Deliverable 6

New concepts in automatic enforcement

Recommended applications in a European enforcement project

The ”Escape” Project

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EXECUTIVE SUMMARY

One main reason for automatic enforcement, except of the safety situation, is that the police will not be able to take direct action to each detected violator at normal police enforcement activities in some environments. By using detectors and camera technology the violators can be identified and sanctioned

Though it's almost three decades of use, automated traffic enforcement has mainly been applied to speed and red light violations. In the recent years, however, there has been an extension to other violations, e.g., following distance, lane keeping, and toll payment violations. The increased use of digital video and image processing technology, as well as the electronic identification of vehicles, has paved the way for extending the applications to a still wider spectrum of violations, as well as making the enforcement considerably more efficient in the future.

Automatic enforcement always consist of at least three different procedures

- Detection of the violation
- Identification of the vehicle involved
- Identification of and contact with the owner of the vehicle

In order to combine these procedures into one system the aim is of course to have to create a fully automatic system. Today the detection of the violation is automatic but the identification processes are more or less manual.

The strategy for automatic enforcement varies a lot between countries depending on detection technology used, police force organisation, traffic legislation and sanction system. It is impossible to recommend a European harmonised solution.

Organisational support for automated enforcement systems

An important prerequisite for an efficient automated enforcement system is the availability of a centralised register of vehicles and their owners at a national level. If the register were not centralised, the process of identifying vehicles and drivers from outside the jurisdiction where the violation takes place would be extremely laborious. That is also a reason why few countries routinely follow up violators from foreign countries. An example of sanctioning across borders is found in Scandinavia, where there are mutual agreements between Norway, Sweden and Denmark regarding the process of fining violators from the neighbouring countries.

Manned vs. unmanned operation

Some automated enforcement applications are manned; for example in those instances where the automatic system is operated from a police car. As long as the detection of violations is automatic, and the purpose of the manning is only to supervise the equipment, these applications are considered within our definition of automated enforcement (whereas applications depending on a police officer to initiate the recording when observing a suspect vehicle, is not automated.). An advantage of manned controls seems to be increased flexibility concerning the choice of sites. Extensive unmanned operation on the other hand requires a certain number of fixed facilities between which the equipment can be rotated. In the long run, however, the costs of such facilities are probably lower than the costs of manned operation for a similar level of enforcement.

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1.1 Introduction

It can be argued that traditional speed management techniques are inefficient and have failed to lower highway driving speeds effectively (Transafety, 1997). Efficiency increases when speed warnings and enforcement are automated. Automatic enforcement has been carried out for more than 25 years by now.

Most subsequent applications of automatic speed enforcement have employed basically the same principle of taking still photos of vehicles committing a violation. Over time there have been some minor variations, such as the use of mobile units, and the use of other devices than radar (induction loops, pneumatic tubes, etc.) for measuring speed. However, in the almost three decades that have passed since the first photoradar was installed, there have been some more substantial extensions and improvements of automatic enforcement systems as well. Automatic enforcement has been extended to several types of violations other than speeding and new technologies for detecting violations as well as for identifying the violating vehicles have appeared. Probably the most notable developments are systems involving the use of digital videorecording with image processing, and systems for electronic recognition and identification of a vehicle.

This deliverable aims to review the latest developments in the field of automatic detection of traffic violations and provide suggestions for the application of new automatic enforcement in European projects. Concepts of automated enforcement of traffic violations can be presented in three types:

- Implemented and evaluated technologies
- Designed and implemented technologies
- Imagined technologies

1.2 Definition and basic concepts

In an early publication by Rothengatter (1991), the basic concepts for automated policing and enforcement systems have been described. Technology has considerably advanced since the early nineties and the present generation of enforcement and supporting detection-, recording- and identification devices is heading towards faster, more reliable detection of various traffic violations and a better integration of information systems. Technological refinement accounts for a important contribution to the progress in enforcement systems. However, this contribution mainly consists of the much better operationalisation of the basic concepts now then say ten years ago. The basic concepts as described themselves have remained unchanged and still constitute the basis of every automatic enforcement system.

Basically, the concept of an on-site registration or information system includes one or more of the following functions:

(a) on-site detection of a traffic offence

(b) on-site registration of a traffic offence

(c) providing information to the driver about the fact that he is committing an offence and that this offence has been registered

(d) feeding the recorded information into an automated offence processing system

Of course, the more of these functions a system can perform, the more the system is integrated and automated.

The concept of an in-car information system requires that feedback information about an offence be transferred to an in-vehicle information system.

There are two concepts for in-car registration of violations: one concept would be transferral of in-car detected offences to on-site registration beacons for further processing; a second concept would be a tachograph system. In theory it would be possible to develop this concept further into an electronic demerit point system where the violation history could be stored on smart cards that may be checked during licence renewal or tax payments.

In-car information systems may be to a large extent based on information coming from on-site registration systems. Partly, the information may also be coming from direct assessment of vehicle parameters or a combination of vehicle and on-site registration. An alerting device based on vehicle parameters alone would be feasible for those behaviours that are illegal irrespective of the situation in which they are displayed.

In this review, an automatic enforcement system is defined as any technical recording device that is triggered automatically by a traffic violation, so that information about the violating vehicle is recorded, allowing the subsequent identification of the vehicle. The vehicle or driver identification and citation process can be either automatic or manual. Accordingly, the use of video equipment for traffic surveillance is not automatic enforcement if it depends upon the visual inspection of the recording to identify the occurrence of a violation. On the other hand, if the tape is handled by an image-processing system to identify violations it is an automatic enforcement system.

2. Technologies and systems

The following is a list of violations that have been reported to be enforced by some automatic system.

- speed
- red light running
- headway violations
- toll payment violations
- illegal use of bus lanes
- violation of vehicle weight restrictions

When discussing the technologies we draw a distinction between technologies for **detecting violations** on one hand, and technologies for **identifying the vehicle** on the other hand. The former category is discussed in this section, whereas the issue of identifying the vehicle is discussed in the next section. The third step in the processing of a violation is the **identification of the owner/driver or possessor of the vehicle**.

2.1 Detecting violations

The basic technologies that have been used for detecting violations are:

- radar
- laser
- inductive loops in pavement
- pneumatic tubes across road
- piezoelectric cables
- infrared detectors, and other optical sensors
- video image processing
- electronic detection based on in-car electronic tags

Some technologies are common to systems for detecting different violations, whereas others are particularly tailored to the detection of specific kinds of violations.

Radar and laser

Several different systems have been used for speed enforcement. Radar is still commonly used. A photo-radar can be easily moved from site to site, in case mobile enforcement is considered desirable.

For *manual* speed enforcement, laser technology seems to have replaced the radar to some extent. For automated enforcement, however, laser systems have not yet been considered suitable, partly due to their small target angle. Recently, however, a new application of laser, called scanning laser, has been tried out. In contrast with traditional use of a laser gun, the scanning laser is focussed vertically down on the roadway, and scans with a high frequency across one or two lanes, detecting vehicles breaking the laser beam. On the basis of the reflected laser beam, the system computes speeds and following distances (as well as width and breadth of vehicles if needed). For enforcement purposes it is combined with a video system for vehicle identification.

Roadway cables

For mobile automatic enforcement of speed, some systems use pneumatic cables (rubber tubes) across the road, for example the Speed Guard system by the South-African company Trans-Atlantic Equipment (see Blackburn and Gilbert, 1995).

For stationary automatic enforcement of speed, on the other hand, cables in the pavement, either inductive loops or piezoelectric ("weigh-in-motion – WIM") cables, are preferred. The advantage of WIM cables is that they can be used for detecting both speed, following distance, and weight (see e.g. Ayland, 1990), whereas the inductive loops, although well suited for speed measurements, cannot measure weight, and they are less accurate than WIM cables for the measurement of following distance.

Concerning automated speed enforcement, the systems discussed so far measure *spot speeds*. However, it may be more useful to enforce average speeds over some distance. A system with the possibility of recognising vehicles at two different sites and compute the average speed between the two sites was developed and tested in the EU project DETER ("Detection, Enforcement & Tutoring for Error Reduction") under the DRIVE programme (Muskaug and Groeger, 1992). This approach, which combined WIM cables for measuring speeds at two different sites and video pictures for identifying the number-plates, has however not been adopted for real enforcement purposes.

Optical sensors

Optical sensors are used to some extent as well. A system that is used extensively in Israel (Kedmi and Langer, 1996) for automated speeding and headway enforcement is based on the reflection of infrared beams from special reflectors in the roadbed. A detector records when a passing vehicle crosses the beam, and record speed and headway. A video image is used for identifying the vehicle.

In their review of different photographic enforcement systems Blackburn and Gilbert (1995) describe one system (Velomatic) that uses passive optical sensors as a basis for speed violation measurements.

