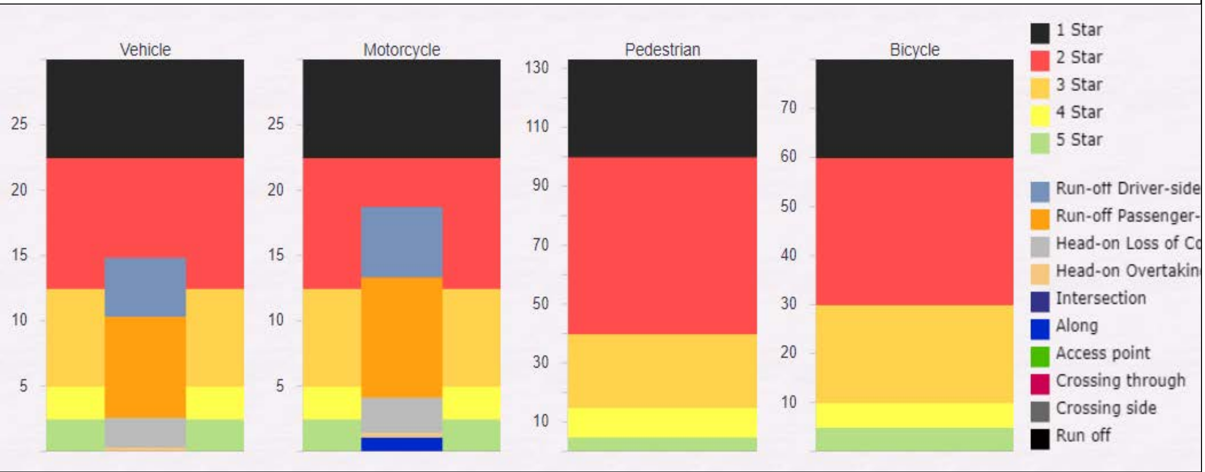
SRS – AFTER COUNTERMEASURES IMPLEMENTATION



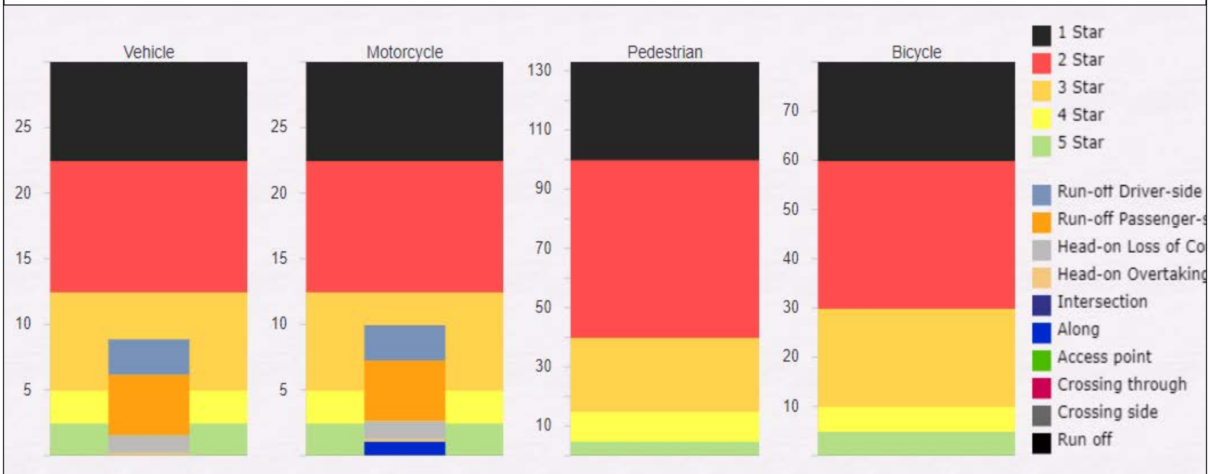
Road	Direction	Chainage
Road 40	2	27+210 – 27+110
Attribute Group	Before	After
MIDBLOCK ATTRIBUTES		
Road condition	Medium	Good
Skid resistance / grip	Sealed - medium	Sealed - adequate

