Design of crosswalks for children
Elaborating on best practise

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Abstract

Actual vehicle speeds should be below 20 km/h where children 7-12 years old are crossing a street. To achieve this, a review of a 'best' design of crosswalks for children, based on the analysis of eight Israeli field studies and three Swedish is conducted. Additional countermeasures for improving pedestrian safety at crosswalks are also reviewed.

The results of the field studies show that a "best design" should include a speed-reducing device located before the crosswalk. The optimal distance of such device from the crosswalk is about 10 m if the speed limit is 30 km/h or lower. For 50 km/h speed limit roads, a longer distance of 15 to 20 m is needed and, as a complimentary measure, the crosswalk itself should be elevated. At approaches with two lanes or more multiple threat conflicts occurring due to a vehicle overtaking a stopped car in the adjacent lane are a threat especially for children, as they are hidden behind the stopped vehicle if it has stopped too close to the crosswalk. To provide a stronger message for alerting drivers to stop, and not to overtake a stopped car in an adjacent lane, advanced yield bars or stop lines are needed. A distance to the crosswalk of about 10 m is recommended. To secure travel speeds below 20 km/h additional measures like cameras surveying speeds near the crosswalk might be needed.

1 Introduction

Höskuldur (2015) concludes that if the goal is to eliminate serious injury accidents, 30 km/h might not be a sufficiently low speed. Actual vehicle speed should be a maximum of 20 km/h where there is a risk of collision between vehicles and unprotected road users. This is of utmost importance on streets where children aged 7 to 12 cross (Johansson & Leden, 2010) as children have difficulties estimating direction, speed and distance (Piaget 1969, von Hofsten, 1980 and 1983 (presented in Arnold & Bennett, 1990), Leden, 1989, Connely et al, 1998, Foot et al, 1999, Mac Gregor et al,1999). To improve clarity and orientation and consequently, pedestrian safety, refuge islands are efficient (Harkey & Zegeer, 2004; Turner et al, 2006). Another option is to limit the number of directions vehicles can approach from e.g. by relocating crosswalks to mid-block locations (Leden, Gårder & Johansson, 2006).

Speed profiles for traffic-calmed roads as a function of the local speed and the type and design of the measure are shown, e.g., in Leden, Gårder & Johansson (2008), and as a function of the distance between measures in e.g. Barbosa et.al. (2000) and Karlgren (2001). Similarly, drivers' and pedestrians' behaviour at pedestrian crossings has been extensively researched, see e.g. Johansson (2004) and Várhelyi (1998). However, the influence of the distance between a speed hump and a pedestrian crossing has not been a focus until 2011. Swedish guidelines still do not discuss the distance between the speed hump and the crossing explicitly. Recent Swedish guidelines for geometric design of roads and streets states that "Regular humps 5-6 meters ahead of crosswalks typically work better than raised crosswalks, so called speed tables. It is easier for motorists to understand that pedestrians cross a roadway if the areas have traditional design" (VGU, 2015). We will explore if the 5-6 meters is in accordance with the best practise starting with the results of Várhelyi (1998).

Várhelyi (1998) analysed drivers' speed behaviour at a mid-block crosswalk using a radar gun, hidden at the road side. The gun sent the speed data to a laptop computer in which the observer also registered pedestrians' arrival at, and start from, the curb. Of the total registered situations the pedestrian passes first in 42 cases. Situations in which the pedestrian passes first include three types of situations: 'No braking' situations, 'Provoked braking´ situations and 'Ideal´ situations from the point of view of the pedestrian. In 'ideal' situations the car starts braking between 30 and 70 m before the crosswalk and speeds are lowest 20 to 10 m before the crosswalk, see Figure 1. Várhelyi & Leden (2016) concludes that a placement of speed humps in the range of 20 to 10 m before the crosswalk support 'ideal interactions'.

