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PEDESTRIAN AND VEHICULAR DETECTORS FOR TRAFFIC MANAGEMENT AND CONTROL

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1 Introduction

Current signal control strategies, ranging from simple Vehicle Actuation, both with and without speed assessment/discrimination (SA/SDE) to the advanced (but now well established) methods of MOVA and SCOOT have been designed around the traditional inductive loop vehicle detectors and make the best use of the information such detectors can provide. Indeed, such detectors are well suited to the purpose of traffic control applications. They can be placed at known locations in the road where they can count accurately, not detecting objects that should not be detected and not missing objects that need to be detected.

Inductive loops are, of course, not the only type of vehicle detector in regular use. Above-ground devices have also been available for a number of years. The simpler devices, which are usually either of the microwave vehicle detector (MVD) type or Infra Red (both passive and active) type, detect presence (or absence) of vehicles within a ‘beam’. In some circumstances, they can be used to replace loops, but generally they are inferior in terms of the information they can gather and most are not suitable for use in advanced signal control systems (although some specialist products exist that can be used in some specific situations).

They do have the attraction, however, of being cheaper to install and maintain. Most of the simple devices have been designed to be mounted either on the top of signal heads, or at some other convenient location at about that height (e.g. lamp column). They are relatively cheap, reliable and easy to install and replace, providing that there is a suitable mounting column available. The installation process does not normally need any traffic management. Hence there are diverging pressures; firstly to use loops for better traffic control and, secondly, to use above-ground detectors to reduce costs.

Traffic control is not, however, exclusively about vehicles, the needs of pedestrians are also of great importance. One significant way in which pedestrians and vehicles interact differently with traffic signals is that traffic signals are seen as advisory by an appreciable proportion of pedestrians, but mandatory by most vehicle drivers. For efficient control it is important not only to ensure that pedestrians’ demands are met, but also that a check is made that the demand is still present. In the UK the kerbside pedestrian detectors used at Puffin crossings, and signal controlled junctions with a near side facility perform this check. Unfortunately the detectors designed to detect pedestrians at the kerbside have not proved as effective as desired.

With the increasing importance of detection for traffic control and the growing cost of loop maintenance the DfT commissioned research on new detector technology. The aim of the research project was to provide DfT, users and the traffic control industry with information and advice on the suitability of new detection systems for current and future pedestrian and vehicle control applications.

The purpose of this paper is to summarise the findings of the research project on the current capabilities of detectors for traffic control and hence identify where efforts to improve detectors should be concentrated. The following detector technologies and purposes are considered:

- Infra-red pedestrian detectors for kerbside detection
    - Passive array
    - Active
- Microwave pedestrian detectors for on-crossing detection
- Image processing pedestrian detectors for kerbside detection
- Sub-surface pedestrian detection for kerbside detection
- Spread spectrum radar pedestrian detectors for both on-crossing and kerbside use
- Microwave vehicle detectors for use with SCOOT
- Active infra-red detectors for use with SCOOT

2 Infra-red pedestrian detectors

2.1 Passive array

Detectors using a small array of passive infra-red sensors are highly successful at counting pedestrians crossing screen lines when mounted above the target area looking vertically down. Typical applications are measurement of pedestrians entering and leaving shops and shopping malls. The same technology has been applied to a pedestrian kerbside detector, but not developed as far as a commercial product.

It is unclear why, having demonstrated a potentially viable detector, the further development to a commercial product has not been undertaken. It is known the there were commercial pressures to concentrate on other products where a larger market was expected. However, it is not known how much technical development would be required to produce a product that would operate successfully in all conditions when mounted on a traffic signal pole with a distorted view compared with a simple overhead mounting. Without further input from the manufacturer the use of this technology for pedestrian detection in traffic control will not happen.

2.2 Active

Active infra-red sensors have a source of infra-red radiation to illuminate the target area and a sensor to measure the returned radiation. There is one product on the UK market using active infra-red to provide kerbside detection of pedestrians. It has a fixed detection zone of 2.4m by 1.6m and so does not have the flexibility to define the detection zone after installation that is a feature of the image processing based kerbside detectors.

3 Microwave pedestrian detectors

Doppler microwave detectors are used for the detection of pedestrians on signal controlled crossings.