Table 31: Star Rating Scores and coded attributes – Pilot Action 1; road 40; between 27+110 -27+010 km sections

SRS – BEFORE COUNTERMEASURES IMPLEMENTATION



SRS – AFTER COUNTERMEASURES IMPLEMENTATION



Road	Direction	Chainage
Road 40	2	27+110 – 27+010
Attribute Group	Before	After
MIDBLOCK ATTRIBUTES		
Road condition	Medium	Good
Skid resistance / grip	Sealed - medium	Sealed - adequate

As can be seen on the charts, the proposed Pilot Action could improve the SRS of the selected road section effectively. The changes are well highlighted and summarized in the following "Risk Worm" diagram (dark blue line: Vehicle occupant SRS before Pilot Action; light blue line: Vehicle occupant SRS after Pilot Action).

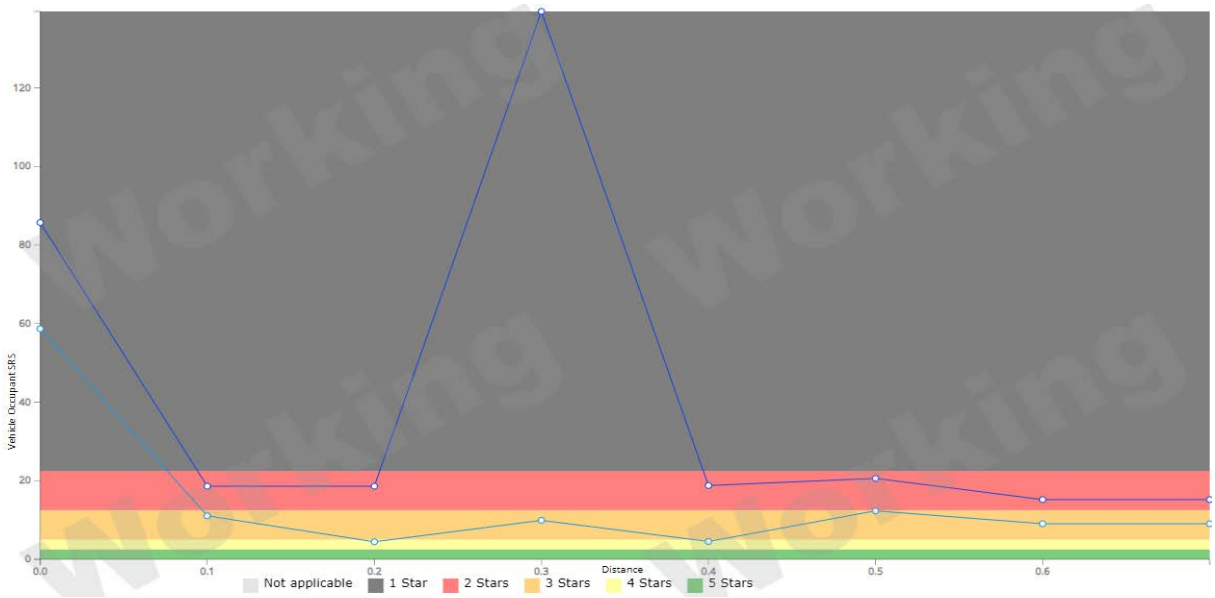


Figure 26: Risk Worm - Pilot Action 1; road 40; between 27+010 -27+710 km sections (direction 2: 0.0-0.1 of the diagram means 27+610-27+710 km section; 0.1-0.2 is 27+510-27+610 km section, etc.)

Currently, the analysed road section is a 1-2 stars section, which means it is well below the acceptable road safety level. The rating is extremely bad at the curve (at km 0.3 in this figure).

Applying the proposed Pilot Action, the SRS could be improved to a value equalling 3-4 stars (even at the curve, which is the most dangerous part of this road section).