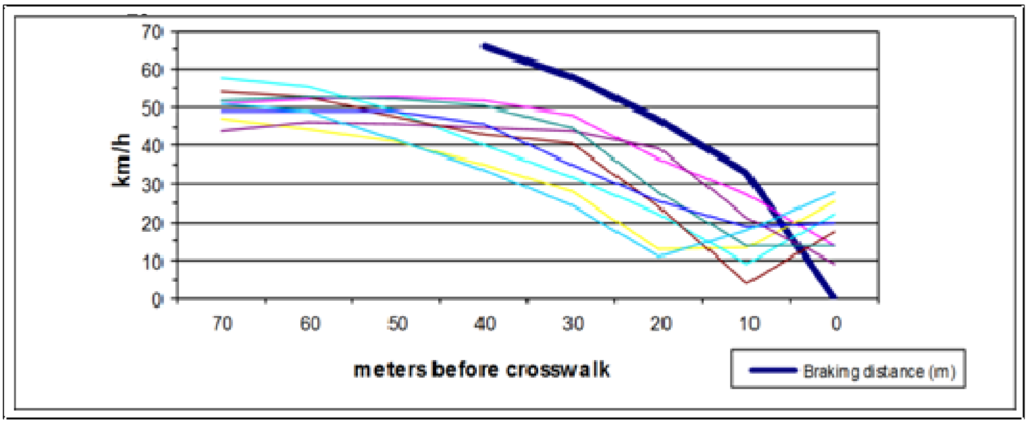

Figure 1 Speed profiles for "ideal" interactions when the driver gives way to the pedestrian in good time (Várhelyi, 1998)

2 Scope and Delimitations

The scope of this paper is to elaborate on the best practice for designing crosswalks for children focusing on physical measures like speed humps, speed cushions and speed tables (also called raised pedestrian crosswalks). ITS measures, Intelligent Transport Systems, are not discussed.

3 Test sites

Studies at three sites in Sweden and eight Israeli test sites form a base, together with review of additional countermeasures that may be needed, to outline a best practice in urban areas. All eight Israeli test sites were major multi-lane arterials with dual-carriageway layouts, and with high traffic volumes and high pedestrian activity in the crossing areas. All three Swedish test sites were on two-lane arterials equipped with speed cushions at distances of about 5 m and 10 m respectively from the pedestrian crosswalk.

3.1 Test sites in Israel

The Israeli test sites are multi-lane arterials with dual-carriageway layout, with high traffic volumes and high pedestrian activity in the crossing areas. The threshold requirements for the study sites were as follows:

– It should be a marked crosswalk situated on a dual-carriageway road segment, with a built median and two travel lanes in each direction.
– A speed limit of 50 km/h, where the 85-percentile speed is above 50 km/h, at least in one of the directions approaching the crosswalk.
– An intensity of pedestrian activity, with at least 25 pedestrian crossings, per hour.
– A straight and flat road segment (without sharp curves or substantial gradients), with a visibility distance for the driver of at least 50 m ahead, in both directions approaching the crosswalk.
– A site without substantial visibility obstacles in the crosswalk area, such as dense vegetation.

The average traffic volume varied between 200 and 1400 vehicles per hour on the eight sites (Gitelman et al., 2016).

Two countermeasure settings were applied at the Israeli study sites: (1) a bolder 15 cm high trapezoidal speed hump at the crosswalk area with 1 m ramps, combined with 8-10 cm high circular humps (Watt's type) before the crosswalk, and (2) a smoother 10-12 cm high trapezoidal hump at the crosswalk area with 2 m ramps, combined with 6-8 cm high preceding circular humps. The circular speed hump was built 15-20 meters before the crosswalk, in each travel direction and lane approaching the crosswalk. The more bold design was applied at five study sites, out of eight. For an example of the setting at the study sites see Figure 2 (from Gitelman et al., 2016).

Notes: 1 - a trapezoidal speed hump on the crosswalk area; 2 - a circular speed hump before the crosswalk; 3 – traffic signs and overhead amber flashing lights.

Figure 2. Main components of a raised crossing arrangement, on the example of site 7 in Israel (Gitelman et al., 2016).

The Israeli guidelines on the design and installation of speed humps (MoT, 2002), recommend a distance of 10 m, at least, between the preceding speed hump and pedestrian crosswalk, in each travel direction. Additionally, warning traffic signs should be installed at a distance of 50-100 m before the first speed hump.

