Appendix D

Review of Automated Technologies for Speed Management and Enforcement

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Speeding (traveling faster than the posted speed limit) is apparently becoming more and more common throughout the world, particularly excessive speeding [exceeding the speed limit by 20 mph (32 km/h) or more]. Many countries have recognized this and have undertaken comprehensive programs to reduce speeding and the traffic crashes to which it contributes. Such programs are in existence in Victoria and New South Wales, Australia; British Columbia and Ontario, Canada; the Netherlands; Sweden; and perhaps others.

In the United States, speed management and speed enforcement are the responsibilities of the states and communities, although the
federal government can pass legislation requiring the states to take certain actions concerning speeding and traffic. Most recently, for example, the federal government canceled its mandatory maximum speed limit of 55 mph (89 km/h), allowing the states to set higher limits.

Speeding, especially excessive speeding, is apparently becoming more common in the United States. On September 19, 1997, the newspaper *USA TODAY* reported the results of a study it performed on some 2.3 million speeding tickets from 11 states between 1991 and 1996. The study indicates that the percentage of tickets written for speeding over 80 mph (129 km/h) rose from 15 percent in 1991 to 25 percent in 1996. Of course, many speed limits increased during this interval. The study also reported on speeding levels as a function of the local speed limit. In 55-mph (89-km/h) zones, the percentage of tickets written for speeding in excess of 75 mph (121 km/h) rose from 21 to 27 percent during this interval, and the percentage exceeding 80 mph (129 km/h) in these zones rose from 7 to 9 percent. In 65-mph (105-km/h) zones the percentage exceeding 85 mph (137 km/h) rose from 8 to 10 percent. It is not stated whether the level of enforcement, as indicated by the total number of speeding tickets written, had changed during this period, or whether the changes observed were statistically significant, although on the basis of the sample sizes they undoubtedly were.

Activities in other countries indicate that speeds and speed-related crashes can be reduced by a combination of speed management and speed enforcement programs. Speed management programs alone were ineffective due to the lack of concomitant enforcement, and speed enforcement programs alone were ineffective because they were too manpower intensive and thus costly. The use of automation has been shown to increase effectiveness, especially for enforcement.

In this review the experiences of automated speed management technologies and programs around the world are examined. Then a brief overview of automated photo radar technologies is given, followed by a presentation of experiences with automated speed enforcement, mostly using photo radar. Finally, some of the political and legal issues associated with the use of photo radar are discussed, and thoughts on the most effective types of implementation of automated speed management and speed enforcement are expressed.
EXPERIENCE WITH AUTOMATED SPEED MANAGEMENT

Speed management may be defined as a process designed to control or affect vehicle speeds, both the average speeds and the dispersion of speeds. Automated speed management is a speed management process that uses automation in some form (usually electronics and other advanced technologies). Police enforcement (with or without automation) is not included in this discussion of speed management; police enforcement (with automation) is treated as a special topic later in this review.

This section of the review is organized as follows. First, the earlier work in speed management is discussed, focusing on automated speed management. Two major types of automated speed management are identified: speed monitoring and warning systems, and variable speed limit systems. Following the review of the early work, more recent experiences of speed monitoring and warning systems and, on a country-by-country basis, of variable speed limit systems are examined. Finally, another type of automated speed management system, drone radar, is reviewed.

Early Experience

An early study of speed management systems was reported by Parker and Tsuchiyama (1985). They examined a broad spectrum of speed management concepts, ranging from static methods such as fixed maximum and minimum speed limit signs to the automated highways of the future. In between are a number of methods mentioned only to illustrate the scope of the options presented; they are not discussed further in this paper:

- Dummy police cars,
- Oversized speed limit signs,
- Painting or striping to create illusions of narrower roads or increasing speed,
- Speed bumps and rumble strips,
- Economic approaches (e.g., tolls increased if elapsed time is too short),
- Legislative approaches (e.g., prohibition of radar detectors), and
• In-vehicle devices ranging from current cruise control systems to future speed-limit-sensing engine governors.

Of all the methods examined, two are most relevant to this review—speed monitoring and warning systems, and variable speed limits.

Parker and Tsuchiyama (1985) state, “The purpose of speed warning systems is to continuously monitor vehicle speeds and provide speed-related informational or warning messages to aid motorists in the selection of appropriate travel speeds.” Two general types of systems are distinguished—those providing group speed information and those providing overspeed or underspeed warnings.

The group speed information systems display average vehicle speeds on the theory that motorists will then check their speedometers and adjust their speeds to more closely match the average. The warning systems provide individualized information to vehicles traveling too fast or too slow in the hope that the drivers will respond appropriately by either slowing down or speeding up.

The researchers identified only two group speed information systems existing at the time of their study, one in Calgary, Canada, and one on the “Maine Facility.” Both displayed data that were updated frequently as real-time data were collected. Effectiveness data were available only from the Canadian facility. They found that whereas average speeds were reduced only 4 percent, the proportion of drivers traveling more than 10 mph (16 km/h) over the speed limit decreased 35 percent, speed violations were reduced 40 percent, and total crashes were reduced 57 percent. Moreover, public reaction was positive.

A number of overspeed and underspeed warning systems were identified in the United States, Canada, and the United Kingdom. Evaluation data were limited. Some sites had no data; the others indicated only modest reductions in average speeds [2 to 4 mph (3 to 6 km/h)] but greater reductions in percentages of speeding vehicles (15 to 24 percent).

Parker and Tsuchiyama (1985) state, “The concept of variable speed limits involves setting minimum and maximum speed limits based on real-time monitoring of prevailing traffic and roadway conditions and using dynamic information displays to inform motorists of the appropriate limits.” They go on to state that no existing sys-
tems (at that time, 1984) fulfilled that concept, but they then examine the five existing systems that came closest to doing so:

- New Jersey Turnpike Control System, United States;
- National Motorway Communication System, United Kingdom;
- Corridor Control System north of Marseilles, France;
- Motorway Control and Signaling System, the Netherlands; and
- Self-Sufficient Speed Control System, Germany.

