Working paper 7

Automatic enforcement technologies and systems

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OBJECTIVES

The present working paper is a deliverable from ESCAPE Workpackage 4 ("Automatic enforcement & new surveillance methods"). It describes current applications of technologies and systems for automated enforcement of traffic violations and presents a brief historical overview of such applications. The objective is to provide some of the necessary background information for identifying the most appropriate automated enforcement concepts and methods to fit the needs, as identified in Workpackage 1, for enforcing various traffic offences in Europe.

INTRODUCTION

The first example of automatic traffic control reported in the research literature (Lamm and Kloeckner, 1984) was the photo-radar on Autobahn A3 between Cologne and Frankfurt installed in May 1973. The system consisted of three radar devices (one for each lane) mounted on a traffic sign bridge on a downgrade section with a very high accident rate. The speed limits were 40 km/h for the right lane and 100 km/h for the middle and left lanes. If speeds exceeded 45 km/h in the right lane or 110 km/h in the two other lanes, a picture was automatically taken (from the rear), showing the site, date, time and licence plate of the vehicle. In darkness a flash light was used. The rolls of film were changed by the police at least once a day. The police inspected the pictures, and speeding tickets were mailed to the vehicle owners. The owners had to declare if they had been driving the vehicle themselves, or to name the driver. The authors report that in 1982, after almost 10 year of operation of the system, only 10 per cent of the owners objected to the fine, whereas the remainder either paid or reported who had been the driver (63 per cent at once and 27 per cent after a reminder).

Most subsequent applications of automatic speed enforcement have employed basically the same principle of taking still photos of vehicles having committed a violation. Over time there have been certain minor variations, however, such as the use of mobile units, and the use of other devices than radar (induction loops, optical sensors, etc.) for measuring the speed. In some jurisdictions a difference is that pictures are taken from the front in order to identify the driver. In that case the flash unit is equipped with a red filter to avoid dazzling the drivers.

There have, however, been some extensions and improvements of automatic enforcement systems in the almost three decades that have passed since the first photo-radar used for automatic enforcement was installed. Automatic enforcement has been extended to several other types of violations than speeding. New technologies for detecting violations as well as for identifying the violating vehicles have appeared; the most notable developments seem to be the use of digital video recording with image processing, and systems for electronic recognition and identification of a vehicle. Some of these developments will be summarised in this working paper, the primary goal of which is to present the current state of the art regarding systems and technologies for automatic traffic enforcement.

As there is a continuous development in this field, there is a fuzzy distinction between systems in routine use and systems that are in an experimental phase. This presentation will be limited to systems that have been used for actual enforcement of violations, even on a test basis, but not systems tested without actually enforcing the detected violations. Some systems in the latter category will be briefly mentioned here, whereas they will be considered more thoroughly in a presentation of "new concepts" in a separate deliverable.

PREVIOUS REVIEWS OF AUTOMATED ENFORCEMENT

A comprehensive review of different systems and technologies for automated enforcement of speeding and red light violations was presented in a report by Blackburn and Gilbert (1995). It contains technical description of the various devices, as well as information about prices, manufacturers etc. The report also discusses operational requirements and experiences, procedures for the processing of citations, legal and acceptability issues, as well as some data on the efficiency of automated enforcement in terms of driving speeds and accidents.

A more recent review of automated enforcement regarding speed control only was presented by Glauz (1998). It contains among other issues a summary of experiences with various automated enforcement technologies in different countries.

In the recently completed EU project GADGET, automatic enforcement was among the issues treated in workpackage 5 on "Legal measures and enforcement" (Mäkinen et al., 1999). Although the review was primarily focused on the efficiency issues of automated enforcement, some considerations of systems and technologies were included.

Other treatments discussing technological issues of automated enforcement systems in general include those of Polk (1998), Freight Transport Association (1995), and Nuttall (1994).

Recent descriptions of specific systems include among others those of Schaufelberger (1997), Wrobel (1997), Kedmi and Langer (1996), Kinnaman (1994), and van den Bosch (1997).

An extensive set of links to various Internet sites containing information about automatic enforcement technologies and systems as well as issues related to their use has been collected by Polk (1998) and can be found on the Internet site http://www.nawgits.com/elec_enf.html. Among other things there are links to descriptions of various enforcement programs in the US, and links to product and technology vendors.

DEFINITION OF AUTOMATED ENFORCEMENT SYSTEMS

An automated enforcement system is defined here as a technical recording device that is triggered automatically by a traffic violation, so that information about the violating vehicle is recorded, making possible the subsequent identification of the vehicle for the purpose of sanctioning the owner or driver.

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 is 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. For further discussion of issues related to the choice and set-up of control sites, we refer to Mäkinen et al. (1999).

HISTORY OF AUTOMATED ENFORCEMENT IN DIFFERENT COUNTRIES

By 1997, according to a review by Glauz (1998) about 75 countries world-wide have used photoradar for speed enforcement. Some of the the countries have used the photoradar for automatic enforcement, as defined here.

Most applications of automated traffic enforcement have been initiated during the last decade. To give some impression of the development of automated enforcement, we will comment briefly on the situation in the countries with the longest history of automated enforcement. The countries are presented approximately chronologically, by order of the first reported trial or application of automated enforcement.