3.1 Detection zone

A pair of detectors is usually used to give complete coverage of a crossing. The beam shape means that a detector does not give good coverage close to the detector. The area near the kerb is covered by the unit on the far side of the road, see Figure 3-1. The figure shows idealised triangular detection zones ending precisely at the opposite kerb, in reality the detection zone is more lobe shaped with the potential for part of the lobe to extend onto the opposite footway. In addition, the adjustment of the range to end at the kerb is by adjusting the angle of the detector. Some error in this adjustment is possible. Therefore, at sites where pedestrians frequently walk across, rather than along, the footway, possibly to a shopping precinct as shown in the figure, the detector may respond to movement on the footway and extend the all-red period when the crossing is empty.

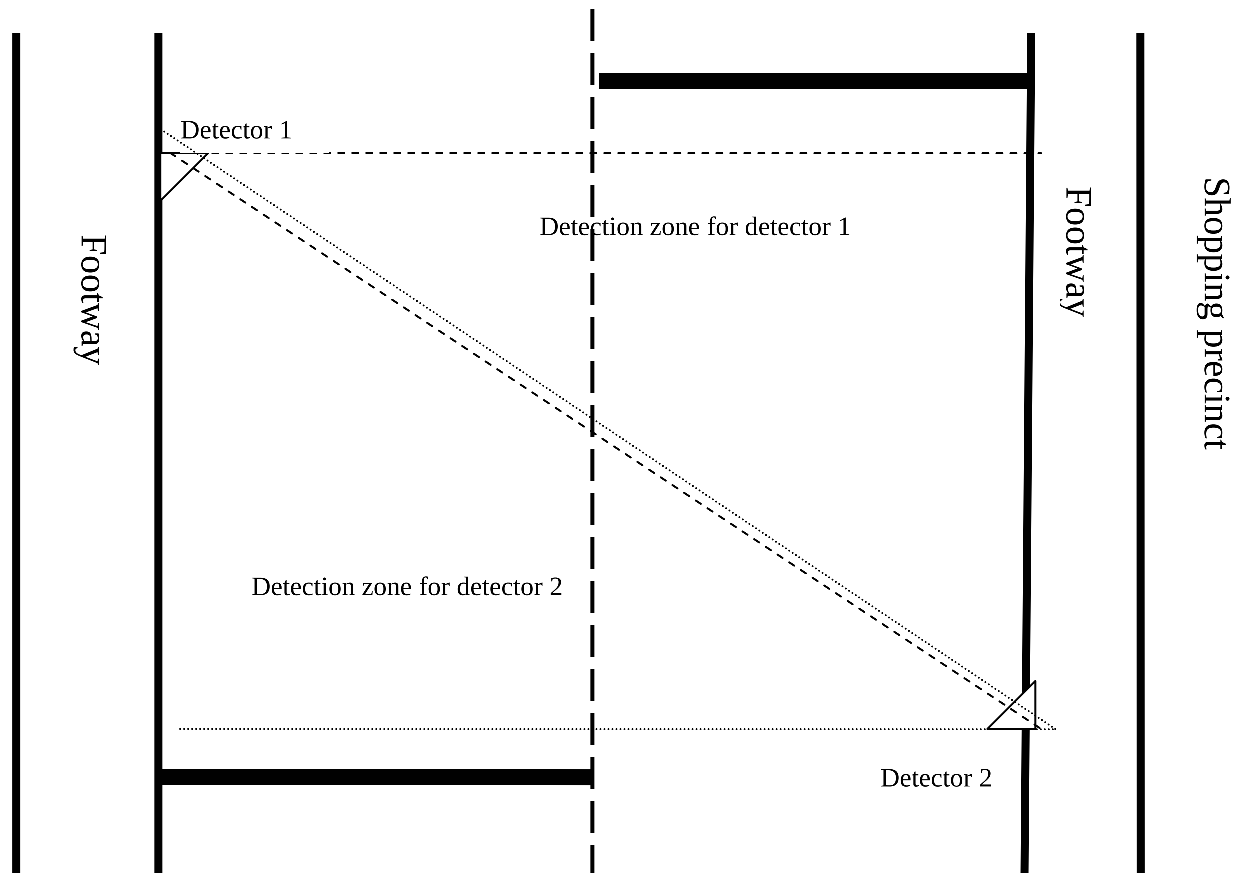

Figure 3-1: On-crossing detection zones

3.2 Detection Criteria

Pedestrians have to be moving above a minimum speed to be detected by the detector. In addition, to initiate a detection, it is necessary for that minimum speed to be continuously recorded over a minimum distance to avoid spurious detections. It is possible for the detector to fail to detect very slow moving, probably mobility impaired individuals, for some time after they to start to cross the road. In an extreme case the time taken for a pedestrian to reach the detection zone from his waiting position on the footway and establish a presence in the detection zone at such a speed as to be detected can be greater than the invitation to cross and minimum extension period. If this is the case, and there are no other pedestrians crossing, then the traffic signals will start to change to the vehicle stage as the pedestrian is starting to cross the road; a very undesirable situation. However, it is equally undesirable to extend the all-red in the absence of pedestrians as this causes confusion and pedestrians may start to cross when the signals are about to change in favour of vehicles.

The HA standard, TR 2506A requires detection of pedestrians moving at between 0.5 and 10 ms^{-1} across the crossing. TRL undertook trials with specially modified units where the minimum detection speed was reduced to 0.2 ms^{-1} and the minimum distance to be walked to initiate at detection was also reduced. At the trial sites in Leeds, these modified detectors worked satisfactorily and no false detections were observed. However, the trials included some tests with pedestrians deliberately walking very slowly and not all these pedestrians were detected within 2m of leaving the kerb. From the results, one detector appeared to have an alignment error, which increased its error rate. Taking just the other detectors, 13% of pedestrians walking at less than 0.35ms^{-1} were not detected within 2m of the kerb. Such a delay would mean that those pedestrians would be in danger of being in the middle of the crossing when the lights changed to the vehicle stage. Very slow pedestrians crossing at signal controlled facilities are rare; none were observed during the 48 hours of recording at the two test sites. However, the consequences of failing to detect a slow pedestrian before the signals have started to change to the vehicle stage are potentially very serious.