All five systems used speed and volume data. The English and Dutch systems used incident detection data along with speed and volume data. The German system used speed and volume data along with daylight (day/night) and rainfall (wet/dry). The English system required manual changing of the speed limits; the U.S. and French systems allowed manual override of the automated speed settings. The automated German system had many built-in backup features such as duplicate computers and message-lighting systems.

Effectiveness data were very limited. The Germans believed that drivers perceived the displayed speed as a recommendation, not a limit; nevertheless they determined that the differences in speeds of consecutive vehicles were decreased, as was the frequency of short headways, and there was a slight increase in the traffic flow rate. The British system produced larger speed reductions with lower speed restrictions, but the speed standard deviation remained constant at about one-seventh of the average speed. The U.S. system (the oldest of these five systems) was judged less sophisticated than the European systems in terms of backup capabilities and the ability to store historical data (which all the European systems had), which would be needed if enforcement were to accompany the use of variable speed limits.

Additional technical details about these variable speed limit systems are provided in a second report by Parker (1985).

**Speed Monitoring and Warning Systems**

Roqué and Roberts (1989) reported on experiments in Alabama, wherein an automated system collected data on traffic speeds a day at a time. After a day of collection, the percentage of vehicles exceeding
the speed limit was determined and displayed on variable message signs the next day. Both truthful and inaccurate results were displayed, in accordance with an experimental design. The hope was that drivers would modify their speeds to provide better compliance than had been observed. No significant changes were observed.

Casey and Lund (1993) examined the effectiveness of “mobile roadside speedometers” in reducing traffic speeds in California. The speedometer used an “undetectable” radar to measure speeds of individual vehicles, which the system displayed to the motorists. The system was deployed at five urban sites with speed limits from 30 to 45 mph (48 to 72 km/h) and at five school zones with speed limits of 25 mph (40 km/h). Significant but modest speed reductions were noted at three of the five urban sites while the system was in place, but the reductions disappeared the following week. Statistically significant speed reductions were found at all five school zone sites, with greater reductions at sites with higher prior average speeds. The researchers also examined the longer-term effectiveness of this system by coupling it with downstream enforcement. They found that adding downstream enforcement greatly increased the longevity of the system’s effectiveness.

Garber and Patel (1994) reported on a very thorough evaluation of the use of variable message signs designed to control driver speeds in work zones. They deployed the system at seven work zone sites in Virginia and collected extensive driver response data. The system determined individual vehicle speeds with radar and then, in accordance with the experimental design, either did nothing (baseline) or displayed one of four predetermined messages for high-speed drivers:

- Excessive Speed Slow Down,
- High Speed Slow Down,
- Reduce Speed in Work Zone, or
- You Are Speeding Slow Down.

Data were collected by roadway sensors and by videotape and were analyzed in detail using formal statistical methods. Effectiveness was judged by the reduction in the percentage of speeders (typically about 50 percent before implementation of the speed warning system), the
percentage of vehicles speeding by 5 mph (8 km/h), the percentage of vehicles speeding by 10 mph (16 km/h) or more, average speeds, 85th percentile speeds, and speed variance. All of the warning messages were effective, although the last was the most effective and the second was second-most effective.

Oei (1996), in a comprehensive report of experiences with automatic speed management in the Netherlands, discusses two types of installations, one to reduce speeds in school zones and one to reduce speeds on two-lane rural roads. For the school zones, three types of speed signs were used: a permanent 31-mph (50-km/h) sign, a 31-mph sign illuminated only during school hours, and a 31-mph sign that flashed only when an approaching vehicle was exceeding the speed limit. The latter was the most effective, reducing average speeds by 3 mph (5 km/h) and producing a theoretical reduction in crashes of 24 to 65 percent. The two-lane road installations covered stretches from 5 to 9 mi (8 to 15 km) in length and cost an average of U.S. $40,000. They consisted of static signs indicating the speed limits [minimum of 37 and maximum of 50 mph (60 and 80 km/h, respectively)], an automated, illuminated, switchable sign saying “60-80” displayed for vehicles outside of these limits, and downstream automatic signs saying “You Are Speeding” (in Dutch) for vehicles still exceeding the speed limit. Evaluations indicated significant reductions in average speeds, 85th percentile speeds, percentages of speeders, and the standard deviation of speeds.

Variable Speed Limit Systems

In this section findings on the use of variable speed limit systems are presented alphabetically by country.

Australia

Coleman et al. (1996), in their report on speed management and enforcement technology in four countries, include a brief discussion of the use of automated speed management in Australia. At the time of their investigation (1995), although Australia had a major speed management program in place, only one automated component was doc-
umented. A fog warning and speed advisory system was installed south of Sydney. The speed of a vehicle passing through a detector is displayed to the next vehicle as an advisory speed. A prototype of the system installed in 1993 notified motorists traveling more than 6 mph (10 km/h) over the speed limit. That system resulted in a 60 percent reduction in the number of speeders, but the effect was temporary; there was no reduction in speeding 1,000 ft (300 m) downstream.

**Finland**

Pilli-Sihvola and Taskula (1996) reported on a Finnish system to warn drivers of black ice and other hazards with a variable speed limit system. Installed on a section of roadway 9 mi (14 km) long, the system includes 36 variable speed limit signs. Sensors detect ice or snow, wet pavement, heavy rain, fog, and high winds. The speed limit is varied between 50, 62, and 75 mph (80, 100, and 120 km/h), depending on conditions. A 3-year evaluation was under way at the time of the report (1996).

**Germany**

Coleman et al. (1996) reported that Germany is a world leader in the application of advanced traffic management technology, with 70 traffic management facilities in operation on the autobahns at the time of the study (1995) and another 60 planned to be in operation by the end of 1997. These systems are located where hazardous conditions exist, especially hazardous environmental conditions. A typical system has variable speed limit signage that displays not only the current speed limit but also its reason. Reasons such as construction, fog, crash ahead, ice, and high winds are included. The researchers report a crash reduction of about 25 percent. The cost of these systems ranged from U.S. $0.6 million to $1.1 million per mile ($0.4 million to $0.7 million per kilometer).