Video-based systems

Video systems, in addition to identifying vehicles for which violations have been detected by some other means, can be used alone for the detection of violations. Although not yet operative for enforcement purposes as far as we know, image processing systems for identifying and tracking vehicles for some distance have been developed (see e.g. Rodriguez and Marzán, 1995). From the video image violations regarding both speed, following distance and lane changes can be determined, and possibly also other violations. Concerning speed, it is possible to extend the enforcement from spot speeds to average speed over the whole distance covered by the camera. The large potential of such systems lies in their double function of both detecting the violation and identifying the vehicle.

Zaal (1994) reports that a number of fully automated video-based systems were developed and tested in Australia in the early 1990s. The systems were based on digital imaging technology for identifying the vehicles and transmitting the picture to a central processing cite. These systems, however, do not yet seem to have been applied in real enforcement.

In the Netherlands, however, a video system is being applied for the automated enforcement of *average speeds*. This enforcement system, as described by Zaidel and Mäkinen (1999), is based on the average travel time of an individual vehicle over a pre-defined stretch of road. The system is designed to operate stand-alone for 7 days a week, 24 hrs a day. The system monitors traffic at 3 different locations on a 3- km section of a busy highway (70,000 cars per day average) between Utrecht and Amsterdam. At each of the three locations, a picture is taken of the rear of each passing vehicle by digital video cameras which are mounted on gantries above the roadway, and a Vehicle Definition Tag (VDT) - a ‘digital fingerprint’ - is generated. From all three locations a dedicated 'digital fingerprint' of the vehicles are sent to a central location which matches exit with entry vehicles, calculates average speeds over the sections, detects violations and prepares evidence information for ticketing.

When a violation over a section is detected the exit and entry pictures are retrieved from the road systems and a license plate reading is done to generate the needed visual evidence. When there is no violation the images are deleted from the temporary storage.

The central processing office sends the processed violation protocols either directly to the national centre of citation issuing of the Ministry of Justice (violation < 30 km/h) or to the public prosecutor's office in Utrecht (violation > 30 km/h). At the citation centre, the vehicle plate number is linked to its owner and tickets are generated automatically from the data-files provided by the police. Within one week the ticket is in the mailbox of the offender.

Recently, video-based systems are being tested and evaluated in the EU project VERA ("Video Enforcement for Road Authorities"). Demonstration sites have been set up for bus lane enforcement, traffic signal violations, speed violations, toll charge violations, time-distance speed checking, as well as traffic flow monitoring. It is a goal of the project to suggest harmonised approaches to video-based enforcement, and to promote the acceptance of video records as evidence in court. (For more details of the VERA project we refer to the Internet site http://www.edt.nl/VERA.htm.)

Electronic detection

A similar double function may also be ascribed to the use of in-car transponders (electronic tags), which in principle and theory can be used for identifying a vehicle's position at any time, with unlimited possibilities of automatic surveillance. Currently, it is only used for identifying vehicles in toll payment systems (see below).

In Table 1 the various possible applications are summarised by cross-tabulation of technologies by violations.

Table 1. Different possible applications of automated enforcement technologies

	speeding	red light running	short headways	toll payment violation	lane occupancy	excessive vehicle weight
radar	X					
inductive loops	X	X	(X)	X	X	
pneumatic tubes	X	X	X		X	
piezoelectric cables	X	X	X	X	X	X
infrared detectors	X		X			
video image processing	X	X	X	X	X	
laser	X		X			
electronic detection (tags)				X		

2.2 Systems for identifying the vehicle

Wet film camera

Once a violation has been committed and subsequently detected with some of the mentioned systems, the next step is to identify the vehicle. The most common technology includes taking a photograph of the vehicle, with a camera triggered automatically by the violation. The film is then manually recovered from the camera, and the licence-plate of the vehicle is identified by visual inspection of the picture. A comprehensive review and description of technical and operational aspects of various photo-based automated enforcement systems in use world-wide by the early 1990s has been presented by Blackburn and Gilbert (1995). Their report also contains a discussion of issues related to the processing of citations as well as the legal and acceptability problems involved.

One drawback with the conventional still picture wet film camera is that further processing is rather laborious.

Digital camera

The digital revolution has facilitated the processing work considerably. The use of digital cameras (either for still pictures or video) has simplified the process of retrieving the pictures. Although not yet in common use, in the future the pictures will most likely be transmitted electronically from the camera to the authority responsible for further action.

Another important advantage of the digital camera is that it facilitates the process of automatic identification of the vehicle by image processing technology. Several systems exist for this, alternatively termed “Automatic Number Plate Recognition – ANPR” (Rumbelow, 1997), “Licence Plate Recognition - LPR”, or “Automatic Vehicle Identification – AVI” (Nelson, 1997).

Some systems combine wet film and digital technology. The wet film is scanned and digitised, so that further processing of the case can be based on the digital picture. Although far from being as flexible as efficient as a complete digital photo system, this system has a certain advantage in terms of saving time, compared to using wet film processing only.

Electronic identification

Electronic identification presupposes some transponder or electronic tag in the vehicle, which can be read by a roadside detector. Such systems are in use for automatic toll payment (road pricing). Payment for a certain number of admissions (or road distance, or time period, which may differ between locations). The system may detect admissions without payment, but only for those vehicles that have the tag. The use of such systems for general enforcement would require that all vehicles were equipped with the tag, and the lack of a tag would be a violation. In that case, the tag alone could identify violating vehicles having a tag, whereas vehicles without the tag could be photographed.

2.3 Identifying and fining the owner of the vehicle

Most automated enforcement systems are based on manual identification of licence plates and checking of these against a register of vehicles to identify the owner. The owner is then notified by mail to pay the fine. This process can also be automated. Automated systems for licence plate identification can be connected with the vehicle register, where the owner's address is retrieved and the letter to the owner is produced without manual intervention. Thus the whole process from detecting the violation to fining the violator can run automatically. Technically, the system could even draw the fine automatically from the owner's bank account. The desirability of the latter step may, however, be questioned, since the deterrent effect of enforcement can be argued to be stronger if the violator has to act personally to pay the fine.

It should also be noted that in jurisdictions where the driver and not the owner is liable, manual processing is necessary in those instances when the owner denies having driven the vehicle. One could, however, imagine future systems making possible the automated identification of the driver, e.g. on the basis of an electronic driver's licence that has to be activated whenever driving a car, and which can be identified by roadside detectors. Further discussion of automated systems for driver and owner identification is beyond the scope of this presentation.

2.4 Automatic enforcement systems

The column heading of Table 2 shows the basic steps in all existing automatic enforcement systems. It starts with a detection device that measures something- speed, the presence of a vehicle, headway, and weight- and has a logical unit that determines if the measured value constitutes a violation. For example, speed over certain value, activation of a loop detector coincident with a red light as indicated by the traffic light controller, or presence of a vehicle in a transaction zone with no response from an on-board unit in an electronic fee collection (EFC) application.

Table 2. Automatic enforcement modes, generic technologies, and areas of application (Zaidel & Mäkinen, 1999).

	Detection Device	**Registration Device**	**Collection Mode**	**Identification Mode**	**Citation Mode**
Applications					
Spot speed	Radar/laser	Wet film or video	Manual	Manual or semi- auto	Manual or semi- auto
Red Light & speed	Loops	Wet film or video	Manual	Manual or semi- auto	Manual or semi- auto
Spot speed	Radar/laser Infra-red / digital video	Digital video	Manual or transmitted	Semi- auto or automatic	Semi- auto or automatic
Headway	Infra- red	Digital video	Manual or transmitted	Semi- auto or automatic	Semi- auto or automatic
Red light & speed	Loops or digital video	Digital video	Manual or transmitted	Semi- auto or automatic	Semi- auto or automatic
Mean speed	Digital video + ANPR	Digital video	Transmitted	Automatic	Automatic
Bus lane or other type	Video	Video	Manual	Manual	Semi- auto
EFC	Loops or video, radar	Digital video	Manual or transmitted	Semi- auto or automatic	Semi- auto or automatic
Over weight (trucks)	Piezo- electric cables	Wet film or Video	Manual	Manual	Semi- auto

Once a violation is detected, it triggers a registration device, which is usually some type of a camera. The basic picture will have a view of the vehicle's license plate and super-imposed in the picture there will be the date, time, location and other information needed for evidence, processing and quality control. Depending on the application and the legal requirements, multiple pictures may be taken with one or more cameras, and pictures may include a full view of the vehicle, the surroundings, driver's face, back or front of car.

In some jurisdictions video (and particularly digital video) is not yet a "type approved" device for registering violation evidence. It is a forgone conclusion, however, that it will be approved in the near future. The EU VERA project (Video Enforcement for Road Authorities) will formalise and harmonise standards of video use in enforcement, but many police forces have already replaced wet- film cameras with video.