The trials in Leeds identified some desirable improvements to the on-crossing detectors:

- Ease and accuracy of alignment to ensure that pedestrians are detected immediately that they step off the kerb, but that there is no undue extension of the pedestrian stage due to detecting movement on the footway to or from the crossing
- Improved initial response to slow moving pedestrians

The detectors work by identifying a Doppler shift in the reflected radiation. There are fundamental difficulties in detecting a very small Doppler shift from the far end of the range of the detector, whilst not giving false detections in response to small movements of the detector mounting, due to wind or vibrations. Small movements of the detector can result in strong signals from metalwork near to the detector. A better approach might be to modify the controller to allow detections from the kerbside detector to extend the first few seconds of the all-red. The extension would have to continue for a couple of seconds after the end of detection to give time for the on-crossing detector to pick up the pedestrian after he or she has left the footway.

4 Image processing pedestrian detectors

Image processing has been chosen as the appropriate technology for kerbside pedestrian detection by several manufacturers. However, some problems have been revealed as the detectors have been used. The problems do not necessarily mean that the detectors fail to meet the requirements of the specification, but they do mean that they do not always operate as the users wish them to. The imaging process may use visible light or infra-red, possibly with a built-in illuminator.

4.1 False negative detections

False negatives are when the detector fails to detect a pedestrian who is waiting to cross. It is important for kerbside detectors to detect pedestrians when they are present and waiting for the green man. For this reason, most of the detectors on the market now, and in the past, have tended to 'over-detect': i.e. to make sure they do not miss pedestrians, they tend to detect also when there are no pedestrians. However, at least one detector was known to have a problem in one part of its detection area where it sometimes missed pedestrians, although the manufacturer did correct the problem relatively early on. Another problem is that of pedestrians pressing the demand button, and then waiting outside of the detection zone. This is a problem with the simpler detection algorithms used which rely on a pre-defined zone to filter out pedestrians who are not waiting to cross. It would be more effective to rely on direction discrimination to filter out unwanted detections. This ability may be available in future detectors. Making the ability to extend the invitation to cross period possible is an attractive side-effect of being able to discriminate pedestrian detections on the basis of direction.

It is going to be recommended that if there is no detection from the kerbside detector when the demand-button is pressed then a pedestrian demand is latched. This modification to the controller logic will help avoid the unwanted cancelling of demands.