**The Netherlands**

Wilkie (1997), in her review of variable speed limit systems, included a discussion of the Dutch speed management system installed in
1992 on the A2 highway between Amsterdam and Utrecht, which was still in operation in 1997. The system covers a 12-mi (20-km) length of highway with three interchanges, with signs spaced at intervals of about 0.6 mi (1 km). The main reason for the installation was frequent congestion at one of the interchanges and resultant traffic backups. The normal speed limit is 75 mph (120 km/h), but lower limits of 56, 43, or 31 mph (90, 70, or 50 km/h) are displayed depending on sensed traffic conditions. The goal was not so much to reduce average speeds as to narrow speed dispersion. Evaluation found that the system was well received by motorists, speeds were effectively reduced in all lanes, the number and severity of shock waves were reduced, the percentage of small headways was reduced, the average headway increased, and the average roadway occupancy increased. More details on this system are provided by van den Hoogen and Smulders (1994).

Coleman et al. (1996) report on a fog advisory system and on the more extensive Motorway Signaling System in the Netherlands. The fog advisory system reduces the speed limit from 62 mph (100 km/h) to 50 or 37 mph (80 or 60 km/h), depending on visibility. The system proved to be effective, reducing average speeds by 5 to 6 mph (8 to 10 km/h) (though the speeds remained higher than the displayed speed limit), reducing the standard deviation of speeds, and reducing the percentage of vehicles with very small headways. The Motor Signaling System, begun in 1981, in 1995 covered about 120 mi (200 km) of highways and is planned to cover 560 mi (900 km) by 2000. Displayed speed limits are reduced depending on traffic and weather conditions. Evaluations indicate a reduction of 50 percent in secondary crashes (when speed limits are reduced because of a crash ahead) and a decrease of 5 to 15 percent in lost travel time. The system costs are U.S. $1.1 million to $1.6 million per mile ($0.7 million to $1.0 million per kilometer).

United Kingdom

Wilkie (1997) reported on British work on the “Controlled Motorway Pilot Scheme.” The Department of Transport established this system on a 14-mi (23-km) section of M25 outside of London;
it was extended in 1995. The system was designed to minimize stop-and-go driving during heavy traffic (one-way peak volumes reach 10,000 vehicles per hour). The system senses volume and reduces the speed limit from 70 to 60 mph (113 to 97 km/h), then further to 50 mph (80 km/h), as volume thresholds are reached. The speed limits are displayed on changeable message signs spaced at 0.6-mi (1-km) intervals. (The speed limits can also be changed manually by the police.) The speed limits are enforced by photo radar. Formal evaluation is under way by the Transportation Research Laboratory, but preliminary results indicate that police are impressed by the system and the obedience of the drivers, compliance is about 98 percent, lane usage is more even, and average headways have increased.

**United States**

Wilkie (1997) included information on two early installations in the United States. One was on the John C. Lodge freeway in Detroit. It was installed in 1962 and dismantled sometime after 1967. The system was intended to display variable speed limits and lane-control information in response to congestion ahead. It was an advisory system, not an enforceable system. It consisted of 21 variable speed signs at 1,600-ft (500-m) intervals, 11 lane control locations at 2,600-ft (800-m) intervals, and 14 television camera locations at 1,300-ft (400-m) intervals. Evaluation found that aspects of the system, especially the lane-control information, were confusing to drivers, and that the variable speed limits did not induce any changes in driver speeds.

In 1986 the U.S. Federal Highway Administration contracted with Farradyne Systems, Inc., to develop a variable speed limit system (VSLS). The system is described in a report by Sumner and Andrews (1990). It appears that the VSLS was well designed and was intended to be flexible in its modes of operation and in the environmental conditions it could sense and act upon. It was estimated that future systems could be built and installed for $30,000 per station, plus $20,000 for the central hardware. The system’s software and hardware were tested in the field in Albuquerque and found to be operating correctly. The system was then turned over to the state of New
Mexico for longer-term evaluation. Whether any further reports are available on the operation of this system is unknown. Some limited applications of VSLSs are under development as part of the Intelligent Transportation Systems program. For example, the Nevada Department of Transportation in conjunction with the U.S. Department of Transportation is developing a VSLS that reflects actual traffic speeds and weather conditions on a stretch of Interstate highway that is frequently subject to adverse weather. Deployment of the system will be accompanied by a monitoring effort to assess effects on driving speeds and crash experience.

Drone Radar

The use of drone (unattended, continuously operating) radar to control driver speeds has been studied in the United States by several authors, including Pigman et al., whose early work was reported in 1989. Two of the most recent reports are those of Streff et al. (1995) and Freedman et al. (1994).

Streff et al. (1995) installed drone radars in 1993 at two freeway sites and one construction zone in Michigan and compared their effectiveness with traditional police enforcement and with no enforcement. Speeds were measured at the drone location and upstream and downstream of the drone location. Overall effects of the drone radar were small [typically 1.5-mph (2.4-km/h) decrease with drone radar present] but statistically significant due to the very large sample sizes. The effects were about the same as those with police presence. Some reductions in the speeds of the highest-speed vehicles, especially trucks [reductions from 30 to 70 percent of trucks exceeding the speed limit by 10 mph (16 km/h) at some sites and times], were found. It was determined that about 5 percent of the cars had radar detectors and that between 19 percent (day) and 28 percent (night) of the trucks had radar detectors.

Freedman et al. (1994) did a similar study in Missouri, comparing speeds of traffic with and without the presence of operational drone radar. Twelve sites were investigated, covering rural construction zones, rural and urban temporary work zones, and rural and urban locations with high crash rates. They also found only modest changes in average
speeds but a greater change in truck speeds than in car speeds. The proportions of vehicles with excessive speeds were often reduced by one-third to one-half when the drone radar devices were activated.

OVERVIEW OF AUTOMATED SPEED ENFORCEMENT TECHNOLOGIES

Automated speed enforcement (ASE) equipment has been in use for more than 30 years (Blackburn and Bauer 1995). Most of it uses some form of radar to sense vehicle speed, although pavement sensors and optical sensors are also used. (The author is unaware of any commercially available automated equipment that uses laser technology.) The remainder of this discussion will focus on photo radar ASE equipment.