The record of registered violations has to be collected and passed from the automatic enforcement site to a processing centre. In the case of a mobile photo-radar operating in automatic mode, a police officer simply removes the film cartridge (or video recording media) from the camera and takes it to the laboratory. In fixed installations utilising wet film or analogue video, someone has to come periodically, collect the used cartridges and replace them with new ones. These collection modes are manual. Although typical wet film cartridges for enforcement purposes contain 400 frames, the logistics of collecting them and servicing the cameras is a significant costly operation.

New systems based on digital video offer the option of transmitting the records of registered violations to a central facility, so that only a small buffer for temporary storage is necessary. This concept has an obvious advantage over the local storage, which delays the processing of the citation and risk a loss of all stored violation information. It also eliminates the logistics of collection.

The next critical step in the process is to identify the offending vehicle to enable linking the violation to either the owner of the vehicle or to the actual driver (depending on the legal requirement). In all existing systems identification is based on vehicle's registration plate. This is usually done in an office with the aid of optical gadgets or computer based programs to improve the legibility of the digitised characters of the plate. The mode is considered manual if an operator has to look at all the frames and type in the license plate id. It is semi- automatic if a character recognition program is used to identify and type the number while the operator only has to approve the id and resolve unclear cases.

Few applications rely on automatic identification. Not only plate recognition programs have to be very sensitive and reliable, also the situation for detecting and registering the violation has to be very restrictive and free of possible confounding factors. Therefore, only in few application identification is completely automatic and even there one suspects that some human eye looks at the evidence pictures attaches to the citation before it is sent.

The last step in the process is issuing a citation based on the recorded violation and the identified license plate. In jurisdictions where vehicle owner is held responsible for the offence (or unless owner proves otherwise) what is required is linking the violation data file with a vehicle owners registry. Depending on how advanced is the office automation at a given agency this step can be either manual, semi- automatic or automatic. The level of automation in the citation mode will reflect more the general procedures for issuing citations in a jurisdiction, and not so much the detection equipment.

A legal requirement to positively identify the driver of an offending vehicle (and at the same time mask the identity of a passenger) practically rules out an automatic identification mode as well as an automatic or even semi- automatic citation mode. Nevertheless, a manual process can sometimes be effective and even cost- effective. In Finland, fixed speed cameras have had a relatively large preventive impact – as evidenced by small number of recorded violations- and their operation saved manpower costs (Mäkinen & Rathmayer, 1994).

The high costs of digital systems may perhaps be justified in areas of dense traffic, since they allow (as Table 2 demonstrates) automating the process of collection, identification and citation. This may improve the efficiency and- by virtue of increasing the possible volume of citations and shortening the delays- the effectiveness of enforcement. However, the anticipated overall efficiency of automatic enforcement may be no better than its least efficient step.

Depending on the boundaries set by the legislative system, other means for enforcing traffic laws are now technologically feasible. The Dutch company R&H Systems BV has developed the Kever vehicle identification system based on a licence-plate reader. Since early 1995, the system has been used for enforcement in real-life conditions on a motorway in The Netherlands. After many tests and improvements under all weather conditions, it has been made durable and successful under almost all circumstances. It now detects all passing vehicles, and identifies them reaching 85 - 90% hit rate. It has proved effective for film reading, traffic surveys, and speed control. It can be interfaced to public and private telecommunication networks, thus saving labour and speeding up law enforcement. Although it can be used for several detection methods, depending on the application's needs, its video-based detector is most suitable for most stationary systems. The licence-plate reader scans an image for licence registration plates, reads the licence number, and checks its syntax for legal values. It can be used also to control access to private parking or industrial facilities and to compare numbers with a 'black list'. Successful Kever applications include: (1) a film reader; (2) a mobile system for traffic surveys; and (3) a feedback system, which could greatly reduce the number of cars exceeding the speed limit (Van den Bosch and Groenendijk, 1997).

Thanks to these and other technological advances, recently an automated system for road section traffic enforcement (Trajectcontrole) was introduced in the Netherlands. The system might generate an answer to the problem mentioned before, of drivers who are aware of and slowing down just before the specific camera location, possibly causing dangerous traffic situations. One of the Dutch motorways with the biggest daily flow of traffic was equipped with a camera above every lane on three different locations. The distance between the first and the second location was 750 meters. The distance between the second and the third location was 2250 meters. To enable the cameras to operate at night, the three portals were equipped with halogen lamps. The enforcement equipment includes at least two cameras and a computer. Each camera is fixed to the portal exactly in the middle of a lane and is continuously recording each and every vehicle that passes underneath. The digital pictures taken at two different points are matched by means of electronic image processing device. For every vehicle that is recognised in two different locations in the section, the average speed is calculated, dividing the distance between the cameras by the difference in recorded passage times. If the average speed is below the limit, the digital image is removed from the system. If the average speed is above the limit, the vehicle registration number is automatically detected on the picture. If the computer is unable to clearly identify the number, the picture is saved and sent to the police or the appropriate authorities for further manual processing. If the registration number is identified, the corresponding data of the owner are automatically retrieved from the national vehicle registration database. Name, address and the amount to be paid are automatically printed on the accept giro form and sent to the owner by regular mail. The system has just been evaluated and so far, the results are promising. A report however is not available yet.

Kaub and Rawls (1993) introduced a similar type of concept. This concept is based on the speed-distance-time relationship and an on-board impulse detector and constant timer to calculate travel time or posted speed of the roadway. The calculated travel time or speed can then be compared with the current vehicle speed or with a constant time to warn the driver of hazardous approaching events (sharp curves, work sites). The system can also be used to issue tickets to the vehicle registration if, for instance, warnings remain unheeded. The authors assume that the speed-monitoring device might save approximately 10.000 lives and 500.000 injury accidents per year in the US only. Costs of implementation or estimated about US$10 per vehicle with roadway detection costs for magnets of under US$10 per installation.

3. Legal frame and Application of systems

There are different ways of using the technology in different countries and it is associated with national legislation, as well as the way the working mechanism of camera enforcement is seen. The following table presents the situation in terms of the European countries most widely using automated methods.

Table 3. Methods for the application of camera enforcement in different European countries.

Country	How the photo is taken	Who is responsible for the violation	Is the surveillance area indicated by signs
Austria	Back of the car	Driver/owner	Yes
Finland	Front + driver's face	Driver	Yes
Denmark	Front + driver's face	Driver	Yes
Netherlands	Back of the car	Owner	Yes
Norway	Front + driver's face	Driver	Yes
Sweden	Front + driver's face	Driver	Not obligatory, but usually yes
United Kingdom	Back of the car	Owner/driver	Not obligatory, but usually yes

According to Zaidel & Mäkinen (1999) the systems have evolved in very different national contexts which differ in size and density of the transport system, in the organisation and responsibilities of local government and of police forces, in the legal system and in other attributes not easily identifiable. Even within a country there are differences in the way enforcement is applied. Nevertheless, the basic issues of applying camera- based automated enforcement were similar, and had to be resolved in the national context.

All countries had to make legal provisions for use of unattended sensor and photo evidence for traffic violations. This was achieved by specific legislation regarding acceptable evidence. Three countries, NL, UK, and Austria deemed the license plate number (in addition to a scene image) as sufficient evidence that the driver of a vehicle committed a violation. Norway requires as evidence a view of the driver of the car. However, all countries considered the possibility that in some cases (all cases in UK and Norway) it is necessary to attach the blame of the violation to a specific driver.

The provisions for this are different in each country. Norway requires either a no contest by the owner of the vehicle to whom the original citation is sent, or a positive identification of the "real" driver with information supplied by owner and further inquiries by police until the real driver is identified by own admission or through police and court investigation. Owner will not be fined unless the police succeeds in establishing that owner was the driver. Consequently, only Norway, in this group of four, requires taking a photo of the front of the vehicle with the possibility of matching the image of driver's face to a person.

In the other three countries police can use either back or front photo of car as long as the plate number is visible and the faces of driver and passengers are not. The three countries differ, however, in the way the identity of a driver is established when it is needed due to the severity of the offence (e.g. speeding 30 km over the limit). In the UK, where all violators have to be identified, owners are assumed to be the violators unless they legally state that they were not and supply the details of the actual driver. Failure to supply carries a fine and extra de-merit points. (Norway does not have de-merit point system, but still requires strict positive identification).

In Austria, (which does not have a point system) most detected violations fall under administrative law and are not registered in drivers' record. The fixed fine goes to the owner and is rarely contested. If driver identification is required, either because owner appeal or severity of violation, it is attempted through correspondence with owner and police investigation. Owner will not be fined if driver identity was not established.

In the NL most traffic violations come under administrative law (so called Law Mulder). Automatic citations are addressed to owners by default. There is no point system either. In appealed cases and severe violations that require driver identity, owner must supply name, but until other driver accepts charges owner is responsible.