3.2 Test sites in Malmö

During the winter of 2000 and spring of 2001, Regementsgatan an arterial in Malmö before the reconstruction, when the roadway was 15 meters wide with one marked lane in each direction, though in reality it operated as two lanes in each direction when there were no parked cars. At each marked crosswalk, there was a refuge island. The traffic flow at Regementsgatan before reconstruction was about 14,000 vehicles per day, decreasing to just below 10,000 vehicles after reconstruction. The street was narrowed to eight meters with refuges in the middle of the crosswalks, and speed cushions were installed before the crosswalks. The traffic signal was removed from the mid-block pedestrian and cyclist crossing Dragonstigen. This site "Dragonstigen" was chosen as test site as the two speed cushions were located at different distances, approximately 10 meters and 5 meters ahead of the marked pedestrian crosswalk, see Figure 3, and because school children are crossing the street frequently at this location as there is a nearby school.

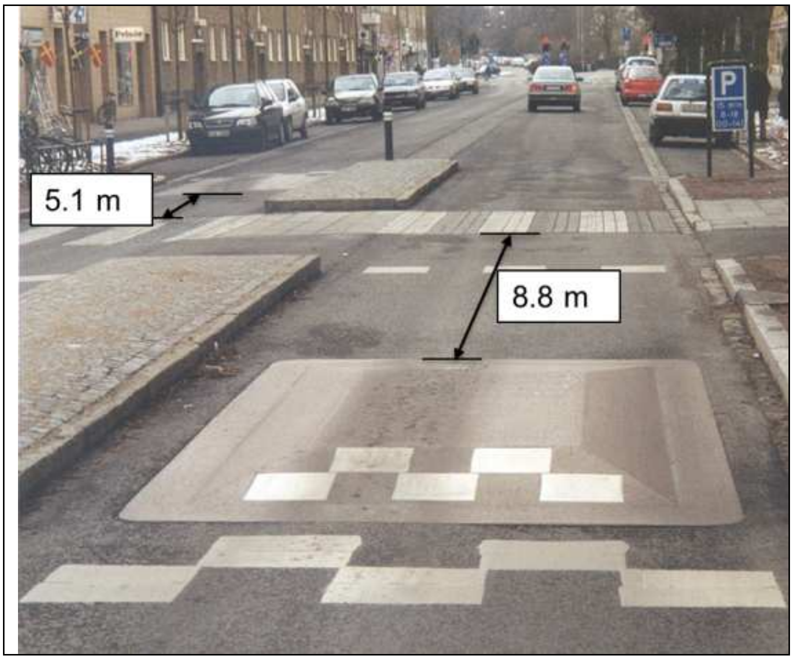

Figure 3 Test site "Dragonstigen" a mid-block pedestrian and cyclist. The shorter distance is 5.1 m to the left in the figure, and the longer distance to the right is 8.8 m.

The second test site "Tessins väg" in Malmö is situated next to the school. Two school surveys administered by the teachers were launched there; one before, to get a foundation to plan countermeasures, and one after the reconstruction to evaluate the effects. The distance between the pedestrian crossing and the speed cushion is 4.2 m for traffic travelling north-east, and 10.2 m for vehicles travelling south-west see Figure 4. Crossings and speed cushions are indicated with painted markings, and the height of the speed cushions is about 10 cm. The posted speed limit through the crossing is 30 km/h at school hours. When school is "off" a 50 km/h limit applies instead. Tessins Väg had a vehicle flow of 4000 vehicles per day in 2005.

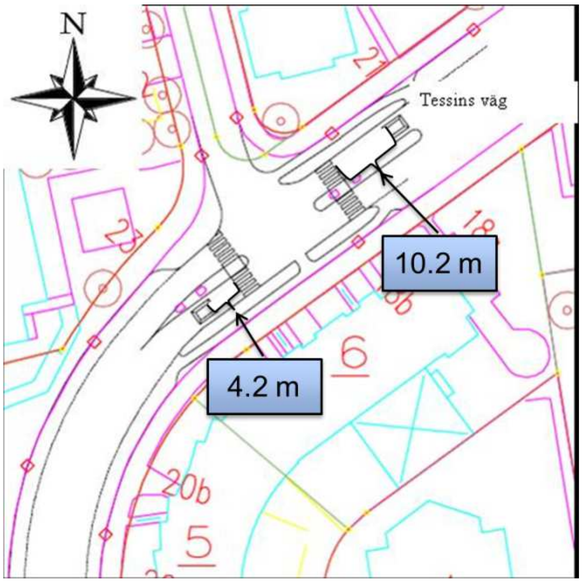

Figure 4 Plan of test site Tessins väg" (the Tessins Väg/Henrik Wranérs Gata crossing) after reconstruction. The shorter distance is 4.2 m to the left in the figure, and the longer distance to the right is 10.2 m.