The concept of the photo radar equipment has not changed during its period of use, although the technologies have improved greatly. The heart of the photo radar is the radar unit. It is much different from the radar guns traditionally used in the United States and elsewhere. Traditional radar produces a powerful but wide beam aimed down the road that can detect speeding vehicles as much as 1 mi (1.6 km) away. Unfortunately, it is not selective and does not identify which of the vehicles in its field of view is the speeder. Furthermore, drivers with radar detectors can usually detect the beam and slow down before they are detected speeding.

The radar used with ASE equipment is usually a type called “cross-the-road” radar. It produces a low-powered, narrow beam that is aimed at a 20- to 25-degree angle to the direction of the road. It is undetectable to drivers until they are within the beam, by which time their speed has been determined. This technology also enables vehicle identification for vehicles with headways of more than about ½ s.

The radar unit is connected to a computer that determines whether the vehicle’s speed is greater than a predetermined threshold. If so, the computer triggers a camera (and a flash if necessary) to photograph the vehicle and its license plate. The photograph has superimposed on it the time, date, recorded speed, location, officer, and so forth. Typically, the film is processed to the negative stage and the license number of the offending vehicle determined. If the speeder is unambiguously identified in the photo and the license number can be read,
a search of files is conducted and the owner identified. A ticket is then mailed to the owner. Depending on local laws, the owner may be required to pay the fine or may be given the opportunity to review the film at the police station or otherwise identify the driver, who then must pay the fine. Appeals are allowed, but they are rare.

As stated, the concepts have not changed over the years, but the technologies have improved. Improved electronics have allowed the units to be made much smaller. The use of lenses with longer focal length and better film (including some units that use a 70-mm format and color rather than black and white) has enabled license plates to be more readily identified. Some units have used video film.

Until recently, all of the equipment development and sales have been from overseas. More recently, a U.S. firm has designed and now builds complete photo radar systems (American Traffic Systems 1997). The systems feature their own military-grade camera with advanced photoelectronic imaging capabilities. They then use a proprietary system to rapidly scan the negatives into a computer (or read digital camera images directly), conduct digital enhancement procedures, read the image of the license plate by the use of optical character recognition, and produce printed traffic tickets if the system is tied to an owner’s license database.

EXPERIENCE WITH ASE

ASE using photo radar has been in existence since the 1970s. The experience has been documented by Glauz and Blackburn (1980), Fitzpatrick (1991), Zaal (1994), and Blackburn and Gilbert (1995). At the time of this review, there are reportedly 75 countries using automated speed enforcement (American Traffic Systems 1997). This review is mainly concerned with the most recent research reports, although some of the more unusual early work is included. The experience is presented in alphabetical order by country.

Australia

Victoria, Australia, has perhaps the most extensive photo radar enforcement program of any jurisdiction in the world. The program
was launched in December 1989, and by January 1991 there were 54 speed cameras in operation across Victoria (Cameron et al. 1992). The program included massive publicity both to increase the level of perception of the use of the cameras and to build a community agenda about speeding and safety. The enforcement occurred primarily on arterial roads with 37-mph (60-km/h) speed limits in both metropolitan and country areas.

The rate of issuance of speeding tickets increased from around 20,000 per month prior to the program to 40,000 to 80,000 per month during the program (Cameron et al. 1992). Over the 2-year period, more than 20 percent of all drivers received at least one speeding ticket. The penalties ranged from a small fine and demerit points to license suspension for speeding 19 mph (30 km/h) over the limit. The incidence of crashes and their severity were carefully analyzed statistically. For these analyses, crashes were separated into “low-alcohol hours,” basically daytime hours, and nighttime hours, to distinguish causality between the speed program and a concurrent drinking/driving campaign; drinking had been shown not to be a concern during the low-alcohol hours prior to 1990. New South Wales was used as a “control” since it had no photo radar program, at least initially.

The frequency of casualty crashes compared with that in New South Wales decreased around 30 percent in Victoria because of the combination of the speed enforcement and publicity programs. The percentage of crashes resulting in serious injury also declined significantly. Most of the reductions occurred on arterial roads in Melbourne and on 37-mph (60-km/h) roads in rural Victoria, where the photo radar operations were conducted. The comparisons did not indicate a like reduction during the last 6 months of this 2-year period, during which time New South Wales also introduced a photo radar program and its crash rate dropped.

Rogerson et al. (1994) further analyzed data from the 2-year Victoria experience. One type of analysis used just the crash data from within 0.6 mi (1 km) of each of the 1,699 photo radar camera sites. The crashes were separated into “influenced” and “not influenced” time periods, where “influenced” was defined to be within 7 days after photo radar operations at the site or within 2 weeks after the traffic tickets were mailed (which usually occurred several weeks
after photo radar operations). There were no control sites; the enforcement sites served as their own controls. As before, the times of the crashes were separated into low-alcohol hours and high-alcohol hours. The only statistically significant reductions in crash frequency found were during the days influenced by mailing of traffic tickets, and then only during the high-alcohol hours.

The second set of analyses presented by Rogerson et al. (1994) dealt with the effects of photo radar on speeds in Melbourne and the rest of Victoria. The researchers analyzed a sample of speeds taken from 44 locations and continuous speed data taken from 8 permanent monitoring sites. They found little change in average speeds or in 85th percentile speeds but significant reductions in the percentage of vehicles exceeding the speed limit by at least 9 mph (15 km/h) (from 11.3 percent to 5.5 percent) and in the percentage exceeding the speed limit by at least 19 mph (30 km/h) (from 2.5 to 3 percent to 1 to 1.5 percent). These reductions were observed on roads with speed limits of 37 and 47 mph (60 and 75 km/h); there were insufficient data on roads with a speed limit of 62 mph (100 km/h) to draw similar conclusions.

An update to the Victoria program was provided by Coleman et al. (1996). In the 5 years since the program was begun (December 1989), the percentage of vehicles exceeding the speed limit tolerance (10 percent above the speed limit) decreased from 23 to 2.9 percent, and virtually no drivers exceeded this tolerance by more than 25 percent. There was a 30 percent reduction in casualty crashes on arterial roads in Melbourne and a 20 percent reduction on the 37-mph (60-km/h) rural roads. In 1989 the safety management plan, which included the photo radar speed enforcement, had a goal of reducing Victoria fatalities to 500 per year by 2000. This goal was met in 1992. In 1994 there were 378 fatalities.