All four countries demand that in a case of a car owned by a company, the owner or secretary of the company provide the name of the driver. In the NL and UK there is a penalty for failure to give the name, higher than the original fine. In Austria and Norway police may have to investigate and until the driver is identified the fine is not paid. In neither country there are satisfactory solutions for handling citations to foreign vehicles, and most of their violations go unpaid. This is more of a serious issue in Austria and the NL that accommodated a large cross border traffic. International and bilateral agreement are minimal, hard to implement and involve a lot of manual paper work.

It is interesting to note that the two countries with very simplified driver identification procedures (despite the contrasting legal requirement for identifying drivers) are the two countries with high traffic volumes and several highly populated metropolitan areas. With the large number of cases it would have been impossible to operate a system with manual procedure for identifying drivers.

As it is, “automatic enforcement” with existing camera technology is somewhat of a misnomer. In practice, there is a considerable amount of additional manual work involved in all stages of the process. All police forces that embraced automatic photo-radar especially fixed installations, had to invest in infrastructure for the camera equipment, laboratories, offices and analysis equipment, maintenance and operating teams. In all countries there was some cost sharing between the police and other participating partners- road authorities, local communities, or other transport related department. For the police, the operation of automatic enforcement is usually an added task, which at this point does not relieve them from any other traffic enforcement activity.

Consequently, in all countries police are looking for alternative ways to pass on some of the work involved in automated enforcement to non-officers. In NL civil personnel (sometimes referred by the unemployment department) are doing the office work; in Austria private laboratories are developing wet film; in Norway the National Road Administration not only funds the infrastructure but also services the camera sites and collects the films. In the UK there are considerations setting up a separate entity for handling automatic enforcement, perhaps similar to the London Parking authority. In deliverable 4 (workpackage 3) this process is described more thoroughly.

4. Automatic speed enforcement

4.1 European activities and experiences

Mäkinen and Oei (1992) reviewed the need for and applications of automatic enforcement, the effects of automatic enforcement on red light violations and accidents and the effects of automatic enforcement on speed and accidents in a number of countries, particularly in the Netherlands. In their paper, it was argued that automatic enforcement needs to be supported by the application of other measures such as information campaigns and warning signs. The technical and tactical methods used for automatic enforcement are a matter of concern for many reasons, for instance: a) photographs should be used to identify a vehicle only, not a driver; and b) the system is vulnerable to vandalism. It is expected now that the judicial process is the only part of traffic enforcement that cannot be automated in the future.

The deployment of automatic monitoring sites is an issue that needs more consideration than what at the first sight might seem necessary. There are several ways of placing boxes (or cars or cameras mounted on tripods) for the use of automatic cameras:

- scattering single boxes as in Norway (Glad & Östvik, 199; Elvik, 1997),
- chaining the boxes in a row aimed at controlling long road stretches (Mäkinen & Rathmayer, 1994),
- linking two or three camera boxes on road links as in Sweden (Nilsson, 1992),
- automatic cameras in police cars, either in marked cars as in Sweden or in unmarked cars as in Denmark (Ágúsrtsson, 1999) having no fixed site and
- Surveillance cameras mounted on tripods having no fixed site as in Germany.

The rationale for different ways and equipment of using automated surveillance methods is based on the belief on a) a significance of site-bound factors in the causation of accidents, where they tend to accumulate on certain locations such as at junction areas and b) the alternative approach is focusing more on behavioural factors - of course they are not excluded in the first approach - and attempts to influence driving manners generally. This approach was supported by a study of Mäkinen (1987), in which speeding was shown to be associated with many other types of violations, especially overtaking violations.

To increase enforcement efforts without increasing the amount of personnel, electronic speed enforcement has been implemented on a wide scale in the Netherlands. One of the most important factors for a successful implementation of this electronic traffic enforcement has been a modification of legislation in a way that it permits holding the owner of the vehicle responsible for the payment of the fine.

The Netherlands

To enable monitoring the speed level in the Netherlands, a traffic-measuring network on secondary rural roads was designed and installed in several provinces. The data from this network served two purposes: use for national policy on speed on the one hand and the use for provincial speed management on the other. Speed management through automatic warning and enforcement combined with information campaigns and feedback signs has been applied and evaluated. Speed warnings and enforcement can be administered locally on a road stretch, and on a road network.

From several studies (Oei, 1994; Oei et al., 1995; Oei & Goldenbeld, 1995; Oei & Goldenbeld, 1996 it can be concluded that automatic systems in the Netherlands can reduce both driving speeds and the percentage of speeders. Different test data showed that the more often the enforcement system was used, the more drivers would comply with speed limits. To be most effective, speed management systems should be a combination of information campaigns that educate all road users, fixed speed signs that inform all road users, dynamic automated signs that warn all violators, and automatic enforcement that catches all persistent violators. It is suggested that the problem of vandalism could be diminished by mounting the camera on a high pole, mechanically preventing climbing of the pole, automatic detection of vandalism, and wireless communication to a nearby police station. It should be well kept in mind though, that the effectiveness of automatic enforcement is not self-evident. This effectiveness is dependent on a number of factors. Important factors that have briefly been mentioned before are the structure and features of the legislative system and, probably the most important factor, the public acceptance of the system.

Norway

Norway is one of the countries having most experience on automated speed enforcement methods. For some years cameras were used also for the enforcing red light violations, but currently there are no such applications in operation. Several toll roads have also camera surveillance. If a driver chooses to use a toll lane having automatic surveillance, an electronic tag is used to check if the driver has paid the entrance. If not, a photo is taken. (There is also a lane where the drivers can pay manually). For speed enforcement a system developed by the Norwegian company “Datainstrument A.S” is used. The number of fixed automatic enforcement sites has increased steadily and was about 200 by the end of 1999, with about 35 cameras alternating between the sites. The first year of operation of automatic enforcement in Norway was 1988. It was then decided on a 10- year test period within 10 of the 19 counties in Norway. In 1997 the test period was completed. Automatic enforcement may now be installed in 7 more counties (in addition to the 10 decided previously). However, this enhancement has to be decided by Stortinget (the Norwegian Parliament) before getting into effect. The plan for the period 1998-2007 is to double the number of installations and to allow installations in all of the 19 counties in Norway.

The day-by-day management of automatic enforcement devices is performed by Public Roads Administration /Directorate of Public Roads which have an administration office in each of the Norwegian counties. Day-by-day management includes maintenance, film installation, emptying a completed film, moving the camera between automatic enforcement units upon police decisions (not all units have cameras). The exposed films are handed over to the police to complete the rest of the process – i.e. consider the evidence, especially the quality of the photos with respect to identify the driver. The police dismiss the case if there are identification problems or they fine/notify the driver if the evidence is considered valid. The police decides on the extent of the enforcement, time schedules and when to remove/install the camera.

The use of the automatic enforcement systems is based on the respect of privacy: the photo of any other person than the driver is masked. At first, it was decided that the photo evidence could not be used against any other crime than the traffic violation – even if other crimes could be detected by means of cameras. This has later been changed after a sentence passed by Norwegian Court.

The process proceeds as follows: the police send a standardised letter to the car owner. The car owner is asked to contact the police if the owner was not the driver of the car. The car owner is then asked to give the name of the driver when the violation was done. When the driver has been identified, a fine is mailed to the driver. In terms of company cars the owner of the company is not personally responsible. If the driver does not accept the fine, the case is brought to court.

Before the introduction of automatic enforcement, ticket fines for traffic violations could only be issued on the road/at the site of the police control. A special legislation allowing an ex post facto issue of a ticket fine (by mail) was hence necessary. The stretch of road on which an automatic enforcement unit is installed must have a road sign placed in advance of the enforcement unit warning the drivers of automatic enforcement on the given stretch of road.

Sweden

Sweden launched its first speed camera experiment in 1990 (Nilsson, 1992). The experiment comprised totally 16 road sections, of which 8 were dual carriageways with a speed limit of 90 km/h and 8 two-lane urban main roads with a speed limit of 50 km/h. Totally, the experiment consisted of 110 km of rural roads and 17 km of urban roads and roughly a respective length of control roads. The design was a statistical experiment, in which pairs of equivalent sections were selected so that another one served as a control section and the other one received treatment, camera box. The treatment was randomised. Each test section had two camera boxes with varying distances from 0,5 km to 11 km. The drivers were informed of the surveillance sites by warning signs. A so-called floating car-method was used by means of following vehicles on the test road. The average speeds decreased by about 3 km/h and the effects on accidents were calculated as - 5 % reduction in injury accidents. Drivers' opinions and experiences regarding automatic enforcement were questioned. The results show that 44 % of the drivers wished more automatic speed camera boxes and 46% were of the opposite opinion. The majority, however, believed that automatic speed enforcement resulted in lower speeds.