3.3 Test site in Borås

The test site in Borås, Hultagatan, had a daily vehicle flow of 5000 vehicles in 2001. The Hulta centre with junior and middle schools and businesses lies south of the site studied in Borås. Posted speed limit was 50 km/h but the recommended speed 30 km/h. The distance between the pedestrian crossing and the speed cushion is 3 m for traffic travelling east, and 8 m for vehicles travelling west, see Figure 5. The height of the speed cushions is 70 mm.

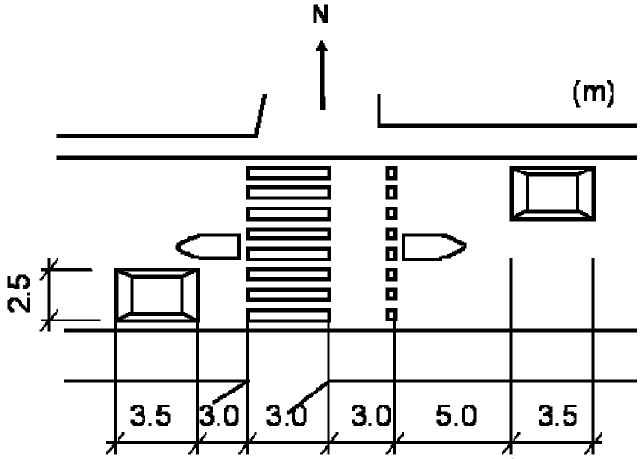

Figure 5 Test site "Hultagatan" in Borås a mid-block pedestrian and cyclist crossing. The shorter distance is 3.0 m to the left in the figure, and the longer distance to the right is 8.0 m.

3.4 Type of countermeasures implemented

Table 1 shows an overview of the countermeasures implemented at the test sites.

Table 1 Type of countermeasures studied in three Swedish and eight Israeli test sites

	Narrowing the street at pedestrian crossing	Speed humps/ cushions	Elevated area/ elevated crossing with paving stone	Posted speed km/h Before	Recommen-ded/Posted Speed Km/h After
Israeli test sites		*	*	50	50
Swedish test sites					
Dragonstigen	*	*		50	30/50
Tessins väg	*	*		30	30
Borås	*	*		30	30/50

4 Method

The parameters important for describing pedestrian safety at crosswalks, according to an expert questionnaire (Johansson & Leden, 2007), are listed below ranked starting with the most important:

1. speed of vehicles,
2. speed of pedestrians or bicyclists,
3. at what distances evasive actions are taken,
4. whether the pedestrian or cyclist looks around before crossing the street, and
5. whether she/he stops at the kerb before crossing the street.

Those parameters were chosen as key variables for analysis of both the Swedish and Israeli studies. To capture data the following methods were used: measurements of vehicle speeds, video recordings of road user behaviour and interviews with children.

5 Results

5.1 Israeli test sites

The bolder Israeli design which was used in most Israeli study sites, in three cities, led to a substantial reduction in speeds, achieving mean speeds below 30 km/h and 85-percentile speeds below 40 km/h. This was attained at sites with a wide range of initial mean speeds (42-58 km/h) and 85-percentile speeds (50-66 km/h), thus, demonstrating a speed-reducing effect of 20-30 km/h, in both speed indicators. Additional positive changes associated with the first setting concerned a remarkable increase in the share of vehicles yielding to pedestrians in the crosswalk zone (from 80% to 96-98%, in the near lane, and from 62-63% to 98-100%, in the far lane) and with an increase in the share of pedestrians who performed a full crossing in the designated zone. Both positive changes occurred instantly and remained in place after two months. At the sites with the second smoother layout, yielding rates were close to 100% already in the before period.