Additional data were provided on the Victoria program by Sinclair (1996). Reported traffic collisions dropped from more than 5,400 per year in 1989 to about 4,000 per year in 1996; fatalities dropped from about 1,050 per year to about 700 per year during the same period, with serious injuries dropping correspondingly. In December 1989, 23.9 percent of vehicles exceeded the camera threshold speeds. This percentage dropped to 13 percent in December 1990 and to 5 percent in December 1996. The percentage of all tickets written that were for
speeds more than 19 mph (30 km/h) above the limit (at which level the driver’s license is suspended) dropped from 1.6 percent in December 1989 to about 0.4 percent in 1996.

Coleman et al. (1996) also reported on the photo radar program in New South Wales, which was begun in mid-1991. As of 1995, 21 speed cameras were operating at 809 sites throughout the state. A 22 percent reduction in serious crashes and a decrease in excessive speeding [6 or 12 mph (10 or 20 km/h) above the limit] were realized. The targeted reduction in fatalities for 2000 was surpassed in 1994.

Canada

An early, limited experiment in Vancouver, British Columbia, was reported by Pedersen-Handrahan (1991) and by Pedersen and McDavid (1994). The Vancouver police used photo radar at a site in Vancouver during fall 1990, and data from that site were compared with a control site. The analyses indicated that both average speeds and the percentage of drivers exceeding the speed limit of 31 mph (50 km/h) decreased during the enforcement period but increased again after enforcement ended.

The use of photo radar has increased substantially in more recent times (personal communication, F. Navin, 1997). Photo radar is in widespread use in British Columbia in a program that is patterned after the Australian experience. The effect on high-speed driver behavior is reportedly very noticeable. At the time of writing this review, results of this program had not yet been published. A report is expected from Peter Cooper of the Insurance Corporation of British Columbia.

The Ontario government developed a program “to make Ontario’s roads the safest in North America” (Ontario Ministry of Transportation 1995). As part of this program, a 1-year pilot project was designed to evaluate the effectiveness of photo radar. Photo radar was deployed at three experimental sites [six-lane 62-mph (100-km/h) divided freeway, four-lane 62-mph divided highway, two-lane 50-mph (80-km/h) undivided urban highway] and three control sites. The ministry’s report covers the effects on speeds after 4 months of operation. Significant decreases in average vehicle speeds, and even more profound declines in the percentages of vehicles...
speeding by various amounts, especially the highest speeds, were found. Decreases were also noted at the control sites, but they were of lesser magnitude. The control site decreases were attributed to extensive media attention to the use of photo radar and to campaigns against speeding in general. Analyses of changes in crash rates await the accumulation of more data.

Germany

One of the earliest studies of the effect of photo radar on speeds and crashes was reported by Glauz and Blackburn (1980); a more detailed study was reported by Lamm and Kloekner (1984). A section of southbound autobahn A3 between Cologne and Frankfurt experienced crash rates ranging from 5 to 10 times that of the rest of the autobahn system. The section was on a long, steep downgrade (the Elzer Berg) and experienced 85th percentile speeds of 93 mph (150 km/h), compared with the local design speed of 62 mph (100 km/h). Therefore, a speed limit of 62 mph for cars (lower for trucks) was put in place. In conjunction with that, automatic photo radar was installed over each of the three lanes. The 85th percentile speed dropped quickly to about 65 mph (105 km/h) in the left lane and remained at that level for at least 10 years. Total crashes dropped from about 300 per year to under 30 per year, and injury crashes dropped by a factor of 20.

Coleman et al. (1996) indicate that photo radar is now used in Germany only on a limited basis. The reason for this, they indicate, is that under German law the driver, not the owner, is liable to pay the fine. The author’s experience, based on travel there in 1997, is that photo radar is much in evidence. It was particularly evident on autobahn A6 from Cologne to Hannover to Berlin, especially in conjunction with reduced speed limits in construction zones. This observation has been confirmed by the coordinator for police traffic activities in the state of Niedersachsen, with headquarters in Hannover (personal communication, E. Klein, 1997). He agrees that enforcement is more difficult because of the German legal system, but “even given these drawbacks, we will not stop using the automatic speed control on autobahns, since it is pretty successful.”
Correspondence received on December 15, 1997, prepared by Herr Brackemeyer of the German Police Academy in Münster provided additional detail. Frontal photos are taken in hopes of identifying the driver. If the registered owner will not identify the driver, and the driver is repeatedly detected speeding, German law enables the police to require the owner to keep a log of all trips and their drivers for later reference. Photo radar is being used in conjunction with the variable speed limit program described in the previous section. In addition, photo radar is used by local communities, although by law they cannot stop vehicles for speeding (only “the police service” can do that).

The Police Academy also furnished statistics on the prevalence of photo radar units in Germany. As of April 1996, there were 593 photo radar units in the 16 states of Germany, of several different manufacturers and models. The states with the most were Nordrhein-Westfalen (104), Bayren (95), Baden-Württemburg (69), and Niedersachsen (67). Each of the states has at least a few.

Kuwait

Ali et al. (1997) report that Kuwait installed 10 automatic (unmanned) photo radar units for speed enforcement purposes. The researchers determined that drivers slow down dramatically as they approach the units, whose permanent locations are now well known, then speed up immediately after passing them. This behavior is attributed to the general lack of visible law enforcement in the Persian Gulf countries. (Ali et al. quote another study involving 112 h of traffic observation by researchers at a number of intersections over a 3-month period, during which they observed more than 10,000 traffic violations and 3 crashes, but never saw a police officer.) Ali et al. believe that photo radar will not be effective in Kuwait unless it is accompanied by a much greater police presence.