The ViDA software proposed the following Safer Road Investment Plan based on the results of the evaluation before the implementation of the Pilot Action:

Table 32: Safer Road Investment Plan – Pilot Action 1; road 40

Countermeasure	Length / Sites	FSIs saved	PV of safety benefit	Estimated Cost	Cost per FSI saved	Program BCR
Skid resistance	0.20 km	10	642.113.487	17.403.149	1.784.720	37
Improve curve delineation	0.10 km	5	315.242.216	1.067.044	222.891	295

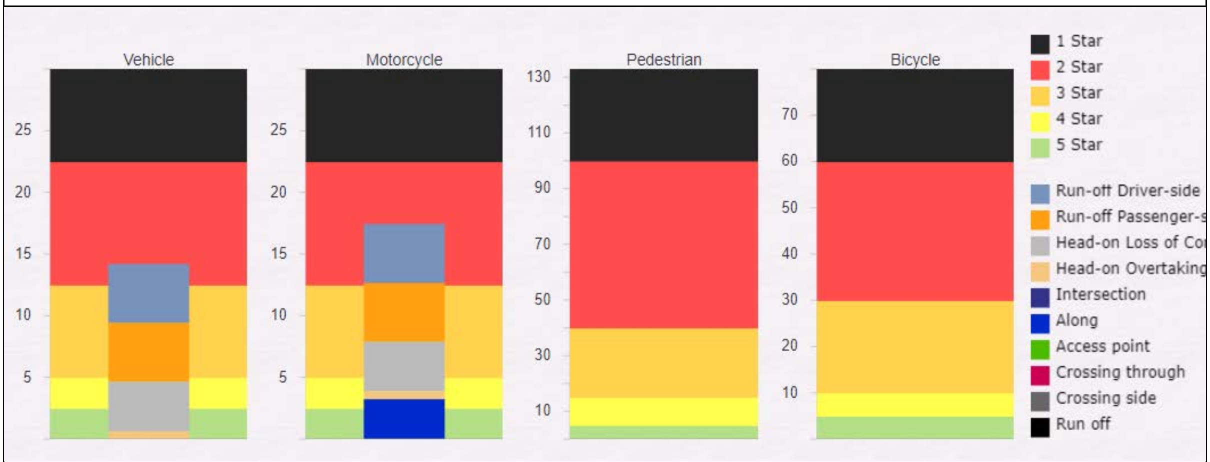
These suggested interventions are well in line with the proposed Pilot Action, and have been considered when elaborating the Implementation Ready Road Layout Concept Plans. The third column shows the total number of fatal and serious injuries (FSI) that can be avoided by the implementation of the countermeasures. The cost values in columns 4,5 and 6 are in Forint, PV means present value. Program BCR refers to the benefit-cost ratio.

5.2.2 Second Pilot Action – Martonvásár, road 7

The selected road section has been analysed at a length of 500 meters (road 7; between 33+330 - 33+830 km sections), in 100-meter sections. We provide here the Star Rating Scores for each 100-meter-long section both before and after the implementation of our Pilot Action, to support the comparison of the different cases. For the first 100-meter-long section, all coded attributes are presented, later we only highlight those parameters, where there is a difference in the before-after scenarios.

Table 33: Star Rating Scores and coded attributes – Pilot Action 2; road 7; between 33+830 -33+730 km sections

SRS – BEFORE COUNTERMEASURES IMPLEMENTATION



SRS – AFTER COUNTERMEASURES IMPLEMENTATION

Road segment not affected by countermeasures.

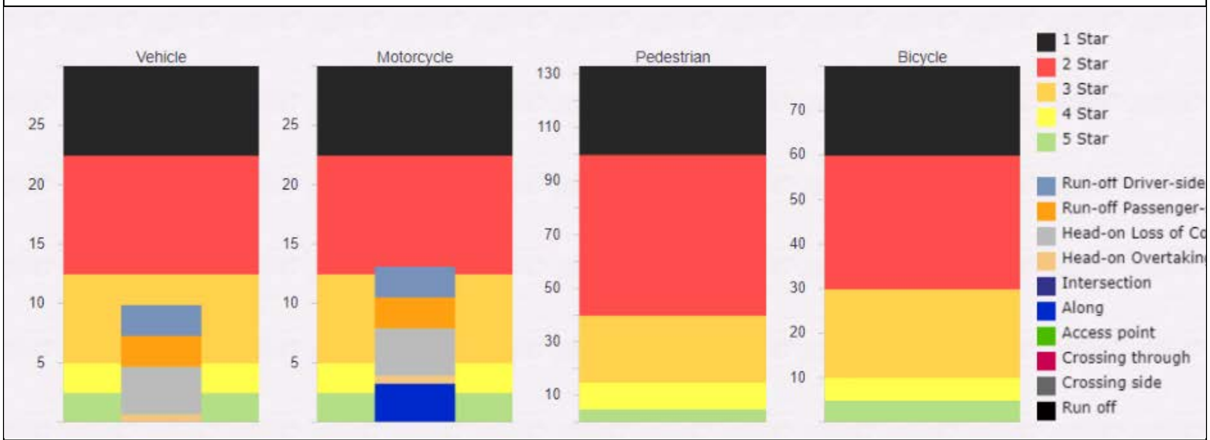
Road	Section	Chainage
Road 7	1	33+830 – 33+730