5.2 Test sites in Sweden

School children aged 9 to 12 pointed out the sites Dragonstigen and Tessins väg as two of the most dangerous sites in the neighbourhood to the school. Therefore, Tessins väg was reconstructed to improve security and safety (Figure 4). As both has different distances between speed cushion and pedestrian crossing the two sites become test sites in Malmö. Unexpectedly, speed was somewhat lower on the pedestrian crossing at the side where the speed cushion was located further away with a 90-percentile speed of 30 km/h for the shorter distance and 2-3 km/h lower for the longer distance, see Table 2. An explanation can be that with the speed cushion at a shorter distance from the pedestrian crossing, drivers are more focused on passing the speed cushion, and therefore adjust their speed less to the approaching crossing compared to when the speed cushion is situated at a further away distance. Speeds 12 m before the speed cushion were also measured. The speed 12 m before the pedestrian crossing was similar with that on the crossing, with the exceptions of one direction at Dragonstigen where the speed cushion was 12 m before the pedestrian crossing. Vehicle speeds are assumed to be lowest at the speed cushions. So the fact that speed 12 m before the crossing was the same or less than on the crossing can most plausible be explained by drivers starting to decelerate in order to drive over the speed cushion, and then starting to accelerate again once they had reached the crossing. At the time speed measurements in Borås were carried out, the measuring accuracy was not sufficient for stating exact speed at the pedestrian crossing. Data was also captured at two comparison sites. (Johansson, Rosander, & Leden, 2011)

Table 2. Free vehicle speeds (km/h) 12 m before and at the pedestrian crossing depending on short or long distance between speed cushion and pedestrian crossing. (PCR = pedestrian crossing). Johansson, Rosander, & Leden (2011).

		Shorter distance		Longer distance	
		12 m before	On PCR	12 m before	On PCR
Dragonstigen	mean	24.2	23.1	17.0	22.1
	std	1.51	1.21	0.59	0.51
	90%	34	30	23	27
	N	37	34	52	53
Tessins Väg	mean	23.6	23.9	23.8	22.5
	std	0.68	0.65	0.54	0.43
	90%	29	30	30	28
	N	39	45	117	132

In all, 802 pedestrians were recorded when encountering a vehicle. Pedestrians were more often given way by the first driver in the near lane if there was a longer distance between the crossing and the speed cushion, 50% at longer distances compared with 40% at shorter ($p < 0.05$). Based on all 255 pedestrian observations from Dragonstigen, the tendency was the same, 50% compared with 43%, and on Hultagatan in Borås 43% compared to 23% ($p < 0.01$). On Tessins Väg the result concerning drivers' yielding behaviour was just the opposite compared to the two other sites. This may possibly be due to lower visibility at the shorter distance compared to the longer distance.

The school survey revealed that some children had problems to predict whether motor vehicle drivers intended to stop or not especially at Dragonstigen. Two of the children interviewed at the location had pointed out this problem in the survey. When interviewed on the site the children stated that it is problematic to foresee if motor vehicle drivers intended to stop or not when they slowed down for the speed cushion. The problem seemed to be accentuated when the speed cushion was situated closer (about 5 meters) to the crosswalk (Leden, Johansson & Leden, 2006). This is probably due to the fact that it is easier for the children to judge if the driver will be braking for them or for the speed-reducing device at the side where the device is located further away. To conclude, locating a speed-reducing devices about ten meters before the crosswalk is more effective than five meters before it (Johansson, Rosander & Leden (2011).

To summarize when the speed cushion is situated at a further away distance from the pedestrian, drivers are more cautious, tentative and more aware of the approaching pedestrian crossing as they then get more time to focus on approaching pedestrians and cyclists after passing the speed cushion and Várhelyi (2016) concludes that a placement of speed humps in the range of 20 to 10 m before the crosswalk support 'ideal interactions' from the point of view of the pedestrian and children crossing receive a stronger message whether drivers intend to stop or not.