The Netherlands

Oei (1996) presents information and data on speed management and speed enforcement in the Netherlands. The government instituted a Multiyear Road Safety Program with the goals of reducing fatalities
by 25 percent between 1985 and 2000, the average speed by 5 to 10 percent, and the number of speeders to less than 10 percent. Photo radar was installed at four locations that also had speed warning systems in place. The 85th percentile speed was reduced by 2 mph (3 km/h) with warning signs alone and by 5 mph (8 km/h) with signs and photo radar enforcement. The percentage of speeders dropped from 38 percent initially to 28 percent with signs only and to 11 percent with enforcement. The latter percentage increased slightly from 11 percent speeders to 16 percent after 3 years of operation. A small experiment using moveable photo radar in unmarked cars was also reported; it had smaller but measurable beneficial effects on speeds.

Coleman et al. (1996) provide additional information on photo radar enforcement in the Netherlands. They point out that recent enabling legislation that holds vehicle owners, as opposed to drivers, liable for speeding violations makes their program more effective. They also quote additional research by Oei, reported by the Dutch Institute for Road Research, that shows the efficiency in the use of automated speed enforcement as compared with manual enforcement, and they quote other research that shows that automated enforcement can be ineffective without accompanying media publicity.

Norway

Elvik (1997) reported on automatic speed enforcement in Norway. Photo radar was deployed at 64 road sections that were classified according to whether they met certain warrants. One warrant was based on crash rates (crashes per million vehicle kilometers before deployment); the other was crash density (crashes per kilometer before deployment). The analyses corrected for regression to the mean, and the effects at each site were weighted statistically. He found a statistically significant reduction in injury crashes of 20 percent for all 64 sections combined. The largest reduction, 26 percent, was found for sections meeting both warrants, and the smallest, 5 percent, was found for sections meeting neither of the warrants.

Elvik (1997) also used a statistical approach to combine his data with 15 other data sets of reported effectiveness of automatic speed enforcement from Germany, Australia, England, Sweden, and the
Netherlands. The weighted mean change (based on the size of the crash sample) was a highly significant 17 percent decline, with 95 percent confidence bounds of 16 to 19 percent.

**Sweden**

A test program of the use of automatic speed enforcement in Sweden was reported by Nilsson (1992). For a 2-year period, 8, and later 16, test sites comprising a total of 68 mi (110 km) of rural road and 11 mi (17 km) of urban main roads had cameras installed; a like number of control sites were also identified. These cameras were tied to sensors buried in the road, not radar (personal communication, G. Nilsson, 1997). They were placed into use according to a plan, for 4 to 6 h at a time, spread over the 24 h of the day and all days of the week. During this period, 14,000 photos were taken of incidents in which the driver exceeded the speed limit of 31 mph (50 km/h) by at least 8 mph (13 km/h), or the speed limit of 56 mph (90 km/h) by at least 9 mph (14 km/h).

The researchers found that average speeds dropped by 3 to 6 mph (5 to 10 km/h) at the experimental sites. The speed reductions started about 0.3 mi (500 m) upstream of the radar units and continued to about 0.6 mi (1 km) past the units. Over the 2-year period the range of influence diminished to be more in the immediate vicinity of the cameras. A reduction in injury crashes and fatalities was also observed, but these changes were too small to be statistically significant.

Additional information is provided by Coleman et al. (1996) and by Nilsson (personal communication, 1997). Photo radar usage in Sweden is now rather limited. Where it is used, it is usually mounted in a police van that can be moved from site to site. Most speed enforcement there is not automated but uses manned radar (without a camera) or manned laser guns. In fact, the use of manned lasers is increasing dramatically in Sweden, as reported by Andersson and Nilsson (1997). The percentage of all tickets written using lasers increased from 36 percent to 53 percent from 1994 to 1995. This enforcement is part of Sweden’s national road safety program, intended to decrease the proportion of drivers exceeding the speed limits by 35 percent by 2000.
United Kingdom

The effects of the use of automated photo enforcement (speed cameras, using radar and other speed-sensing systems) on trunk roads in West London were reported by Swali (1993) and later with additional data by Winnett (1994). The early results reported by Swali indicated very significant reductions in speeds; one site with a 40-mph (64-km/h) speed limit indicated a change from 1,090 drivers per day traveling more than 20 mph (32 km/h) over the limit before enforcement to 30 drivers per day after, a reduction of 97 percent. For all sites combined, total crashes were reduced by 22 percent, and fatal plus serious injury crashes were reduced by 38 percent.

The later report by Winnett (1994) indicates that, after correcting for general crash trends, total crashes at speed camera sites declined 14 percent, significant at the 1 percent level. Furthermore, the decrease in fatal and serious injury crashes was highly significant, whereas the 8 percent decrease in slight crashes was not statistically significant.

United States

The first use of ASE in the United States was in Arlington, Texas, in 1976 (Blackburn and Gilbert 1995). For a 3-month period a photo radar system known as Orbis III was used. Photo radar was not used again for actual enforcement until 1986, although, as will be noted, there was much field testing of various systems. In July 1986, Precinct 8 of Galveston County, Texas, began an ASE program that lasted for 1 year. In 1987 the city police of La Marque, Texas, used ASE equipment for a 3-month period. Both programs were stopped because of adverse public opinion.

Blackburn and Gilbert (1995) report that, as of about 1994, 13 additional U.S. communities used photo radar for speed enforcement for some period. At the time they wrote their report, the ASE programs in 6 of the 13 communities had ceased for a variety of reasons. Programs still operational at that time were Paradise Valley, Arizona; Campbell, National City, and Riverside, California; and Garland, Wellington, and West Valley, Utah. The Pasadena program, no longer
operational, was well known for its intensity and the fact that it was in a fairly large community. It ran for 4 years until it ended in 1992 for several reasons (judicial and public support eroded, the equipment vendor went out of business, police manpower was reduced, and the cost of the program was excessive).

At the present time the following U.S. communities are using ASE: Portland, Oregon; Scottsdale, Mesa, Tempe, and Paradise Valley, Arizona; National City and perhaps San Jose, California; and Fort Collins and Commerce City, Colorado (personal communication, A. Tuton, 1997). (Canadian locations with current ASE programs include British Columbia and Edmonton, Calgary, and Lethbridge, Alberta.) Boulder and Denver, Colorado, have issued RFPs to establish ASE programs.