Finland

Experiences on automatic enforcement from Finland shows that both speed and accident reductions can be achieved with the intensive use of camera surveillance (Mäkinen & Rathmayer, 1994). The first experiment was launched in 1992 extending over the stretch of 50 kilometres with 12 roadside camera boxes. The drop in mean speeds was not very great, 1-2 km/h. However, the proportion of high speeds (> 20 km/h over the posted limit) was decreased by 50 % to 80 %. The halo effects of camera surveillance were also measured. Speed reductions as far as 4 and 10 km from the site of the camera in terms of very high speeds (> 20 km/h over the posted limit) were recorded. However, the speed reductions in terms of mean speeds had their maximum at distances of 0,5 to 2,5 km from the camera site. However, a reduction in the proportion of high speeds (>20 km/h over the posted limit) was measured as far as 10 km from the surveillance source. Since the number of these high speeds is relatively small, their effect on mean speed is negligible. The proportion of injury accidents was decreased by 19%. The design of the experiment included a comparable control section. However, after an extension of the follow-up period up to three years, the most probable effect of camera enforcement was a 9 % reduction in injury accidents. It was calculated that the operating costs of manual enforcement sites were about 8,2 times higher compared to automatic operation of the same sites in the experimental area. The survey carried out the experimental area showed that 88% of the drivers found automatic speed enforcement acceptable or very acceptable, provided they are informed of the surveillance area through road side information boards as was the case in this experiment.

Another study carried out in Finland dealt with the effects of automatic red light enforcement on both speed and red light violations, the frequency of lane changes at junctions and the number of conflicts (Anila and Mäkinen, 1998). The data were collected at twelve signalised junctions of which four were on suburban roads in 70 km/h speed limit zones, three on suburban roads in 60 km/h speed limit zones and the remaining five on urban streets in 50 km/h-zones. Five of the twelve junctions were chosen as controls. The results of camera surveillance after one year's follow-up period did not show that red running had decreased at the camera junctions. However, the effects of surveillance on driving speeds were strong and consistently seen at all camera sites. The effect was especially great on those travelling at highest speeds. The speed level even slightly increased at the control junctions in the city of Lahti at the distance of about 120 kilometres from the test area. The number of illegal lane changes decreased significantly more in the experimental junctions than in the control area. Also the number of conflicts decreased more in the test area than in the control area. Since the number of junctions was relatively small, no accident monitoring was carried out.

Denmark

Denmark has recently initiated experiments on automated enforcement methods (Ágútsson, 1999a, Ágútsson, 1999b). The first results are from an experiment dealing with speed enforcement, which was started in September 1997. The method was to rotate in pre-selected sites unmarked police cars equipped with a speed camera. Two speed limit areas, 50 km/h and 60 km/h were selected as experimental areas. Control areas were also used. Mean speeds were decreased in areas with 50 km/h speed limits by 0,7 - 1,6 km/h more than in control areas compared to respective April - July before-period in 1998. The proportion of those travelling faster 10 km/h over the limit dropped by 3 % more than in the control areas. The situation in 60 km/h areas was different, and no mean speed change or a change in the proportion of vehicles travelling faster than 10 km/h was shown. In addition to these two speed limit areas, five police districts and communities took part in the experiment. Generally it was shown clear mean speed decreases also in these areas. Moreover, also an experiment dealing with red running and speeding is being planned. The expected start of the project is the year 2000.

Germany

Speed enforcement in Germany operates in a less obtrusive manner than elsewhere. The police is the only authority who can stop a violator in traffic. Police intervention seems however to be an exception. Generally, they do not stop a motorist, but ascertain the facts primarily by means of radar devices, ensuring due prosecution. In built-up areas, local authorities that post cameras, working in conjunction with the police guarantee imposition of limits. There is considerable commercial vehicle travel on German roads. Special speed enforcement programs are targeted toward trucks because the injuries are more severe when they are involved in accidents. Other than commercial vehicles, no special segments of the vehicle population are subjected to antispeeding campaigns.

On the local level, there is some experimentation with photo radar to determine its impact on vehicle speeds. Speed cameras have not been widely used because German law requires positive identification of the driver for a traffic infraction. Current speed camera technology does not consistently and reliably identifies drivers. There is a technical tolerance of 3 km/h to account for measurement error and an additional so-called "opportunity tolerance" of another 3 km/h. The threshold from which speeding is detected by cameras varies according to local conditions. Police indicate they are moving away from photo radar in favour of a laser-video camera interface installed in the police vehicle. The primary reason for this change is to provide the courts with additional evidence of a driver violation, and to eliminate the problems associated with identifying the driver with photo radar.

Based on a review of the literature, a long-term investigation of automatic radar devices was conducted at Elzer Mountain on the A3 autobahn. To reduce accidents and accident severity, a speed limit of 100 km/h was posted and speed cameras were placed above each lane. Passenger cars exceeding 110 km/h and trucks exceeding 95 km/h were photographed. Tickets were sent to the vehicle owners by mail. In addition to speed cameras, police patrols were used, especially on weekends, to cite drivers for speeding. Immediately after this 100 km/h speed limit was imposed, a 30 km/h reduction in mean speed was noted. Following installation of the speed cameras, an additional 20 km/h reduction in speed occurred. The combined effects of the speed limit and speed cameras produced a 91 percent reduction in accidents on that stretch of autobahn.

Photo radar is used on a limited basis in Germany, but its effectiveness has not been adequately measured or studied. German law requires positive identification of the driver, which poses limitations on the use of photo radar. Also, due to some of the problems associated with this technology, i.e., repair costs, bad photos, out-of-country drivers, etc., police are moving toward laser speed measuring devices. Also, in some jurisdictions, the German police videotape traffic violations, including speed. This practice provides additional support in court, which results in an almost 100 percent conviction rate.

German officials use technology more to manage speed than to enforce it. Variable speed limits are much more accepted and used than fixed speed limits. Variable speed limits, which advise motorists of the safe speed for prevailing conditions, are more beneficial than a fixed limit, which does not give drivers useful information during adverse traffic flow and weather conditions. Due to the use of electronic signage, the variable limits are enforceable. More importantly, they appear to have major beneficial safety and operational effects.

The UK

Camera enforcement is used extensively in London metropolitan area. In an experiment to reduce speeding and red light running totally 17 intersections were equipped with a camera and a flash unit. Also dummy flash units were used. (Swali, 1993). Signs warned drivers that speed cameras were installed. The results showed a 43 - 57 % reduction in violations. It was estimated that speed cameras could save 1,5 million £ in accident costs. Moreover, it has been indicated by TRL that speed cameras could effectively reduce 85 percentile speeds to their potential limit and eliminate those travelling over 20 mph above the speed limit (Stark, 1996). It was concluded that fixed-site speed cameras could control speeds well in critical locations, whereas mobile units can control speeds better over larger sections of road network.

A recent study by Chin (1999) also corroborates the many findings reviewed above. Following an installation of cameras travel speeds tend to decrease, especially in the vicinity of camera boxes. His conclusions are as follows: the installation of speed cameras has resulted in a significant drop in vehicle speeds, speed compliance and the overall crash reduction in almost the whole study area. So, while speed cameras may have rather short halo effects in space, increased compliance will significantly reduce the probability of an accident.

Metaanalysis

Eventually, it is the effects on accidents that are the most relevant factors when the application of automated enforcement methods are considered. In a meta-analysis of the effects of automatic speed enforcement on accidents the following 10 studies were merged by Elvik & al. (1997): Lamm and Kloeckner (Germany 1984), Cameron, Cavallo and Gilbert (Australia 1992), Nilsson (Sweden 1992), Swali (England 1993), Winnet (England 1994), Oei (the Netherlands 1994), Blackburn and Gilbert (USA 1995), Hook, Kirkwood and Evans (England 1995), Krohn (Norway 1996). Of these, Cameron et al's (1992) study is by far the largest as it comprises as many as 20,000 to

60,000 accidents. Based on the results from all 10 studies, the best estimates of the effects on accidents are presented in table 4.

Table 4. Best estimates and confidence intervals (CI = 95%) of the effects of automatic speed enforcement on accidents. Percentage change in the number of accidents (Elvik, Mysen and Vaa, 1997).

Injury level	Accident types affected	Best estimate % change	Confidence interval
All	All	- 19%	-20/-18
Casualties	All	-17%	-19/-16
All	Accident in urban areas	-28%	-31/-26
All	Accidents in rural areas	-4%	-6/-2

When all levels of injury are taken together, the effect on the number of accidents shows a total reduction of 19%. Considering casualties only, the accident reduction is 17 % (CI: -19/-16). As a traffic safety measure, automatic speed enforcement seems to have a larger effect in urban areas (28% reduction) than in rural areas (4% reduction). All studies but one are before-after studies with control groups or reference stretches of road (Blackburn and Gilbert is a before-after study without control group). The accident data do not allow a separate estimation of the effect on fatalities only.