GERMANY

In addition to the early system on Autobahn A3, mentioned in the introduction, automated enforcement for speed control has been adopted in all states. As of April 1996, there were 593 units in operation (Glauz, 1998).

SWITZERLAND

Switzerland started trials of automatic enforcement of red light running in the 1970s. Currently there are 119 automatic (unmanned) enforcement units in operation (83 for speed only, and 36 for red light and speed).

USA

Although trials with automated enforcement for speed control started rather early in the US, at present there are relatively few ongoing automated enforcement programmes. The first trials sites were all in Texas. A 3-month test was carried out in Arlington in 1976. The next one was ten years later, with a one-year test in Galveston, starting July 1986, and a 90-day test in La Marque early in 1987. (Blackburn and Gilbert, 1995). Several additional programs started in the late 1980s and early 1990s, many of which have been discontinued, mostly due to lack of judicial and/or public support.

AUSTRALIA

Victoria, Australia, has a very extensive automated enforcement program for the control of speeding and red light violations. Ten red light cameras were put into use in August 1983, after a six-month trial period in 1981. The number of cameras have increased progressively to 35 cameras which are rotated through 132 sites within the Melbourne metropolitan region. The use of speed cameras started in December 1989, and by January 1991 there were 54 speed cameras in operation. An integrated processing technology package ("Traffic Infringement Management System" – TIMS) was developed to facilitate the identification of owners, the issuing of penalties and related administrative matters.

According to Fildes (1995), two characteristics made this programme different from most other automated enforcement applications throughout the world. First, the cameras were mobile and inconspicuous; they were fitted to unmarked police cars that could be parked anywhere on any road, and their presence was deliberately not advertised. Second, the level of surveillance was unprecedented; from July 1990 to December 1991 close to 12 million vehicle checks were performed, which is a considerable number in a state with about 4 million inhabitants.

In 1997 approximately 25 million vehicle speed measurements were made. Only 2.3 per cent of the vehicles were speeding, which was a reduction from about 24 per cent at the start of the programme in 1989.

A similar programme was started in New South Wales in 1991. As of 1995, 21 speed cameras were in operation at 809 sites (Coleman et al. 1996).

UNITED KINGDOM
Red light automated enforcement trials started in Nottingham in 1987 and in London in 1989 (Toogood, 1993), whereas speed control by automated enforcement was tried out first at Twickenham bridge in 1990 and became fully operational in the London area in 1992. According to Zaidel and Mäkinen (1999) there are now 520 automated enforcement cameras in London, divided about equally between red light and speed enforcement. This makes up about one-fourth of all automated enforcement cameras in the United Kingdom. In London there are further 14 bus-mounted cameras for bus-lane violation enforcement, and an additional 40 fixed cameras have been proposed for this purpose. Virtually the whole of the London trunk network is covered, as well as numerous other primary routes, and there is a continual increase in camera installations.

NORWAY
Automated enforcement for speed control was introduced in June 1988, with four enforcement sites on a 17 km road section, and one photo-radar equipment unit alternating between the sites (Glad and Østvik, 1991). Since then, the number of cameras has increased to about 35 in 1999, rotating between 195 different sites (fixed boxes with roadway inductive loops). A further doubling is planned for the next ten years. Automated enforcement of red light violations has been used only to a small extent in Norway, and it is not used at present.

SWEDEN
Automated enforcement for speed control was tried during a two-year period from 1990 to 1992 (Nilsson, 1992). For some years following the first trial period, automated enforcement was not used in Sweden. The automatic speed enforcement started again in 1997-98 with some 20 mobile units. In addition, in 1999 an evaluation project with fixed boxes has been initiated, including 7 boxes on a 8-km road section.

CANADA
A limited experiment with photo radar was carried out in Vancouver during fall 1990 (Glauz, 1998), and automatic speed enforcement is now in widespread use in British Columbia, in a programme drawing on the experiences from Australia. Also in Ontario automated enforcement is employed in a speed control programme.

THE NETHERLANDS
Automatic speed enforcement systems were installed on four road sections in 1991. The system was part of a more comprehensive speed management system, which in addition to the photo-radar included a fixed warning sign and a warning sign triggered by speeding vehicles. After this first trial, the system was not put into operation again until 1994. From then on, automated enforcement has been used extensively, often in combinations with information campaigns.

FINLAND
The first experiment with automatic enforcement in Finland took place in 1992 on a 50-km road section where 12 camera boxes were installed. Later the use of automated enforcement has been extended to red light violations. The Finnish police set a target to cover about 800 km of main road network by cameras, which equals about 10 % of the traffic volume by the year 2000. Currently, less than half of the target has been met.

OTHER COUNTRIES
Other European countries having started to use automated enforcement more recently include Austria, Denmark, and Ireland. Outside Europe it has been used in Kuwait, and more lately in New Zealand.

WHICH VIOLATIONS ARE DETECTED WITH WHICH 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 of the vehicle**.

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 infraread beams from special reflectors in the road bed. A detector records when a passing vehicle crosses the beam, and records 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	shot 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		

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, violating vehicles having a tag could be identified by the tag alone, whereas vehicles without the tag could be photographed.

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.

CONCLUSIONS

Throughout its 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.

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