Generally, the U.S. programs did not receive as much evaluation as many of the foreign programs did. However, some data are presented by Blackburn and Gilbert (1995). In Paradise Valley (the longest running of any U.S. ASE program) the annual number of crashes went from 460 in 1986, the year before the program was begun, to 224 in 1992, the last year data were available to the authors. In West Valley, Utah, the annual number of crashes fell from 2,130 to 1,710 after 2 years of ASE use. The police of National City, California, reported a 26 percent decline in crashes during the first 10 months of photo radar use.

The Scottsdale ASE program was begun in 1996. American Traffic Systems (1997) reports that crashes declined from 181 to 120 during comparable 10-week periods before and after enforcement. Similarly, an 81 percent drop in speeding violations, from about 6.6 percent to about 1.2 percent as a percent of all vehicles, was reported in Commerce City, Colorado (American Traffic Systems 1997).

Midwest Research Institute provided an evaluation of the ASE program in Riverside, California (Blackburn and Bauer 1995). Data were obtained from 13 test sites in the community by the police department. Unfortunately, broad generalizations are not possible because the amount of data collected varied greatly from site to site and at different times of the day; at some sites no data were obtained after the beginning of enforcement and at some sites there
were no before-enforcement data. Following are some of the findings:

- Average speeds were changed by an amount ranging from a decrease of 14 mph (23 km/h) (at a school zone) to an increase of 1.1 mph (1.8 km/h).
- The 85th percentile speed (calculated as the mean plus one standard deviation) was reduced at all sites and times of day for which data are available by a maximum of 16.4 mph (26.4 km/h) (at the school zone) and a minimum of 0.2 mph (0.3 km/h).
- The percentage of vehicles exceeding the speed limits by various amounts was examined. For example, the percentage speeding by 11 mph (18 km/h) or more decreased in all but 1 of the 39 site/time combinations for which data were available. Again, the largest reduction was at the school zone, where, in the a.m. peak, for example, the percentage dropped from 77.7 to 19.9. [At this 25-mph (40-km/h) speed zone, nearly everyone was speeding before the ASE program; some speeds of 70 to 80 mph (113 to 129 km/h) were recorded.]
- Reductions in crashes in Riverside were compared with those in a control city, Santa Ana. The monthly average of speed-related (by police report) fatal and injury crashes decreased by 5.3 in Riverside, while it increased by 2.4 in Santa Ana. The total number of speed-related crashes dropped by 14.2 per month in Riverside and increased by 1.1 per month in Santa Ana.
- The percentage reduction in speed-related fatal and injury crashes in Riverside was 14.7, whereas the comparable reduction in fatal and injury crashes judged not to be speed related was 18.1 percent. Similar results were obtained for total crashes.

Finally, it is of interest to report the number of evaluations of photo radar systems in the United States that stopped short of issuing speeding citations. Pilot tests of ASE equipment are reported by Blackburn and Gilbert (1995) in the early 1980s by state police agencies in Washington, Michigan, and New Jersey. Lynn et al. (1992) report on feasibility studies conducted in Virginia and Maryland, with the intent of ultimately installing such systems on the Capital Beltway (which has not happened).
SUMMARY OF LEGAL AND POLITICAL ISSUES ASSOCIATED WITH ASE

A short selection of some of the more commonly discussed legal and political issues is presented here, with brief discussions of each. Much of this material is taken from Blackburn and Gilbert (1995).

Constitutional Issues

Issues such as right to privacy and illegal search and seizure have been raised from time to time. Many state and Supreme Court decisions have consistently found that the use of photo radar does not violate rights under the Fourth Amendment.

Admissibility of Photographic Evidence

Some have argued that photographs taken by photo radar should not be allowed as evidence in a courtroom. This issue has been addressed by a number of state supreme courts and appellate courts, and it was found consistently that photographic evidence of this type, if it can be shown to be authentic and competent, is admissible.

Scientific Reliability

The issue here is whether the photo radar equipment can be shown to be scientifically valid and reliable. In some countries the equipment (not just a sample, but every single device) must be tested periodically by a government testing agency and certified to be accurate. In the United States a formal set of standards for such equipment is under development and should be available soon (personal communication, A. Tuton, 1997).

Frontal Versus Rear Photographs

There was much debate on this issue 15 years ago, and some continues. The argument is that a frontal photograph is required to provide some identification of the driver. Others argue that such photographs
have occasionally created unpleasant repercussions if a motorist was shown in a potentially embarrassing situation. If the owner of the vehicle can be made liable for the speeding infraction (see next issue), then frontal photographs would not be necessary since it would only be necessary to identify the vehicle. A related issue is that some states do not require front license plates, so a frontal photograph would not identify the vehicle. In other states that require front plates, the police find that a significant fraction of vehicles (10 to 20 percent) do not display such plates. Therefore, they set up their photo radar with two cameras and manually take a second photo of the rear of the vehicle if the front plate is missing. It is also possible for an automatic system to routinely take both front and rear photos of detected speeders.

**Owner Liability**

In most jurisdictions where photo radar is used, the legal system makes the driver, not the owner, liable for the violation. Exceptions include Australia, the Netherlands, and Paradise Valley, Arizona, where the owner is held responsible (vicarious liability). Otherwise, the police can mail the registered owner the ticket and the owner has the option of paying the fine, identifying the driver, coming to the police station to view the photograph (most jurisdictions do not mail the photos), or contesting the ticket and going to court. Laws in some countries require owners to follow these steps; in others such as Germany they are voluntary, but the majority of owners pay the fine.