4.2 Non-European experience

Australia (Victoria)

A good example of the application of integrated approach is from the state of Victoria, Australia, where an intensive enforcement campaign - alcohol and speed - was launched in 1989 and was continued subsequently. Publicity was very intensive, showing on TV simulated crashes with the resulting misery for victims, their family, and the drivers, who caused them. There were 2,500 camera sites, 54 radar plus camera systems, 4,000 camera hours in operation every month. Each car was checked nine times a year on average, 66% of the car fleet checked every month. The processing of violations was highly automated. A demerit-point system was used and for persistent speeders even stricter sanctions were applied. Car owners were primarily held responsible for offences committed and the driving license could be withdrawn or the car license for company cars. Although average speed was not decreased, the percentage of excessive speeding was cut to half. The results after five years of enforcement on speed and alcohol is a 21% reduction in collisions, a 38% in major injuries and a 51% reduction in fatalities.

It should be stressed that automatic enforcement was one method being a part of an integrative approach consisting of several measures applied simultaneously in the course of several years and the design of the experiment did not allow isolation of the effects of camera surveillance only.

The enforcement tolerance is 10 percent of the speed limit, plus 3 km/h for measurement error. Approximately 28 percent of vehicles photographed are not prosecuted due to a variety of reasons, including inadequate vehicle identification, resulting from obscured license plates or database mismatches. Typically, there is a three-day turnaround between the time a motorist is detected for speeding and the speeding infringement notice is mailed. Fines in Victoria for speeding range from $105 A ($78 US) and one demerit point for exceeding the speed limit up to 15 km/h per hour to $360 A ($266 US) and six demerit points and loss of license for six months for exceeding the speed limit by 50 km/h or more. Overall, approximately 35,000 speeding infringements are issued each month. In four years, only five cases have been lost in court.

In five years of camera operation, the percent of vehicles exceeding the speed limit tolerance was reduced from 23 percent to 2.9 percent, with virtually no drivers exceeding the tolerance speed by more than 25 percent. Obviously, very high-speed driving has nearly been eliminated.

The impact of the probability of being detected speeding, and the penalty applied if apprehended, has led to few repeat offenders.

Australia (New South Wales)

Radar speed cameras were first introduced in New South Wales in March 1991.[23] Initially, nine cameras were used at 93 sites. Prior to using the cameras, an intense public information campaign was undertaken that included radio, television, and press coverage. Pamphlets, containing questions and answers, were distributed to all police stations. Based on the advice of the speed management task force, which included officials from enforcement, the Roads and Traffic Authority, the National Roads, and Motorists Association, signs with the message "Speed cameras used in this area" were erected on roadway sections where the cameras were likely to be used. Speed cameras were initially used in urban areas; however, in November 1993, the operations were extended to rural locations. Currently, New South Wales has 21 speed cameras, which operate, at 809 sites throughout the State. The cameras are located at high-accident sites.

In New South Wales, a 10 percent tolerance is used as a general guideline in enforcing the speed limit. Typically, there is a five-day turnaround between the time a motorist is detected for speeding and a speeding infringement notice is mailed. Fines for speeding range from $99 A ($73 US) and one demerit point for exceeding the speed limit up to 15 km/h to $608 A ($450 US), six demerit points, and loss of license for 3 months for exceeding the speed limit by more than 45 km/h. In 1994, 51,393 speed camera infringements were issued. A total of $4.5 million A ($3.3 million US) was collected in fines.

A before-and-after evaluation indicated a 22 percent reduction in serious accidents occurred at the speed camera locations. There was also a decrease in excessive speeding, i.e., the proportion of vehicles travelling 10 km/h or more, and 20 km/h or more above the speed limit.

Attitudinal surveys conducted before and after the speed cameras were introduced revealed that there was high public acceptance of the cameras. The public was also familiar with the fact that the cameras were used to improve safety.

5. Automated enforcement of red light running

5.1 Introduction

Red light cameras are devices that, when linked to the signal controller, automatically photograph vehicles that enters the intersection after the onset of the red light. Typically offending drivers enter the intersection 1-2 seconds after the onset of the red and most cameras are set to start photographing the drivers upon the 2 second after red.

Red light cameras are used to improve safety at signalised intersections. Typically, the cameras are installed at high-accident intersections or at locations where drivers are disobeying traffic signals. Experience with red light camera installations in the Netherlands and in Australia indicates that this technology can reduce incidents of running the red light by 35 to 60 percent. Furthermore, reductions in right-angle accidents of 32 percent have been reported. In order to effectively use red light cameras, it is necessary to have legislation that permits issuing tickets for infractions to vehicle owners. Due to the beneficial safety effects of red light cameras, the United States Department of Transportation has initiated a red light program for local governments.

5.2 Description of technology

35-mm cameras are the most common cameras used for automated enforcement of red light violation systems. When the traffic signal switches to the red phase, the camera used by the system becomes active (ready to take photographs). Vehicles travelling over the detectors while the camera is active signal the system to photograph the vehicle. A small period of time (usually 0,3 seconds) and a pre-set speed (usually 8 to 30 km/h) necessary to activate the system are incorporated to differentiate between vehicles attempting to stop or turn right on red and vehicles that are clearly running the red light (Passetti and Carlson, 1998).

When a vehicle running a red light activates the system, at least two pictures are taken. The first picture shows that the front of the vehicle is not in the intersection when the signal is red. This picture must show the pavement marking defining the intersection (usually the stop bar), the traffic signal displaying a red light and the vehicle in question. The second picture then shows the vehicle in the intersection a short time later (0,5 to 1,5 seconds). If driver identification is necessary, a third picture of the driver may be taken. From the pictures taken, the license plate will be magnified to allow for identification of the vehicle

Information pertinent to the violation is superimposed on the photos. The data time of day, intersection number, photo number, yellow phase time, and time into red phase are usually shown on the first photo. The second photo may include date, time of day, photo number, yellow phase time, time into red phase, and vehicle speed.

Current technology allows video cameras to be used as part of an automated enforcement program. In countries that currently have laws forbidding the use of automated enforcement video cameras may be used to record and view the large number of violations on certain intersections. In this way evidence can be presented to officials about the severity of the red light running problem.

Digital imaging promises further advancement in the automation of red light citation processing. Digital cameras have the capability to produce higher resolution, more sharply detailed images of vehicles, and are equipped to prevent reflections or headlight from smearing images. Digital cameras are in operation in New South Wales, Australia. Along with producing better vehicle images, the major (expected) benefit of digital cameras is in improving the processing and distribution of notices of violation (tickets). Digital cameras have the capability to be linked using dedicated lines or existing phone lines to a computer located in a central facility. Once the images have been transferred from the digital cameras to the central facility, pattern and optimal character algorithms can be used to determine the owner of the vehicle by cross-referencing the license number with records of vehicle registration databases. After license plate numbers are successfully matched with registered vehicle owners, tickets can be automatically processed and mailed to violators.

Implementation of a digital camera based system is a major step in creating a truly automated enforcement system. Current systems require many tasks to be performed manually (the film must be picked up, developed, reviewed, and matched to an owner or driver). True automation can only be achieved with a digital camera based system. The benefits include reduced labour and potentially more accurate evaluations of the photographs.

On the other hand, drawbacks associated with digital camera systems remain (Passetti and Carlson, 1998). The more salient issues include cost (currently, a digital system costs about eight times that of a 35-mm system), legal support (photos are recorded electronically onto a WORM (write once, read many) device to ensure integrity but the effectiveness of the WORM device has not been thoroughly evaluated), and digital camera capabilities such as data management, resolution, contrast latitude, frame rate, etc.

In the field of monitoring red light offences, the Swedish firm Sensys has adapted a slightly different approach. Rather than concentrating just on capturing the offender with a photograph, Sensys SICAS (Signalised Intersection Collision Avoidance System) detects every vehicle that approaches the intersection. By using a special algorithm, any vehicle that passes a set distance with a speed higher than a pre-set speed, gives a signal to the traffic controller to extend the red light phase for the drivers on the crossing road, long enough to allow the offender to pass the intersection. In this way, the system both captures the offender and avoids a collision in the intersection.

The UK

Red light cameras have been shown in most cases to be an effective means of reducing red light running. Chin (1989) found that cameras reduced the rate of red light running by about 40 percent. An UK study (County Surveyors' Society (1990) also indicated that red light violations at sites with cameras were reduced by some 55 percent. Studies evaluating the effects of red light cameras on accidents at signalised junctions generally report a reduction in right-angle accidents. South et al (1988) report an overall reduction of about 7 % in all intersection accidents and a 10 % percent reduction in injury accidents at sites with red light cameras. A dissenting view is put forward by Andreassen (1995). His conclusion of the study of the operation of red light cameras (RLCs) at 41 signalised junctions in Victoria, Australia during the period of 1979-1989 indicated that the installation of RLCs at these sites did not provide any reduction in accidents.