4.2 False positive detections

In strong sunlight the shadow of a passing vehicle can be falsely detected as an object of interest in the detection zone. Similarly when the ground is wet, particularly if there is a puddle in the detection zone, then the reflection of a vehicle can be detected. Another source of false detections is of vehicle headlights illuminating part of the waiting area after dark. This latter effect is most likely where the road geometry results in turning vehicles facing the waiting area at some point in their trajectory. All such false detections are undesirable, but not usually serious for traffic control. The "hold" time, the time for which a detection is maintained after the target has left the detection zone, is normally less than a second. If the time gap between one vehicle's shadow leaving the detection zone and the next one's arrival is greater than the hold time, then false detections of the shadows will not maintain a pedestrian demand between vehicles. Pedestrians are unlikely to be able to cross the road in gaps between vehicles that are shorter than the hold time, but they could walk away along the footway. Therefore, it is unlikely that a pedestrian demand will be serviced due to a false detection maintaining the demand when the pedestrian has crossed the road.

4.3 Changing light conditions

Image processing detectors learn the background, the image of the detection zone without any pedestrians present, as part of the setting up process. A significant change in the image from the background is taken to indicate the presence of a target in the detection zone and trigger a detection. The detectors adjust the background as lighting conditions change during the day. The default condition of each pixel will vary with the intensity of the illumination. However, this process only follows gradual changes: both the change in illumination as the sun rises and falls over the course of a day and the movement of shadows of fixed object across the detection zone as the sun moves across the sky. At some times there can be a sudden large change. In bright sunny conditions there will be a sudden large decrease in illumination when a cloud obscures the sun and a large increase as the cloud clears the sun. When such a change occurs, many pixels will show a large change from the background resulting in the detector going on. If the light stays at the new level, then the detector will remain on for the presence time after this time the detector will assume that the detected "object" is a new quasi-fixed object, not a pedestrian and will relearn the background, taking some seconds to refresh.

Therefore, a large change in illumination will result in a permanent detect state for somewhat longer than the presence time and can result in unjustified occurrences of the pedestrian stage.

4.4 Low light conditions

Vision based image processing requires a minimum illumination level to operate successfully. Although minimum lighting levels are recommended for pedestrian crossings, in practice image processing detectors have had problems at some sites, including ones that appear well lit. Relying on street lighting meeting the recommended level will not always result in successful operation even if the detector will operate reliably at that level. Street lights may fail or become obscured by tree leaves for example. When the detector internal check indicates that the light level is insufficient for reliable detection, the detector will "fail safe" and go into a continuous on state. However, failing to operate, even if always "failing safe," is not satisfactory to users. They do not wish to invest considerable sums in detection that results in no benefits for considerable periods, noticeably the evening peak for several months in winter.

4.5 Ease of use and setting up

A major advantage of vision based detectors is that the image can be viewed by the engineer when setting up the detector. The latest detectors using Bluetooth communications are even easier to use than the earlier versions that required the engineer to physically connect a cable to the detector. Software tools are provided to enable simple definition of the detection zone. Drawing lines on an image of the detection zone and its surroundings is much easier to perform accurately than physically pointing a detector at the edge of the required zone.

The second advantage of defining the zone in software on an image is that the zone is well defined in the detector in relation to the position in the image. Other technologies, such as the Doppler microwave detectors for on-crossing detectors rely on the strength of the signal exceeding a threshold to indicate that it originates from within the desired zone. The strength of the signal will depend on the properties of the target (e.g. whether it is a good reflector of microwaves) as well as on its position, resulting in a less well defined detection zone. Defining the detection zone as part of an image means that no part of the zone should be at the extremities where the detector is working at the limit of its capabilities.

4.6 Maintenance

Image processing detectors rely on a clear view of the detection zone and therefore require regular cleaning of the front of the detector and possibly application of a water repellent. Such cleaning should be simply a part of the regular maintenance of the signals and cleaning of the aspects, but there may be problems in ensuring that the maintenance contractors fully comply with the requirements.

5 Sub-surface pedestrian detectors

When Puffin crossings were first developed some used pressure sensitive mats to detect the presence of waiting pedestrians. There were considerable problems with these mats and they are no longer used. However, a sub-surface pedestrian detector is available. It utilises a standard inductive loop detector with the pre-formed loop installed under a metal plate that is displaced down towards the loop by the weight of a person standing on the detector. Reading Borough Council purchased several units and installed them at a signalised roundabout with pedestrian facilities. When the sensitivity of the loop detectors was correctly set, the detectors correctly detected persons waiting on them.