Attribute Group	Before	After
ROADSIDE ATTRIBUTES		
Roadside severity - driver-side distance	1 to 5m	1 to 5m
Roadside severity - driver-side object	Deep drainage ditch	Deep drainage ditch
Roadside severity - passenger-side distance	1 to 5m	1 to 5m
Roadside severity - passenger-side object	Deep drainage ditch	Deep drainage ditch
Shoulder rumble strips	Not present	Not present
Paved shoulder - driver-side	Narrow (>=0 to <1.0m)	Narrow (>=0 to <1.0m)
Paved shoulder - passenger-side	Narrow (>=0 to <1.0m)	Narrow (>=0 to <1.0m)
MIDBLOCK ATTRIBUTES		
Carriageway label	Undivided road	Undivided road
Upgrade cost	Low	Low
Median type	Centre line	Centre line
Centreline rumble strips	Not present	Not present
Number of lanes	One	One
Lane width	Wide (>=3.25m)	Wide (>=3.25m)
Curvature	Straight or gently curving	Straight or gently curving
Quality of curve	Not applicable	Not applicable
Grade	0% to 7.5%	0% to 7.5%
Road condition	Good	Good
Skid resistance / grip	Sealed - adequate	Sealed - adequate
Delineation	Adequate	Adequate
Street lighting	Not present	Not present
Vehicle parking	None	None
Service road	Not present	Not present
Roadworks	No road works	No road works
Sight distance	Adequate	Adequate
INTERSECTION ATTRIBUTES		
Intersection type	None	None
Intersection channelization	Not present	Not present
Intersecting road volume	None	None
Intersection quality	Not applicable	Not applicable
Property access points	None	None
FLOW ATTRIBUTES		
Vehicle flow (AADT)	8634	8634
Motorcyclist %	1%-5%	1%-5%
Pedestrian peak hour flow across the road	0	0
Pedestrian peak hour flow along the road driver-side	0	0
Pedestrian peak hour flow along the road passenger-side	0	0
Bicyclist peak hour flow	0	0
VRU FACILITIES AND LAND USE ATTRIBUTES		
Land use - driver-side	Farming and agricultural	Farming and agricultural
Land use - passenger-side	Farming and agricultural	Farming and agricultural

Area type	Rural/open area	Rural/open area
Pedestrian crossing facilities - inspected road	No facility	No facility
Pedestrian crossing quality	Not applicable	Not applicable
Pedestrian crossing facilities - intersecting road	No Facility	No Facility
Pedestrian fencing	Not present	Not present
Sidewalk - driver-side	None	None
Sidewalk - passenger-side	None	None
Facilities for motorised two wheelers	None	None
Facilities for bicycles	None	None
School zone warning	Not applicable	Not applicable
School zone crossing supervisor	Not applicable	Not applicable
SPEEDS		
Speed limit	90 km/h	90 km/h
Differential speed limits	Not present	Not present
Speed management / traffic calming	Not present	Not present
Operating Speed (85th percentile)	85 km/h	85 km/h
Operating Speed (mean)	75 km/h	75 km/h

Table 34: Star Rating Scores and coded attributes – Pilot Action 2; road 7; between 33+730 -33+630 km sections