**Penalties**

In some jurisdictions the fines for speeding when detected by photo radar are modest, and the violations are considered civil (not criminal) offenses. As such, they are treated much like parking tickets; this approach makes it easier for the jurisdiction to hold the owner vicariously liable. In many European countries and in Australia, the fines can be stiff (hundreds of dollars). Moreover, points may be assessed against the driver's record. It is not uncommon for countries to impose license suspension for excessive speeding [19 mph (30 km/h) over the limit, for example].
Manned Versus Unmanned Operation

It is possible for photo radar to be operated in a totally automatic, unmanned mode. In this mode, a large spool of film is placed in the camera, the system is placed in a roadside box or cabinet, power is supplied, and the system then operates by itself until an officer comes to retrieve the film. With this mode, many boxes are usually installed at the locations to be used for speed enforcement, the locations being evident to the motorists. However, there are far fewer photo radar units than boxes, so the photo radar units are rotated among the boxes. This mode can be effective because the motorists do not know which boxes are active. Experience indicates that vandalism can be expected, however.

Alternatively, a manned operation requires an officer to be present with the equipment. Some jurisdictions require this, so the officer can vouch for the operation and that the photographed vehicles were witnessed by the officer. The equipment can either be set up alongside the road on a stand or tripod or, more commonly, mounted in the back of a police van, enabling rapid mobility.

Public Opinion

The demise of a photo radar program is often the result of adverse public opinion being brought to the attention of the community officials (city council, mayor, etc.), causing them to cancel the program. This happens not only in the United States but also on occasion in foreign countries.

There have been only two formal surveys of public opinion about photo radar in North America in recent years. A well-publicized survey by the Insurance Institute for Highway Safety was conducted in 1989, using random digit dialing in two communities with ongoing photo radar programs, Paradise Valley, Arizona, and Pasadena, California, and in the surrounding areas (Freedman et al. 1990). There was great awareness of the ongoing programs in both communities and in the surrounding areas. In all, 58 percent either approved or strongly approved of the program, with the residents of Paradise Valley and Pasadena more likely to approve than those in the nearby
communities. (However, the majority of all subpopulations approved, after removing those who had no opinion.) The percentage of those interviewed who strongly disapproved ranged from 12 percent in the two communities with active enforcement to 15 and 20 percent, respectively, in the surrounding areas of the two communities. Reasons given by those who disapproved were that the wrong person may be ticketed, it gives police an unfair advantage, it violates rights to privacy, it does not give the driver a chance to explain, and it is not effective in reducing speeds.

A later survey was conducted in British Columbia by Zuo and Cooper (1991). Surveys of randomly selected drivers in British Columbia during the period 1988 to 1990 were conducted about red light cameras. Roughly 500 to 600 driver responses were obtained in telephone interviews in each of the 3 years. In 1989 and 1990, questions about photo radar were added. The positive response to photo radar increased from 71 percent in 1989 to 74 percent in 1990, which was not statistically significant. Drivers who were against photo radar tended to be young to middle-aged males with two or more moving violations in the past 3 years and who tend to respond more aggressively to frustrating traffic situations.

In a parallel survey in 1990, drivers were presented with a hypothetical situation where they were speeding to “keep up with traffic” (Zuo and Cooper 1991). If they received a ticket from a policeman using conventional enforcement, 39 percent felt that the ticket was unfair, and 51 percent said that it would make them angry. If they received the ticket because of photo radar enforcement, 45 percent said that it would be unfair and 60 percent said that it would make them angry. The authors conclude that “there are obviously a number of drivers whose attitude towards the cameras simply reflects their attitude towards enforcement in general.”

DEPLOYMENT STRATEGIES FOR ASE

Automated Speed Monitoring and Warning Systems

Experience with these systems indicates that they can be effective at selective locations, such as in school zones and work zones. They
must react to the speeds of individual vehicles. They must display messages dynamically, by flashing or giving appropriate messages. They must be enforceable speeds, not advisory speeds, and they must be backed up by enforcement, at least occasionally.

**Variable Speed Limit Systems**

These systems can be effective when installed at locations where the public senses that they are believable. Locations where there is frequent fog or traffic backups are prime candidates. (At a cost on the order of $1 million per installation, they must be used selectively.) Dynamically displaying the reason for a reduced speed limit is recommended. The displayed speeds must be appropriate to the conditions of the moment and enforceable. Actual enforcement must accompany the reduced speed limit, at least some of the time, and must be accompanied by publicity about both the variable speed limit and the presence of enforcement.

**Automated Speed Enforcement**

ASE and, in particular, photo radar can be effective in detecting and convicting drivers traveling at excessive speeds, provided that enabling legislation that is supported by the politicians and the courts is in force. It is critical that public support be gained before the legislation is implemented. The public must be convinced that there is a safety problem, that high speeds are a primary cause of the problem, and that enforcement is aimed at only a small minority of drivers (the focus population of automated enforcement travel at very high speeds). If the public becomes convinced that ASE is being used to generate revenue, the program is doomed to failure.

ASE should be used where there is a perceived speeding problem. Candidates include school zones (during hours when students are likely to be about), work zones (when there is actually work going on or where the road geometrics have been temporarily and radically modified), and known high-crash locations. Especially appropriate are high-crash locations where traditional police enforcement is not feasible due to lack of adequate shoulders, high traffic volumes, and
so forth. The installations must be publicized and defended. Signage upstream or downstream of the actual installation is often used to allay driver complaints of police unfairness. It must be understood that the purpose of the enforcement is to reduce high speeds, not to “catch” speeders.

The ASE equipment should be used, at least initially, with a fairly high threshold—say, 20 mph (32 km/h) over the limit. It has been found that there are enough drivers with such speeds to keep the equipment, the police, and the courts busy. As the public becomes more used to the equipment, it may be possible to reduce the threshold.

If a state, a community, or the nation decides on a major program to reduce speeding in general and not just at selected locations as part of a greater program to reduce serious crashes, then a wider deployment of ASE would be in order. Either a large number of boxes or cabinets could be installed to house ASE equipment on a rotating basis or mobile equipment housed in police vans could be used. The public must be convinced of the importance of the program and know that they cannot predict where the equipment might be located on a day-by-day or hour-by-hour basis. The types of roads where such equipment is deployed should be determined on the basis of speed surveys; the road class in itself is not particularly important. Modern ASE equipment can easily be deployed to survey two or three lanes of traffic in one direction, perhaps more. If the jurisdiction is serious about the program, convictions should be accompanied not only by fines but also by points, and consideration should be given to license suspension if the violation is serious enough.

REFERENCES