Unfortunately, not all waiting pedestrians chose to stand on the mats. At the trial site, around a third of waiting individuals did not wait on the mat. Even when there was more than one pedestrian waiting, in about 6% of cases no pedestrian waited on the mat. TRL staff noted that the mats feel strange to stand on. Compared with the normal hard surface of a pavement, the rubber mats feel slightly insecure; the give in the rubber material can be unsettling. Without advice to stand on the mat to obtain an invitation to cross, the feeling of the group of TRL staff was that they would prefer to wait off the mat rather than on it.

The TRL trials did not consider the long term reliability of the detectors, such as susceptibility to jamming by bits of grit and other problems with a moving device in a hostile environment. The detectors have been marketed successfully for several years in their home market (New Zealand) and may be assumed to be considerably more reliable than the early pressure sensitive mats that are no longer actively marketed.

6 Pedestrian radar detectors

A new approach to pedestrian detectors uses spread spectrum radar technology that has been developed for other applications, including reversing warning systems for the automotive industry. The technology is potentially applicable to both on-crossing and kerbside detection. As the method utilises both direction and time of the reflected radiation, it is able to locate targets in three dimensions. The detection zone can, therefore, be defined in the software as a subset of the potential detection zone in the same way that the detection zone in vision based detectors is defined within the total field of view of the detector. The method of setting up the required zone has not been finalised, but the simplest method envisaged is to hold a radar reflector at the corners of the required zone and have the detector learn the zone from the resulting extra strong reflections.

A trial of a detector in development was undertaken by TRL at a Puffin crossing in Bracknell. The physical alignment of the detector was fairly simple. The vertical alignment was preset by the mounting bracket and the horizontal alignment was achieved with an angle guide to align the detector at 45^{o} across the road for the on-crossing function and 45^{o} across the pavement for the kerbside function.

6.1 On-crossing function

The detector successfully detected pedestrians crossing the road, but there were some short dropouts. Radar reflections change as people move; different parts of the body give a strong reflection as their orientations change, resulting in a jittery appearance to the detection indications viewed on a mimic of the crossing. Further development of the detection algorithms is needed to track the individual (x, y) coordinates of the detections into pedestrian tracks across the crossing. The method of detecting the (x, y) coordinates of targets allowed good coverage of the detection zone together with rejection of targets outside the zone.

6.2 Kerbside function

The detector successfully detected and located pedestrians in the waiting area to give an indication of the number of people waiting, but not a true count as pedestrians waiting close together could not always be separated. Examination of the trajectories over time enabled the identification of some targets as waiting for an invitation to cross, some walking from the road into and through the waiting area having crossed the road and some walking straight out onto the crossing without needing to wait. Detection of pedestrians stepping out onto the crossing appeared to continue until they were around 1m onto the crossing, but arriving pedestrians were detected as they stepped on to the pavement after crossing the road.

Overall the trial resulted in a promising demonstration of the potential capabilities of the detector, but some development is still required. One problem observed was that the detector was sensitive to fluctuations in the power supply. The explanation was that the strength of the returned signal from strong reflectors, pedestrian barriers and other metal objects in the detection zone varied enough to give false detections when the detector was set at its normal, high sensitivity. The varying voltage was due to using a generator for part of the trial, however, the sensitivity to strong signals from metal objects raised the possibility that movement of the detector, through wind or vibrations from heavy vehicles might cause similar false detections.

7 SCOOT vehicle detectors

SCOOT has a particular requirement for detection in a specific zone. The standard requirements are an inductive loop that is 2m long in the direction of travel, sited 10 to 15m downstream of the previous junction, or 100 to 150m in advance of the stopline where there is no upstream junction. The location of the detector may have to be adjusted for site specific factors.

The specification that a loop should be 2m long in the direction of travel is a consequence of the way that SCOOT uses information from the detectors. SCOOT detectors are required to provide good information on the traffic approaching signals. In particular, the detectors should not be so long that they fail to detect the gaps between individual vehicles when they are following each other closely. The gaps are usually shortest when vehicles are in slow moving queues. The second major requirement is that detectors should register continuous occupancy when there is a stationary queue back to the detection zone. Therefore, the detection zone should not be so short that there is an appreciable probability of failing to detect congestion because the limited detection zone is completely between the rear of one stationary vehicle and the front of the following one.