SRS – BEFORE COUNTERMEASURES IMPLEMENTATION



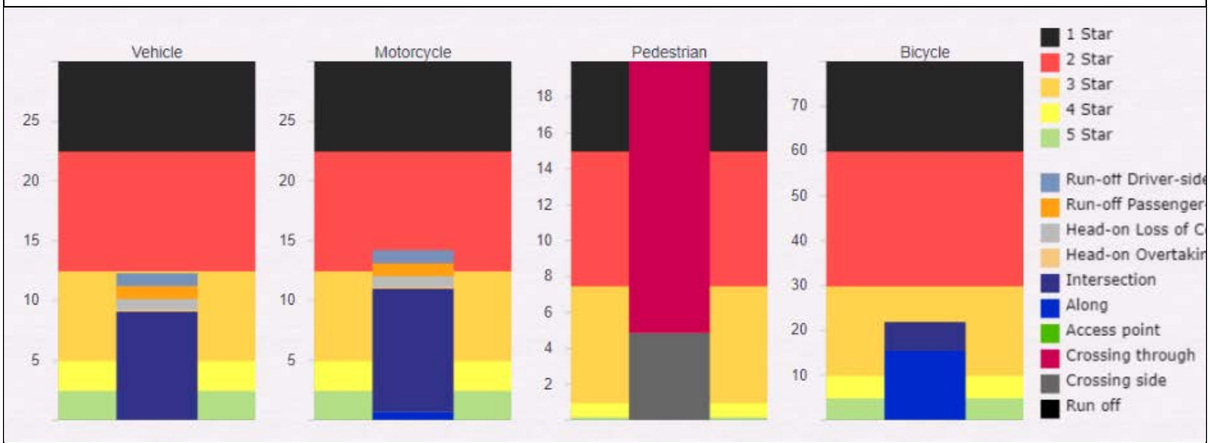
SRS – AFTER COUNTERMEASURES IMPLEMENTATION

Road segment not affected by countermeasures.

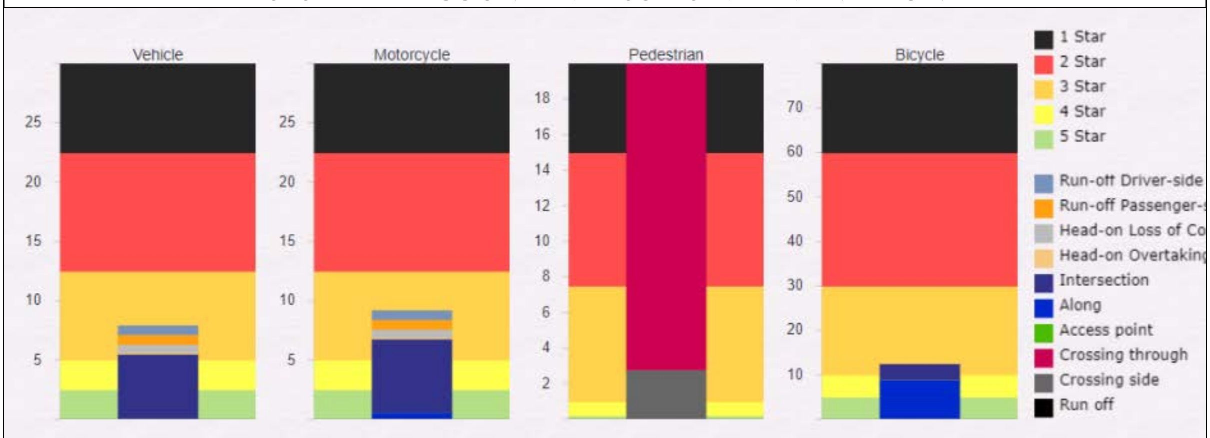
Road	Section	Chainage
Road 7	1	33+730 – 33+630

Table 35: Star Rating Scores and coded attributes – Pilot Action 2; road 7; between 33+630 -33+530 km sections