6 Other measures

Traffic signs and road markings can be used to increase the awareness among drivers and also different types of enforcement and or concepts as "shared space" (Fontaine & Carlson, 2001, and Daniel, Chien, & Liu, 2005). Currently, applications of the "shared space" concept i.e. assuming walking speeds of motor vehicles are reported from several countries, besides the Netherlands where a predecessor to shared space - the Woonerf concept was launched in the 1970's. Different concepts of "shared space" could be used more extensively in walking speed zones and at intersections where pedestrians dominate (Gustafsson, Jägerbrand & Grumert, 2011). The primary explanation for a probable positive effect on traffic safety of shared space is the lower speed level and higher attention to pedestrians among motorists and improved mobility for pedestrians (Sörensen, 2010).

Gitelman et al (2016) concludes that the Israeli design has a potential for reducing multiple threat conflicts occurring due to a vehicle overtaking a stopped car in the adjacent lane, which is a hazard especially to children crossing (Leden, Gårder & Johansson, 2006). To achieve a stronger message to alert drivers to stop and not to overtake a stopped car in the adjacent lane, advanced yield or stop lines are needed. Adding yield or stop lines in advance of the crosswalk is likely to be efficient if it is accompanied by a comprehensive information campaign explaining the message. However, this is not yet an option available in many countries. For example, according to Finnish and Israeli regulations, yield lines cannot be installed except for at signalised crosswalks, though it is already used in, for example, Spain and the United States – see examples in Figures 6-7. In Sweden, yield bars has to be used at marked crossings for cyclists, which also have to be speed secured to about 30 km/h, but yield bars are not mandated at pedestrian crosswalks (SKL, 2015).

Fig. 6 Speed-reducing devices and stop lines or yield bars 8 – 10 m before the crosswalk Playa de las Americanos Arquitecto Gomez Cuesto, Tenerife

The US guidelines MUTCD (2009) recommends a distance between yield bars and a crosswalk of 6-15 m. An example from Los Angeles is given in Figure 7. It is also recommended to consider using advanced warning markings for speed humps.

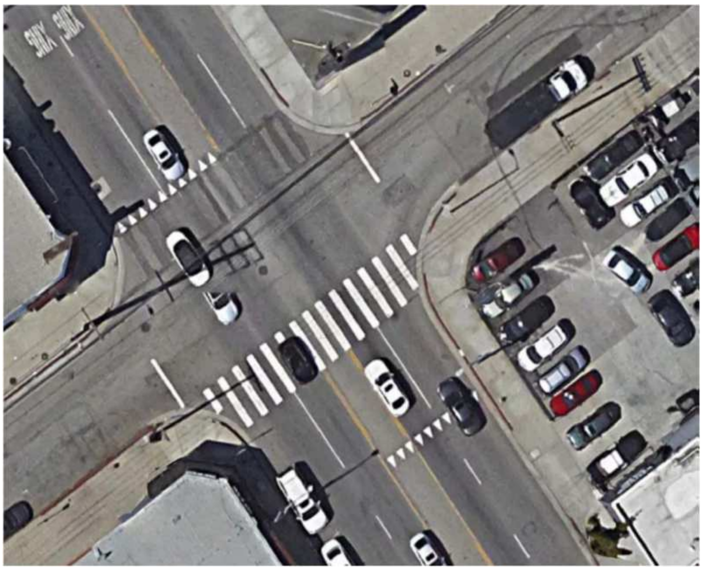

Fig 7 Early yield bars Los Angeles US

As established in the introduction, the key issue when children 7-12 years old are to cross a street is to secure speeds to 20 km/h or lower. An effective option to achieving this is to implement speed cameras to survey a posted speed limit of 20 km/h. An example is given in Figure 8. Further development of intelligent “platforms” or speed-activated trapdoors type Edeva (2016) is another option to secure speeds of 20 km/h. Ideally, the street should have a speed-reducing device that is clearly felt by drivers going above the desired speed but the street should be kept flat and comfortable for road-users traveling at or below the desired speed. This is of special benefit to standing passengers in buses and to patients traveling in ambulances.