USA

Both conventional, wet- film technology and the most recent digital video technology are currently tried out in Howard County, Maryland USA. Red light running was considered a serious problem in Howard County. Motorists in one direction at a busy intersection run a red light on average every 16 minutes. During the evening rush hour, the rate soars to every seven minutes. The State Legislature approved the use of red light cameras at signalised intersections so violators can be sent a ticket when they deliberately go through a red light. The new law recognised photo- radar picture taken without the personal presence of a police officer as admissible evidence. The cameras are connected to a traffic signal with sensors embedded in the pavement. The owner of the vehicle receives a violation notice in the mail. The cameras do not violate privacy because the picture only identifies the vehicle's license plate and never shows the driver's face. Since the cameras only activate after the light turns red, only pictures of actual violations are snapped. This procedure is, of course, common place in Europe with the exception that in some jurisdictions the requirement is for taking the front end of the vehicle and to identify the driver. The program was implemented in1998 with 14 to 20 cameras in operation.

With such large quantity of cameras to service and films to manually process and convert to citations, the administrative load became quite high, and no sooner this system was in place a search was on for a digital system that might further automate the process. Digital cameras can electronically transmit pictures to a central computer for identifying vehicle owners and issuing violation notices. This may speeds up the process between the occurrence of a violation and issuance of a violation notice. There is an expectation that there will be substantial savings in time and manpower as the cameras no longer need servicing on a daily basis. So far, the results concerning the safety effects from Howard County, Maryland are not available.

Australia

In terms of cost-effectiveness most authors conclude that red light programs are highly cost-effective. South et al., (1988) estimated, on the basis of accepted accident cost figures for Victoria, the calculated accident reductions and the cost of installation of RLCs. They concluded that the benefit-cost ratio was about 2.7:1, excluding fine revenue. Lawson (1992) in England also evaluated the effectiveness of RLCs and concluded that the cost of installation and maintenance would be returned in about one year, based on the savings in accident costs.

Zaal (1994) mentions some problems and limitations in regard to the use of red light cameras. In some studies relatively low red light apprehension rates of between 40% and 60% have been reported. Low apprehension rates can result from a number of reasons including equipment limitations, poor quality images in certain lighting conditions, weather and road conditions, and vehicle identification problems in multiple lane and heavy traffic flow situations.

The on-site permanency of red-light cameras can reduce the potential deterrence effect of these devices. Drivers soon become aware, due to the presence of the camera hardware, of which junctions are treated and may modify their behaviour only at those sites where they perceive the risk of detection as being high.

With more innovative technology, such as digital imaging systems, some of these problems can possibly be overcome. A new laser and digital imaging detection system, developed in Australia, has been shown to significantly improve the effectiveness and efficiency of red light camera operations (Zaal, 1994). One of the main advantages of this new laser based system is that it is fully portable and requires no physical connection with the traffic signal control system. This significantly increases the mobility and deterrence effect of red light camera operations by enabling any signalised junction to be automatically monitored.

When an offence is detected, the information is digitally recorded and security coded and can be stored on location or sent direct, via telephone line, to a central location for immediate processing. The high resolution digital image produced is significantly clearer than existing photographic images and has been reported to result in 95% detection rate, almost twice that of existing systems.

In general the deterrence potential of red light camera operations can be maximised by the use of clear posted warning signs, highly visible hardware installations, the rotation of a small number of cameras through a large series of treated junctions, widespread use of publicity to raise community awareness, and the visible deployment of a flash unit at sites where a camera is not installed (Zaal, 1994).

5.3 Experiences

The Netherlands

The PROject against Red light violations Or Speeding (PROROS-Project) in the Netherlands is a comprehensive effort utilising engineering, enforcement, and education to reduce red light offences and speeding. Accident, speed, and other data were used to identify problem locations in Amsterdam. Based on follow-up studies, engineering improvements such as intersection modifications, signing and signalization changes, etc., were made where appropriate. In addition, two traffic light cameras and five cabinets were installed on major crossroads.

In autumn 1993, selective enforcement was undertaken at 12 locations using a variety of methods including marked police motorbikes, unmarked motorcycles with video equipment, unmarked police cars, radar speed checks with marked police cars, unmarked speed checks with cameras, etc. During the period, publicity included posters, leaflets, and stickers, in addition to press coverage in the newspapers and on television stations. Education of drivers to change their attitudes is also an important part of the project. A music video was developed to educate 18- to 24-year-olds concerning the dangers of speeding on mopeds. A module was also prepared for driving schools to distribute the message to a wider audience. The PROROS-Project is an ongoing effort. While final conclusions are not available at this time, some preliminary findings have been reported. During the three months of checks in 1993, 3,550 people were observed speeding and 121 ran the red light. At several locations, speeding was reduced by 40 percent; however, at other locations, there was no measurable effect. It is felt that continuing the program will reduce speeds and accidents.

Australia

Studies evaluating the effect of red light cameras on accidents at signalised intersections generally report a reduction in right angle accidents. South et. al (1988) reports an overall reduction of 6.7 percent in all intersection accidents and a 10.4 percent reduction in injury accidents at sites with red light cameras. A dissenting view is put forward by Andreassen (1995). His conclusion of the study of the operation of red light cameras (RLCs) at 41 signalised intersections in Victoria, Australia during the period of 1979-1989 indicated that the installation of RLCs at these sites did not provide any reduction in accidents.

In terms of cost-effectiveness most authors conclude that red light programs are highly cost-effective. South et al (1988) estimated on the basis of accepted accident cost figures for Victoria, the calculated accident reductions and the cost of installation RLCs that the benefit-cost ratio was about 2.7 : 1, excluding fine revenue. Lawson (1992) in England also evaluated the effectiveness of RLCs and concluded that the cost of installation and maintenance would be returned in about one year, based on the savings in accident costs.

Red light cameras at signalised intersections have been used in Australia since 1979. The cameras are presently used in New South Wales and Victoria, and in several other States. In Victoria, 35 cameras are rotated among 132 sites in the Melbourne metropolitan area. A fixed sign displaying the message "Red Light Camera Ahead" is posted in advance of each intersection where cameras are used. The cameras are usually installed at high-accident intersections or other locations where motorists have been observed running a red light.

The consensus of evaluations is that red light cameras reduce the incidents of running the red light by 35 to 60 percent. [34] An evaluation of the reported accidents indicates a 6.7 percent reduction in total intersection accidents and a 10.4 percent reduction in injury accidents. It is also interesting to note that right-angle accidents were reduced by 32 percent, right-angle turning accidents decreased 25 percent, and rear-end accidents decreased by 30.8 percent. A 28.2 percent increase in rear-end turning accidents was also found.

A recent evaluation of the red light camera program in New South Wales found that right angle and right-turn-against accidents decreased by 50 percent. However, rear-end accidents increased between 25 and 60 percent at the red light camera sites.

Table 5. Findings in different studies concerning red light running enforcement

Researchers	Country	Accident reductions	Cost-benefit
South, Harrison, Portans (1988)	Australia Victoria	46 sites The final analysis indicated that there had been a 6,7% reduction in all intersection accidents and a 10,4% reduction in the number of casualties at red light camera sites.	The researchers concluded that the benefit-cost ratio of the program, excluding fine revenue, was approximately 2,7 to 1.
Hillier, Ronczka, Schnerring (1993)	Australia Sydney	Rotation of six cameras among twenty selected intersections. Red light cameras in general appeared to reduce right angle and right turn against crashes by about 50% and increase rear end crashes by 25% to 60% resulting in an overall reduction in crashes and casualties	No mention of cost-benefit ratio Important: Other suitable countermeasures (e.g. right turn lanes, S lanes, added signal phases) appeared to be similarly effective in reducing target crash types by about 50% and also reducing rear end crashes by about 15 to 20%. It could be argued that the other measures were even more effective than red light cameras since they achieved similar benefits without producing rear end accident disbenefits.
Andreassen (1995)	Australia Mel-bourne	No demonstrated value of red light cameras at 41 signalised intersections in Melbourne Increase in rear-end crashes	Not reported, but obviously not positive since no effect on accidents could be demonstrated
Hooke, Knox and Portas (1996)	UK	36 traffic light cameras used on 254 traffic light sites in ten police forces Accidents fell by 18% at traffic light sites or by 0,48 per site per year	For traffic light areas all areas but three achieved a positive benefit within a year of the investment. Overall, the return was nearly twice the investment after one year and twelve times this by year five
Retting, Williams, Farmer and Feldman (1998)	California Oxnard	Oxnard has 150.000 inhabitants. Red light running was punished with $ 104 plus one point on a driver's license. 9 camera sites and 3 non-camera sites and 2 control sites. Overall, the red light violation was reduced approximately 42 percent several months after the enforcement program began. There was also a spillover effect to non-camera intersection sites. Six months after the camera enforcement program nearly 80 percent of Oxnard residents supported using red light cameras as a supplement to police efforts to enforce traffic signal laws.	Not reported.