SRS – BEFORE COUNTERMEASURES IMPLEMENTATION



SRS – AFTER COUNTERMEASURES IMPLEMENTATION

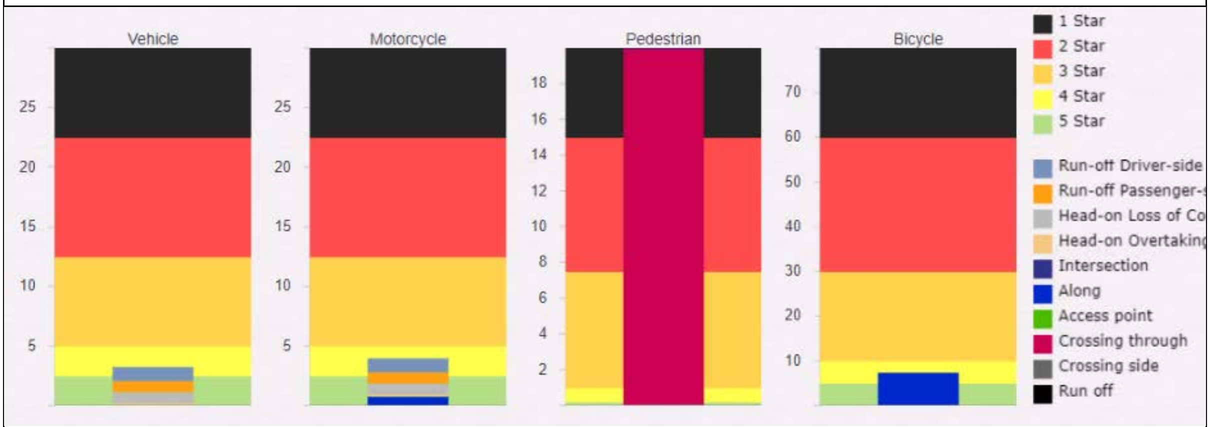


Road	Section	Chainage
Road 7	1	33+630 – 33+530

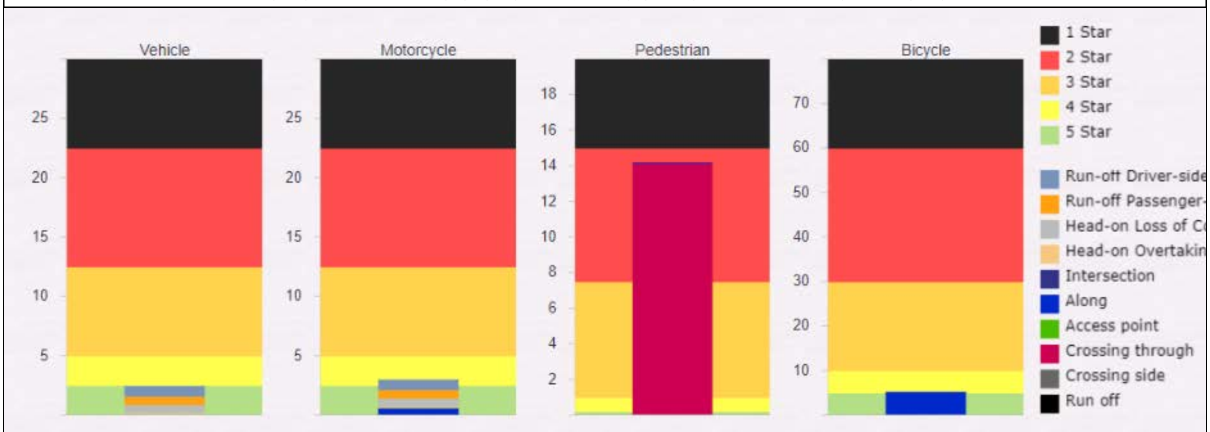
Attribute Group	Before	After
SPEEDS		
Speed management / traffic calming	Not present	Present
Operating Speed (85th percentile)	55 km/h	45 km/h
Operating Speed (mean)	50 km/h	40 km/h

Table 36: Star Rating Scores and coded attributes – Pilot Action 2; road 7; between 33+530 -33+430 km sections