Recent work for the SCOOT consortium has examined how much flexibility can be allowed in the length of the detection zone in the direction of travel and still meet these requirements. The recommendation from that study was that the detection zone should be:

> Between 1.8 and 2.3m long in the direction of travel.

Because the effective detection zone of an inductive loop is somewhat larger than the physical dimension it is recommended that if inductive loop detectors are used, the loop dimension should not exceed 2m in the direction of travel. Similarly, the minimum length of 1.8m corresponds to a slightly shorter loop.

A detector mounted at the side of the road operating in the side-fire mode can potentially provide the desired detection. A single detection zone over two lanes is acceptable, but for roads with 3 or 4 lanes at least two zones, each detecting in no more than 2 lanes and only detecting vehicles approaching the stopline are required.

Tests of two detectors, one using radar and one infra-red, were undertaken in Winchester at a one lane site where a detector mounted on a lamp column could be aimed at the existing SCOOT loop.

7.1 Radar detector

This detector was mounted at about 3m high, within its recommended range of 2 – 3.5m. It reproduced the SCOOT loop count data with acceptable accuracy, within about 1% overall, but there was some cancelling of under and over counting. False positive and false negative detection rates were around 1% and should be acceptable for SCOOT control. The figures for occupancy showed somewhat larger discrepancies, 6%. However, such a difference is not significant for SCOOT. Each link is validated during the commissioning of SCOOT and that process calibrates small differences in average occupancy per vehicle between detectors.

7.2 Active infra-red

The active infra-red detector was also mounted 3m high, below the recommended height of 4m due to lack of facilities for mounting it higher. It was acknowledged that the lower height would result in a somewhat smaller detection zone and, hence, lower occupancy per vehicle. The count performance of the detector was again acceptable, within 1 to 2% of the SCOOT loop, but the occupancy was lower as expected. It recorded 25% less occupancy than the loop. Mounting at 4m high would be expected to eliminate most of this difference. A 25% drop in occupancy would be about the most that SCOOT could accept without a significant risk of failing to detect congestion. The optimum mounting height being above that which is normally acceptable for working on a ladder at the roadside is a disadvantage. A problem was observed at one time during the trial when there was a long period of continuous occupancy, which was presumed to be due to a system reset. This long system reset time (15 minutes) is undesirable.

8 Summary

Various detectors have been studied and their advantages and disadvantages are summarised in

Technology	Objective	Mode of operation	Advantages	Disadvantages
Passive infra-red array	Pedestrian kerbside detection	Overhead, signal pole mounted	Potentially could count pedestrians	Not proven and not developed into commercial product.
Microwave, Doppler radar	Pedestrian on-crossing detection	Overhead, signal pole mounted	Existing economic product	Alignment and difficult to quickly detect very slow moving pedestrians
Image processing	Pedestrian, mainly kerbside	Overhead, signal pole mounted	Ease of setting detection zone accurately	False detection, problems in low light without illuminator
Sub-surface	Pedestrian kerbside	Sub-surface detection of weight of pedestrian	Well defined detection zone. Uses reliable loop detection technology	Pedestrians choosing not to stand on detector
Active Infra-red	Pedestrian kerbside	Overhead, signal pole mounted	Not sensitive to illumination levels (manufacturer's information)	Fixed detection zone.
Spread spectrum radar	Pedestrian kerbside	Overhead, signal pole mounted	Potentially simple zone definition, some capability to separate waiting pedestrians from those passing	Not yet fully developed
Spread spectrum radar	Pedestrian on-crossing	Overhead, signal pole mounted	Potentially simple zone definition and fast response to very slow moving pedestrians	Not yet fully developed
Microwave	SCOOT	Overhead, side-fire lamp column or similar mounting	Overhead, not vulnerable to damage as are loops	Not suitable for sites with more than two lanes
Active Infra-red	SCOOT	Overhead, side-fire lamp column or similar mounting	Overhead, not vulnerable to damage as are loops	Not suitable for sites with more than two lanes. Long reset time and the recommended mounting height may require (expensive) use of a cherry picker as too high for safe ladder access

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