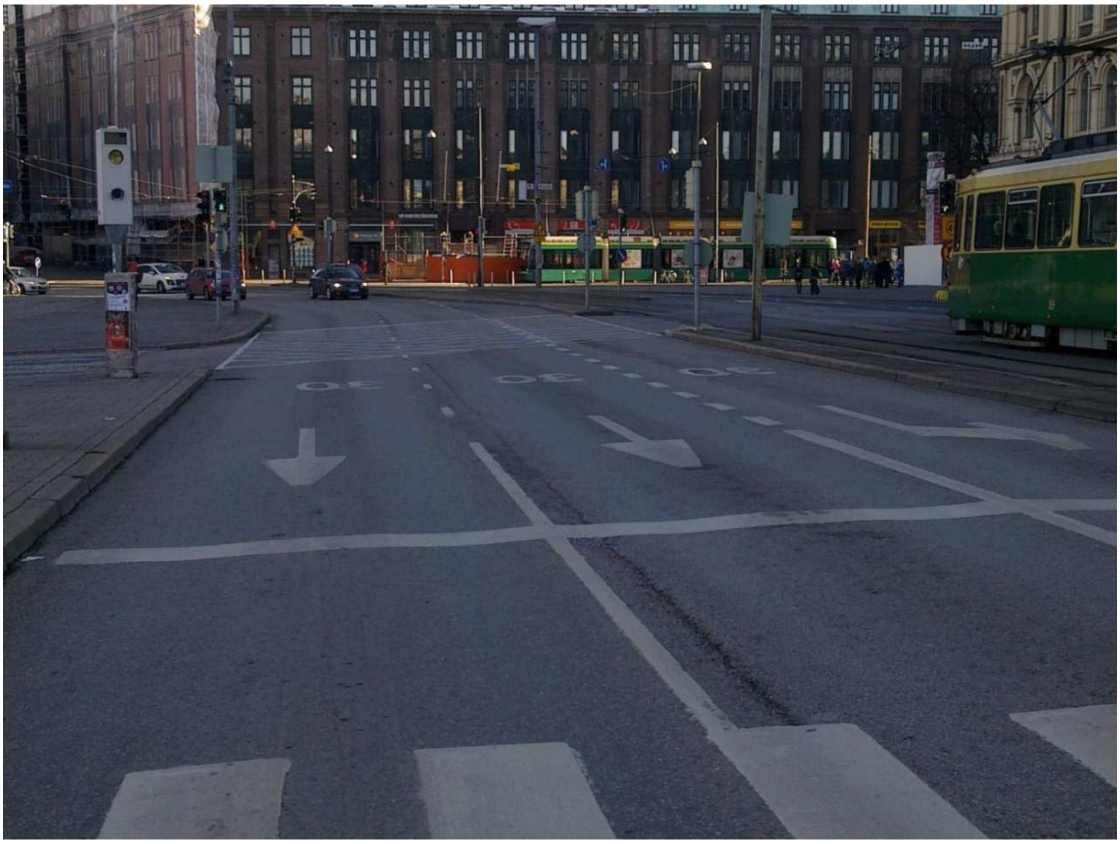

Fig. 8 Speed camera surveying a posted speed, signed and marked in the carriage way, at the crosswalk which had more pedestrians injuries in Helsinki than any other one before the camera was installed (at the railway station).

To summarize advanced yield bars or stop lines before the crosswalk are needed to give a stronger message for alerting drivers to stop, and not to overtake a stopped car in an adjacent lane on multi-lane arterials. A distance to the crosswalk of about 10 m is recommended (Várhelyi & Leden, 2016). To secure travel speeds below 20 km/h additional measures like cameras surveying speeds near the crosswalk might be needed.

Epilogue

It took four years to form a working group, gather available knowledge about speed-reducing measures, analyze, initiate new tests, synthesize, draft new Swedish guidelines, consult available experts, redraft and publish an official "best practice" concerning speed-reducing devices in residential areas from the Swedish road safety office (Leden, Källström & Andersson, 1982). As it was published at a time when the Swedish traffic engineers desperately were looking for advice how to design speed reducing devices and an efficient network was in place to disseminate the message it became a success story. Now it is urgent to promote a 'best' design also for multi-lane arterials, especially in 'busy' city districts with high pedestrian activity including children, and to establish a network to support the implementation.

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