SRS – BEFORE COUNTERMEASURES IMPLEMENTATION



SRS – AFTER COUNTERMEASURES IMPLEMENTATION

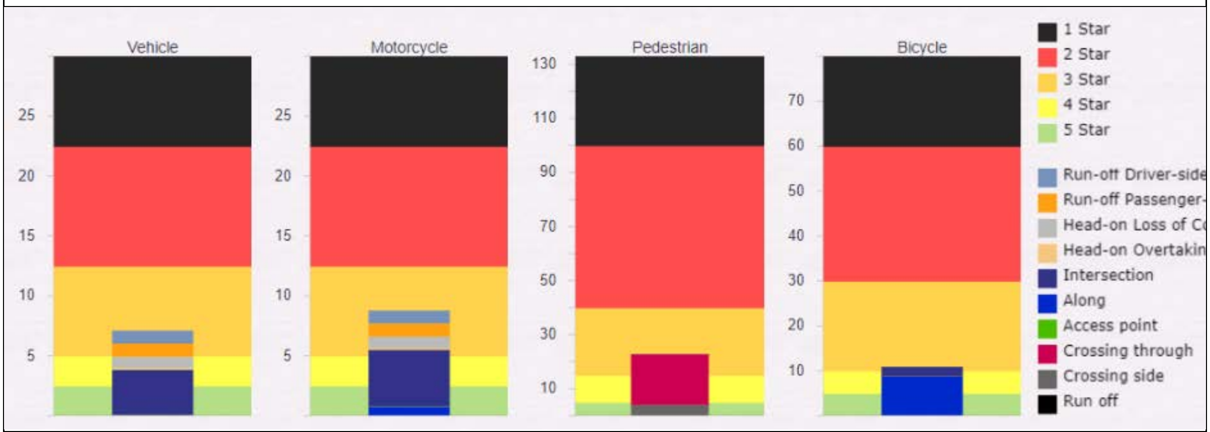


Road	Section	Chainage
Road 7	1	33+530 – 33+430
Attribute Group	Before	After

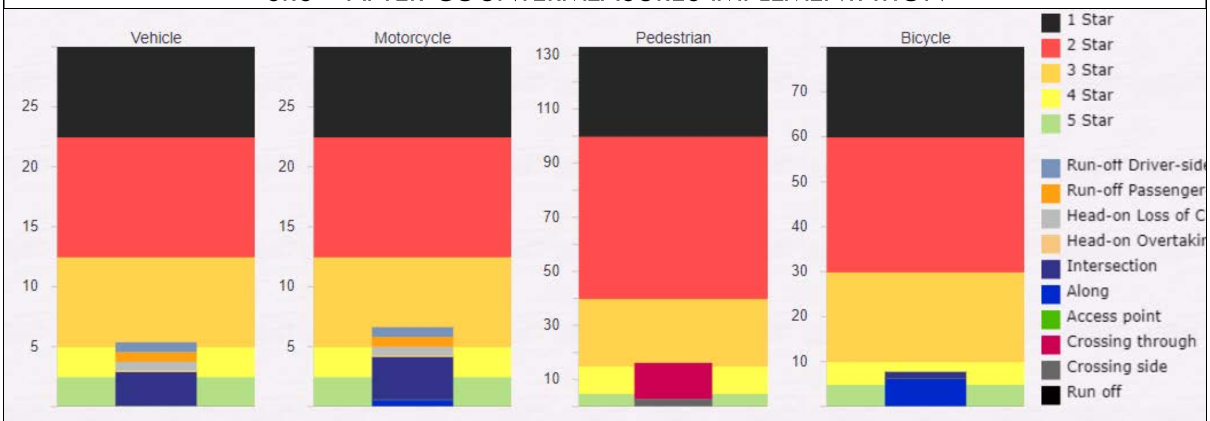
SPEEDS		
Speed management / traffic calming	Not present	Present
Operating Speed (85th percentile)	55 km/h	45 km/h
Operating Speed (mean)	50 km/h	40 km/h

Table 37: Star Rating Scores and coded attributes – Pilot Action 2; road 7; between 33+430 -33+330 km sections

SRS – BEFORE COUNTERMEASURES IMPLEMENTATION



SRS – AFTER COUNTERMEASURES IMPLEMENTATION



Road	Section	Chainage

Road 7	1	33+430 – 33+330
Attribute Group	Before	After
SPEEDS		
Operating Speed (85th percentile)	55 km/h	45 km/h
Operating Speed (mean)	50 km/h	40 km/h

As can be seen on the above charts, the proposed Pilot Action doesn't have any effect on the road section in the approach to the border of the city. However, when arriving in the urban area, the proposed fixed speed camera decreases vehicle speeds. As no other interventions were planned here, the only affected parameters are:

- speed management/traffic calming,
- operating speed (85^{th} percentile),
- operating speed (mean).