6. Automated enforcement of other violations

6.1 Multi-offence detection systems

Video imaging may be installed on existing camera systems to broaden the scope of enforceable offences. Video image processing can be used to automate detection of traffic incidents, including violations such as speeding, driving in the wrong direction, or forbidden stopping or turning Versavel and Boucke, 1998). The main argument for video image processing is that very often cameras are already part of the standard equipment. Adding automatic detection of traffic incidents to the cameras could optimise the activities of the traffic managers by informing them better about the traffic parameters and the detected incidents, including violations.

Automated Incident Detection (AID) Systems should have a high detection rate (DR), a low false alarm rate (FAR) and a small mean time to detect (MTTD). These criteria can be conflicting so that often a compromise has to be made. As reported in Versavel and Boecke the system has been tested with good results in Bern (1996) and Stockholm (1997). Although the main purpose of AID systems is not enforcement of traffic violations, the detection of violations in the system may be used for enforcement purposes.

New technology broadens scope of enforceable offences:

The digital camera technology is not only meant to replace the old wet-film cameras. This new technology has the potential to open up a whole new area of traffic regulations that may have existed before but, in practice, were unenforceable. Lorry bans through towns, illegal U-turns and set-downs, dangerous or careless driving, illegal right turns, illegal use of bus lanes, and more - all transgressions that require more manpower than is currently available - could be captured automatically on hard disk (Bagot, 1998).

6.1.1 Detection of offences by heavy vehicles: safe-T-cam system

The system employs two cameras. The first takes a digital image, which is immediately processed, to separate trucks from light vehicles. The arrival time of the truck is also noted and the second camera is triggered to capture an image of the license plate on the front of the truck. The driver is not photographed.

An optical scanner reads the license plate number and enters the number in the computer. At the control centre, the number is checked to see if the registration is current. If not, action can be taken. Currently, only letters are sent to the vehicle owner;

however, it is hoped that future legislation will allow the imposition of a violation and fine.

Each time a truck license plate number is captured at a location, it can be compared with truck information recorded at an upstream Safe-T-Cam location. Based on the travel time between the two stations, the average speed of the truck is calculated and compared to the speed limit. Currently, only letters are sent to the registered owner for speed violations. At this time, penalty citations are not issued for speeding; however, the issue will be addressed during the next session of Parliament. Legislation to make exceeding the average speed a violation is also pending in Parliament.

Another potential use of this technology is the ability to monitor the commercial driver's hours of service. A vehicle that continues to be operated beyond the maximum driving time can be contacted, the driver's logs inspected, and appropriate enforcement action taken.

If the necessary legislation is enacted, the Roads and Traffic Authority believes the fines collected will greatly exceed the system costs. Based on data collected at two test sites, it is estimated that $10 million A ($7.5 million US) per year in lost revenue occurs due to unregistered commercial vehicles. In addition, $1 million A ($0.75 million US) per year would be generated by fines for speeding.

The enforcement potential of this system is as yet unresolved in Australia. Privacy issues have arisen, as well as the concept of citing drivers for speeding based on average speed. It is expected that these same concerns will arise in the United States.
The Safe-T-Cam system was installed in New South Wales to monitor heavy vehicle driver behaviour and improve safety. [29]

A pilot study was conducted to demonstrate and further develop the technology. After four years of development, the system is now ready for deployment. A contract has been signed to install 20 sites across the State at a cost of approximately $200,000 to $250,000 A ($150,000 to $188,000 US) per site. The contract also included the establishment of a central monitoring and control centre. The total cost, including development, communication links, and the control centre is $13 million A ($9.8 million US).

The operation of the system involves the following steps:

- A video camera detects moving vehicles and classifies them by size and shape.
- When a vehicle meets a certain size and shape criteria, i.e., a heavy vehicle, a low-powered infrared flash and a high-resolution digital camera takes an image of the front of the vehicle.

- The digital image is processed to read the vehicle license plate. The location, time, and license number are transmitted to the central traffic management centre and compared to the licenses in the database. If the vehicle is exceeding the travel speed or the license information is suspect, the information is transmitted to the report centre for further action.

6.1.2 Fog warning and advisory Speed Limit System

Although not directly associated with enforcement we describe the fog warning and advisory that has been evaluated in Sydney. It is conceivable that such a system could be broadened to encompass an enforcement part.

A fog warning and speed advisory system has been installed along an 11-km section of the F6 Tollway south of Sydney.[27,28] The F6 is a four-lane divided motorway carrying an average of 12,500 vehicles a day in each direction. There are 12 fibre-optic sign locations, with signs in each direction, so the motorist encounters a sign about once per km. Each location is equipped with a sign connected to road loops and a visibility detector to provide motorists with an advisory speed for road conditions. The speeds of individual vehicles are measured over a distance of 200 m, and this speed is used to present an advisory speed to the next vehicle passing the station. The advisory speed is based on visibility distance and the speed of the preceding vehicle, i.e., a driver is advised of the speed to travel in order to avoid a rear-end collision with the preceding vehicle.

A prototype of the system was installed in 1993 at the request of the State Government to replace a driver aid system installed in 1974. Experiments were conducted to determine if the sign could be used to modify driver behaviour for motorists exceeding the speed limit. [28] A motorist travelling more than 10 km/h over the 110 km/h speed limit was given a message displaying their speed and reminding them of the speed limit. The dynamic sign system resulted in a reduction of 60 percent of the vehicles travelling in excess of the speed limit. The system had a temporary effect in reducing speeds. At 300 m downstream, there was no reduction in speeds.

Currently data are being collected to conduct an accident evaluation of the system. Extensive data on the number of fog days at various locations (1 to 14 per month), the number of fog hours per year and by season of the year, and accidents by type, fog condition, and time of day, have been collected. There is no enforcement associated with the system at this time.

6.1.3 Detection of bus lane offences

Bus lane cameras are installed in Melbourne on roadways where a lane is reserved for buses, transit bicycles, or trucks. The cameras photograph vehicles that unlawfully use these lanes. As in the case of the speed and red light cameras, the infringement notice is sent to the owner of the vehicle. The penalty for unlawfully using a priority lane is $75 A ($55 US).

Slinn and Hewitt describe a concept for a bus lane deterrence system in Brigmingham. The bus lane deterrence system makes use of a video camera and vision processing equipment mounted within a standard operational bus (Slinn and Hewitt, 1997). The system detects vehicles in the bus lane ahead of it at a pre-determined distance and transmits the registration number of offending vehicles to a variable message sign up to 200 metres ahead of the bus. A database of registration numbers of exempt vehicles is held on the bus and these plates are ignored. The video record can be used for subsequent inspection and enforcement procedures whilst the variable message sign will advise the driver that he has incorrectly used a bus lane and will display his vehicle registration number. The system involves equipment located at three points: on board the bus, at the roadside and in the bus station.

6.14 Detection of vehicle weight violations

Piezoelectric axle sensors have been utilised for a lorry monitoring system. These kinds of sensors give clean axle detection signals, and may also be used to measure axle loads. With a camera system, there the camera is activated by a signal from the vehicle detection system, the suspected violator is identified (Ayland, N. 1990).

7. Conclusions and recommendations

To find a solution to adjust the driver speeds to the speed limits is very important for safety reasons, but also concerning the energy and the environment. It is also from safety reasons a lack of proper behaviour concerning other traffic regulations, which need to be enforced in an effective way. Automatic speed enforcement is one solution until the speed is restricted by the vehicle itself and depending of the speed limit.

Before and if the last solution is not generally accepted automatic enforcement ought to and will be used in different ways.

One main reason, except of the safety reason, is that the police will not be able to take direct action to each detected violator at normal police enforcement activities in some environments. By using detectors and camera technology the violators can be identified and sanctioned

The automatic enforcement can of course be used for all kind of violations, which can be related to the traffic regulation at a spot or in an intersection.

When introducing or developing automatic enforcement on a national level it is important to

- ***Adjust the legislation in order to achieve an effective system***
- ***Try to influence the speed behaviour on road sections***
- ***Improve the feedback from automatic enforcement systems to the driver***

The limitations to use the method will be less and less, which will result in increasing use of automatic enforcement. This will however result in political considerations into what extent in can be used, hidden or announced, lower or normal fines, law systems for the owner/driver responsibility problem etc.

It is therefore important to regard the traffic as a system, where the enforcement is an integrated part in the transport system and not just a safety measure of itself.

In the near future in-vehicle detection systems will appear, which adjust the (maximum) speed of the vehicle to the conditions. A taxation or fee system depending on distance driven in different road environment – toll system - is the next step and will probably be developed as computerised in-vehicle systems, which also can take violations into consideration.

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