These attributes however have significant effect on road safety and on Star Rating Scores as well. Changes of SRS are highlighted and summarized in the following "Risk Worm" diagram (dark blue line: Vehicle occupant SRS before Pilot Action; light blue line: Vehicle occupant SRS after Pilot Action).

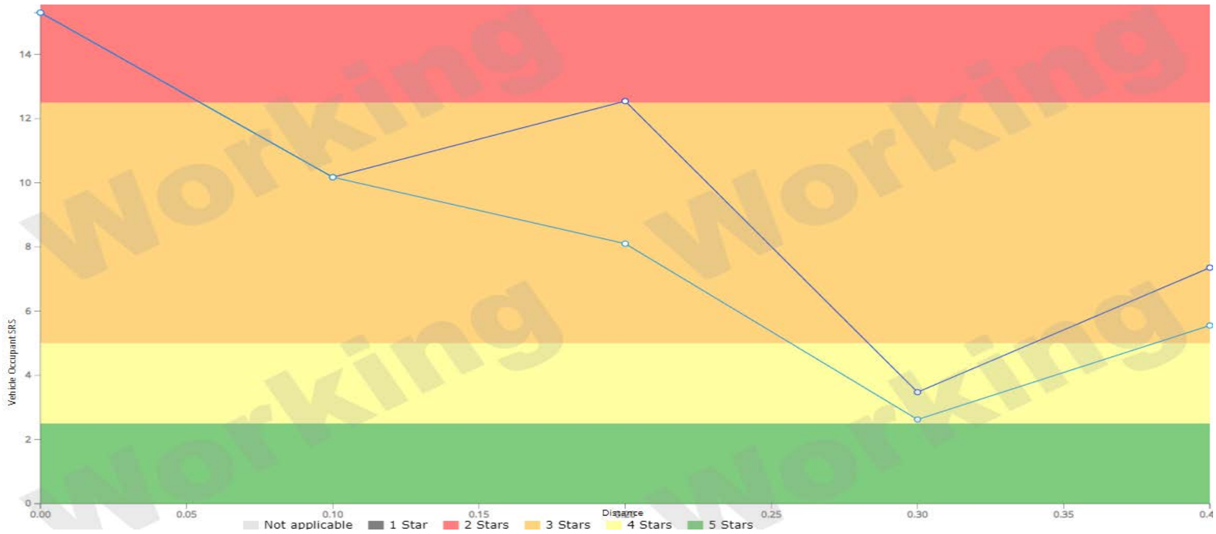


Figure 27: Risk Worm - Pilot Action 2; road 7; between 33+330 -33+830 km sections (direction 2: 0.0-0.1 of the diagram means 33+830-33+730 km section; 0.1-0.2 is 33+730-33+630 km section, etc.)

Currently, the analysed road section is a 2-4 stars section for vehicle occupants. Applying the proposed Pilot Action, the SRS could be improved, especially at the section in front of the planned fixed speed camera (which is currently a 2 stars section that can be improved to 3 stars). The location of the planned speed camera is at about the 0.30 point of the chart.

As the aim of this Pilot Action is mainly to improve the safety of vulnerable road users by reducing vehicle speeds, it is also interesting to examine the SRS values related to these road user groups (pedestrians, cyclists). From the Tables above, we can conclude that vulnerable road users could have high benefits from the proposed Pilot Action.

At section 33+530-33+430 (camera is planned at section 33+539, where the bicycle lane is opening), the SRS for pedestrians and cyclists also improve by one star (in case of pedestrians: from 1 star to 2 stars; in case of cyclists: from 4 stars to 5 stars).

At section 33+430-33+330 (which contains the pedestrian crossing), the SRS for pedestrians and for cyclists also can be improved from 3 stars to 4 stars by the proposed Pilot Action.